Population dynamics of 0-group flounder (*Platichthys flesus* L.) in Galway Bay, west of Ireland and the value of flounder from shore angling tourism in Ireland.

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Abstract

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The economic value of flounder from shore angling around Ireland was assessed. Flounder catches from shore angling tournaments around Ireland were related to domestic and overseas shore angling expenditure in order to determine an economic value for the species. Temporal trends in flounder angling catches, and specimen (trophy) flounder reports were also investigated. Flounder was found to be the most caught shore angling species in competitions around Ireland constituting roughly one third of the shore angling competition catch although this did vary by area. The total value of flounder from shore angling tourism was estimated to be of the order of €8.4 million. No significant temporal trends in flounder angling catches and specimen reports were found. Thus there is no evidence from the current study for any decline in flounder stocks.

The population dynamics of 0-group flounder during the early benthic stage was investigated at estuarine sites in Galway Bay, west of Ireland. Information was analysed from the March to June sampling period over five years (2002 to 2006). Spatial and temporal variations in settlement and population length structure were analysed between beach and river habitats and sites. Settlement of flounder began from late March to early May of each year, most commonly in April. Peak settlement was usually in April or early May. Settlement was recorded earlier than elsewhere, although most commonly was similar to the southern part of the UK and northern France. Settlement was generally later in tidal rivers than on sandy beaches. Abundance of 0-group flounder in Galway Bay did not exhibit significant inter - annual variability. 0-group flounder were observed in dense aggregations of up to 105 m^{-2}, which were patchy in distribution. Highest densities of 0-group flounder

were recorded in limnetic and oligohaline areas as compared with the lower densities in polyhaline and to a lesser extent mesohaline areas. Measurements to of salinity allowed the classification of beaches, and tidal river sections near the mouth, into a salinity based scheme for length comparisons. Beaches were classified as polyhaline, the lower section of rivers as mesohaline, and the middle and upper sections as oligohaline. Over the March to June sampling period 0-group flounder utilised different sections at different length ranges and were significantly larger in more upstream sections. During initial settlement in April, 0-group flounder of 8-10 mm (standard length, SL) were present in abundance on polyhaline sandy beaches. By about 10mm (SL), flounder were present in all (polyhaline, mesohaline and oligohaline) sections. 0-group flounder became absent or in insignificant numbers in polyhaline and mesohaline sections in a matter of weeks after first appearance. From April to June, 0-group flounder of 12-30mm (SL) were found in more upstream locations in the oligohaline sections. About one month (May or June) after initial settlement, 0-group flounder became absent from the oligohaline sections. Concurrently, flounder start to reappear in mesohaline and polyhaline areas at approximately 30mm (SL) in June. The results indicate 0-group flounder in the early benthic stage are associated with low salinity areas, but as they grow, this association diminishes. Results strongly suggest that migration of 0-group flounder between habitats takes place during the early benthic phase.

Flounder otoliths were examined to determine if hatch checks and accessory primordia were deposited as occurs in other flatfish species. Otolith microstructure was used to determine hatch dates, larval durations, larval growth, settlement dates and total age (days). Spatial and temporal patterns were analysed for flounder sampled during peak settlement in April 2004 and 2005 in Galway Bay. Flounder otoliths exhibited a dark band at about 10μm which was assumed to be the hatch check, similar to that of plaice. Hatching times ranged from early February to mid March. The mean larval duration was 38 ± 5 and ranged from 32-47 days. The transition from beach to river habitats was found to be an important factor in the deposition of the accessory primordia and completion of metamorphosis. Settlement dates for 0-group flounder ranged from the 28th of March to the 14th of April in 2005. Flounder in the present study ranged from 27 – 59 days old with a mean of 40 days old. Significant spatial and temporal patterns in the pelagic and benthic life history of flounder were observed from otolith microstructure. Significant differences between life history parameters on a spatial scale most commonly involved the furthest sampling site from the others. This suggests a differing pelagic and benthic life history for 0-group flounder sampled from the furthest site. Temporal differences in life history on one site were found between 2004 and 2005.

Table of Contents

Chapter 4:

Hatching, larval and post-larval duration, settlement, age and growth dynamics of 0-group flounder in Galway Bay determined using otolith microstructure.

Chapter 5:

Chapter 1: General Introduction

Flatfish are an important component of Irish commercial landings. Species such as plaice, *Pleuronectes platessa* L., turbot, *Scopthalmus maximus* L., and brill, *Scophthalmus rhombus* L. are all valuable components of Irish commercial fisheries (Anon, 2006). In recent years, the value of recreational fisheries in Ireland is being realised. Species such as flounder, (*Plathichthys flesus,* Linnaeus 1758) and dab, *Limanda limanda* L. are non-commercial but important for recreational sea angling in Ireland (see Chapter 2). Flounder are one of the top shore angling species in Ireland. Despite this, little research has been done on the species in Ireland.

Flounder Biology and Ecology

The European flounder is a member of the *Pleuronectidae* family of fishes (right eyed flounders). The family also includes other common flatfish species such as plaice *Pleuronectes platessa* L, dab, *Limanda limanda* L., and halibut, *Hippoglossus hippoglossus* L. (Wheeler, 1969). The species is distributed in the eastern Atlantic from the White Sea to the Mediterranean and Black Sea (Wheeler, 1969). A subspecies of flounder (*Platichthys flesus luscus,* Pallas, 1814) exists in the eastern Mediterranean and Black Sea. Flounder have also been introduced into the USA and Canada accidentally through transport in ballast waters (Welcomme, 1988). Flounder are known to hybridise with plaice (Pape, 1935) especially in the Baltic.

Flounder populations have been subject to many studies roughly divided into two main areas; environmental pollution and flounder biology (Bos, 1999 b). Recently there have been a number of studies on larval (Bos, 1999 a; Jager 1998; 1999; 2001; Bos, 2006) and 0-group (Riley *et al.*, 1981; Kersten, 1991; Van der Veer, *et al.*, 1991; Hutchinson, 1993, 1996; Jager *et al.*, 1993, 1995; Anderson *et al.*, 2005 a; Bos, 2006) population dynamics of flounder. Studies on 0-group flatfish populations in Ireland included beach seining surveys (Mansoor, 1982; Allen; 2004). The population dynamics of 0-group plaice has been studied in the Galway Bay area by Allen (2004) and Allard (2007) using push net sampling. Grove (1981) conducted a beach seining survey for 0-group flounder on Sherkin Island, south west Ireland. This was the only paper published on 0-group flounder in Ireland.

The flounder, is found in inshore areas and estuaries (Wheeler, 1969). In winter, adults leave the estuary (Russell 1976; Dando and Ling, 1980; Johnson, 1981; Bos, 1999, b) and move offshore to spawn in spring (Wheeler, 1969; Dando and Ling, 1980; Johnson, 1981), in about 20-40m depth of water. (Wheeler, 1969). Aggregation of flounder at sea occurs during late winter to early spring and lasts on average about one month (Sims *et al.*, 2004). Flounder spawning migrations appear to be driven by short term climatic induced changes in their over wintering habitat, with populations exhibiting more synchronous and earlier spawning migrations in response to lower temperatures in the estuary (Sims *et al.*, 2004). Adult flounder leave the estuaries to spawn from December to March in the deeper parts of the Southern Bight of the North Sea (Russell, 1976, Harding *et al.*, 1978). Other spawning grounds have been reported off south-west England (Sims *et al.*, 2004) and in the Baltic Sea (Cieglewicz, 1947; Nissling *et al.*, 2002). In the Baltic Sea, there are two types of flounder, one with demersal eggs and the other with pelagic eggs (Nissling *et al.*, 2002). A laboratory study showed the eggs of flounder hatching at 6-7 days (Hutchinson and Hawkins, 2004). The pelagic eggs drift with the water currents (Campos *et al.* 1994). After hatching, larval flounder migrate into estuaries (Hutchinson and Hawkins, 1993; Jager, 1999, 2001; Bos, 1999 a, b) utilising tidal currents for transport. (Jager, 1999, 2001; Bos, 1999 a, b).

The process of settlement takes place when the larval flounder metamorphose into a benthic form. The onset of metamorphosis in flounder is size dependant occurring at 8.14 ± 0.61mm (Hutchinson and Hawkins, 2004). The time taken to reach this critical length has been shown by laboratory studies to be temperature dependent (Hutchinson and Hawkins, 2004). The evidence from laboratory (Hutchinson and Hawkins, 2004) and field studies (Berghahn, 1984, cited in Van der Veer *et al*, 1991) suggests that flounder settlement takes place once they reach reduced salinity areas. The timing of first settlement of flounder varies according to the location. In general, settlement occurs from April to May, and later in more northerly regions.

Following metamorphosis, many flatfish species spend at least the first six months of the juvenile phase in coastal nursery grounds (Gibson, 1997). Nursery grounds provide a partial refuge from predation in a productive area that promotes growth (Nash and Geffen, 2005). Juvenile flounder utilise low salinity habitats in estuaries and tidal rivers as nursery grounds (Summer, 1979; Kerstern, 1991; Van der Veer *et al.*, 1991; Berghahn, 1984 in Van der Veer *et al.*, 1991; Hutchinson and Hawkins, 1993) where they exhibit tidal migrations (Berghahn 1984 in Van der Veer, 1991). The preference for water with lower salinity of flounder post-larvae has been shown experimentally by Bos (2006). Juvenile flounder commonly use sheltered soft bottom bare sand habitats (Andersen *et al.*, 2005 a) and have a preference for the shallower water (Riley *et al.*, 1981; Fonds *et al.*, 1992; Modin and Pihl, 1996).

Recreational, commercial fisheries

The most important fisheries for the species are in the Baltic and Danish waters (URL 1). In 1999 the total catch of flounder reported to the FAO was 11,879t with Denmark (3 528 t) and the Netherlands (3 159 t) having the largest catches (URL 1). Flounder is not commercially fished in Irish waters. However, flounder constitute a sporadic bycatch in a number of inshore fisheries in Ireland and there is evidence that the species has been sold for pot-bait (Steve Coates, Environment Agency, pers. comm.) and for human consumption in certain areas such as south-east Ireland (pers obs.).

Recreational fisheries are a valuable resource worldwide especially to peripheral communities with few other sources of income and employment. Flounder are regularly caught by recreational anglers in Ireland particularly on sediment shores. In spite of this no attempt has been made to determine an economic value for the species. Several studies have attempted to quantify the economic value of various species from angling (O'Conner *et al.*, 1975; Radford *et al.*, 1991; Pickett *et al.*, 1995; O'Bara, 1999; Herrmann *et al.*, 2001; Curtis, 2002; Isaksson and Oskarsson, 2002; Mawle, 2002; Ruseski, 2002; Indecon, 2003; Kelch *et al.*, 2006). In an Irish context, such studies are confined to salmon (O'Conner 1975; Fingleton and Whelan, 1993; Curtis, 2002; Indecon, 2003). The value of domestic and overseas sea shore angling in Ireland can be estimated of the order of €24 million (see Chapter 2). However, the value spent on individual shore angling species in Ireland are unknown. Values of up to €20 million (£13.1 million) have been recorded for shore bass angling in England and Wales (Pickett *et al.*, 1995). We know of no previous attempt to estimate the value of any sea angling species to the Irish economy.

There is no information on the abundance or health of flounder stocks in Ireland. Shifts towards smaller size fish and reductions in abundance can be caused by intense commercial exploitation (e.g. Greenstreet and Hall, 1996; Pauly *et al.*, 1998; Jennings *et al.*, 1999). Recreational angling can also reduce target fish stock abundance (e.g. Olsen and Cunningham, 1989; Beard and Essington, 2000; Post *et al.*, 2002) and depress size structure (e.g. Beard and Essington, 2000). Catch Per Unit Effort from recreational fisheries have been used as an indicator of the health of a stock (e.g. Fitzmaurice *et al.*, 2005). Similarly, trophy fish reports can be used to investigate temporal trends in the size structure of a population (e.g. Richardson *et al.*, 2006). Temporal trends in angling catches from a reliable source whose practices have not changed over the years may provide a estimate of stock abundance.

Recruitment and abundance

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). Recruitment processes cover everything that affects survival between spawning and the stage of life where year-class strength is more or less fixed (Van der Veer *et al.*, 2000). Recruitment variability can be studied by comparing estimates of abundance during various life stages over a number of years (Beverton, 1984; Van der Veer, 1991). Trends in variability of abundance during the early life stages give an indication of mortality processes and of the period in which year class strength is determined (Van der Veer *et al.*, 1991). Inter-annual recruitment variation in marine fishes is enormous and has major biological and economic implications for the management of commercial fisheries (Leggett and De Blois 1994). However flatfish are characterised by relatively low recruitment variability (Beverton, 1995).

In flatfish, recruitment variability is generally determined during the pre juvenile phase (Van der Veer, 1986; Leggett and De Blois 1994; Rijnsdorp *et al.*, 1995). Recruitment must be seen as a result of the interplay between habitat quality and quantity (Gibson, 1994). Information on growth of 0-group flatfish suggests that carrying capacity of nursery areas is never reached (Van der Veer *et al.* 2000). Other factors such as the larval supply, hydrodynamic processes and fecundity may also have an influence on recruitment. Success of recruitment of a cohort or year-class depends on the growth and survival of its members (Gibson, 1994). Factors such as predation may generate variability in recruitment of juvenile flatfish (Bailey, 1994).

Recruitment studies of flounder consist of those on 0-group and larval recruitment, and those focused on the juvenile and adult components of the population. Claridge *et al.* (1986) investigated recruitment of flounder and other species from 1972-1977 through impingement of flounder in the intake of a number of power stations in the Bristol Channel and the Severn Estuary. Their study described the duration and peak period of spawning, and the seasonal occurrence, distribution and abundance of larvae, post larvae, and 0-group flounder recruits. There was found to be a period of approximately nine weeks between the time of maximum abundance of flounder larvae and post-larvae (mid-May) in the Bristol Channel and 0-group flounder recruits in the middle of the inner estuary (early August). Variations in the number of flounder (juvenile and adult) impinging on a power station intake in the lower Severn estuary was investigated over a ten year period by Henderson and Holmes (1991). They found high inter-annual variability of up to 8-fold in catches of flounder, which were linked to enhanced abundance of one year olds in the winter and all age groups in the summer. Van der Veer *et al.,* (1991) investigated recruitment of 0-group flounder in the Wadden Sea from 1974-1986 using both plankton and beam trawl sampling. The life history pattern of flounder was similar to plaice in the same area with year-class strength generated in the open sea and after settlement (Van der Veer *et al.,* 1991). However, no relationships between the year-class strengths of plaice and flounder were found (Van der Veer *et al.,* 1991). Draganik *et al.,* (1992) estimated the stock biomass of flounder in the Baltic Sea from bottom trawl surveys and fish catch statistics and found an upward trend in recruitment of flounder to the stock from 1983-1988. Modin and Pihl (1996) investigated recruitment of 0-group flounder in a Swedish bay over a two year period using drop traps. A 1.5 (approx) inter-annual variation in the abundance of flounder was found (Modin and Pihl, 1996). Abundance of 0-group flounder was measured against predation and wind stress with flounder found to settle during or subsequent to the high risk period of shrimp (*Crangon crangon L.*) immigration (Modin and Pihl, 1996). However, survivors occupy a less predator hazardous environment (Modin and Pihl, 1996). Inter-annual variability in abundance of flounder in two Portuguese estuaries from flatfish trawl surveys over the period 1990 - 2004 was investigated by Cabral *et al.* (2007) who found high inter-annual variability (up to approximately 30-fold) in the densities of flounder juveniles, with a decadal trend shown in one estuary (the Tejo) where it has become extremely rare since the early 1990s.

Settlement dynamics

There are several studies documenting the effects of habitat and abiotic factors on flounder settlement. It is generally accepted that flounder larvae migrate into estuaries utilising tidal currents for transport (Jager, 1999, 2001; Bos, 1999 a, b). However there have been few studies on the dynamics of flounder settlement in estuaries.

0-group flounder are usually found in waters of salinities lower than 28ppt (Riley *et al.*, 1981). Postlarval and juvenile flounder were shown in the laboratory to have a preference for freshwater over salinities of 5, 10, 15 and 20ppt by Bos (2006). Indeed, larval flounder can be induced to metamorphose when transferred to reduced salinities once a critical length is reached (Hutchinson and Hawkins, 2004). Field studies have shown 0-group flounder to be abundant in areas of low salinity (Hutchinson and Hawkins, 1993; Jager *et al.*, 1993; Kersten, 1991; Bos, 1999 b; Vinagre *et al.*, 2005). Comparisons of abundance and lengths of 0-group flounder within various habitats have been documented by Bregnballe (1961) and Kersten, (1991). However the aforementioned studies did not deal with the settlement dynamics of flounder in relation to habitat and other abiotic factors. A gap therefore exists in our knowledge between the larval ecology and the dynamics of 0-group flounder. The influence of abiotic factors such as habitat, salinity and temperature on flounder settlement has not been documented from field studies.

Otoliths are calcified structures located in a fish's head which may be used to determine life history characters in some fishes. Otoliths provide a permanent record of fish life history events which show annual and daily patterns. Otolith microstructure analysis allows the estimation of individual age at different stages during the early life history of juveniles. There are only two published studies on ageing of flounder using otolith microstructure. Bos (1999a, b) aged larval flounder from the river Elbe from daily increment counts using light microscopy. There are no published studies dealing with the dynamics of flounder settlement using otolith microstructure. Flatfish otoliths contain a number of structures associated with particular life stages such as the check associated with hatching (e.g. Hovenkamp, 1990; Legardere and Troadec, 1997) and the accessory primordia associated with metamorphosis (e.g. Sogard, 1991; Toole *et al.*, 1993; Modin *et al.*, 1996). There is a deficit of research into the deposition into of such structures in flounder otoliths. Hatching dates for flounder have not previously been calculated, although it is uncertain whether flounder deposit the distinctive hatch checks on their otoliths associated with hatching. Larval durations, settlement dates and larval otolith growth rates have also not previously been calculated for flounder. There is a dearth of information on the dynamics of flounder settlement and the affect of settlement on otolith microstructure such as the deposition of the accessory primordia.

Aims and background of the present study

The research reported in this thesis had two aims. The first was to establish a socio-economic value for the species from angling tourism. The second was to address the deficit in our knowledge of the population dynamics of 0-group flounder both in an Irish and overall context. The research carried out forms part of an ongoing programme at the Galway-Mayo Institute of Technology on the ecology of commercial flatfish species. There were three years of archival information (2002-2004) available from a push net sampling programme on sandy beaches in Galway Bay for 0-group plaice (Allen, 2004). 0-group flounder constituted a bycatch of this programme. This programme was continued in 2005 and 2006. However, given the paucity of spatial and temporal data for 0-group flounder in the push net samples (see Chapter 3) it soon became apparent that the sampling programme needed to be expanded in 2005 and 2006. The need to sample tidal rivers was identified and the sampling was expanded into tidal rivers in 2005 and 2006. This added a new dimension to the project and enabled us to investigate the population dynamics of 0-group flounder in relation two different habitats (beaches and rivers) in Galway Bay. The push net was unsuitable for sampling in tidal rivers so new methods of sampling needed to be investigated. The analysis of the population dynamics included the use of otolith microstructure. There has been little previous work done on otolith microstructure for flounder and the project aimed to address some of the issues discussed above.

The thesis contains a series of self contained chapters. One chapter deals with the value of flounder from shore angling tourism and the other two contain aspects of 0-group flounder biology and ecology as follows:

Chapter 2: The value of flounder from shore angling around Ireland was assessed. Flounder catches from shore angling tournaments around Ireland were estimated and its relative contribution related to domestic and overseas shore angling expenditure in order to determine an economic value for the species. Flounder angling catches, and specimen (trophy) flounder reports were examined for temporal trends and evidence for a decline in the stock.

Chapter 3: The aim was to determine the population dynamics of 0-group flounder during the early benthic phase of life history in Galway Bay. The abundance of 0-group flounder from five years of push net sampling and two years of tidal river sampling was investigated. The settlement and early benthic life of flounder in sandy beach and tidal river habitats was examined over a number of temporal and spatial scales and in relation to abiotic factors.

Chapter 4: The aim was to age newly settled flounder using otolith microstructure. The hatch dates, larval and post larval durations, settlement dates and the deposition of the accessory primordia (often associated with metamorphosis) on flounder otoliths were examined in relation to beach and river habitats. Otolith daily increments from day 20 to 25 after hatching were used as an index of larval growth. The information from hatch dates was used to determine spatial and temporal patterns and the early benthic life history of flounder.

The results of these studies are discussed separately with the general discussion combining the results of the thesis for an overall analysis.

Chapter 2: Flounder: A valuable and sustainable resource from shore angling in Ireland

Abstract

Flounder are a non-commercial species in Ireland caught by anglers particularly on sandy shores. The value of flounder from shore angling around Ireland was determined. Information was gathered from shore angling competitions around the Irish coast and the percentage flounder in the overall shore angling catch was calculated. Angling score cards from shore angling competitions were obtained for the Munster (south west Ireland) region for the period 1989-2005. Temporal trends in the percentage flounder caught were analysed. These percentages were then related to tourism income for overseas and domestic angling tourism to calculate a value for the species. Flounder was found to be the most caught shore angling species in competitions around Ireland constituting roughly one third of the shore angling competition catch, although this did vary by area. A total value of flounder from shore angling tourism was estimated to be in the order of €8.4 million. Conservative estimates for the value of flounder from shore angling, classifying the species as "non-preference", were €1.16 million from overseas shore angling in 2002 and €1.63 million from domestic shore angling in 2003. Angling Catch Per Unit Effort was calculated from the Munster tournament data to examine temporal trends in flounder stocks. There has been no significant change in the flounder angling Catch Per Unit Effort for the Munster region from 1989-2005. Specimen (trophy) fish records from 1963-2005 were used to examine whether flounder specimens were becoming smaller or less abundant. There has been no significant change in the size or number of flounder specimens (>1.361Kg) caught from 1963-2005 although the values have fluctuated over the time period. Flounder were shown to be a valuable and sustainable resource from shore angling in Ireland.

Intoduction

Sea shore angling is an important contributor to the Irish economy generating employment in peripheral regions of the country with few other alternative industries. The importance of angling to the Irish tourism industry has been emphasised by figures collected by the national tourism development authority (Failte Ireland). Failte Ireland figures (Anon, 2000) estimate that in 2002, 87,000 anglers visiting Ireland from overseas generated a total revenue of €55.1 million from all angling activities. It can be estimated that in 2002, 16,000 overseas sea shore anglers spent €10 million in revenue (Anne Wilkinson, Marine Institute, pers. comm.). Overseas anglers who engaged in angling spent an estimated €65.8 million in 2004 (Anon, 2004a) with seventy three percent of holidaymakers who went angling in Ireland stating that angling was important in their decision to come to Ireland for a holiday (Anon, 2004a).

In 2003, the domestic tourism revenue generated from all angling activities was €58.9 million (Anon, 2004b). In 2003, 74,000 domestic participants spent €13.9 million on shore angling activities (daytrips, equipment, overnight expenditure) in Ireland (Anon, 2004b). Information gathered from questionnaires compiled for the Anon (2004b)' study indicate that the majority of these shore angling activities are based on sandy shore environments (Anne Wilkinson, Marine Institute, pers. comm.). Combining the figures for domestic and overseas shore angling the estimated total value is in the order of €24 million.

Several studies have attempted to quantify the economic value of various species from angling (O'Conner *et al.*, 1975; Radford *et al.*, 1991; Pickett *et al.*, 1995; O'Bara, 1999; Herrmann *et al.*, 2001; Curtis, 2002; Isaksson, 2002; Mawle, 2002; Ruseski, 2002; Indecon, 2003; Kelch *et al.*, 2006). In an Irish context, these are confined to salmon (O'Conner 1975; Fingleton and Whelan, 1993; Curtis, 2002; Indecon, 2003). The studies are based on expenditure of anglers from angling tourist information (Indecon 2003), recreational fishers' surveys (O'Conner 1975; Radford *et al.*, 1991; O'Bara, 1999; Rusedski, 2002; Indecon 2003; Nautilus Consultants, 2005; Kelch *et al.*, 2006), angling figures (Fingleton and Whelan, 1993; Isaksson, 2002) and predictive models (Herrmann *et al.*, 2001; Curtis, 2002a). We know of no previous attempt to estimate the value of any sea angling species to the Irish economy.

Flounder (*Platichthys flesus L.*), a non-commercial species in terms of the Irish fishing industry, are regularly caught by recreational anglers particularly on sandy shores. In this paper, we set out to determine the value of flounder as an angling species to the Irish economy and investigate temporal catch trends in the flounder angling tournament data.

Sea anglers in Ireland commonly complain that the fish they catch are noticeably smaller and less numerous and often blame commercial fishing. Indeed 15% of sea anglers questioned in Anon' (2004b)' study listed "poor fish stocks" as a comment about the state of the marine environment in Ireland. A similar situation was observed in the UK (Richardson *et al.*, 2006). There is a perceived reduction in flounder catches by anglers in parts of the UK with 70% of anglers surveyed in south west England noticing a decrease in flounder stocks (Nautilus Consultants, 2005). In Ireland, reductions in abundance of the blue shark have been recorded from boat angling CPUE information (Fitzmaurice *et al.*, 2005). Shifts towards smaller size fish and reductions in abundance can be caused by intense commercial exploitation (e.g. Greenstreet and Hall, 1996; Pauly *et al.*, 1998; Jennings *et al.*, 1999). Recreational angling can also reduce target fish stock abundance (e.g. Olsen and Cunningham, 1989; Beard and Essington, 2000; Post *et al.*, 2002), depress size structure (e.g. Beard and Kamp, 1999; Beard and Essington, 2000) and have negative ecological impacts (Coleman *et al.*, 2004). Richardson *et al.*, (2006) investigated perceived and actual trends in anglers' trophy fish catches and investigated whether catches bore any relationship to abundance trends in commercial target stocks. Perceived trends were identified by means of a survey while actual trends were taken from national anglers federation catch data, information from sea angling magazine reports and commercial landings data (Richarson *et al.*, 2005). Of the sea anglers surveyed, decreases in the sizes and numbers of fish were noticed by 63% and 64% respectively. Of the anglers that proposed an explanation for the declines, 67% of anglers suggesting that commercial overfishing was responsible (Richardson *et al.*, 2006). However, there were few correlations of trophy fish catch data with commercial landings per unit effort (LPUE) (Richardson *et al.*, 2006).

There are no data on the catches of flounder by tourist anglers in general. In fact, many of these fish would be released following capture. However, there are good data on the catch rates of flounder from beach angling tournaments. We will use the proportion of flounder caught during tournament fishing to estimate the proportion caught by tourist anglers in general. This proportion may then be used to estimate the value of this fish to the Irish tourism angling revenue. To our knowledge this approach has not been adopted previously when estimating the value of a species.

There has been no stock assessment carried out for flounder in Irish waters. Flounder are a non-commercial species in Irish waters so it is not possible to compare catch data with commercial landings. Fitzmaurice *et al.*, (2005) used Catch Per Unit Effort information from Irish recreational charter boat skippers to provide an estimate of stock abundance of blue shark. Catch and effort information from angling tournaments in the Munster region and specimen (trophy) fish information was used in this account to investigate if there was any temporal trends in catches of flounder.

Two data sets were explored for the stock assessment work:

1. CPUE for Munster tournaments alone (only place with the appropriate temporal data): To test the hypothesis that there has been a decline in flounder catch rate.
2. National specimen fish data: To test the hypothesis that the larger fish have been harvested out. Have the specimen fish reported got smaller? Or have specimen fish abundances declined?

Materials and Methods

Angling tournaments take place throughout the year around the Irish coast. Score cards and catch records from various shore angling tournaments around Ireland were collected through various shore angling clubs, individual anglers and the Irish Federation of Sea Anglers (IFSA)(Table 1). Information extracted from the score cards included the number of flounder caught, the number of fish caught, and the number of anglers. It is assumed that the number of flounder listed on angling score cards represents the actual number of flounder caught. There may be some problems with misidentification of flounder as dabs, plaice, hybrids and other flatfish species in some areas but this is unlikely to be so for most angling tournaments, where experienced anglers are present.

Table 1. List of the angling clubs, organisations and companies who provided information during the course of this study.

Organisation
Irish Federation of Sea Anglers Munster/Leinster/National Councils
Galway Bay Sea Angling Club
Rinnashark Sea Angling Club
Kilmore Sea Angling Club
Bray Sea Anglers
Lisdonvarna-Fanore Sea Angling Club
Organisers of the 2005 Dingle Pairs
Shoreline Angling, Cork

The percentage flounder of the total catch was calculated for a random selection of tournaments around Ireland in recent years. The percentage of flounder of the total competition angling catch was also calculated for each year from 1989-2005 for the IFSA Munster shore angling competition data. The percentage of flounder caught in shore angling tournaments was used to assess the value of flounder to the Irish economy by relating it to the total shore angling spend.

The Catch Per Unit Effort (CPUE) of flounder was calculated for each year in the Munster tournaments by dividing the total number of flounder caught in one year by the total number of anglers. Each angler was counted once for fishing in one tournament therefore the value derived will be the number of flounder per angler per tournament. This value was used to assess if there was any long term declines in flounder angling catches and can be used as a measure of stock assessment for flounder populations in Ireland.

The number of specimen flounder was extracted from the 1963-2005 specimen fish reports. The specimen size for flounder was increased in 1967, it also increased to 1.361Kg in 1984 and is currently at this level. Thus, from 1963-2005 only fish above 1.361Kg were considered as specimens in order to standardise the data. The data was tested for normality using Ryan-Joiner tests, and where the assumption of normality was violated, analysed statistically using non-parametric tests. A Spearman Rank test was used as a non-parametiric measure of correlation. Similar to the CPUE data, trends in the specimen fish reports can be used to assess flounder stock health through evidence of declines in specimen numbers and size.

Results

Club tournaments, Ireland:

Club results were from areas in the mid east coast, the south east, south coast, south west and the west coast. The results are summarised in Table 2. The mean percentage of flounder of the total catch was 35%. The percentage ranged from 0% in a tournament in Galway Bay to 95% from the Dingle Pairs in an unknown year. There are certain areas such as the mid east coast south of Dublin where few flounder are caught. Other areas such as the south east and south west have a considerable number of "flounder venues" in which flounder are the dominant species caught.

Information gathered indicates that most of the shore angling tournaments carried out in Ireland are on sandy shores. There are however, certain areas of Ireland where rocky shore angling takes place and anglers are not generally fishing onto sand either through preference or lack of available sandy shore habitat. One such example is the area fished by Lisdonvarna - Fanore Sea Angling Club where most of the club angling is done over foul rocky areas and typically only 10-20 flounder are caught per season (J. Linnane, Lisdonvarna - Fanore Sea Angling Club, pers. comm.). The contribution of flounder to the total catch in boat angling tournaments is relatively insignificant when comparing with shore angling (Peter Green, Central Fisheries Board, pers. comm.) with only 3 flounder caught in a total of 13,407 fish in the Munster region in the 2004/2005 boat angling season (IFSA). They may however be an important species in some areas where dinghy tournaments are taken place (Norman Cook, Central Fisheries Board, pers. comm.).

Table 2. Results of various shore angling tournaments around Ireland. N/A information not available. Information from angling clubs around Ireland.

Festival	No competitions	No. anglers	No. flounder	No.fish	% Flounder
Dingle Pairs 2005	4	128	725	1146	63
Dingle Pairs 2000	4	140	950	1000	95
Kilmore SAC winter festival 2004	N/A	N/A	1057	1692	62
Bray Sea Anglers beach master angler results 03/04	6	66	6	212	3
Bray Sea Anglers beach master angler results 02/03	8	88	3	234	1
Bray Sea Anglers beach master angler results 01/02	7	32	2	171	1
Rinnashark SAC 2004	9	197	175	408	43
Rinnashark SAC 2005	9	139	71	208	34
Galway Bay SAC 2005	3	N/A	0	131	0
Galway Bay SAC 2005	1	10	25	59	42
Mean					35

Munster tournaments

The yearly (1989-2005) contribution of flounder to shore angling tournament catches in the Munster region are shown in Fig 1. This included shore angling from beaches and other areas such as piers. The percentage flounder of the total number of fish caught ranged from 17% in 1997 to 42% in 2005 (Fig 1), with a mean of 28% from 1989-2005. There was no correlation between percentage flounder and time (Spearman rank coefficient R_s=0.2, p = 0.43).

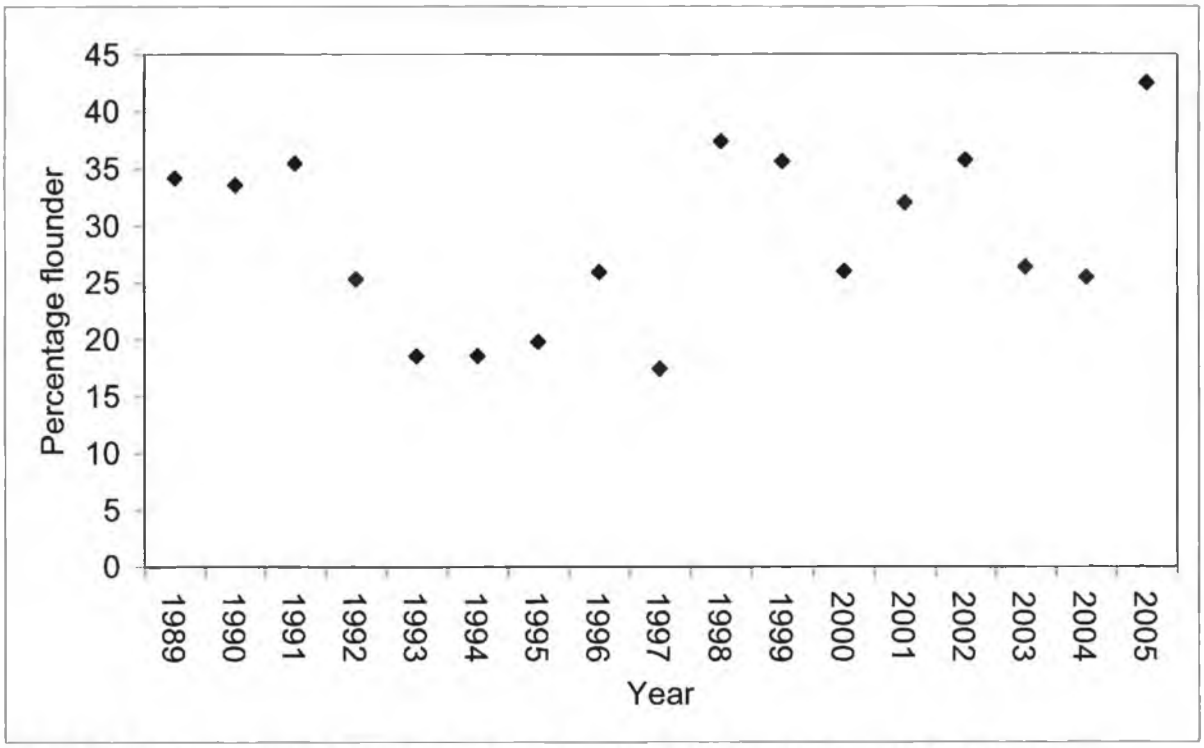

Fig 1. The percentage flounder of total marine fish species caught in Munster shore angling tournaments from 1989-2005. Information from Liam Power, Munster Recorder, IFSA.

Taking into account that the percentage flounder of the total marine species in the Munster shore angling competitions did not significantly change over the period 1989-2005 it is reasonable to assume the contribution of the species to the total annual shore angling catch stays relatively constant and their value depends on the number of shore angling visitors.

Value of flounder:

The percentage contribution of flounder to the tournaments for Munster only and for Ireland as a whole are in broad agreement, thus a value for the contribution of flounder to the angling catch of 35% is used here.

Using the shore angling monetary values available and the percentage of flounder in shore angling catches, flounder were worth €4.9 million from domestic shore angling in 2003 and €3.5 million from overseas shore angling in 2002. Thus the total estimated value of flounder from shore angling tourism to be of the order of €8.4 million.

Flounder CPUE Munster tournaments

A total of 30,681 anglers took part in 1219 IFSA Munster tournaments over the period 1989-2005. The numbers of anglers participating varied by as much as 900 from one year to the next. The mean number of flounder caught per angler per tournament (Catch Per Unit Effort) scarcely fluctuated during this period (Fig 2), with an average of 0.4 flounder caught per angler per tournament. There was no significant trend in the CPUE of flounder against time (Spearman rank coefficient, R_s=0.43, p=0.88)

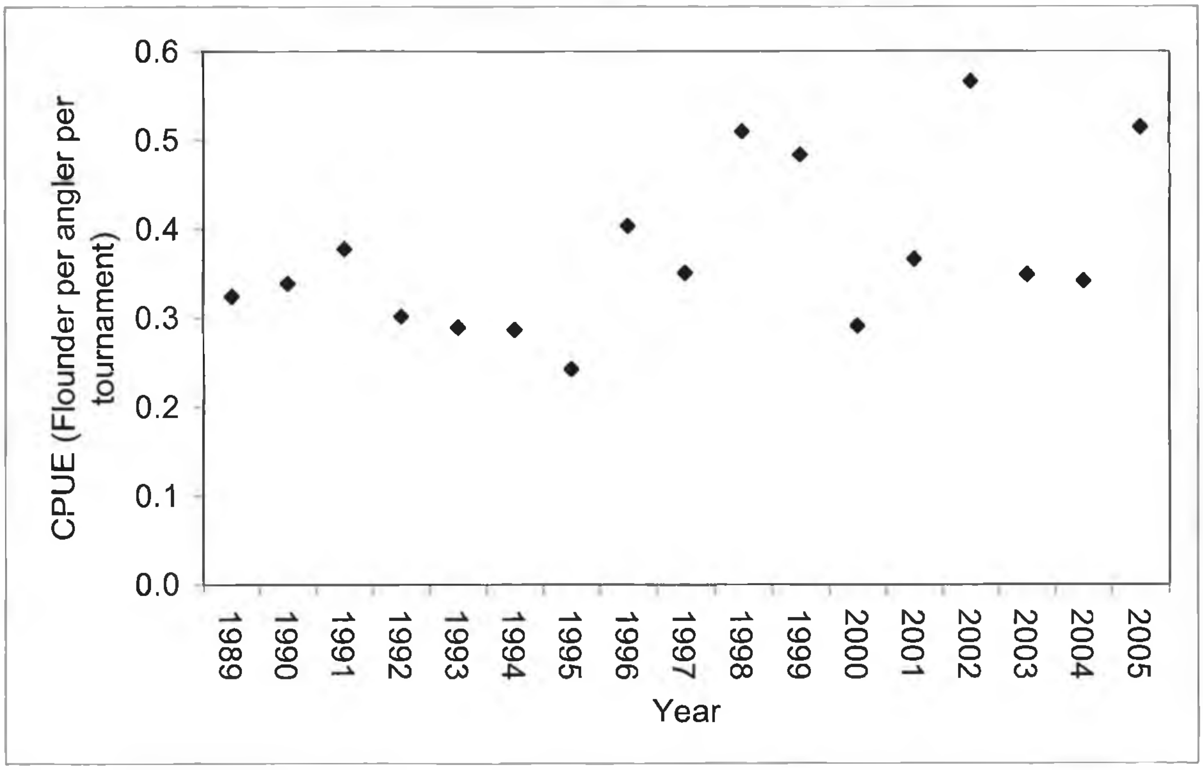

Fig 2. Catch Per Unit Effort (Flounder per angler per tournament) of anglers in Munster shore angling tournaments from 1989-2005, (number of anglers = 30,681). Information from Liam Power, Munster Recorder, IFSA.

Specimen fish list

A total of 313 flounder were reported to the ISFC over the period 1963-2005. The number of flounder specimens (>1.361 Kg) caught has fluctuated from 1963-2005 (Fig 4). Highest numbers were recorded in the late 70s and early eighties with a peak of 34 in 1978. This was followed by a smaller peak in the early nineties, with 15 specimens recorded in 1993. The number of flounder specimens has mostly been below five per year for the rest of the time period. There was no significant correlation of the number of flounder specimens with time (Spearman rank coefficient, R_s= -0.11, p = 0.48).

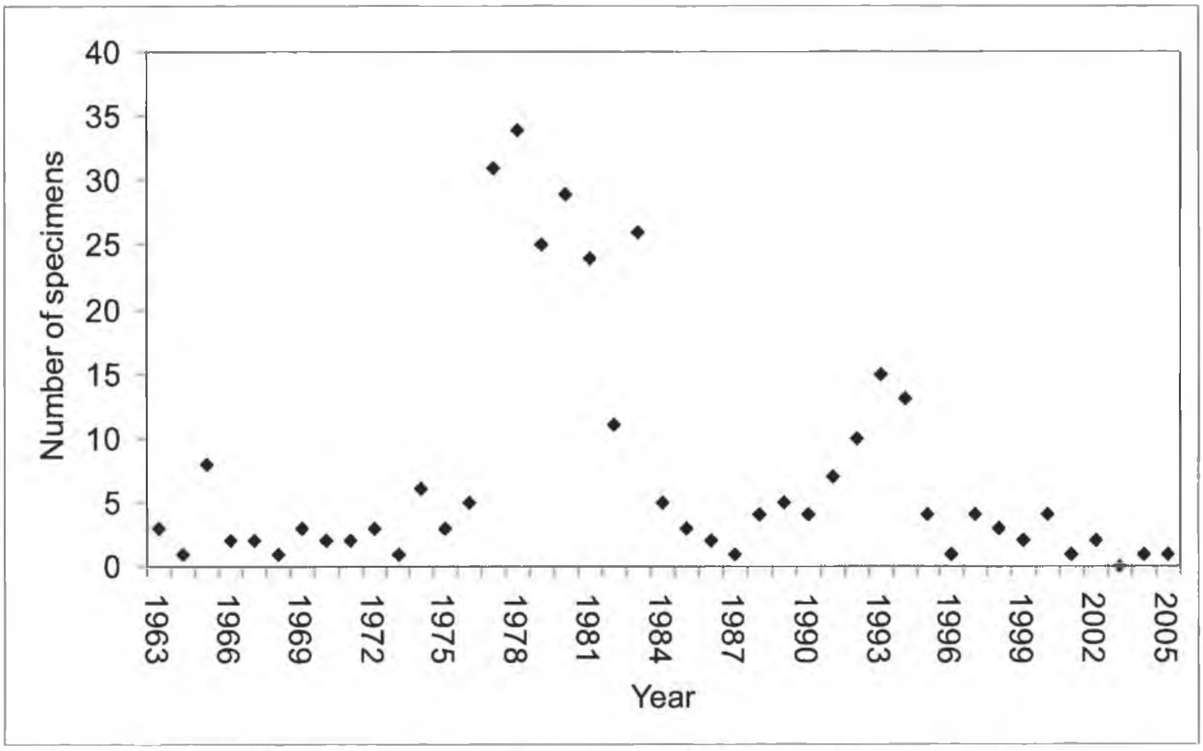

Fig 4. The numbers of specimen flounder (>1.361Kg) reported to the Irish Specimen Fish Committee from 1963-2005. Information from annual reports of the Irish Specimen Fish Committee.

The mean and maximum weights per year of Irish flounder specimen fish are shown in Figure 5. There was no significant correlations with time in the data over the period of the study (Spearman rank coefficient, $R_s = -0.05$, $p = 0.75$ for mean weight; Spearman rank coefficient, $R_s = -0.1$, $p = 0.5$ for max weight).

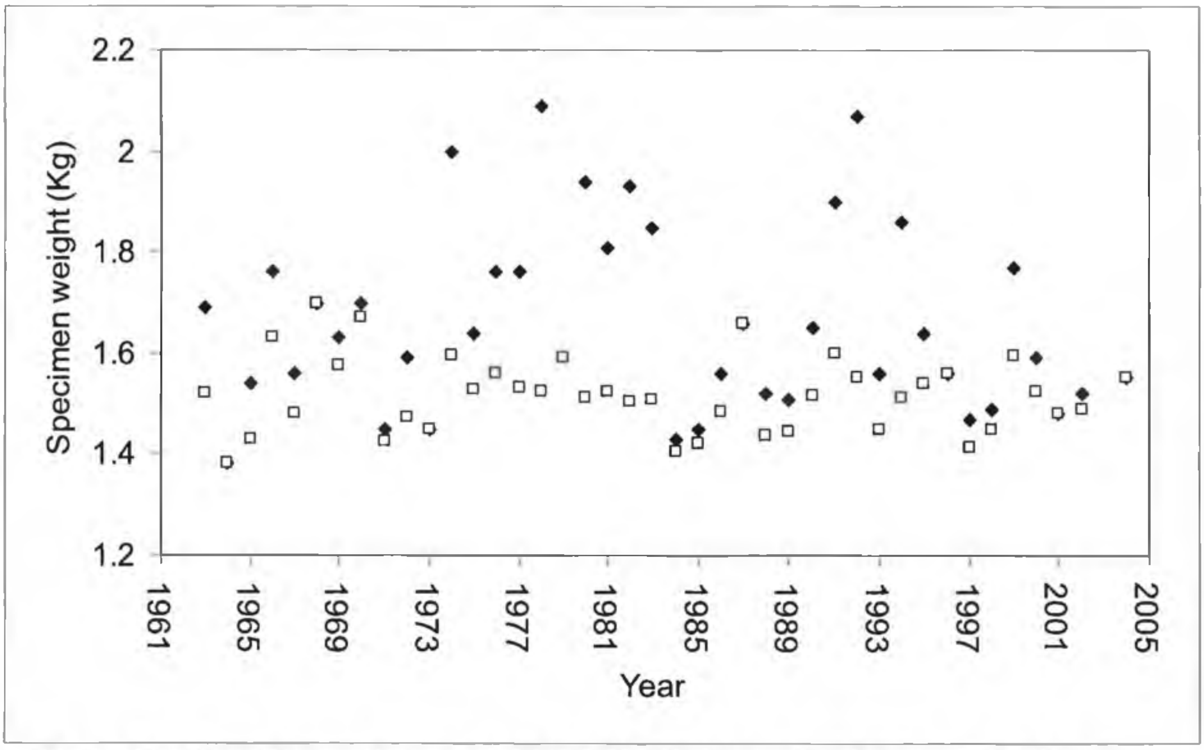

Fig 5. The flounder specimen weight (>1.361 Kg) over the time period with mean (open squares) and maximum (diamonds) weights per year (1963-2005).

Discusion

Value of flounder

Seventy three percent of the 78,000 holidaymakers who went angling while in Ireland stated that angling was important in their decision to come to Ireland for a holiday (Anon, 2004a). The present study has quantified the value of flounder as a contributor to angling tourism in Ireland. It is difficult to compare values with other studies given the variety of survey methods used, monetary inflation over time, and the variety of currency involved. The values for overseas or domestic flounder angling compare favourably with €534,351 (US $700,000) for the walleye recreational fishery in the USA (O' Bara, 1999) and are generally less than those reported for salmonids (Radford *et al*,. 1991; Isaksson, 2002; Rusedski, 2002; Kelch *et al.*, 2006) or sea bass (Pickett *et al.*, 1995). The Indecon (2003) report values average annual income generated by overseas salmon anglers between 1998 and 2000 at €6.43million, greater than the €3.5million for overseas flounder angling. The value for domestic salmon angling was €4.59 million in 2001 (Indecon, 2003) which is less than the €4.9 million for domestic flounder angling. Pickett *et al.* (1995) estimated that in 1992, €20 million (£13.1 million) was spent on shore bass angling in England and Wales. The indications are that flounder are worth more to the Irish economy than commercial flatfish species such as Turbot and Brill which were worth €2 and €0.7 million respectively to the Irish commercial fishery in 2002 (Anon, 2003).

Lawrence (2005), states that anglers would pay only a third as much for increased catches of non favourite species. This value is based on survey of 240, 900 sea anglers in south west England, where respondents were subjected to a choice experiment evaluating the contribution of different attributes to an angling experience (e.g. the trade off between the size and number of fish caught). The present study does not take into account anglers' species preference. It may be the case that a days' fishing catching numerous flounder may be of less value than a week's fishing catching one or two bass. Although bass were well below the average number of fish caught per day in the Nautilus Consultants (2005) report they were listed as a favourite species by approximately 45% of anglers questioned. However, a national survey of bass angling in the UK revealed that over two thirds of boat and shore anglers in the UK admitted to fishing for "anything" (Pickett at al., 1995). The

Nautilus Consultants (2005) south west England report found that flounder was nominated as a favourite target species by few (<5%) of the anglers questioned in a survey of species preferences (although the study notes that feedback from anglers suggest that this may be understated, and only 59% of the respondents were shore anglers). The National Federation of Sea Anglers (NFSA) in the UK lists flounder as fourth in the lists of preferred species and sixth in the list of most caught species for UK sea anglers (URL 2). Given Lawrence' (2005) study, the values given above are possibly one third of the value (€1.63 million from domestic shore angling in 2003 and €1.16 million from overseas shore angling in 2002) if flounder turn out to be a non favoured species. In terms of shore angling tournaments in Ireland, several are located in "flounder venues" in which the vast majority of fish caught are flounder (P. Atkins; C. Busher; P. Green; L. Power, pers. comm.) showing that anglers are actively targeting flounder and thus it is a preferred species. The species is also of value from a points scoring point of view for shore angling tournaments (IFSA). It appears that more information is needed on anglers' species preferences in an Irish context.

Stock

It is uncertain if the metrics used in this study are a good indication of the overall health of the stock. Fitzmaurice *et al.*, (2005) suggested that angling CPUE from a reliable source whose practices have not changed over the years can provide a reasonably good estimate of stock abundance. The extent of changing shore angling tournament practices is largely unknown although the information is likely to be reliable. Morales-Nin (2005) reported that the government in the Balearic Islands routinely monitors recreational fishing competitions and used this catch and weight information to calculate the yield for target species from the fishery. Despite the absence of weight data, there exists the potential to calculate exploitation levels of Irish recreational fisheries although catch and release may be operational in many. One of the advantages of using tournament data rather than questionnaires to calculate the number of a particular species caught is that it tends to be more accurate. The Nautilus Consultants' (2005) report states that an average of six fish per day across all species in south west England is likely to be an overestimate as respondents in a questionnaire tend to report the number of fish on a "good day" rather than a "typical day". This is unlikely to happen in tournaments where the species and numbers are accurately recorded on the day.

Shifts towards smaller size fish and reductions in abundance can be caused by intense commercial exploitation (e.g. Greenstreet and Hall, 1996; Jennings *et al.*, 1999; Pauly *et al.*, 1998). In the absence of any commercial data for flounder in Irish waters it is not possible to relate angling catch levels to commercial information. The extent of unregulated commercial fishing for flounder in Irish waters is largely unknown. There are some trawl fisheries for the species in the Munster Blackwater (Edward Fahy, Marine Institute, pers. comm.). Evidence from the UK suggests that Irish flounder are being sold for pot bait in the UK (Steve Coates, Environment Agency, pers. com.). Given the value of this species to recreational angling it appears prudent to adopt the precautionary approach to commercial fisheries exploitation of the species.

Decreases in abundance of target stocks due to recreational fishing have been reported by a number of authors (Olsen and Cunningham, 1989; Beard and Essington, 2000; Post *et al.*, 2002). The IFSA competition rules state that all fish in IFSA competitions are to be returned alive with the exception of trophy fish and those retained for culinary use, of which a minimum landing size of 250mm applies to flatfish. The fact that that catch and release for flounder is widespread appears to be beneficial to the conservation of flounder stocks although Fitmaurice *et al.*, (2005) found a decline in CPUE for blue shark in the Irish boat angling fishery over the period 1989-2002 even though all of the blue shark caught in the fishery were tagged and released (pers. obs.).

It appears that the hypothesis that flounder specimens have become less numerous now than in the past can be rejected. Although there is no significant change in the number of flounder specimens caught from 1963-2005, the number of flounder exhibited a boom and bust pattern. In contrast, Richardson *et al.*, (2006) found strong temporal declines in the number of trophy thornback ray, cod and the total number of trophy fish in Wales, UK.

The fact that there is no significant decrease in CPUE of flounder over time (1989-2005) in the Munster region is encouraging news for angling tourism. In contrast 70% of anglers surveyed in south west England noticed a decrease in flounder stocks (Nautilus Consultants, 2005). It appears unlikely that perceived trends of "poor fish stocks" by sea anglers in Ireland (Anon, 2004b) can be applied to flounder as there has been no decrease in CPUE from 1989-2005 and flounder make up a substantial portion (35%) of the national shore angling tournament catch.

There was also no evidence that flounder specimens were getting smaller. This contrasts to perceived and actual trends showing a decline in specimen thornback ray sizes in Wales (Richardson *et al.*, 2006). Recreational fishing can have a negative effects through size selectivity for example through hook size (Beard and Kampa, 1999). A stunting effect of bluegill individuals was found in the United States recreational fishery by selectively removing individuals greater than 150mm (Beard and Kampa, 1999). It appears likely that, as many of the flounder specimens caught are confined to just a few localised areas or "hot spots", they may be particularly vulnerable to localised effects. Given that the IFSA allows retention of flounder greater than 25cm and the full body for specimen flounder must be submitted to the Irish Specimen Fish Committee (ISFC) there may be some selective removal of larger specimens in certain areas. Without definitive information on the angling effort and reporting levels for specimen fish some caution must be exercised in drawing strong conclusions from the specimen fish data.

The present study has shown the importance of flounder as an angling species in Ireland. The contribution the species makes to the domestic economy exceeds that of many commercial species which are subject to quota controls and management plans. Its value would suggest that it is prudent to introduce management measures to protect the species and its habitats. Flounder were found to be a substantial component of shore angling tournaments in Ireland. Thus flounder appear to be one of the commonest species on sandy beach and estuarine environments in Ireland. Although no long term declines in the angling catches or the size and number of specimens were found, local declines may be evident and require further research. Flounder were shown to be a valuable and sustainable resource to the Irish economy.

Chapter 3: The population dynamics of 0-group flounder in Galway Bay

Abstract

0-group flounder were sampled from Galway Bay sandy beaches and tidal rivers using push nets, drop traps and hand nets. Information from the March to June sampling period from 2002 to 2006 was analysed in order to determine the population dynamics of 0-group flounder during the early stages of benthic life.

First appearance of 0-group flounder ranged from late March – early May of each year and occurred most commonly in April. Late March settlement on sandy beaches is earlier than observed in any other known study. Peak densities of 0-group flounder on sandy beaches and tidal rivers were recorded in April or early May. Settlement was generally later in tidal rivers than on sandy beaches. Flounder disappeared from beach samples in a matter of weeks but were present later in tidal river samples. April settlement in rivers was similar to that in tidal rivers in the southern part of the UK and northern France.

Abundance of 0-group flounder in Galway Bay did not exhibit significant inter - annual variability. There was also no significant difference in densities between beach and river habitats or sites over a three week period during peak settlement in April of 2005. Therefore, both habitats are equally important for settlement. Highest densities of 0-group flounder were recorded in limnetic and oligohaline areas as compared with the lower densities in polyhaline and to a lesser extent mesohaline areas. Densities ranged from 0 m^{-2} up to a maximum of 15m^{-2} on sandy beaches, and 0 m^{-2} to 105 m^{-2} in tidal rivers. 0-group flounder were observed to form dense aggregations which were patchy in distribution in beach and tidal river habitats.

Tidal rivers near the mouth were divided into upstream to downstream sections and along with beaches categorised according to salinity. Sandy beaches were classified as polyhaline, the lower section of tidal rivers as mesohaline, and the middle and upper sections of tidal rivers as oligohaline. 0-group flounder in Galway

Bay utilised different sections at different length ranges and were significantly larger in more upstream sections. During initial settlement in April 0-group flounder of 8-10 mm (Standard Length) are present in abundance on polyhaline sandy beaches. By about 10mm (SL), flounder are present in all (polyhaline, mesohaline and oligohaline) sections. 0-group flounder then became absent or in insignificant numbers in polyhaline and mesohaline sections in a matter of weeks. From April –June, larger 0-group flounder of 12-30mm (SL) were found in more upstream locations in the oligohaline section. About one month (May or June) after initial settlement 0-group flounder become absent from the oligohaline areas. This happens at about 30mm in length. Concurrently, flounder start to reappear in mesohaline and polyhaline areas in about June at approximately 30mm in length. The results indicate 0-group flounder in the early benthic stage have a preference for low salinity areas, but as they grow, this preference wanes. Length frequencies distributions strongly suggest immigration of 0-group flounder between sections takes place.

Growth rate, taken as the increase in mean standard length per month of 0-group flounder over the main growth period was assessed. The average daily observed growth rate for 0 group flounder in Galway Bay was 0.25 $mm.d^{-1}$. Growth rates were generally less than those recorded elsewhere with possible density dependant factors operating at least one of the sites (Oranmore).

Introduction

Flatfish are an important component of Irish commercial landings. Species such as plaice, *Pleuronectes platessa* L., turbot, *Scopthalmus maximus* L., and brill, *Scophthalmus rhombus* L. are all valuable components of Irish commercial fisheries (Anon, 2005). In recent years, the value of recreational fisheries in Ireland is being realised. Species such as flounder, *Platichthys flesus* L and dab, *Limanda limanda* L. are non-commercial, but important for recreational sea angling in Ireland (see Chapter 2). Flounder are one of the main shore angling species in Ireland. Despite this fact, little research has been done on the species in Ireland.

The flounder, a member of the *Pleuronectidae* family of fishes (right-eyed flounders), is a species found in inshore areas and estuaries (Wheeler, 1969). In winter, adults leave the estuary (Russell 1976; Dando & Ling, 1980; Johnson 1981; Bos, 1999 b). They move offshore to spawn in Spring (Wheeler, 1969; Dando & Ling, 1980; Johnson 1981) in about 20-40m depth of water. (Wheeler, 1969). Aggregation of flounder at sea occurs during late winter to early spring and lasts on average about 1 month (Sims *et al.*, 2004). Flounder spawning migrations appear to be driven by short term climatic induced changes in their over wintering habitat, with populations exhibiting more synchronous and earlier spawning migrations in response to lower temperatures in the estuary (Sims *et al.*, 2004). In parts of western Europe, adult flounders leave the estuaries to spawn from December – March in the deeper parts of the Southern Bight of the North Sea (Russell, 1976, Harding, 1978). Other spawning grounds have been reported off south-west England (Sims *et al.*, 2004) and in the Baltic Sea (Cieglewicz, 1947; Nissling *et al.*, 2002). In the Baltic Sea, there are two types of flounder, one with demersal eggs and the other with pelagic eggs (Nissling *et al.*, 2002). A laboratory study showed the eggs of flounder hatching at 6-7 days (Hutchinson and Hawkins, 2004). The pelagic eggs drift with the water currents (Campos *et al.* 1994). After hatching, larval flounder migrate into estuaries (Hutchinson & Hawkins, 1993; Jager, 1998, 1999, 2001; Bos, 1999a,b) utilising tidal currents for transport. (Jager, 1999, 2001; Bos, 1999a,b).

The process of settlement takes place when the larval flounder metamorphose into a benthic form. The onset of metamorphosis in flounder is size dependant occurring at 8.14 ± 0.61mm (Total Length) (Hutchinson and Hawkins, 2004). The time taken to reach this critical length has been shown by laboratory studies to be temperature dependant (Hutchinson and Hawkins, 2004). The evidence from laboratory and field studies suggests that flounder settlement takes place once they reach reduced salinity areas. In the laboratory, post larvae that have reached critical length, show immediate onset of metamorphosis once transferred to reduced salinity (Hutchinson and Hawkins, 2004). In the Wadden Sea, settlement was observed close to fresh water inlets (Berghahn, 1984 in Van der Veer *et al*, 1991).

The timing of settlement of flounder varies according to the location. In general, settlement occurs from April to May, and later in more northerly regions. Robin (1991) first sampled 0-group flounder from early April at the Cordemais power station intake, France. The first appearance of 0-group flounder occurred in mid April in the Bristol Channel (Russel, 1980 in Claridge *et al* 1986) and the river Itchen on the south coast of England (Hutchinson and Hawkins, 1993). 0-group flounder first occurred in May in the Dee estuary, north Wales (Johnson, 1981), the Ythan estuary, Scotland (Summers, 1979), the Dutch Wadden Sea (de Vlas, 1979 in Van der Ver *et al.*, 1991; Van der Ver *et al.*, 1991) and brackish river Dollard (Jager *et al.*, 1995), the tidal river Elbe Germany (Bos, 1999) and Gullmar Fjord on the west Swedish coast (Modin and Pihl, 1996). Bregnballe (1961) found 0-group flounder of 9-10mm (TL) in a Danish fjord and surrounding coastal area in early – mid June. Beaumont & Mann (1984) reported that the first 0 group flounder of the year occurred in July in the river Frome, south eastern England although sampling was confined to the freshwater section.

Following metamorphosis, many flatfish species spend at least the first six months of their life cycle in coastal nursery grounds (Gibson, 1997). The distribution of juvenile flounder appears to be influenced by salinity (Kersten, 1991; Riley *et al.* 1981; Jager *et al.*, 1993; Hutchinson & Hawkins, 2004), temperature (Henderson & Seaby, 1994; Power *et al.*, 2000), dissolved oxygen concentrations (Pomfret *et al.*, 1991), daily light cycles (Nash *et al.*, 1994) and tidal condition (Bregneballe, 1961; Raffaelli *et al.*, 1990, Greenwood & Hill, 2003). Juvenile flounder utilise low salinity habitats in estuaries and tidal rivers as nursery grounds (Summer, 1979; Kerstern, 1991; Van der Veer *et al.*, 1991; Berghahn, 1984 in Van der Veer *et al.*, 1991)

Hutchinson & Hawkins, 1993) where they exhibit tidal migrations (Berghahn 1984 in Van der Veer, 1991). The preference for water with lower salinity of flounder post-larvae has been shown experimentally by Bos (2006). Bregnballe (1961) compared the length frequency distributions of 0-group flounder inside and outside a Danish fjord using a manually dragged trawl. The small newly metamorphosed flounder were found in the polyhaline areas outside the fjord while the flounder in the mesohaline and oligohaline areas within the fjord were somewhat larger (Bregnballe, 1961). Bregnballe (1961) suggests that the differences in sizes inside and outside the fjord indicate that transport and immigration takes place. Kersten (1991) assessed the importance of rivers as nursery grounds for 0 and 1 group flounder in comparison to the Wadden Sea using beam trawl surveys. Densities of flounder increased significantly with decreasing salinity, with highest abundances in the limnetic sections and lowest in the polyhaline habitats (Kersten, 1991). Vinagre *et al.* (2005) investigated the distribution and abundance pattern of juvenile flounder in a Portuguese estuary and surrounding coastal area over a two year period using otter trawls and found highest densities in the middle estuary. Juvenile flounder commonly use sheltered soft bottom bare sand habitats (Andersen *et al.*, 2005 a) and have a preference for the shallower water (Riley *et al.*, 1981; Fonds *et al.*, 1992; Modin & Pihl, 1996). In the Wadden Sea settlement of 0 group flounder has been observed in the siltier parts (de Vlas, 1979 in Van der Veer *et al.*, 1991) but in the Dollard the catch numbers of 0-group flounder were relatively low in the siltiest locations (Jager *et al.*, 1993).

After metamorphosis, juvenile flatfish enter a rapid phase of growth. Nursery grounds provide a partial refuge from predation in a productive area that promotes growth (Nash & Geffen, 2005). The increase in size of a fish over a sampling period can be used to measure growth. Newly settled fish must be excluded from the growth calculations as they can cause underestimation (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). Growth rates of flounder from Galway Bay may be used as an indicator of the quality of each of the sites as a flounder habitat in comparison to each other and other European areas. Observed growth may be compared with predicted growth to see if food is a limiting factor on flounder growth as was done by Van der Veer *et al.* (1991).

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). Recruitment processes cover everything that affects survival between spawning and the stage of life where year-class strength is more or less fixed (Van der veer *et al.*, 2000). Recruitment variability can be studied by comparing estimates of abundance during various life stages over a number of years (Beverton, 1984; Van der Veer, 1986, 1991). Trends in variability of abundance during the early life stages give an indication of mortality processes and of the period in which year class strength is determined (Van der Veer *et al.*, 1991). Recruitment variation in marine fishes is enormous and has major biological and economic implications for the management of commercial fisheries (Leggett & De Blois 1994).

Recruitment studies of flounder consist of those on 0-group and larval recruitment, and those focused on the juvenile and adult components of the population. Claridge *et al.* (1986) investigated recruitment of flounder and other species from 1972-1977 through impingement of flounder in the intake of a number of power stations in the Bristol Channel and the Severn Estuary. Claridge *et al*'s. (1986) results were in the form of duration and peak period of spawning, larvae and post larvae, and 0-group flounder recruits. Claridge *et al.* (1986) found a period approximately nine weeks between the time of maximum abundance of flounder larvae and post-larvae (mid-May) in the Bristol Channel and 0-group flounder recruits in the middle of the inner estuary (early August). Variations in the number of flounder (juvenile and adult) impinging on a power station intake in the lower Severn estuary was investigated over a ten year period by Henderson and Holmes (1991). Henderson and Holmes (1991) found high inter-annual variability of up to 8-fold in catches of flounder linked to enhanced abundance of one year olds in the winter and all age groups in the summer. Van der Veer *et al.*, (1991) investigated recruitment of 0-group flounder in the Wadden Sea from 1974-1986 using both plankton and beam trawl sampling. The life history pattern of flounder was similar to plaice in the same area with year-class strength generated in the open sea and after settlement (Van der Ver *et al.*, 1991). However, no relationship between the year-class strengths of plaice and flounder were found (Van der Ver *et al.,* 1991). Draganik (1992) estimated the stock biomass of flounder in the Baltic Sea from bottom trawl surveys and fish catch statistics. Draganik (1992) found an upward trend in recruitment of flounder to the stock from 1983-1988. Modin and Pihl (1996) investigated recruitment of 0-group flounder in a Swedish bay over a two year period using drop traps. Inter-annual variability in abundance of up to approximately 1.5 fold of flounder was found (Modin and Pihl, 1996). Abundance of 0-group flounder was measured against predation and wind stress with flounder found to settle during or subsequent to the high risk period of shrimp (*Crangon crangon L.*) immigration (Modin and Pihl, 1996). However, survivors occupy a less predator hazardous environment (Modin and Pihl, 1996). Inter-annual variability in abundance of flounder in two Portuguese estuaries from flatfish trawl surveys over the period 1990 - 2004 was investigated by Cabral *et al.* (2007) who found high inter-annual variability (up to approximately 30-fold) in the densities of flounder juveniles, with a decadal trend shown in one estuary (the Tejo) where it has become extremely rare since the early 1990s.

The aim was to determine the population dynamics of 0-group flounder during the early benthic phase of life history in Galway Bay. The abundance of 0-group flounder from five years of push net sampling and two years of tidal river sampling was investigated. The settlement of flounder in sandy beach and tidal river habitats was examined over temporal and spatial scales and in relation to abiotic factors.

Given that juvenile flounder utilise low salinity habitats in estuaries and tidal rivers as nursery grounds (Summer, 1979; Berghahn, 1984; Kerstern, 1991; Van der Veer *et al.*, 1991; Hutchinson & Hawkins, 1993), and the lack of sufficient samples of 0 group flounder from sandy beaches, the need for sampling in tidal rivers was identified in April 2005. A bi-monthly sampling programme was initiated from April –June in 2005. This was continued from February to June 2006 in with the earlier sampling time in 2006 in order to determine the earliest arrival of flounder postlarve in tidal rivers. The information gathered was used in order to assess the population dynamics of flounder in tidal rivers in the Galway Bay area.

Materials and Methods

Study area and Sampling Regime

Galway Bay (Fig 1) west of Ireland, is a temperate, neritic bay which has a considerable estuarine influence from a number of rivers. Push netting was carried out at three beaches on the north eastern side of Galway Bay (Fig 2). Three years archival information was available from push netting undertaken by Allen (2004) from January 2002 until June 2004 on Ballyloughaun and Silverstrand. Flounder constituted a sporadic bycatch of this sampling programme and samples were archived (Allen, 2004). The push netting was continued in 2005 and 2006, as part of the current study, in order to establish the population dynamics of 0-group plaice (Allard, 2007) and flounder. There were few (<2) flounder sampled on Silverstrand and so the site was not considered for analysis in this study. Sampling commenced on Murrogh, in April of 2005, and this was selected as the second sandy beach site in which 0-group flounder were present. Thus, only two beaches (Ballyloughaun and Murrogh) were considered for analysis as they had sufficient 0-group flounder present. Sampling frequency during Allen (2004) was once a month, this was increased to twice a month in 2005 during the present study.

Ballyloughaun, (54° 15.2`N, 09° 01.6`W) is a sandy beach approximately 500 meters in length (at low water) and 400 meters wide located approximately 2 kilometres east of Galway City centre. This was the principle site for sampling 0-group flounder. There is a strong freshwater influence at the site due to its close proximity to the river Corrib outflow and several small fresh water outflows. Archival data for 0-group flounder was available for three previous years of sampling on Ballyloughaun from January 2002-June 2004. During the sampling period of Allen (2004) 0-group juvenile flounder were observed on Ballyloughaun in late March of 2004. Thus it was decided to commence sampling in February 2005.

A second site was selected at Murrogh House (53° 16.01`N, 08° 59.59`W) in mid-April of 2005 with juvenile flounder found at the site. This is a sheltered shore located behind several islands within 1km distance from Ballyloughaun and with a similar freshwater influence from the Corrib and Roscam stream. Sampling frequency on all sites was increased to twice a month in 2005. In 2006 sampling was continued on Ballyloughaun and Murrogh House twice monthly from February – June.

The method of sampling for 0 group flounder on sandy beaches in Galway Bay was the Riley push net (Holmes and McIntyre 1971). This sampling method has been used successfully for juvenile flatfish research by Corlett (1967), Jones (1973), Mansoor (1982), Wyche and Shackley (1986), Allen (2004) and Allard (2007). Juvenile flounder have been sampled successfully with a similar size push net by Hutchinson & Hawkins (1993).

Due to the scarcity of flounder in sandy beach samples, the need to sample tidal rivers was recognised in April 2005. Oranmore, Roscam and the river Corrib were the sites selected for sampling as sufficient numbers of 0-group flounder were caught in these areas (Fig 2). Oranmore river (53° 16.16`N, 08° 55.46`W) is a small tidal river approximately 15 meters wide at the mouth located in the north eastern corner of Galway Bay. The river is characterised by a number of weirs (Fig 3) which constrain fish movements and limit tidal exchange. A 200m long tidally influenced section was sampled near the mouth. The Corrib (53° 16.04`N, 09° 02.5`W) is one of the largest systems in Ireland. The river is fed by a large lake several kilometres upstream of the mouth. Due to a quite steep slope and a number of weirs the tidally influenced section of the river is quite small and fast flowing through a 150m wide section at the mouth which is constrained by sea walls. A 200m long section was sampled on the western shore close to the mouth at Nimmos Pier (Fig 4). Roscam (53° 16.06`N, 08° 59.51`W) is a small stream, approximately 3 meters wide at the mouth which feeds into the beach at Murrogh house. Due to its relatively narrow channel compared with the Corrib and Oranmore a longer section of 400m from the mouth was sampled. Sampling was carried out twice a month in the three tidal rivers (Corrib, Oranmore, and Roscam) from mid-April 2005 – July 2005. Due to time constraints and the low numbers of flounder sampled in 2005, Roscam was abandoned in 2006 and the remaining two sites were sampled twice a month from February – June 2006.

The methods chosen for sampling in tidal rivers were drop traps and hand nets. This is because the Riley push net was too heavy and cumbersome to use on the soft substrates and fast flowing environments of the tidal rivers. Thus the need for smaller lighter sampling gear was identified. Small, 0.63m wide hand nets were used by Andersen *et al.* (2005a, b) to sample juvenile flounder in a Danish fjord. A small hand net of 0.5m was also used by Summers (1979) and Johnson (1981) to sample 0 group flounder in tidal rivers. Flounder post larvae were sampled by Hutchinson and Hawkins in and English tidal river using a 1 m^2 box quadrant. Drop traps were also used successfully to sample 0-group flounder by Modin and Pihl (1996) in a Swedish fjord, and assumed to be a non-size selective method (Modin and Pihl, 1996).

Fig 1. Map of western Europe showing sampling area.

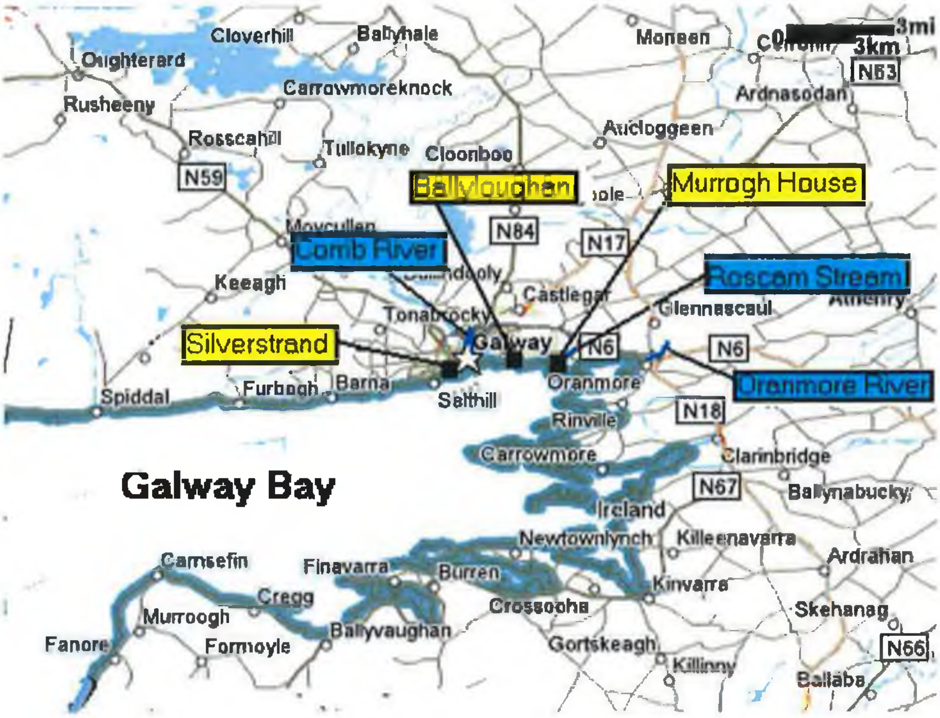

Fig 2. Map showing the sampling locations within Galway Bay. Silverstrand, Ballyloughan, Murrogh House are sandy beaches. The Corrib, Roscam and Oranmore are tidal rivers.

Fig 3. One of the weirs in the tidal section of the Oranmore River

Fig 4. The sampling area of the river Corrib, at Nimmos pier.

Sampling gear

Sampling on sandy beaches was carried out using the Riley push-net (Holmes and McIntyre, 1971) (Fig 5). The Riley push-net was constructed and modified during the sampling regime of a previous MSc. thesis (Allen 2004). The push-net had a 1.5m x 0.3m frame made from 4cm box iron. This frame was mounted on two 7.5cm x 70cm skis made from 0.4cm thick sheet metal. A handle was attached to the frame enabling it to be pushed. The net was a 10mm square mesh shrimp net, lined with a 2mm heavy-duty curtain mesh and was divided into a double cod-end. Three tickler chains were attached at the front of the frame between the skis.

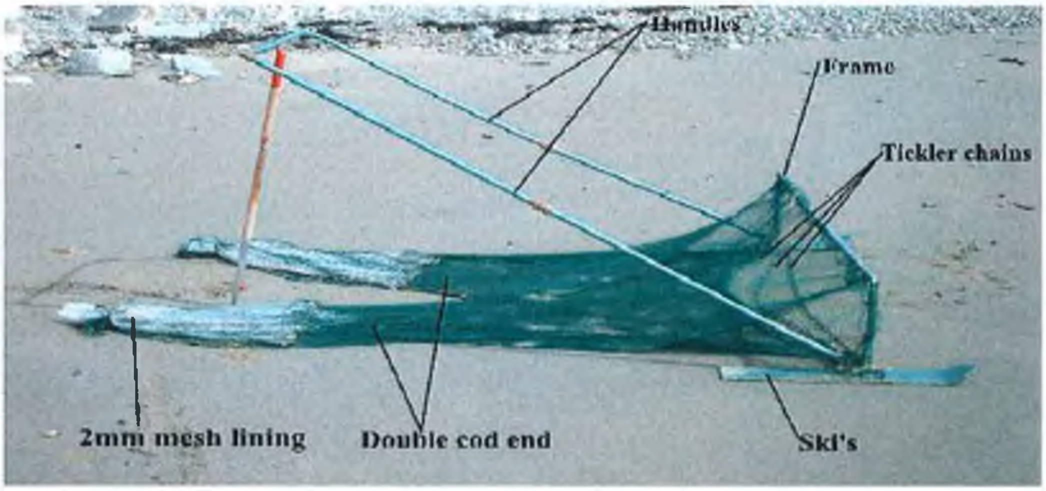

Fig 5. Picture of the Riley push net (reproduced from Allen, 2004)

It was decided that tidal rivers were unsuitable for sampling with the Riley push-net due to the relatively small areas involved compared with sandy beaches and the soft under foot conditions making sampling with heavy equipment difficult. Drop traps and hand nets were the methods selected for tidal river sampling. An improvised drop-trap was made using a small rectangle plastic container 39cm * 31cm at the base and 23cm high (Fig 6). This could be used in water of less than approximately 30cm and on soft sediment types. A hole was cut in the base of the plastic container and after the trap was set in the sediment the inside area was scooped using a small hand net. The hand net consisted of a square metal frame 29cm * 29cm attached to a wooden handle 1m in length. The net of depth 12 cm was attached to the frame, the mesh size was 1mm. Hand netting (Fig 7) could also be carried out in shallow water (< 0.5m).

Fig 6. Picture of the drop trap in operation.

Fig 7. Hand netting taking place in Galway Bay tidal rivers.

Sampling procedure

Training was provided by Allen in the push netting sampling methodology to maximise consistency among projects. A survey team of two carried out the sampling of beaches. The sampling was done twice a month over the sampling period at low water on flooding spring tides of less than 1 metre. The beach was divided up into eight segments with four random replicates taken in each. Each replicate was 50 paces (approx. 50m) long. The length of the replicate was marked using bamboo poles. At the start point the net was carried out to approximately 0.3-0.5m in depth (knee height) and pushed (in either direction) parallel to the shore at a walking pace giving a swept area of $75m^2$.

Similar to the push netting, sampling in tidal rivers was carried out on a flooding spring tide close in time to low water. The areas sampled in each of the river sites varied in accordance with the physical conditions at the site. Oranmore and Roscam were shallow enough (<1m depth at LW) to sample across the entire length and width of the river. The Corrib estuary (Nimmos pier) could only be sampled up to about 5m from the shore as the river had too steep a drop off (Fig 8). In certain areas of the river sites sampling was not carried out because the sediment was too soft and conditions under foot were therefore hazardous. On each occasion the river was divided into three equal sections, these were the upper, middle and lower sections of the estuarine component of the river (i.e. lower section close to the river mouth) (Fig 8-10). Three random drop traps were placed in each area at approximately 30cm depth. The hand net sample consisted of one, three meter sample taken on the surface of the sediment in about knee depth (~0.5m), giving a swept area of $0.84m^2$. One hand net sample was taken in each of the three sections of the estuary. A survey sheet was completed on every sampling visit. Samples were sorted on site and juvenile flatfish brought back to the laboratory and frozen at -18°C. The physical parameters of temperature and salinity were measured in situ on each sampling occasion. At each hand net sample a salinity value was recorded. Other species and weather conditions were also recorded.

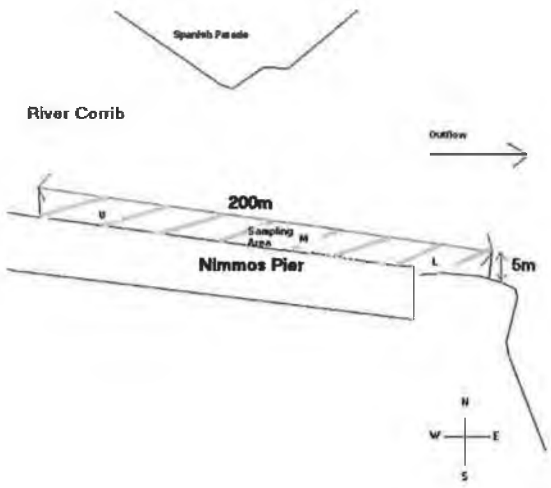

Fig: 8. Diagram showing the sampling area of the river Corrib at Nimmos pier.

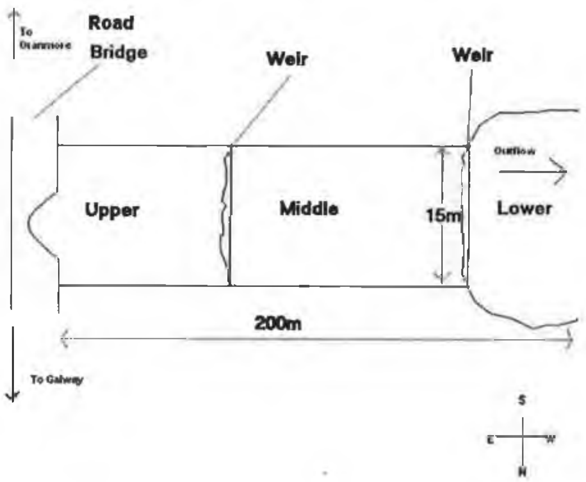

Fig: 9. Diagram showing the sampling area of the Oranmore river.

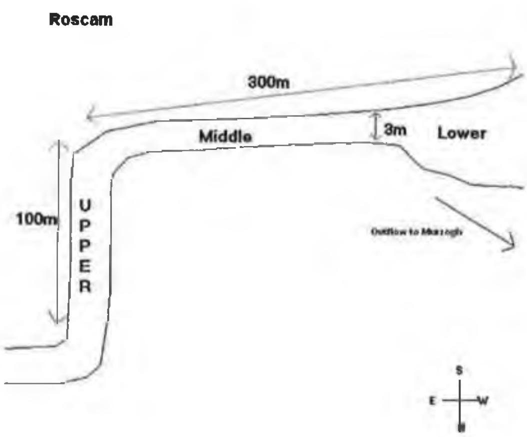

Fig: 10. Diagram showing the sampling area of Roscam stream.

Laboratory work

Flounder were distinguished from plaice and other flatfish using caudal and anal fin ray counts from the key presented in Russell (1976). All fish from an individual replicate were stored in labelled vials. The total length (from the tip of the mouth to the end of the tail) and standard length (from the tip of the mouth to the end of the body where the caudal fin begins) of fish were measured to the nearest 0.1mm using callipers. Damage was observed on the fin rays of many of the caudal fins in which case only the standard length was measured. It was therefore decided to take only the standard lengths for analysis. The Sagittal otoliths were removed from a sub sample of flounder using pins and placed in labelled vial lids for storage and processing, as described in Chapter 4.

Data Analysis

The data were input and analysed using Microsoft office Excel spreadsheets. Statistical analysis was carried out using MINITAB (version 14). Mean densities and ± S.D were calculated using EXCEL. All data were subjected to Ryan-Joiner normality tests and checked for homogeneity of variance using Cochran's test. If data were not normal, non parametric tests were used.

Density data

The densities were calculated per 1000m^2 for beach samples however due to much higher densities and a smaller sampling area they were calculated per m^2 for rivers. Densities were calculated as follows.

$$\textbf{Push net densities} = \frac{D}{A} \times 1000$$

Where D is the density of 0-group flounder for each replicate. And A is the area fished (75m^2).

$$\textbf{Hand net densities} = \frac{D}{A}$$

Where D is the density of 0-group flounder for each replicate. And A is the area fished (0.84m^2).

$$\textbf{Drop trap densities} = \frac{D}{A}$$

Where D is the density of 0-group flounder for each replicate. And A is the area of the drop trap ($0.12m^2$).

Length data

Length frequency results aid in determining the time and size at which flounder settle. Length frequency distributions were plotted for 0-group flounder to visually assess the timing of settlement, the modal size of the samples, the mean sizes of fish per sample and the contribution of different sites and habitats to length cohorts. Lengths were compared from each of the three sections of tidal rivers and sandy beaches.

Length frequencies were plotted for all the beach samples from 2003-2005 and river samples from 2005-2006 in order to compare the size structure of the 0-group flounder populations between years. However, there were insufficient numbers of 0-group flounder caught in 2002 and 2006 on beach sites to be considered. Length frequency tables show 0-group flounder length distributions from each sampling occasion in tidal river sites in 2005 and 2006 and aid in determining the duration of settlement. Mean lengths were plotted for beach and river sites, and for each sampling occasion in tidal rivers.

The lengths of 0-group flounder in different habitats were compared. A length frequency was plotted to compare lengths for 0-group flounder between beaches and rivers in Galway Bay. Tidal rivers were divided into sections near the river mouth and, along with the beach section, classified according to salinity. Length frequencies were plotted along a sectional and monthly basis in tidal rivers in order to see if there were any shifts in the length frequency distributions between sections over the April – June sampling period. Finally length frequencies for all the sections over the whole of the sampling period were plotted to see if there was a difference in habitat utilisation between sections during the early benthic phase.

Growth

Observed growth was taken as the increase in mean standard length per month of 0-group flounder over the main growth period. Observed growth was calculated by dividing the increase in mean length of 0-group flounder between samples by the number of days between samples. Growth rates were estimated for the river sites only due to the lack of monthly temporal data on the beaches. Growth rates were calculated over the period from April to June. Newly settled fish must be excluded from the growth calculations as they can cause underestimation of growth rates (Nash and Geffen, 2005). This was not possible for the present sampling programme due to the large number of newly settled fish in the samples. Therefore, observed growth rates must be taken as a minimum as newly settled flounder (which may not be growing fish) are included.

Observed growth rates were compared to predicted growth rates using a growth model obtained under excess feeding conditions in the laboratory (Glazenburg 1983 in Van der Veer, 1991). Glazenburg's (1983) model was applied to juvenile flounder predicted growth (ΔL) rates by Van der Veer *et al.* (1991):

$$\Delta L = 1.2 \times T - 7.2 \ (\mathrm{mm\ mo^{-1}})$$

Where T is the mean monthly temperature (°C) taken from the Marine institute M1 data buoy off the west coast of Ireland. The above equation was converted to daily predicted growth rates by dividing the mean increase in length of 0-group flounder between samples by the number of days between samples. Where two growth values were given for one month, an average growth value was taken.

Results

Abiotic factors

Environmental parameters (temperature, salinity and weather conditions) were measured on most visits to the sampling sites and are summarised in the Appendix. It must be borne in mind that all of the salinity values were taken around the time of low water. For beach sampling sites, sea state was also recorded. Salinities recorded on Ballyloughaun ranged from 7-30ppt in 2005 with a mean of 21ppt. In 2006, salinities recorded on Ballyloughaun ranged from 14-26ppt with a mean of 21ppt. Murrogh salinities ranged from 19-33ppt in 2005 with a mean of 25ppt. In 2006, salinities on Murrogh ranged from 14-28ppt with a mean of 21ppt. Salinities on Silverstrand were the highest of the three beach sites ranging from 16-36ppt with a mean of 29ppt in 2005. Values in the range 22-31ppt with a mean of 29ppt were recorded on Silverstrand in 2006. Thus salinity values on sandy beaches in Galway Bay could be categorised as being in the polyhaline range (18-30ppt).

Salinities were relatively low in tidal rivers as compared with sandy beaches. Salinity values in the Corrib ranged from 0-11ppt with a mean of 4ppt. Oranmore had a salinity range of 0-13 ppt with and a mean of 4ppt. Thus salinity values in tidal rives were mostly in the oligohaline (0.5-5ppt) or mesohaline (5-18ppt) categories. Salinity values were taken in three sections of the tidal rivers. The upper section being the furthermost from the mouth, the lower section being at the river mouth, and the middle section in between. Each section was categorised according to salinity. Salinities in the upper sections of tidal rivers ranged from 0-12ppt with a mean of 3ppt (Table 1). Salinities in the middle sections ranged from 0-13ppt with a mean of 3ppt (Table 1). Salinities in the lower section ranged from 0-14ppt with a mean of 6ppt (Table 1). A similar pattern of salinity was observed on all three sites with mean salinities in the upper and middle sections in the oligohaline range and mean salinity in the lower section in the mesohaline range.

Table 1. The mean salinity values (standard deviation) in parts per thousand, in the upper, middle and lower sections of tidal rivers in Galway Bay, during the April – July settlement period 2005 and 2006.

Section	Corrib	Oranmore	Roscam	Mean
Lower	6(4)	5(6)	7(5)	6(5)
Middle	2(1)	4(6)	2(3)	3(4)
Upper	1(2)	3(6)	4(4)	3(4)

Settlement: Beaches

The mean densities of flounder on Ballyloughaun per month over the five years of sampling (2002-2006) are shown in Fig 11. Peak mean densities occurred in April in all of the years with the exception of 2003 when a small peak was observed in May (Fig 11).

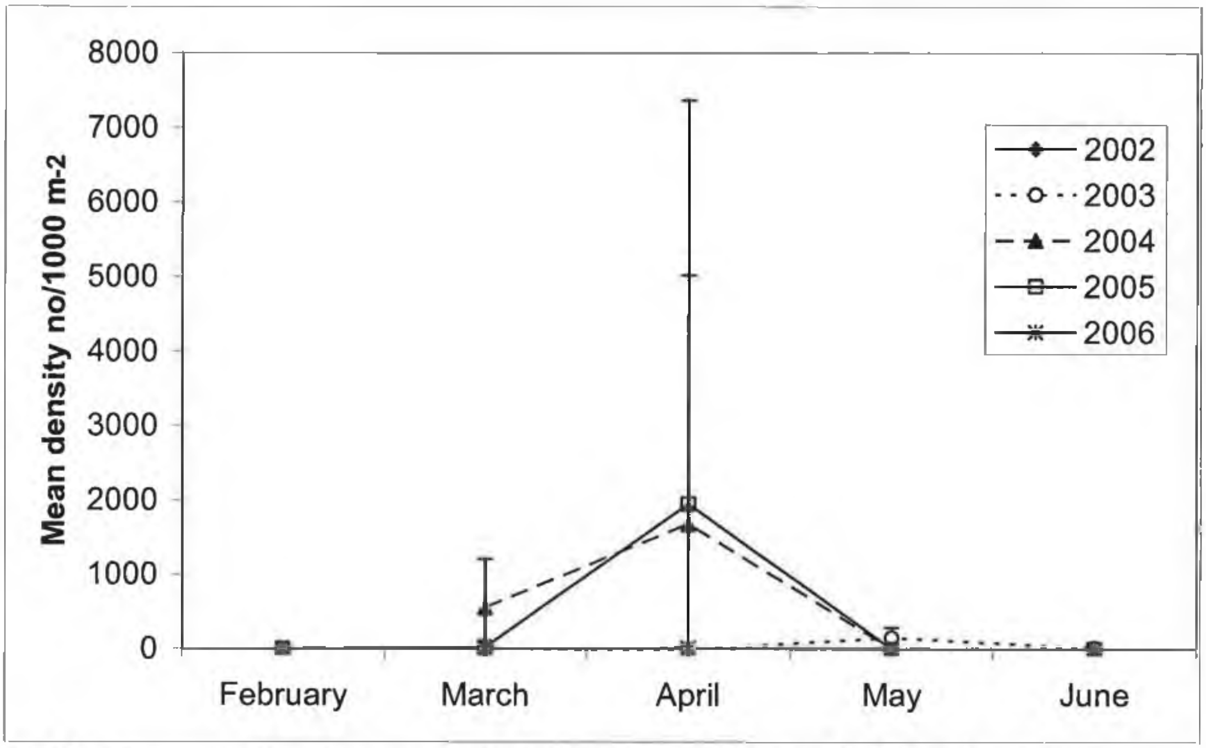

Fig 11. The mean density per month of 0-group flounder on Ballyloughaun over five years (2002-2005) of push net sampling from February to June. Note, there was one sampling per month from 2002-2004 and two samplings per month from 2004-2005.

The mean densities of flounder on Murrogh per month over the two years of sampling are shown in Fig 12. Peak mean densities on Murrogh occurred in April in both years although sampling only began in April in 2005 (Fig 12).

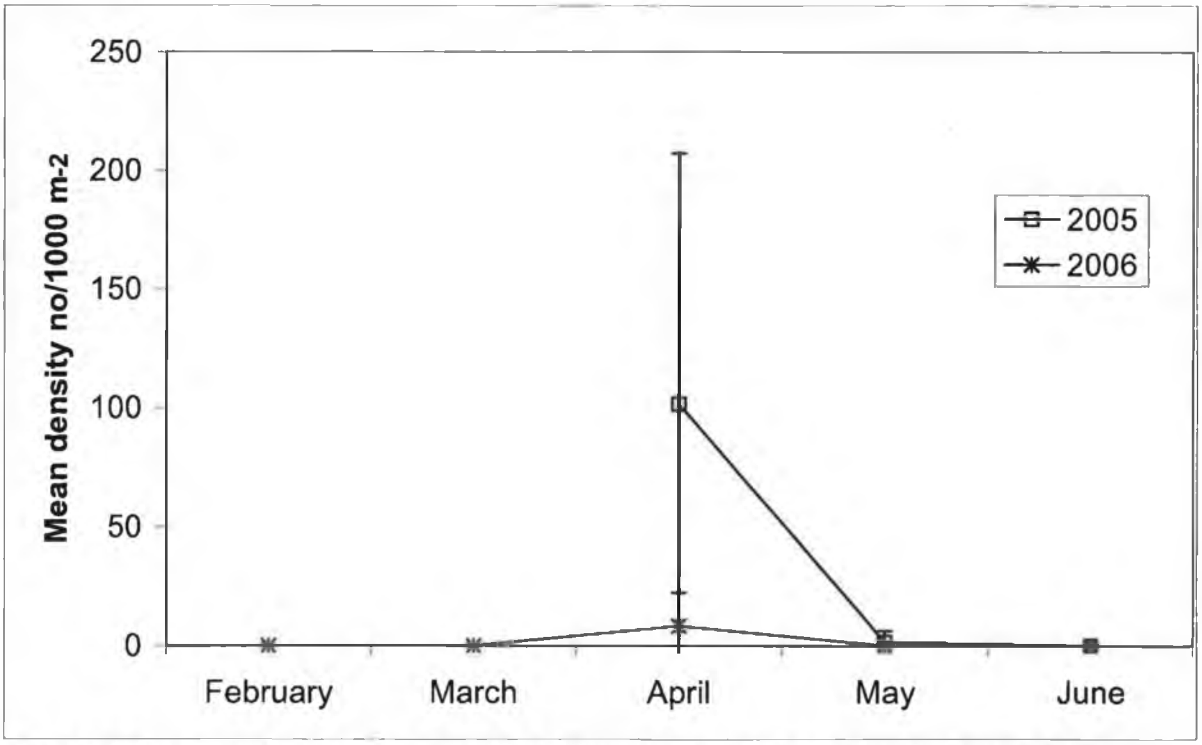

Fig 12. The mean density per month of 0-group flounder on Murrogh over two years (2005-2006) of push net sampling from April to June in 2005 and March to June in 2006.

There were few 0-group flounder caught on Ballyloughaun in 2002 (Table 2). 0-group flounder were first encountered on Ballyloughaun in early May of 2003 with peak densities of 320 $1000m^{-2}$ (Table 2). 0-group flounder were first encountered in late March of 2004 (although sampling only began in late March in 2004) and 2005 in densities up to 1373 $1000m^{-2}$ and 160 $1000m^{-2}$ respectively (Table 1). Flounder (0-group) were only recorded on one occasion at Ballyloughaun in 2006 in late April (up to 93 $1000m^{-2}$, Table 2). Peak densities of 0-group flounder were sampled on the 7th of April in 2004 (6080 $1000m^{-2}$) and the 8th of April 2005 (15,360 $1000m^{-2}$) (Table 2). On both occasions, peak densities were in the first replicate with decreases in densities in the following three. Indeed the highest densities of flounder on Ballyloughaun were usually in the first two replicates. In both years, subsequent push-netting sampling in Ballyloughan yielded zero 0- group flounder. There were few 0-group flounder (<2 individuals) sampled on Silverstrand in five years of push net sampling and so the Silverstrand data were not analysed further. 0-group flounder were sampled in densities up to 213 $1000m^{-2}$ when sampling commenced at Murrogh in early April 2005 (Table 2). Thereafter densities were low in Murrogh in 2005. Peak densities recorded at Murrogh in 2006 were in late April (up to 40 $1000m^{-2}$, Table 2). In general, 0-group flounder are encountered on sandy beaches in Galway Bay from late March to early May, with peaks usually in April. 0-group flounder occurred on beaches for, at most, two consecutive sampling occasions, often a single sampling session only.

Table 2. Densities of flounder on sandy beaches in Galway Bay from 2002-2006

			Ballyloughaun		Murrogh	
Year	Date	Replicate	No. of fish	No.1000m^{-2}	No. of fish	No.1000m^{-2}
2002	Early March	R1-R4	0	0		
	Late March	R1-R4	0	0		
	Early April	R1-R4	1	13		
	Early May	R1-R4	0	0		
	Late June	R1-R4	0	0		
2003	Late February	R1-R4	0	0		
	Late March	R1-R4	0	0		
	Early April	R1-R4	0	0		
	Early May	R1	14	187		
		R2	24	320		
		R3	7	93		
		R4	0	0		
	Late June	R1	2	27		
		R2	2	27		
		R3	0	0		
		R4	0	0		
2004	Late March	R1	59	787		
		R2	103	1373		
		R3	4	53		
		R4	0	0		
	Early April	R1	456	6080		
		R2	45	600		
		R3	2	27		
		R4	1	13		
	Late May		0	0		
2005	Early February	R1-R4	0	0		
	Late February	R1-R4	0	0		
	Early March	R1-R4	0	0		
	Late March	R1	12	160		
		R2	0	0		
		R3	1	13		
		R4	0	0		
	Early April	R1	1152	15360	16	213
		R2	16	213	14	187
		R3	1	13	14	187
		R4	1	13	16	213
	Late April	R1	0	0	0	0
		R2	0	0	0	0
		R3	0	0	1	13
		R4	0	0	0	0
	Early May	R1	0	0	0	0
		R2	0	0	0	0
		R3	0	0	1	13
		R4	0	0	0	0
	Late May	R1-R4	0	0	0	0
	Early June	R1-R4	0	0	0	0
	Late June	R1-R4	0	0	0	0
2006	Early February	R1-R4	0	0	0	0
	Early March	R1-R4	0	0	0	0
	Late March	R1-R4	0	0	0	0
	Early April	R1	0	0	0	0
		R2	0	0	0	0
		R3	0	0	1	13
		R4	0	0	0	0
	Late April	R1	0	0	0	0
		R2	7	93	1	13
		R3	1	13	3	40
		R4	0	0	0	0
	Early May	R1-R4	0	0	0	0
	Late May	R1-R4	0	0	0	0
	Early June	R1-R4	0	0	0	0
	Late June	R1-R4	0	0	0	0

Settlement: Tidal Rivers

Hand net sampling

Fig 13 and 14 respectively show the mean densities of flounder per sampling occasion in hand nets in tidal rivers in 2005 and 2006. Peak mean densities occurred in late April in 2005 on all rivers. Peak mean densities occurred in early April on the Corrib (Fig 13) and early May in Oranmore in 2006 (Fig 14).

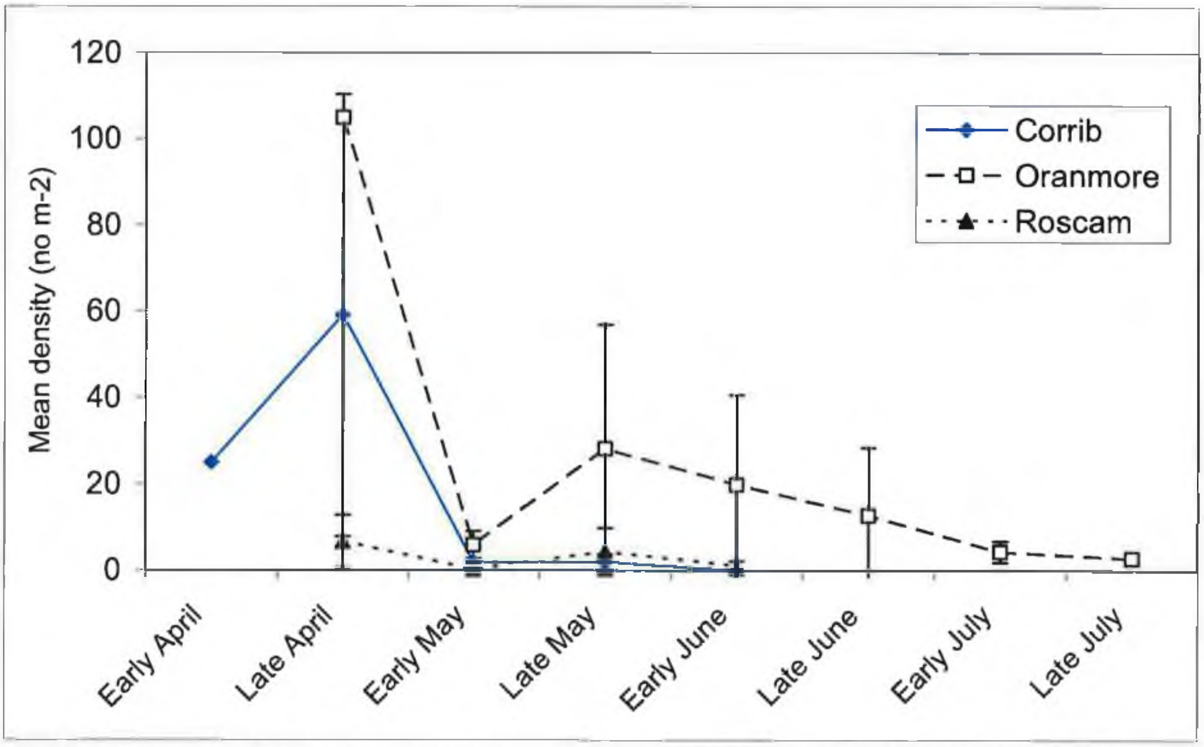

Fig 13. The mean density per sampling occasion of 0-group flounder in hand nets (3 replicates, one from each section) from tidal rivers in Galway Bay in 2005. Note, one replicate only for the Corrib in early April and Oranmore in late April.

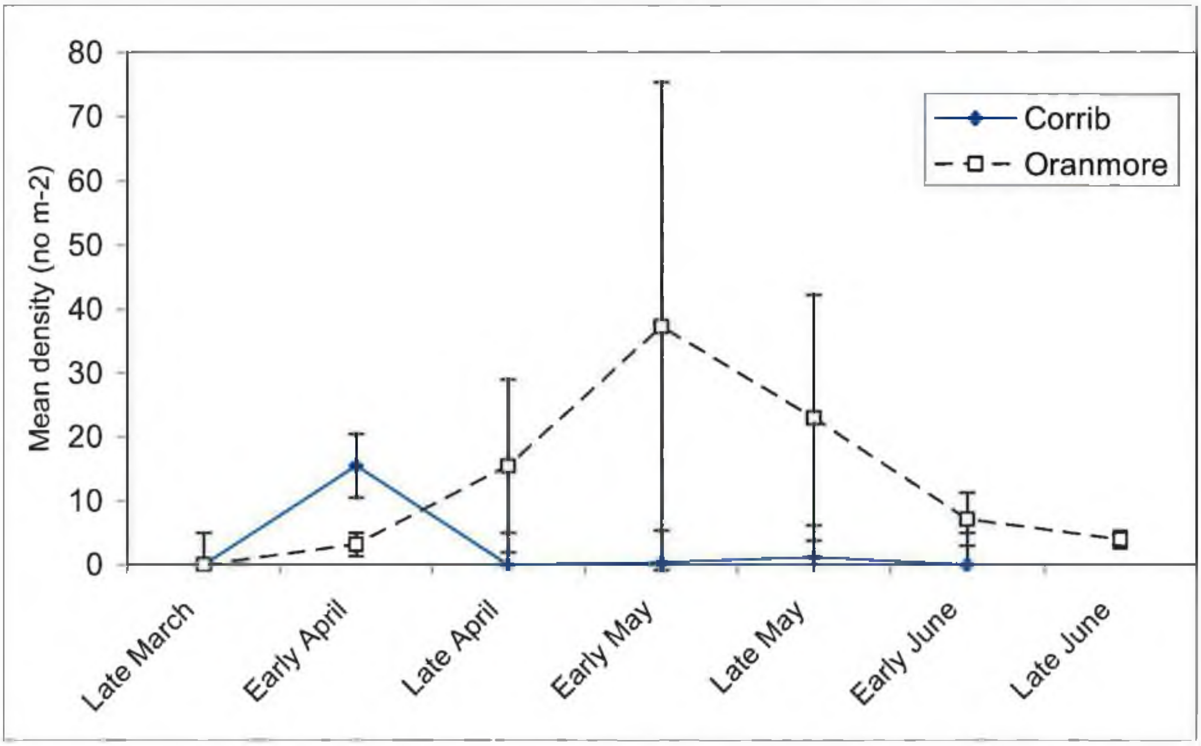

Fig 14. The mean density per sampling occasion of 0-group flounder in hand nets (3 replicates, one from each section) from tidal rivers in Galway Bay in 2006.

0-group flounder were first sampled in early April in the Corrib in 2005 and 2006 in densities of up to 25 m^{-2} and 40 m^{-2} respectively (Table 3). Sampling did not start till late April of 2005 in Oranmore and Roscam rivers when 0-group flounder were encountered in densities of up to 105 m^{-2} and 14 m^{-2} respectively (Table 3). 0-group flounder were first sampled in early April 2006 in Oranmore in densities of up to 5 m^{-2} (Table 3). Peak densities of 0-group flounder occurred in late April in all three rivers in 2005 with Oranmore having the highest peak density (105 m^{-2}) followed by the Corrib (92 m^{-2}) and Roscam (14 m^{-2}) (Table 3). Peak densities occurred in early April in the Corrib in 2006 (40 m^{-2}) (Table 3). Peak densities recorded in Oranmore were in early May of 2006 (76 m^{-2}) (Table 3). 0-group flounder were not present in hand net samples from the Corrib and Roscam from early June. In summary, 0-group flounder were found in hand net samples from the rivers from April to the end of sampling in June / July, with peak abundances in April and early May.

Table 3. Densities of flounder in hand nets from tidal rivers in Galway Bay from 2005-2006.

Year	Date	Replicate	Corrib No. of fish	Corrib No m^{-2}	Oranmore No. of fish captured	Oranmore No m^{-2}	Roscam No. of fish captured	Roscam No m^{-2}
2005	Early April	R1	71*	25				
	Late April	R1	0	0	295*	105	5	6
		R2	72	86			12	14
		R3	77	92			0	0
	Early May	R1	2	2	2	6	0	0
		R2	2	2	9	11	1	1
		R3	1	1	4	5	0	0
	Late May	R1	0	0	3	4	10	12
		R2	2	2	17	20	1	1
		R3	3	4	50	60	0	0
	Early June	R1	0	0	2	2	2	2
		R2	0	0	12	14	1	1
		R3	0	0	36	43	0	0
	Late June	R1			3	4	0	0
		R2			26	31	0	0
		R3			3	4	0	0
	Early July	R1			3	4		
		R2			6	7		
		R3			2	2		
	Late July	R1			3	4		
		R2			1	1		
		R3			3	4		
2006	Late March	R1	0	0	0	0		
		R2	0	0	0	0		
		R3	0	0	0	0		
	Early April	R1	34	40	1	1		
		R2	2	2	3	4		
		R3	3	4	4	5		
	Late April	R1	0	0	0	0		
		R2	0	0	21	25		
		R3	0	0	18	21		
	Early May	R1	0	0	0	0		
		R2	0	0	64	76		
		R3	1	1	30	36		
	Late May	R1	0	0	2	2		
		R2	2	2	34	40		
		R3	1	1	22	26		
	Early June	R1	0	0	4	5		
		R2	0	0	4	5		
		R3	0	0	10	12		
	Late June	R1			2	2		
		R2			4	5		
		R3			4	5		

* = 1 * 10m replicate

Drop trap sampling

0-group flounder were encountered in drop traps when sampling commenced in late April of 2005 in densities up to 8 m^{-2} in the Corrib and Roscam and 89 m^{-2} in Oranmore (Table 4). Peak densities in drop traps were low in the Corrib and Roscam in 2005 (8 m^{-2}) and in the Corrib in 2006 (16 m^{-2}) (Tables 4 and 5). Densities were generally higher in drop traps in Oranmore with a peak of 220 m^{-2} in late June of 2005 and 65 m^{-2} in early June 2006 (Table 4, 5). Drop trap densities varied considerably and were generally lower than those from the hand nets. There were a considerable number of zeros in the drop trap samples reflecting the small size and limited sampling area covered by the trap. Peak density timing generally reflected the peaks in the hand nets.

Table 4. Densities of flounder in drop traps in tidal rivers in Galway Bay in 2005

			Corrib		Oranmore		Roscam	
Year	Date	Replicate	No. of fish captured	No m^{-2}	No. of fish captured	No m^{-2}	No. of fish captured	No m^{-2}
2005	Late April	R1	0	0	0	0	0	0
		R2	0	0	0	0	0	0
		R3	0	0	2	16	0	0
		R4	0	0	0	0	1	8
		R5	1	8	8	65	0	0
		R6	1	8	3	24	1	8
		R7	0	0	3	24	0	0
		R8	0	0	11	89	0	0
		R9	0	0	10	81	0	0
	Early May	R1	0	0	0	0	0	0
		R2	0	0	0	0	1	8
		R3	0	0	0	0	0	0
		R4	0	0	0	0	0	0
		R5	0	0	2	16	1	8
		R6	0	0	3	24	0	0
		R7	0	0	2	16	1	8
		R8	0	0	1	8	0	0
		R9	0	0	5	41	0	0
	Late May	R1	1	8	0	0	0	0
		R2	0	0	1	8	0	0
		R3	0	0	0	0	0	0
		R4	0	0	0	0	1	8
		R5	1	8	0	0	0	0
		R6	0	0	0	0	0	0
		R7	0	0	0	0	0	0
		R8	0	0	2	16	0	0
		R9	0	0	2	16	0	0
	Early June	R1	0	0	0	0	0	0
		R2	0	0	0	0	0	0
		R3	0	0	0	0	0	0
		R4	0	0	0	0	0	0
		R5	0	0	1	8	0	0
		R6	0	0	0	0	0	0
		R7	0	0	4	33	1	8
		R8	0	0	0	0	0	0
		R9	0	0	1	8	0	0
	Late June	R1			0	0	0	0
		R2			0	0	0	0
		R3			0	0	0	0
		R4			0	0	0	0
		R5			1	8	0	0
		R6			3	24	0	0
		R7			27	220	0	0
		R8			3	24	0	0
		R9			0	0	0	0
	Early July	R1			0	0		
		R2			0	0		
		R3			0	0		
		R4			0	0		
		R5			1	8		
		R6			0	0		
		R7			4	33		
		R8			0	0		
		R9			1	8		
	Late July	R1			0	0		
		R2			0	0		
		R3			0	0		
		R4			0	0		
		R5			1	8		
		R6			3	24		
		R7			0	0		
		R8			0	0		
		R9			1	8		

Table 5. Densities of flounder in drop traps in tidal rivers in Galway Bay in 2006

Year	Date	Replicate	Corrib No. of fish captured	Corrib No m^{-2}	Oranmore No. of fish captured	Oranmore No m^{-2}
2006	Late March	R1-R9	0	0	0	0
	Early April	R1	0	0	0	0
		R2	0	0	0	0
		R3	0	0	0	0
		R4	0	0	0	0
		R5	2	16	0	0
		R6	0	0	0	0
		R7	0	0	2	16
		R8	0	0	0	0
		R9	0	0	4	33
	Late April	R1	0	0	0	0
		R2	0	0	0	0
		R3	0	0	0	0
		R4	0	0	0	0
		R5	0	0	0	0
		R6	0	0	0	0
		R7	0	0	0	0
		R8	0	0	0	0
		R9	0	0	3	24
	Early May	R1			0	0
		R2			0	0
		R3			0	0
		R4			4	33
		R5			1	8
		R6			2	16
		R7			0	0
		R8			4	33
		R9			2	16
	Late May	R1			0	0
		R2			1	8
		R3			0	0
		R4			0	0
		R5			0	0
		R6			0	0
		R7			0	0
		R8			0	0
		R9			2	16
	Early June	R1			0	0
		R2			0	0
		R3			1	8
		R4			0	0
		R5			0	0
		R6			0	0
		R7			8	65
		R8			1	8
		R9			1	8
	Late June	R1			0	0
		R2			0	0
		R3			1	8
		R4			0	0
		R5			0	0
		R6			1	8
		R7			0	0
		R8			0	0
		R9			0	0

Inter-annual variability in densities

Densities were compared over five years (2002-2006) on Ballyloughaun and over two years on Murrogh (2005-2006). Densities were also compared from drop trap samples from Oranmore in 2005 and 2006. There were insufficient numbers to compare densities in the Corrib between years. Comparisons were made from sampling occasions in which flounder were present in samples. In each comparison the null hypotheses was that there was no difference in densities between years on each of the sites. The data were non normal and unbalanced so non parametric test were used.

In each case the null hypothesis was accepted as there was found to be no significant difference in densities between years for Ballyloughaun (Kruskal-Wallis, p=0.09); Murrogh (Mann Whitney, p=0.37) and Oranmore (Mann Whitney, p=0.09)

Settlement: beaches vs. rivers

In summary, peaks in 0-group flounder abundance on beaches generally coincided with or preceded peaks in 0-group flounder abundance in rivers (Table 6). Flounder disappeared from the beach samples earlier than from the river samples. The estimated mean densities per month in rivers were generally less using drop traps compared to hand nets (Table 6). However, the mean peak densities coincided between drop traps and hand nets (Table 6).

Table 6. Mean densities (no.m^{-2}) of 0-group flounder per month for beach and river habitats in 2005 and 2006. Beach (4 replicates), River HN = hand net (3 replicates, one from each section), River DT = drop trap (9 replicates, 3 from each section).

Year	Month	Beach	River HN	River DT
2005	February	0	-	-
	March	0.03	-	-
	April	1	41	12
	May	0	7	4
	June	0	7	7
	July	-	4	5
2006	February	0	-	-
	March	0	0	0
	April	0.01	9	2
	May	0	15	7
	June	0	4	6

Analysis of variance for densities beaches vs rivers

Densities of 0-group flounder from two beaches and two rivers sampled over a three week period from the 8th – 27th of April 2005 were analysed. This was the only period where sufficient numbers of 0-group flounder were available from both habitats for comparison. Densities from push nets (beaches) and hand nets (rivers) were compared as these are broadly similar sampling techniques. The null hypothesis was that there was no difference in densities between beaches and rivers over the settlement period. A nested ANOVA was carried out to test the hypothesis that there was no difference between flounder from beaches and rivers. The habitats beaches and rivers were fixed factors, river locations Corrib and Roscam, and beaches Ballyloughan and Murrough, were nested in river and beach respectively and were treated as random factors. Three replicate samples were taken from each location. The null hypothesis was accepted as there was no significant difference in densities between habitats (nested ANOVA, $p=0.369$) and sites (nested ANOVA, $p=0.105$).

Densities vs abiotic factors

Salinities and temperature were taken at each hand net and push net sample on most sampling occasions. The relationship between salinity and density is shown in fig 15. The highest densities of 0-group flounder were found below 5ppt in the limnetic (freshwater, 0ppt) and oligohaline (0.5-5ppt) areas of tidal rivers (Fig 15). This was followed by mesohaline (5.1-18ppt) areas (Fig 15). The highest density on beaches was found during the first arrival of 0-group flounder where densities of up to 15 m^{-2} were recorded coinciding with onshore winds and a high salinity of 35ppt (Fig 15). Lowest densities of flounder were recorded in the polyhaline areas (18-30ppt) where densities were always less than 1 m^{-2}.

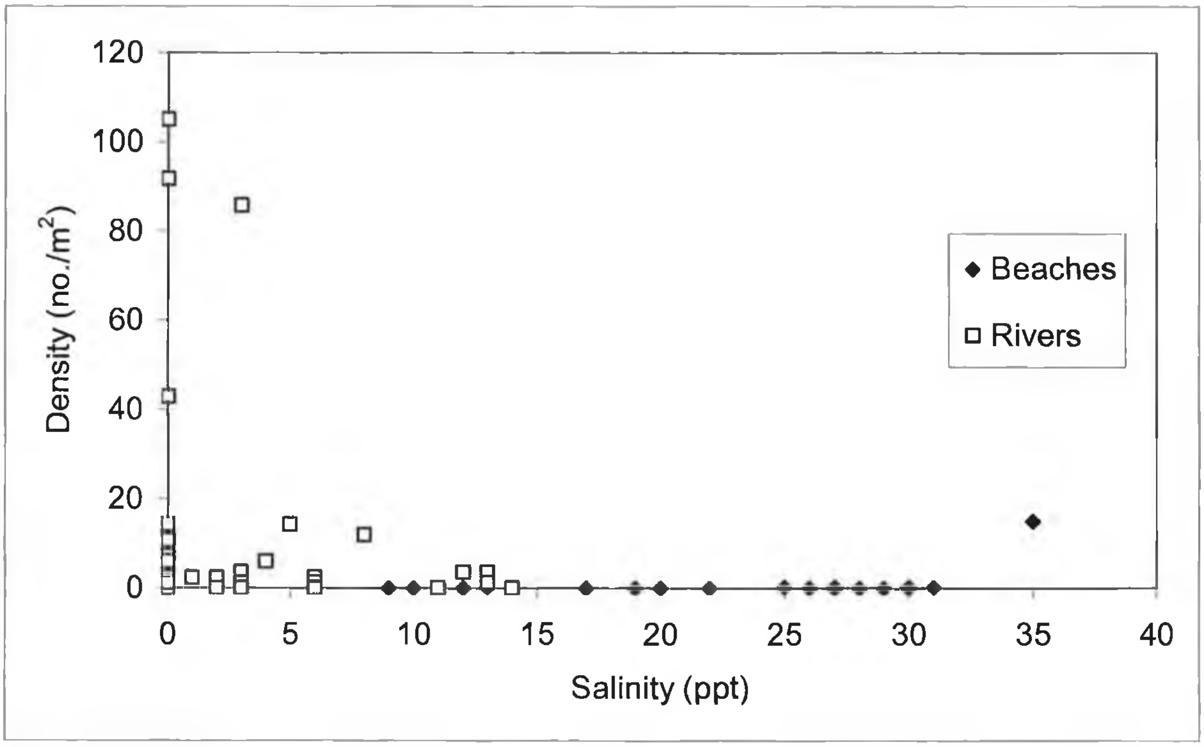

Fig 15. The salinity taken at beach and river sites vs. the density of 0-group flounder during the period late March to late June when 0-group flounder were observed.

There did not appear to be any relationship between densities and temperature (Fig 16). However, higher temperatures were generally recorded in tidal rivers than beaches.

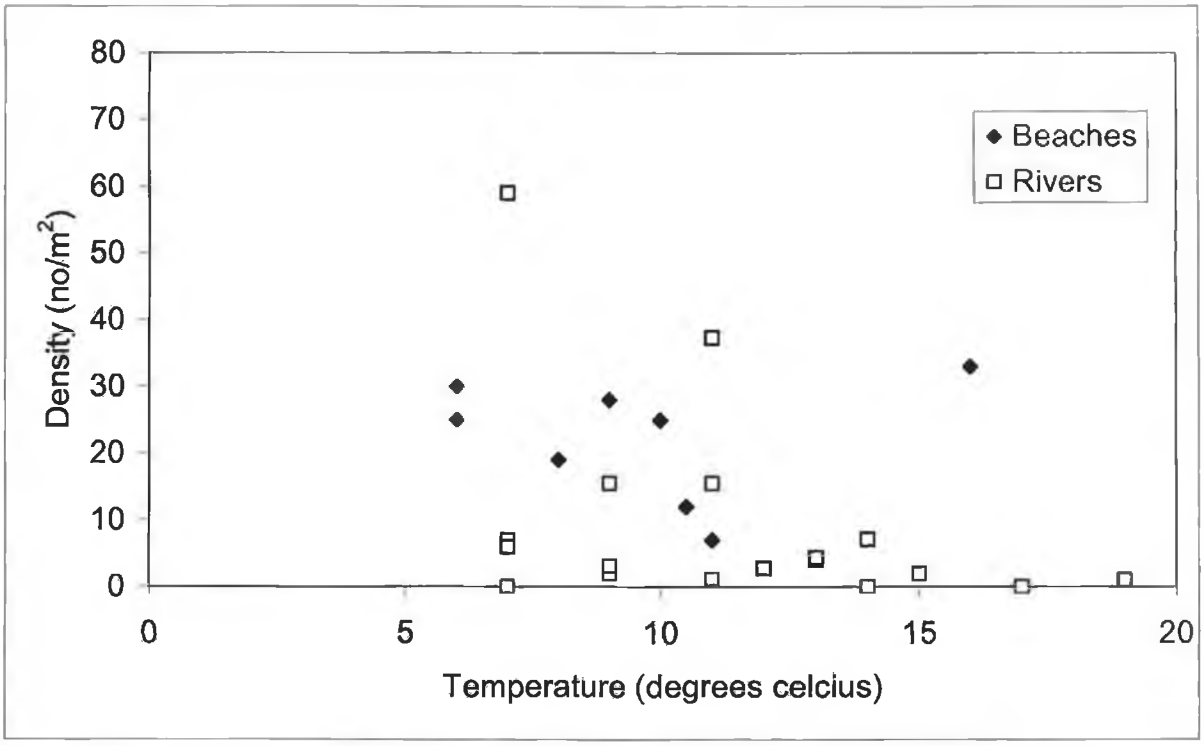

Fig 16. The temperature taken at beach and river sites vs. the density of 0-group flounder during the period late March to late June when 0-group flounder were observed.

Length frequencies

The overall length range for 0-group flounder sampled in Galway Bay from March – July was 8-48mm standard length. The length frequencies for 0-group flounder from various areas in Galway Bay were described as follows.

Beaches 03-05

Due to low sample sizes information from beaches in 2002 and 2006 was excluded. Flounder ranged in size from 6-38mm and 6-28mm on Ballyloughaun in 2003 and 2004 respectively. Length ranges on beaches were narrower in 2005 with flounder ranging from 6-12mm on Ballyloughaun and 8-11mm on Murrogh. In general there were few 0 group flounder above 11mm sampled on beaches during the February–June sampling period.

Modal lengths of 9 mm and 8mm were recorded on Ballyloughaun in 2003 in 2004 respectively (Fig 17). A modal length of 9mm was also recorded on both Ballyloughaun and Murrogh in 2005 (Fig 17).

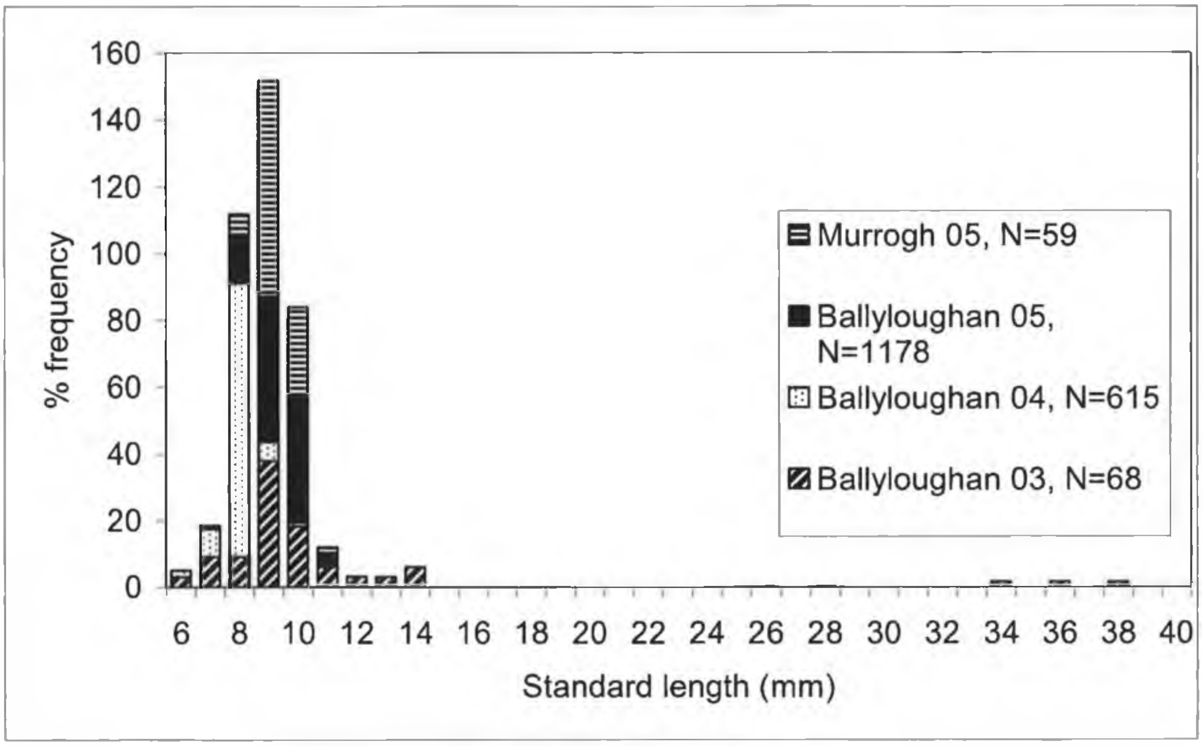

Fig 17. Length frequencies for Ballyloughaun 2003-2005 and Murrogh in 2005 from March-June.

Rivers 2005-2006

Length frequencies in tidal rivers had similar distributions in 2005 and 2006. Flounder in the Corrib had a length range of 8-41mm in 2005 and 9-31mm in 2006. Flounder in Roscam river had a length range of 10-35mm in 2005. Flounder in Oranmore had a narrower length range than those from the Corrib with a range of 8-33mm and 9-27mm in 2005 and 2006 respectively. Length ranges on Oranmore were similar in 2005 and 2006, despite the fact that sampling finished a month later (in July) in 2005. The Corrib generally had few fish above 14mm in both years.

The modal length was 10mm for both Oranmore and the Corrib in 2005. Roscam had a modal length distribution of 15mm in 2005 (Fig 18). The modal length for the Corrib was 11mm in 2006 while Oranmore had a modal distribution of 16mm in 2006 (Fig 19).

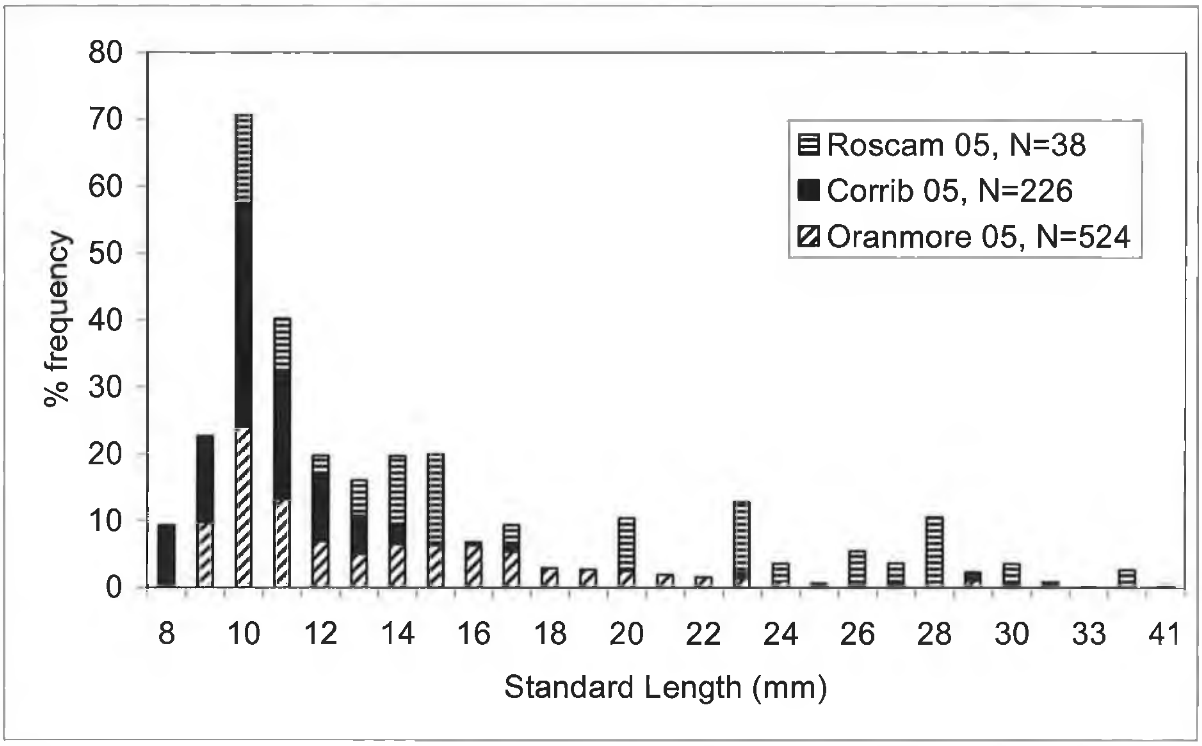

Fig 18. Length frequency for flounder in Galway Bay tidal rivers in 2005 during the period April-July.

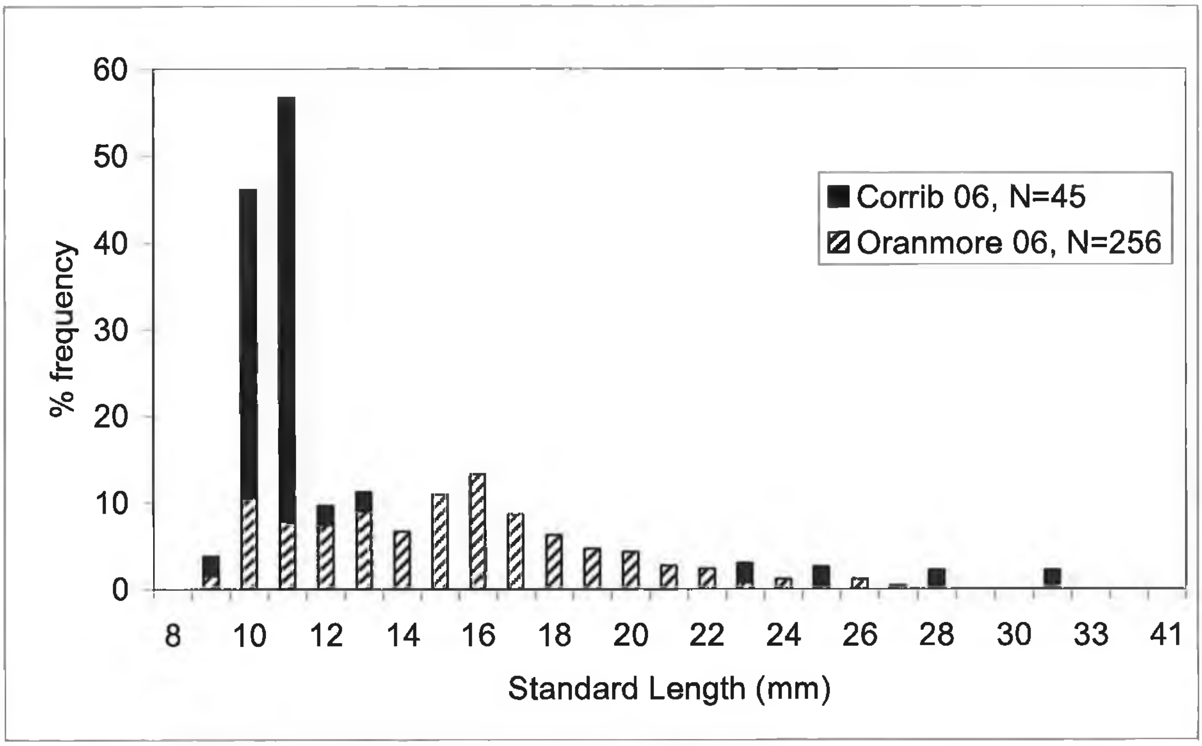

Fig 19. Length frequency for flounder in Galway Bay tidal rivers in 2006 during the period April-June.

0-group flounder of about 10mm first appeared in both the Corrib and Oranmore in early April of 2005 (Table 7). These 0-group flounder continued to appear in late April of 2005 in both the Corrib and Roscam (Table 7). There followed a large reduction in numbers of 0-group flounder from the Corrib and Roscam samples in May of 2005 (Table 7). 0-group flounder continued to appear in the Oranmore samples until sampling finished in July (Table 7).

Table 7. Length frequency distributions for each sampling occasion for tidal rivers in Galway Bay in 2005.

	2005														
	Corrib				Oranmore							Roscam			
Std Lt	9/4/05	20/4/05	9/5/05	31/5/05	19/4/05	5/5/05	25/5/05	8/6/05	21/6/05	6/7/05	20/7/05	27/4/05	6/5/05	23/5/05	10/6/05
8		20			2										
9	4	25			51										
10	44	31			124	2						5			
11	18	25			63	5	1					3			
12	3	20			16	8	11	1				1			
13		13			7	4	13	2				2			
14	1	5			5	3	13	10	3			4			
15		1			3	2	10	5	12		1	4	1		
16		1			1	1	6	13	11		1				
17		2	1		2	1	4	8	8	5			1		
18						1	3	3	6	2					
19							3	3	5	3					
20							2	3	7		1		2		1
21							2	3	5						
22						1		2	4	1					
23			1	1			2		2	1	2			4	
24							1	2		1	1			1	
25			1								1				
26							1							1	1
27			1							2	1			1	
28														4	
29			1	2				1		1	3				
30				2											1
31				1					1	1					
33									1						
35															1
41				1											

0-group flounder of 10mm first appeared in the Corrib and Oranmore in early April of 2006 (Table 8). Similar to 2005, there was a large reduction in 0-group flounder numbers in the Corrib samples in May of 2006. Unlike 2005 there was no appearance of 0-group flounder in the Corrib in late April of 2006. Oranmore exhibited several cohorts of 0-group 10mm flounder in 2006. The first appearance was in early April followed by subsequent appearances in late April and early May (Table 8).

Table 8. Length frequency distributions per sampling occasion for tidal rivers in Galway Bay in 2006.

	2006									
	Corrib				OR					
Std Lt	12/4/06	29/4/06	13/5/06	26/5/06	12/4/06	29/4/06	13/5/06	26/5/06	10/6/06	26/6/06
8										
9	1				1	2	1			
10	16				9	9	9			
11	22				3	5	10	1	1	
12	1				1	8	9	1		
13	1					7	6	10		
14						3	6	6	2	
15						1	11	8	5	3
16						1	11	12	8	2
17						1	10	5	2	4
18						1	5	4	5	1
19							6	4	2	
20							8	2	1	
21							4	3		
22						1	3	1	1	
23				1			1			1
24							1	2		
25			1							1
26							2		1	
27								1		
28				1						
29										
30										
31				1						
33										
35										
41										

Mean lengths

The mean length of 0-group flounder on beaches in 2005 and 2006 (all data combined) was 9 ± 0.73 mm for Ballyloughaun and 9 ± 0.45 mm for Murrogh (Fig 21). Mean length in rivers in 2005 and 2006 (all data combined) ranged from 11.5 ± 4.46 mm on the Corrib, to 13.97 ± 4.32 mm on Oranmore and, 18.41 ± 7 in Roscam (Fig 20).

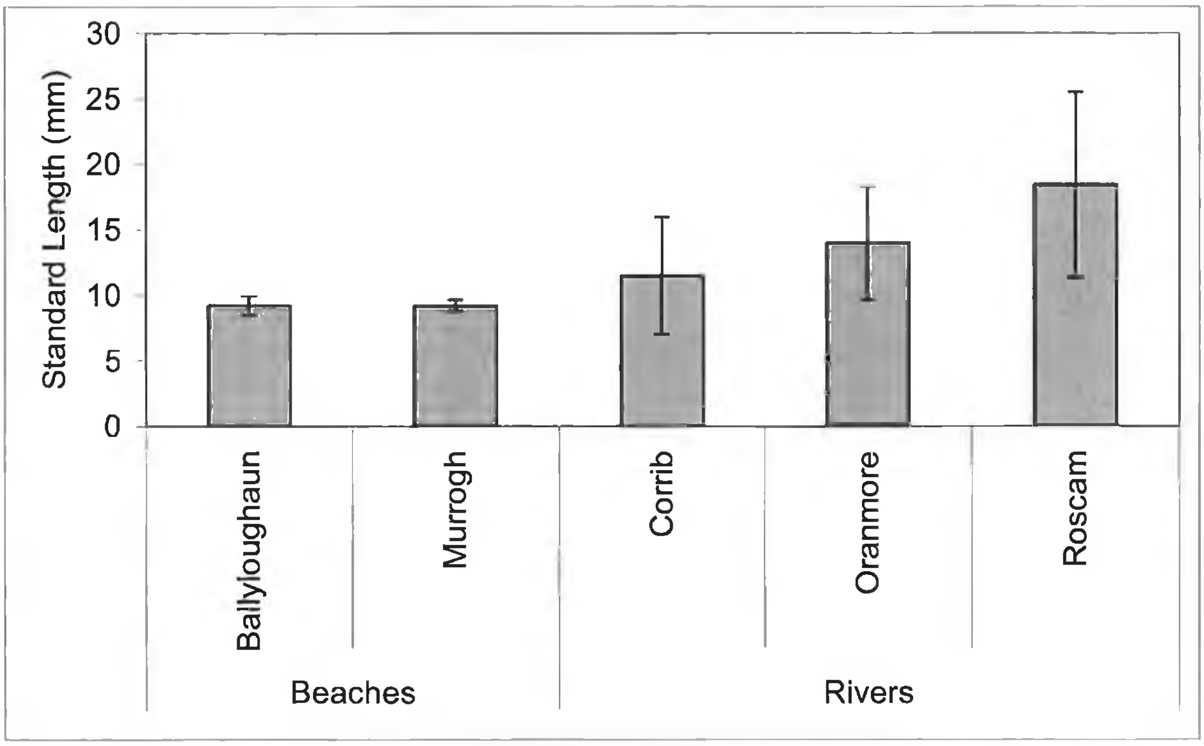

Fig 20. Mean length for 0-group flounder from beach (4 replicates) and river (12 replicates) sites from 2005-2006 March-July sampling.

The mean length of 0 group flounder when they were first recorded was 10mm in both the Corrib and Oranmore in 2005 and 2006 (Fig 21, 22). The first recorded mean length in Roscam was 12mm (Fig 21) but as this sample was taken in late April of 2005 it is likely that the appearance of the first 0-group flounder was missed at this site. Thereafter the mean lengths on all sites increased although a mean length of 11mm ±2 on the second sampling in the Corrib 2005 indicates there was still substantial appearance of newly settled flounder in mid April 2005 (Fig 21).

Large differences in mean lengths between tidal rivers were observed from early May. The Corrib had a higher mean length than Oranmore in early May with a difference of 11mm in 2005 and 9mm in 2006 (Fig 21, 22). By late May the Corrib had a higher mean length than Oranmore with a difference of 15mm in 2005 and 11mm in 2006 (Fig 21, 22). The differences in mean length between the Corrib and Roscam were less pronounced, with a difference of 6mm in early May and 5mm in late May in favour of the Corrib (Fig 22).

Mean lengths were similar in the same sites in 2005 and 2006 when comparable dates were sampled. Flounder in Oranmore had a mean length of 15mm on 25/5/05 and 16mm on the 26/5/06, and 18mm on the 21/6/05 and 18mm on the 24/6/06 (Fig 21, 22). In the Corrib flounder had a mean length of 24mm on the 9/5/05 and 25mm on the 13/5/05, and 30 on the 31/5/05 and 27 on the 26/5/06 (Fig 21, 22). Mean lengths were higher in the Corrib and Roscam than Oranmore in 2005 and higher in the Corrib than Oranmore in 2006.

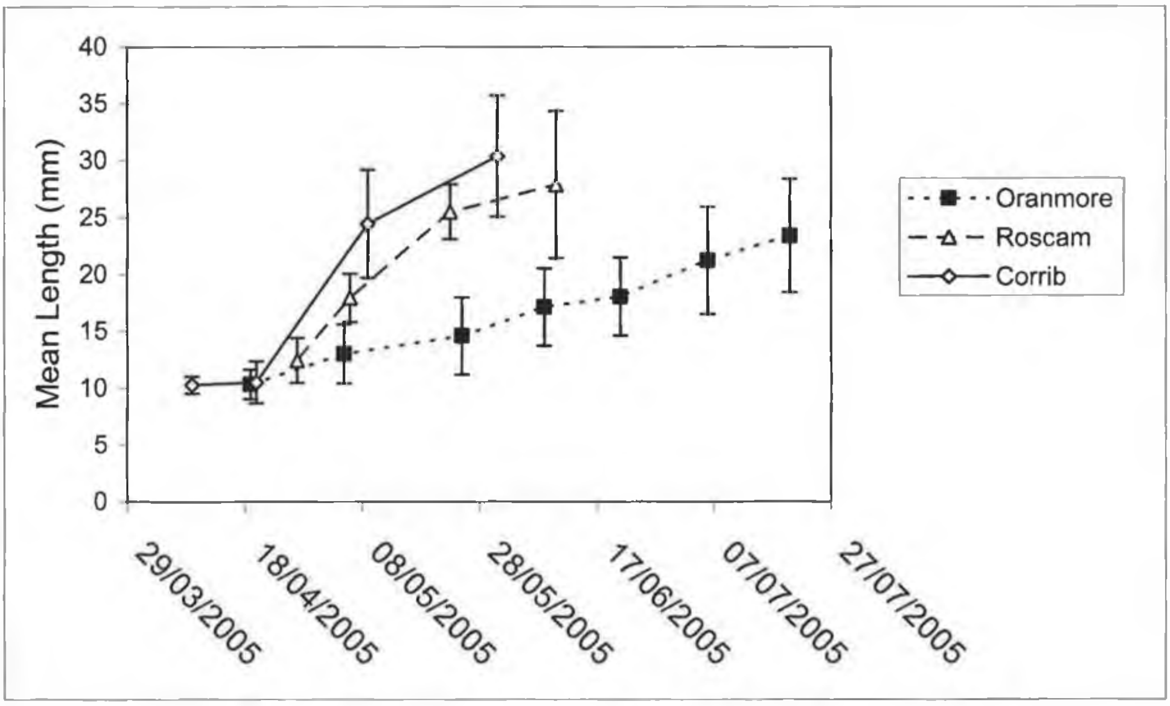

Fig 21. The mean length of 0-group flounder in tidal rivers (12 replicates) in 2005.

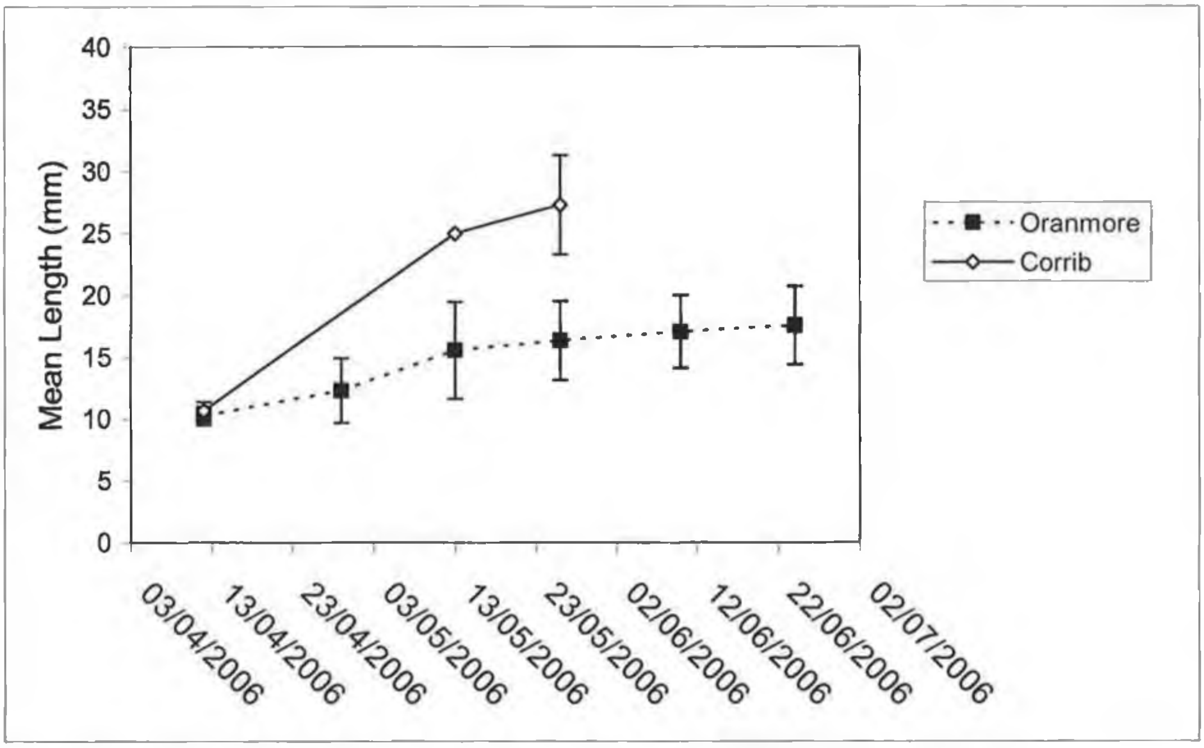

Fig 22. The mean length of 0-group flounder in tidal rivers (12 replicates) in 2006.

Beaches vs. rivers length frequency

0-group flounder length frequencies on beaches from 2003-2005 ranged from 6– 48 mm with a modal length of 8mm (Fig 20). The majority (91%) of the flounder sampled on beaches were in the range 8-10mm. There were no flounder sampled on beaches in the range 16-22mm during the March – July sampling period (2002-2006). Flounder length frequencies from rivers ranged from 8-41mm with a modal length of 10 mm (Fig 23). In contrast to the beaches, 0-group flounder were present in abundance above 11mm in tidal rivers, with 55% of the flounder sampled in the range 12-36mm. In summary, flounder were present on sandy beaches in Galway Bay close to the mouth of tidal rivers mostly at sizes 8-10mm before appearance in tidal rivers mostly at around 10mm in length where they are present in shallow areas up to about 30mm.

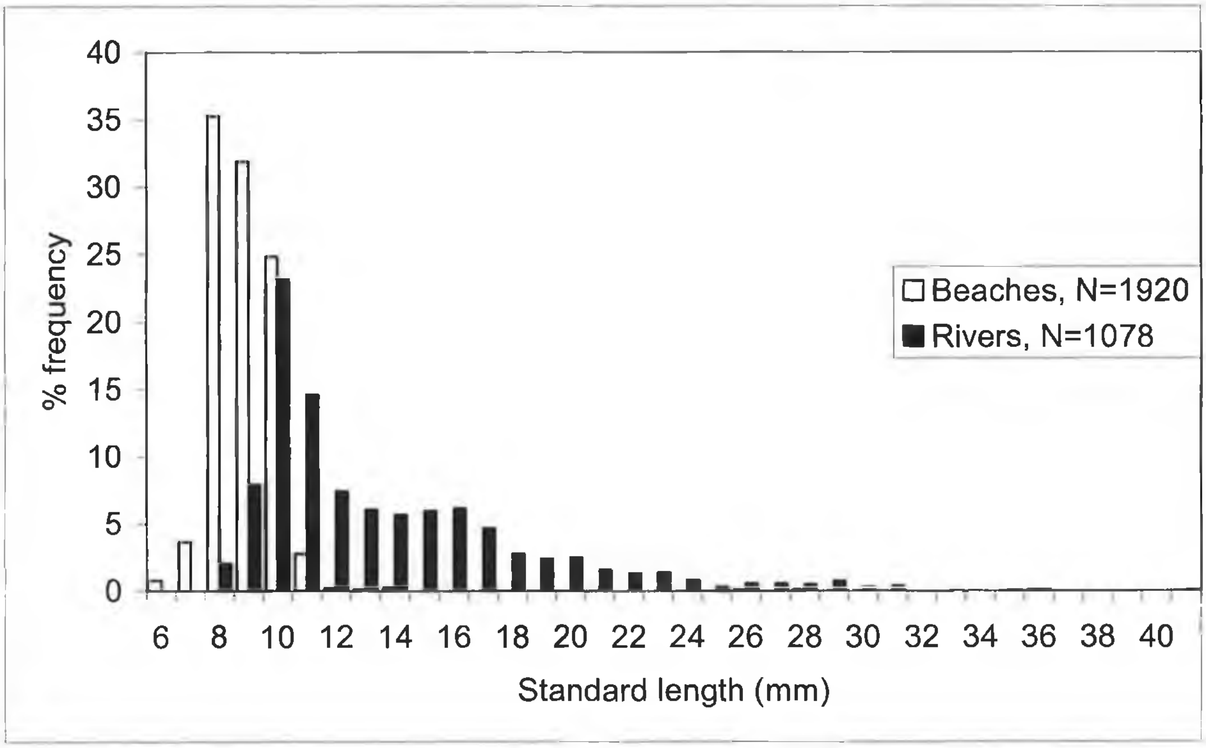

Fig 23. Length frequencies for 0-group flounder by habitat. Beaches 2003-2005, rivers 2005-2006 from March-July sampling.

0-group flounder length on beaches and rivers during settlement

Comparisons were made between lengths on two beaches and two rivers sampled over a two week period during peak settlement from the 8th – 20th of April 2005. This was the only time when there was sufficient length data for comparison between the two habitats at the same time. The data were non-normal so non-parametric tests were used. The null hypotheses were:

(1) There is no difference in the standard lengths of 0-group flounder between sites within each habitat.

(2) There is no difference in the standard lengths of 0-group flounder between habitats.

The null hypothesis 1 was rejected as there was a significant difference in lengths between sites (Kruskal-Wallis, $p<0.001$) during the aforementioned period. The Moods-Median test ($p=0.0001$) revealed that 0-group flounder were larger in Oranmore than Ballyloughaun or Murrogh, and the Corrib than Ballyloughaun. The null hypothesis 2 can be accepted, as there was no consistent difference in lengths between habitats.

Monthly length frequency distributions in tidal river sections from April – June

It was found that 0-group flounder of about 10mm were found in all sections in April (Fig 24, 25, 26). There were few flounder above 13mm present in the lower section (Fig 24). 0-group flounder were scarce in the lower section from May onwards (Fig 24). 0-group flounder above 11mm were present in the middle section in May and June when they were mostly in the size range 15-23mm (Fig 25). 0-group flounder of about 13mm became abundant in the upper section in May (Fig 26). Flounder above 15mm became abundant in the upper section in June (Fig 26). The upper section had the highest proportion of 13-36mm 0-group flounder of any section in May and June.

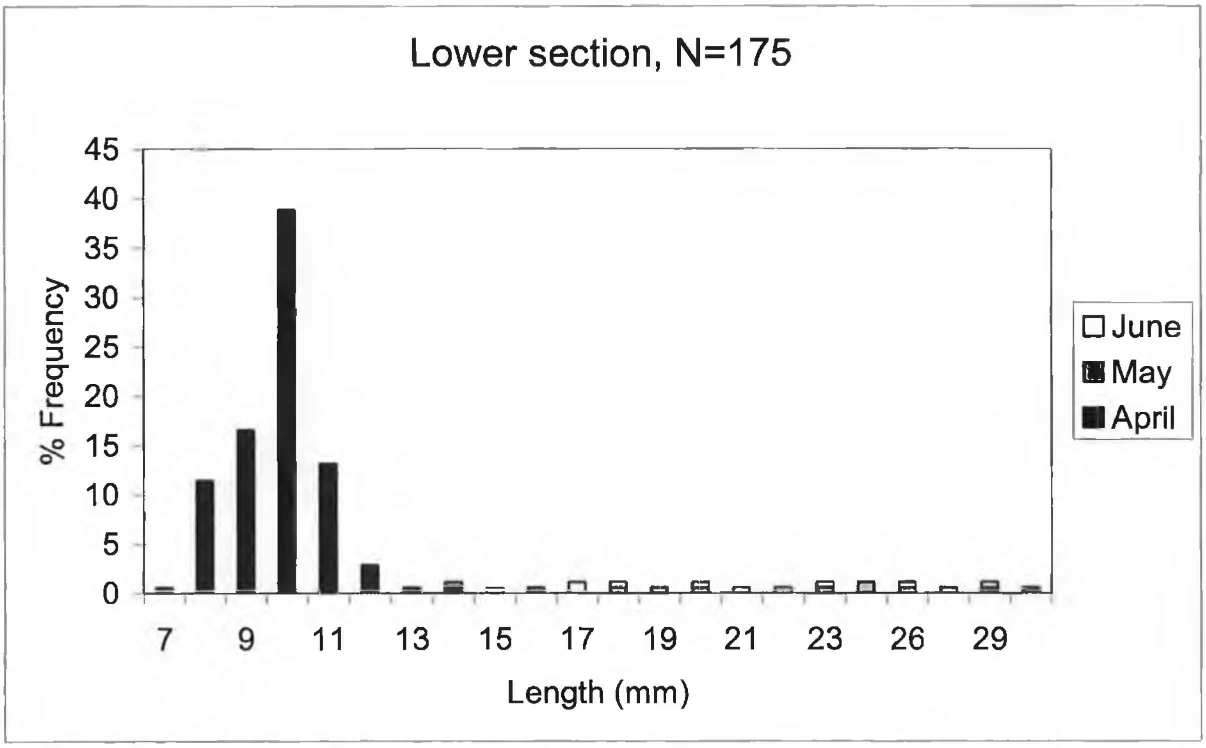

Fig 24. Length frequency per month of 0-group flounder from the lower sampling section of tidal rivers in Galway Bay from the 2005 and 2006 April-June period.

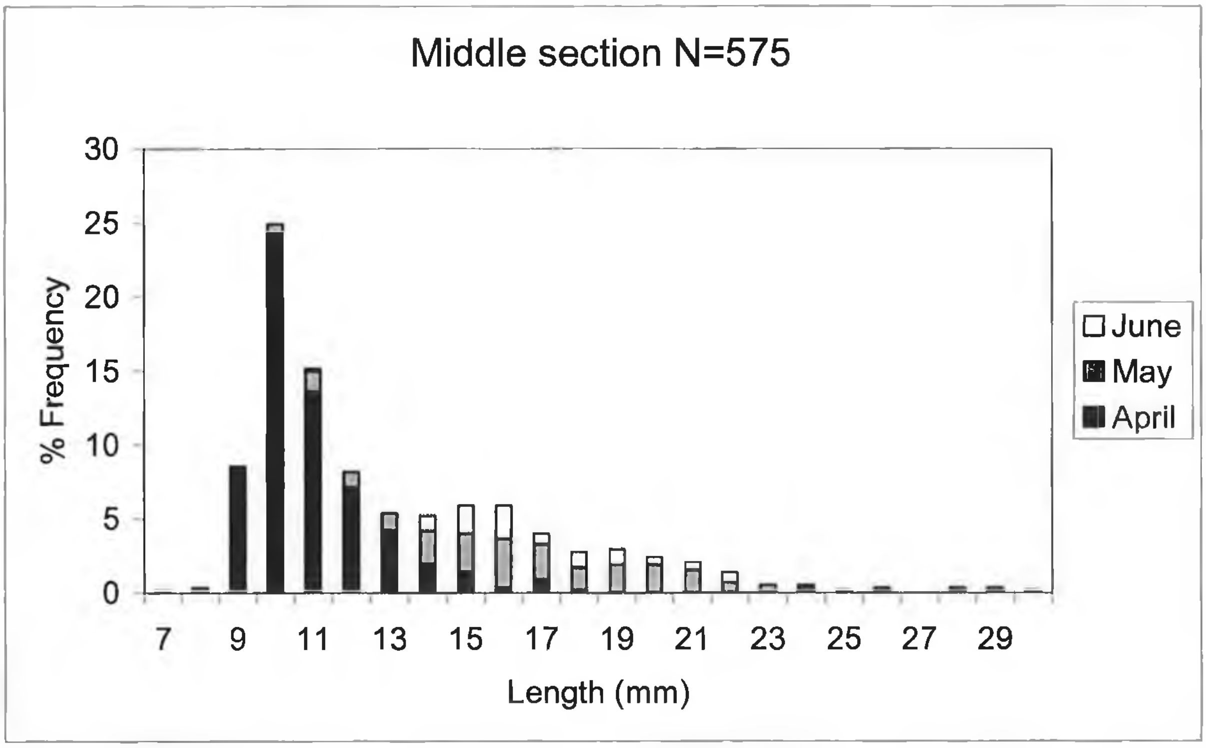

Fig 25. Length frequency per month of 0-group flounder from the middle sampling section of tidal rivers in Galway Bay from the 2005 and 2006 April-June period.

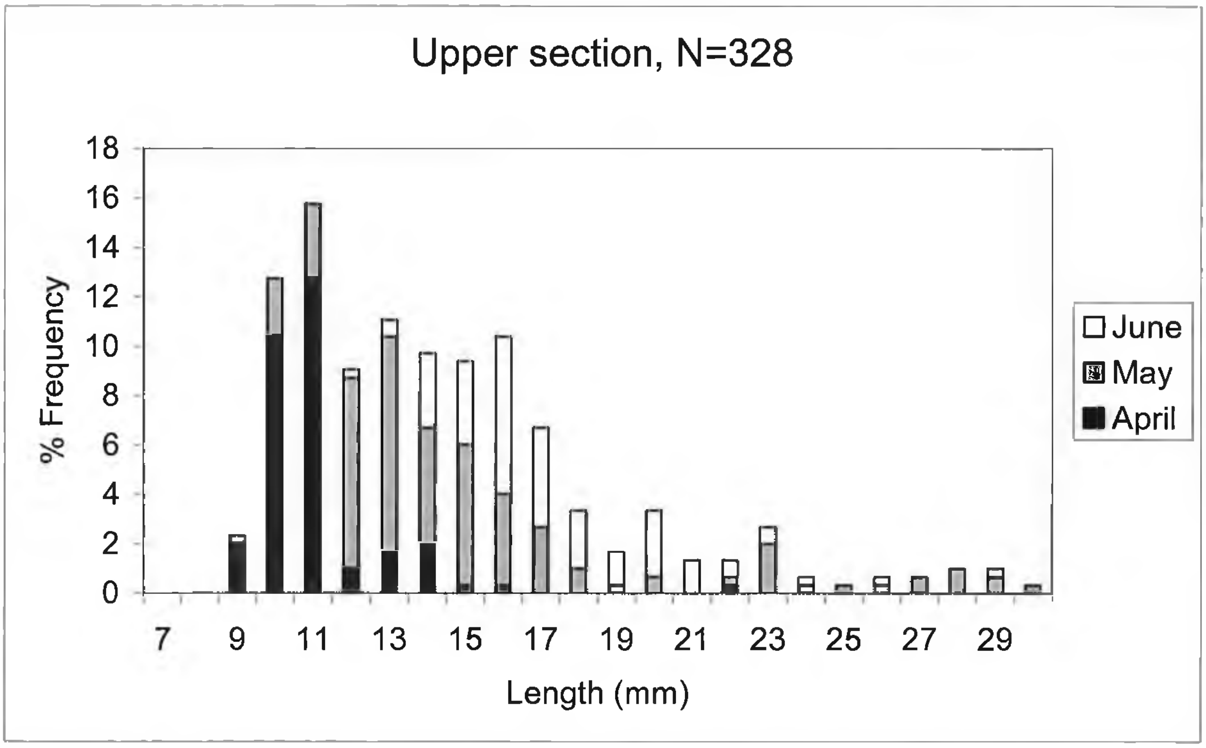

Fig 26. Length frequency per month of 0-group flounder from the upper sampling section of tidal rivers in Galway Bay from the 2005 and 2006 April-June period.

<u>Beach and tidal river sections analysis of variance</u>

ANOVA was used to determine if there was any significant difference in lengths of 0-group flounder between sections (upper, middle, lower, beach) over the March –June sampling period from 2005-2006. The data were pooled across each section. The null hypothesis was that there was no difference in the lengths between sections. The data was non-normal and unbalanced so a Kruskal-Wallis test was applied. The null hypothesis was rejected as there was found to be a significant difference in lengths between sections (Kruskal-Wallis, p=0.000). Moods median test (p=0.000) revealed flounder were: significantly larger in the upper than the middle, lower and beach sections, significantly larger in the middle than the lower and beach sections and significantly larger in the lower than the beach section. Thus 0-group flounder were significantly larger in more upstream sections.

Conclusions

Each section had a different length range with the more upstream sections containing the larger 0-group flounder (Fig 27). Flounder first appear on polyhaline beaches at about 8-10mm usually in late March or early April. By about 10mm in April flounder are present in all sections. Flounder are absent or present in insignificant numbers in polyhaline and mesohaline sections, by about 12mm, within weeks after first appearance. The evidence suggests that 0-group flounder move upstream in April, into the oligohaline sections of tidal rivers where they grow, before departing these areas from May on at around 30 mm in length.

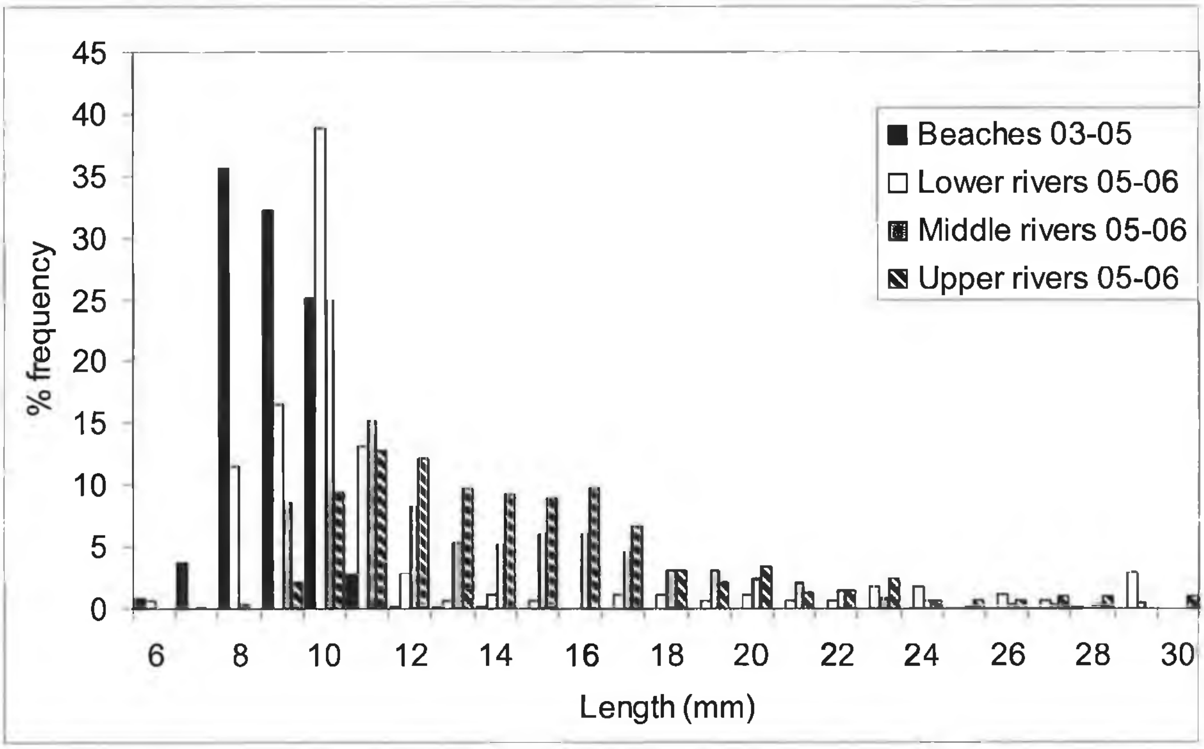

Fig 27. Length frequency from beaches (2003-2005), and the lower, middle and upper sampling sections of tidal rivers (2005-2006) in Galway Bay from March-July.

Growth

The average daily observed growth rate for 0 group flounder in Galway Bay was 0.25 $mm.d^{-1}$. Roscam was excluded from growth rate observations due to a short sampling period. The observed growth rates in Oranmore were similar to predicted growth rates, with less than 0.08 $mm.d^{-1}$ of a difference in April and May of 2005 and 2006 (Table 9). However observed growth in Oranmore was 0.19 $mm.d^{-1}$ and 0.25 $mm.d^{-1}$ less than predicted growth in June of 2005 and 2006 respectively (Table 9). Observed growth rates on the Corrib were considerably greater that predicted growth rates in both 2005 and 2006 (Table 9). The difference between observed growth rate for the Corrib and predicted growth rates was greater in May and June than in April (Table 9).

Growth rates were similar in 2006 and 2005. Daily growth rates for Oranmore were similar in 2005 and 2006 with an average daily growth rate from April to June of 0.15$mm.d^{-1}$ in 2005 and 0.12$mm.d^{-1}$ in 2006 (Table 9). Daily growth rates were also similar in the Corrib in 2006, with an average daily growth rate from April to May of 0.45$mm.d^{-1}$ in 2005 and 0.39$mm.d^{-1}$ in 2006. Growth rates in the Corrib were higher than in Oranmore in both years with on average of 0.26 $mm.d^{-1}$ difference between the sites.

Table 9. Mean monthly temperature °C for Galway Bay from the M1 data buoy, Daily observed growth rates for Oranmore and the Corrib ($mm.d^{-1}$) and predicted daily growth rates (Glazenburg 1983 in Van der Veer 1991) ($mm.d^{-1}$) for 0-group flounder in Galway Bay, from 2005 to 2006.

Year	Month	Mean Monthly Temp. °C	Observed daily growth ($mm.d^{-1}$) in Oranmore	Observed daily growth ($mm.d^{-1}$) in Corrib	Predicted Daily growth ($mm.d^{-1}$)
2005	April	10.8	0.2	0.4	0.192
	May	11.7	0.15	0.5	0.228
	June	13.7	0.12		0.308
2006	April	10.4	0.13	0.47	0.176
	May	11.2	0.17	0.32	0.208
	June	13.9	0.07		0.316

Discussion

Settlement timing

The first appearance of 0-group flounder on sandy beaches in the Galway Bay area varied from year to year ranging from late March to early May. The timing of settlement may have been less resolved from 2002-2004, due to the fact that sampling was only carried out once a month, as opposed to twice a month from 2005-2006. The appearance of 0-group flounder in March on sandy beaches was earlier than any other study although most of the studies on settlement of flounder were confined to estuaries and tidal rivers. In general the timing of flounder settlement in tidal rivers coincided with or succeeded settlement on sandy beaches. 0-group flounder first appeared in tidal rivers from early to late April in the Galway Bay area, around the same time as those in southern England (Claridge *et al* 1986), southern Wales (Hutchinson and Hawkins, 1993) and northern France (Robin, 1991). In other studies, settlement was generally later in more northerly locations (e.g. Bos, 1999; Bregneballe, 1961; de Vlas, 1979 in Van der Veer *et al.*, 1991; Jager *et al.*, 1995; Modin and Pihl, 1996; Summers, 1979; Van der Veer *et al.*, 1991) probably reflecting lower sea temperatures.

Peak Densities

Peak densities of 0-group flounder on sandy beaches in Galway Bay were in early to late April with the exception of 2003 when they occurred in early May. Peak densities on sandy beaches were generally recorded close to the time of first occurrence of 0-group flounder. Peak abundance in Galway Bay was earlier than studies carried out in comparative coastal areas. In the tidal flats of the Wadden Sea, peak densities of 0-group flounder occurred in June (Van der Veer *et al.*, 1991). In a small bay (Gullmar Fjord) on the west Swedish coast 0-group flounder reached peak abundance in mid June (Modin and Pihl, 1996).

Peak densities of 0-group flounder in tidal rivers ranged from early April to early May. Peak densities in tidal rivers generally occurred after peak densities in sandy beaches with the exception of the Corrib in 2006 when they occurred earlier. This may have been because the first settlement on sandy beaches was missed in 2006.

Peak densities of 0-group flounder in tidal rivers were generally later in other studies with the exception of the Loire estuary and the river Itchen. Peak densities of 0-group flounder occurred in April in the River Itchen (Hutchinson and Hawkins, 1993) and the Loire estuary (Robin, 1991), June in the River Dee (Johnson, 1981) and the brackish Dollard (Jager *et al.*, 1995) and July in the Ythan estuary (Summers, 1979). Claridge *et al.* (1986) found peak abundance of 0-group flounder recruits in the Bristol Channel in August: However peak abundance of larvae and post larvae was in mid May. Bos (1999 b) found peak abundances of 0-group flounder in 1996 and 1997 at several stations in the tidal river Elbe ranged from May – August.

When comparing peak densities with other studies we did not take into account the gear efficiencies of the respective sampling gears. Peak densities of 0-group flounder on sandy beaches in Galway Bay ranged from 0.0013 m^{-2} to 15.3 m^{-2} from 2002 to 2006. Peak densities recorded elsewhere, in comparative areas, were mostly within the range of those recorded in Galway Bay. On a tidal flat area near Hamburg (Schnakenback, 1940 in Kersten, 1991) found that densities of 0-group flounder were as high as 0.94 m^{-2}. Grove *et al.* (1981) recorded average 0-group flounder densities of 1-2 m^{-2} in Kinish Harbour on Sherkin Island in June 1979. Van der Veer *et al.* (1991) recorded peak densities of 0.01 m^{-2} to 0.26 m^{-2} in the Wadden Sea from 1974-1982. In the Wadden Sea, 0-group flounder may occur in densities in excess of 18.7 m^{-2} in puddles or nearshore tidal mudflats (Berghahn, 1984 in Kerstan, 1991). This is likely to be artificially high as 0-group flounder may be concentrated in puddles as they are trapped by the falling tide. Modin and Pihl (1996) recorded peak densities of juvenile flounder of 2.3 m^{-2} in Gullmar Fjord, Sweden in June of 1991 and 0.5 m^{-2} in June of 1992.

Peak densities in tidal rivers in Galway Bay ranged from 14 m^{-2} to 105 m^{-2} from 2005 to 2006. Johnson (1981) recorded a peak density of 0-group flounder of 271 m^{-2} at Chester Weir in June 1977. Similar to Oranmore, Johnson's (1981) densities may have been artificially high because of the presence of weirs. The weirs may cause a barrier to movement of juvenile flounder causing artificially high densities as observed downstream of the weirs in Oranmore. Hutchinson and Hawkins (1993) found dense aggregations of flounder post-larvae of up to 300 m^{-2} in the water margins of the River Itchen in April and May. Jager *et al.* (1995) recorded a peak density of 26 m^{-2} in late June in the Brackish River Dollard. In the tidal river Elbe, a maximum density of 0 group flounder of 0.44 m^{-2} was recorded after larval immigration in May (Möller, 1984 in Kersten, 1991). Also in the Elbe, Bos (1999, b) found a maximum abundance of 1.7 m^{-2} for 0 group flounder. The evidence from the above studies suggests that 0-group flounder can be found in dense aggregations.

There was no significant inter-annual variability in abundance of 0-group flounder in Galway Bay. In contrast, several other studies reported inter-annual variability in abundance of 0-group (Van der Veer *et al.*, 1991; Modin and Pihl, 1996) and juvenile flounder (Cabral *et al.*, 2007), but did not analyse the results statistically. In Galway Bay, 0-group flounder were observed in dense aggregations during sampling with often large numbers in a single replicate followed by low numbers in the other replicates (see Table 2). Similar dense aggregations of 0-group flounder have been observed by Berghahn, (1984) cited in Kerstan (1991) and Hutchinson and Hawkins (1993). Patterns of temporal and spatial variability are hard to analyse given the patchy distribution of the species. Thus caution must be exercised when drawing conclusions about abundance of the species.

There was no significant difference in peak densities between tidal rivers and beaches over a two week period in 2005. In other studies, higher densities of 0-group flounder were generally recorded in tidal river areas (see above). This suggests that tidal rivers are a more important nursery habitat for 0-group flounder than beaches. 0-group flounder appear largely as a transient population on beaches in Galway Bay appearing for only a short time before what seems likely to be immigration to tidal rivers. Highest densities of 0-group flounder occurred in limnetic (0ppt) and oligohaline (0.5-5ppt) areas as compared with the lower polyhaline (18-30 ppt) and to a lesser extent mesohaline (5.1 -18ppt) areas. It thus appears that salinity is an important factor in determining the suitability of these habitats. 0-group flounder are usually found in waters of salinities lower than 28ppt (Riley *et al.*, 1981). This may explain their absence from Silverstrand beach, where the mean salinity was 29ppt. Postlarval and juvenile flounder were shown in the laboratory to have a preference for freshwater over salinities of 5, 10, 15 and 20ppt by Bos (2006). Indeed, larval flounder can be induced to metamorphose when transferred to reduced salinities once a critical length is reached (Hutchinson and Hawkins, 2004). Hutchinson and Hawkins (1993) found that 0-group flounder in the river Itchen remained in very low salinities (<2ppt) and avoided contact with the saline water (20ppt) brought in on the flood tide. Jager *et al.* (1993) investigated the distribution of flatfish in the Ems – Dollard estuary in relation to abiotic factors over a year and found that salinity correlated negatively with 0-group flounder distribution later in the year. Kersten (1991) found a ten fold increase in abundances of 0 group flounder in the mesohaline areas of estuaries and river mouths as opposed to the polyhaline areas of the Wadden Sea. In the oligohaline and limnetic sections of the river Elbe, densities of 0-group flounder increased again, by several factors (Kersten, 1991). The maximum increase in abundance between areas was found in the freshwater section where abundance was 200 times that of the polyhaline Wadden Sea (Kersten, 1991). Densities in the freshwater and oligohaline sections of tidal rivers in Galway Bay were up to several orders of magnitude higher than those on the polyhaline sandy beaches, with the highest density recorded in freshwater, so the present study does appear to concur with the findings of Kersten, (1991). Bos (1999 b) observed post-metamorphosed flounders invading the fresh water section of the tidal river Elbe at the end of May 1996 and beginning of June 1997. In contrast, Jager *et al.* (1995) found no substantial numbers of 0-group flounder when occasionally sampling freshwater around high water from April – September. Peak densities of 0-group flounder were in June with salinities recorded throughout the sampling period in the mesohaline and polyhaline categories (Jager at al., 1995). Vinagre *et al.* (2005), sampling a Portuguese estuary every two months from November 2000 to March 2002. Vinagre *et al.* (2005), found highest densities of flounder (90% juvenile) in the mesohaline part of a Portuguese estuary as opposed to lower densities in oligohaline, freshwater and the surrounding coastal areas. It must be borne in mind that salinity values for Kersten (1991) and Vinagre (2007) were taken at all stages of the tide as opposed to solely at low water in the present study. Trawl sampling (Kersten, 1991; Jager *et al*, 1995; Vinagre, 2007) is generally carried out in deeper water (>1m) as opposed to the shallow water sampling of the present study and that of Hutchinson and Hawkins (1993). The present study appears to be sampling 0-group flounder at an earlier life stage than the other studies mentioned above. It does not appear from the lengths given that any 0-group flounder of approximately 12mm (TL) were sampled by Kersten (1991) or Jager *et al.* (1995). The findings of the present study concur with those of Kersten

(1991) showing highest densities of 0-group flounder in the freshwater and oligohaline sections of tidal rivers as opposed to polyhaline and to a lesser extent mesohaline areas. The present study corroborates there findings of Bos' (2006) laboratory study showing flounder post-larvae having a preference for freshwater. It also supports Bos (1999 b) findings from the field showing post-metamorphosed flounder invading the fresh water section of a tidal river. Given the patchy distribution of the species in Galway Bay, abundance estimates must be interpreted with caution.

Growth and lengths

The overall recruitment success of flatfishes will depend on both survival and growth of recruits through the highly variable larval stages and during the juvenile years in the coastal nursery grounds (Van der Veer, 1986; Van der Veer *et al.*, 1994; Beverton, 1995 in Anderson *et al.*, 2005). 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.* 2000).

Given that mean lengths for most of the other studies are in total length the lengths from the present study were converted to total length for comparative purposes using the standard – total length conversion in the Appendix. A mean length of 11mm (TL) was recorded on beaches in Galway Bay during settlement. A mean length of 12mm (TL) was recorded in tidal rivers in Galway Bay in April. The mean lengths of 0-group flounder caught early in the year were similar to those first sampled elsewhere. Van der Veer *et al.* (1991) found flounder of mean length ~ 10mm (TL) in May of 1979-1981. Hutchinson and Hawkins (1993) showed the arrival in April of 0-group post larvae of 7-9mm (TL) to low salinity areas (<2ppt) in the River Itchen. Modin and Pihl (1996) found 0-group flounder of 8-11mm (TL) when they first appeared in May / June.

Later in the season mean lengths of 18mm were recorded in June in Oranmore (there were no corresponding mean lengths for any other site). This was similar to those recorded in other studies elsewhere. Summers (1979) and Hutchinson and Hawkins (1993) recorded mean lengths of 0-group flounder in June in UK tidal rivers of 20mm and 23mm respectively. In south-west Ireland, Grove *et al.* (1981) recorded slightly higher mean lengths of 30, 28 and 37mm. Henderson and Holmes (1991) found flounder of 30-40mm (TL) in June in the Bristol Channel. Kersten (1991) recorded 0-group flounder ranging from 20-60mm in the limnetic river Elbe in late June. Van der Veer *et al.* (1991) found 0-group flounder of mean length 20mm in the Wadden Sea in June. Jager *et al.* (1995) recorded higher mean lengths of ~29mm (TL) in June in the Ems Estuary, Wadden Sea. Modin and Pihl (1996) found a median length in late June in a Swedish fjord of 17mm of 1991 and 22mm in 1992. Claridge *et al.* (1986) found 0-group flounder recruits of 30-120mm (SL) at the power station in take in the middle and inner Bristol Channel during July and August.

A significant difference was found in lengths between sites over the two week peak settlement period in 2005. Flounder were larger on Oranmore than Ballyloughaun and Murrogh and the Corrib than Ballyoughaun. The differences in lengths probably reflect the migration of flounder into tidal rivers. 0-group flounder were usually absent from samples on sandy beaches in a matter of weeks. In contrast, 0-group flounder remained for longer in tidal rivers, especially in Oranmore. The significant difference between both tidal river sites and Ballyloughaun may be because it is further from a river mouth than Murrogh.

A significant difference in 0-group flounder lengths over the March – June sampling period was found between sampling sections in the tidal rivers. Larger 0-group flounder are found in more upstream areas. It appears that smaller 0-group flounder utilise higher salinity estuarine habitats at a narrow size range close to metamorphosis. 0-group flounder on beaches in Galway Bay were mostly within the size range 10-12 mm (TL). Those from the lower section of tidal rivers were mostly in the range 10-13mm (TL). In the present study there were no flounder sampled on beaches in the range 18-24mm (TL) during the February – June sampling period (2002-2006). Similarly only 9 out of the 175 flounder sampled from the lower section of tidal rivers were in the length range 18-24mm (TL). Bregnballe (1961) also found a narrow size range of 0-group flounder of mostly 9-15mm (TL) flounder at sites outside a Danish fjord. Salinities on Irish beaches, lower sections of rivers, and the sites outside the Danish fjord were mostly in the mesohaline / polyhaline categories.

In the lower salinity environments of tidal rivers larger 0-group flounder were present. A wider size range of 10-42mm (TL) was found within oligohaline sections of tidal rivers in Galway Bay with 0-group flounder 12-30mm present in abundance This was also apparent at sites within the Danish fjord where larger 0-group flounder in the length range 9-33mm (TL) were found (Bregnballe, 1961). Kersten (1991) found that in late June, 0-group flounder of 20-60mm (TL) became abundant in the limnetic Elbe river section but did not occur in the polyhaline areas. Hutchinson and Hawkins (1993) found that in April, flounder post-larvae of 7-9mm (TL) remaining in very low salinities (<2 ppt) in the River Itchen and avoiding contact with the saline water (>20ppt) brought in by the tide. These 0-group flounder were present in River Itchen until they reached about 60mm in Winter (Hutchinson and Hawkins, 1993). Salinity ranges in the aforementioned tidal river and fjord habitats were in the freshwater – mesohaline range. Bos (2006) demonstrated experimentally that larger flounder that had finished metamorphosis had a stronger preference for a lower salinity. The flounder ranged from 7.5-21mm, with preference for a salinity of 0.5ppt as opposed to salinities of 5, 10, 15 and 20 ppt strongest in flounder of 15 and 13mm (TL) Bos (2006). This preference is apparent in the distribution of the sizes of 0-group flounder in Galway Bay with flounder above 14mm (TL) showing a preference for oligohaline upstream areas.

The difference in mean lengths of 0-group flounder between polyhaline coastal areas and lower salinity tidal rivers seems to support Bregnballe' (1961) suggestion of immigration of 0-group flounder to the lower salinity areas. Migration of 0-group flounder into low salinity (0.5ppt) has been shown in the laboratory by Bos (2006). The migration of larval flounder into estuaries has already been shown by Hutchinson & Hawkins, (1993); Jager (1999, 2001); Bos, (1999a,b). The present study and those of Kersten (1991), Hutchinson and Hawkins, (1993) indicate that 0-group flounder, during the early stages of post settlement, favour the limnetic and oligohaline areas of tidal rivers.

Migration of 0-group flounder into more upstream areas may be caused by density dependent factors where emigration is necessary as food resources are exhausted. Another possible explanation for the absence of larger 0-group flounder in the mesohaline and polyhaline areas is predation. Evidence for coelenterate predation on flounder larvae was found by Van der Veer (1985) who found decreases in larval density in coincidence with increased coelenterate numbers. Van der Veer (1985) suggested that flounder larvae may be particularly vulnerable given their small size relative to plaice larvae. There may be heavy predation by marine predators in the higher salinity areas in Galway Bay causing mortalities in 0-group flounder. There are likely to be fewer predators in low salinity areas. Thus the immigration of flounder larvae to oligohaline and limnetic areas may be a mechanism to avoid predation.

Observed growth was compared to Glazenburg's (1983) (cited in Van der Veer et al., 1991) growth model which was applied to juvenile flounder predicted growth rates by Van der Veer *et al.* (1991). Observed growth rates in Oranmore were similar to predicted growth rates in April and May of 2005 and 2006. However observed growth in Oranmore were less than predicted growth in June of 2005 and 2006. Van der Veer *et al.* (1991) found that from May on there was a high similarity between observed and predicted growth suggesting that flounder were not food limited in the Dutch Wadden Sea. The similarity in growth rates in the early season in Oranmore also suggests that 0-group flounder are not food limited. However, lower than predicted growth rates later in June in Oranmore may result from density dependent factors. Kersten (1991), Hutchinson and Hawkins (1993) found that 0-group flounders lagging behind in growth did not leave the limnetic sections in winter. This would explain absence of flounder from the samples in the Corrib earlier in the year than Oranmore. In the Corrib, observed growth rates were higher than predicted growth rates suggesting a plentiful food supply, so emigration from the limnetic area (see below) can occur sooner. Growth rates were higher in the Corrib than Oranmore in both 2005 and 2006 with on average of 0.26 $mm.d^{-1}$ difference between the sites. This suggests that feeding conditions were better in the Corrib than Oranmore. 0-group flounder in the Corrib were observed avoiding the sampling gear in June and it appears that most of the flounder at the site have migrated by the end of May. In contrast, the small size and constraints (weirs) of the site at Oranmore may cause density dependent limitations on growth and restrict emigration.

The average daily observed growth rate for 0 group flounder in Galway Bay was 0.25 $mm.d^{-1}$ from April to June in 2005 and 2006. Observed growth rates were generally less than those recorded elsewhere. Bregnballe (1961) recorded daily observed growth rated of 0.91 $mm.d^{-1}$ in June in Denmark. Jager *et al.* (1995) found observed growth rates of 0.7 $mm.d^{-1}$ in the Netherlands. Anderson *et al.*, (2005) found growth rates based on increase in median length of 0.58 $mm.d^{-1}$ in a bare sand and 0.48 $mm.d^{-1}$ in a vegetated habitat of a Danish fjord.

Flounder greater than 28 mm (TL) were first found on Ballyloughaun in late May but more often in late June and appear to have returned to the site from tidal rivers. A length of 30 mm (TL) is the approximate size where flounder start to become absent from the tidal river samples. Larger 0-group flounder of approximately 25-30mm (TL) in length were observed in the lower reaches of Oranmore from the end of May and may be leaving the river. Kersten (1991), observed that 0-group flounder reached peak densities at approximately 50mm in June at the earliest in the limnetic section of tidal rivers, thereafter departing with those who lagged behind in growth remaining in the limnetic section over winter. There followed a peak in densities of 0-group flounder in the polyhaline and mesohaline areas at sizes greater than 70mm later in the year. Hartley (1939) found flounder present in tuck net-seine samples in the Rivers Tamar and Lynher only from October to March and only greater than 70mm. Hartley (1939) stated that this was not related to mesh size and speculated that they were utilising different areas of the estuary. Doornbos and Twisk (1984) sampled Leke Gravelingen in the Netherlands with beam trawls twice monthly from 1979-1981 and found no flounder below 60mm (TL) in the samples. Jager *et al.* (1995) found flounder of mean length 29mm in beam trawl samples from June in the mesohaline and polyhaline areas of the Ems Estuary which coincided with peak density. Jager *et al.* (1995) found no substantial numbers of 0-group flounder prior to this during April and May and no lengths for these flounder were given. Claridge *et al.* (1986) found 0-group flounder recruits of 30-120mm (SL) in the middle and inner Bristol Channel during July and August coinciding with maximum abundance. Evidence from beach seine surveys (Keirse, 2006 unpubl. data) on Ballyloughaun in August of 2005 and 2006 found that 0-group flounder >50mm abundant on the site so they appear to have moved back to the site from the tidal rivers. The evidence points to larger 0-group flounder (>30 mm), departing the oligohaline sections of tidal rivers, and moving down the estuary into mesohaline and polyhaline areas later in the year. However, the fact that flounder > 30mm were rare (n=21) in the present study, and that beach seine sampling (Keirse, 2006), was not carried out over a longer period on both habitats means these results must be interpreted with caution. A simultaneous sampling programme of the two habitats sampling the full range of salinities and depths may be appropriate to resolve the question of the movements of larger (>30mm) 0-group flounder.

In summary, from the results of the present study and others it appears that 0-group flounder use different habitats during the juvenile phase of benthic life history. They appear on sandy beaches immediately following settlement at 8-10mm. They then disappear from these habitats and reappear some months later at around 30mm. The intermediate time is spent in tidal rivers with the growing fish moving upstream into lower salinity areas before departing to the beach habitats. Salinity and length appear to be key factors with the association with low salinity diminishing as the flounder get larger.

Chapter 4: Hatching, larval duration, settlement, age and growth dynamics of 0-group flounder in Galway Bay determined using otolith microstructure.

Abstract

Otolith microstructure of 0-group flounder was analysed in Galway Bay, west of Ireland. Flounder otoliths were examined to determine if hatch checks were deposited, as occurs in other flatfish species. Hatch checks were identified and the presence of the accessory primordium associated with metamorphosis in many flatfish species was confirmed. Hatch dates, larval durations, settlement dates and age (days) were calculated using daily increment counts. Otolith increment width measurements from increments 20-25 was used as an index of growth. Newly settled flounder otolith microstructure was compared from two sandy beach (Ballyloughaun, Murrogh) and two tidal river (Corrib, Oranmore) habitats in Galway Bay over a two week period during peak settlement in April of 2005. Inter-annual variability in flounder otolith microstructure was compared on comparative dates in April of 2004 and 2005 on one beach site (Ballyloughaun). Inter-annual variability in larval durations was also compared from 2002, 2003 and 2005 in Galway Bay.

Flounder otoliths exhibited a dark band at about 10μm which was assumed to be the hatch check, similar to that of plaice. Hatching times of flounder in Galway Bay ranged from early February to mid March. In 2005, there was no significant difference in hatching times between flounder sampled on beach and river habitats. However, in 2005, significant differences in hatching times were found between sites, with flounder sampled from Murrogh hatching later than any other site. There was no significant difference in hatching between years for flounder sampled on Ballyloughaun.

The mean larval duration of the flounder sampled was 38 ± 5 and ranged from 32-47 days. There was found to be no significant difference in larval duration between flounder sampled at Oranmore and the Corrib in 2005. There was also found to be no significant difference in larval durations for flounder sampled at

Ballyloughaun in three years (2002, 2003 and 2005). Larval durations were similar to those in a laboratory study of reared flounder.

The larval growth rates from day 20 to 25 from hatching, for Galway Bay in 2004 and 2005, ranged from 0.73 to 3.98 μm with a mean of 1.74 μm. There was found to be a significant difference in growth rates between sites in 2005 from day 20 to 25 from hatching. Growth was significantly faster for flounder sampled on Oranmore than Ballyloughaun. The results point to differing larval growth rates between areas. The larval growth rates from the present study were less than those reported for other species.

Flounder on sandy beaches in Galway Bay were not fully metamorphosed and generally did not have accessory primordia on their sagittal otoliths. In contrast, accessory primordia were present on the majority of flounders' otoliths in tidal rivers. Fully metamorphosed flounder were therefore observed only from those flounder sampled from tidal rivers. Flounder were found to deposit accessory primordia at 9mm (Standard Length) and above on both habitats. There was no significant difference in age (in days) between those flounder without accessory primordia and the larval duration of those with accessory primordia. This suggests that flounder settlement in tidal rivers and beaches takes place at around the same age. The evidence points to the transition from beach to river habitats being an important factor in the deposition of the accessory primordia and metamorphosis.

Settlement dates for 0-group flounder in Galway Bay ranged from the 28th of March to the 14th of April. Flounder were found to settle significantly earlier in the Corrib than Oranmore in 2005. Flounder post-larval durations ranged from 5 -17 days with a mean of 10 ± 4 days and were not significantly different between river sites.

Flounder in the present study ranged from 27 – 59 days old with a mean of 40 days old. In 2005, there was no significant difference in 0-group flounder age between beach and river habitats. In 2005, there was a significant difference in age of 0-group flounder between sites. Those on Oranmore were significantly older than those on Ballyloughaun or Murrogh. 0-group flounder on Ballyloughaun were found to be significantly older in 2004 than 2005.

Introduction

The determination of the age of a fish is an important component of fisheries science and for the management of fish stocks. Fish are much easier to age than other organisms and the age can be used to determine some of the most influential life characteristics controlling the productivity of a fish population such as growth and mortality rates (Campana and Thorrold 2001). Ageing of fish often involves looking at bony or calcified structures such as otoliths, spines and vertebrae. Otoliths and scales can be used to determine the age of a fish by counting concentric rings similar to the rings of a tree trunk. Otoliths provide a permanent record of fish life history events which show annual and daily patterns. Otolith research is broadly divided into three areas, (1) otolith annuli analysis (2) otolith microstructure analysis and (3) otolith chemistry analysis. The present study deals with otolith microstructure on the Sagittal pair of otoliths.

Otolith microstructure examination may be used to determine both growth rates and life history characters in some fishes (Brothers and McFarland, 1981; Methot 1981; Campana, 1984; Victor, 1983, in Campana 1983). Microstructure analysis allows the estimation of individual age at different stages during the early life history of juveniles. Validation studies have confirmed that primary increments are formed daily in otoliths of many species of larval and juvenile flatfish (e.g. Al-Hossaini and Pitcher, 1988, for plaice). 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). The starry flounder (*Platichthys stellatus L.*) has been shown to lay down both daily and sub-daily increments (Campana and Neilson, 1982). Non-daily increment formation has only been recorded in sub optimal (low temperature and poor food supply) laboratory conditions. Daily increment deposition in larval flounder (*p. flesus*) otoliths was validated by Bos (1999a, b) using the marginal increment technique (Tanaka *et al.*, 1981). It expresses completion (or width) of the increment being formed on the edge of the otolith as a percentage of the immediately preceding increment (Bos, 1999a, b). Researchers generally count the primary increments in larval and juvenile flatfish otoliths as daily increments as is done in this study.

Otoliths often include characteristic structures associated with particular life stages. Among these are hatch checks associated with the hatching of the egg, which are often included among the larval increments. For example, the hatch check is deposited at about 10µm from the otolith core in larval plaice, *Pleuronectes platessa*, L., (Hovenkamp, 1990) and characterised by a dark band (Brophy, 2006 pers. comm.). The formation of hatch checks in the otoliths of flatfish species has be validated by the hatching of eggs in the laboratory (e.g. Hovenkamp, 1990; Legardere and Troadec, 1997). However, validation of hatch checks has not been done for flounder and it is not known if flounder deposit hatch checks on their otolith. Bos (1999 a, b) in studies of flounder otolith microstructure made no mention of hatch checks. If the hatch check is the first increment formed, hatch dates can be calculated. Hatch dates can be calculated by subtracting the number of daily increments from the capture date of the fish.

From the hatch check, larval duration (age in days) can be calculated by counting the daily growth rings up to the edge of the first accessory primordium, a structure in the otolith laid down at metamorphosis (see below). There are no studies documenting larval duration of flounder from otolith microstucture. Bos (1999a) reported the total age of flounder larvae from otolith microstructure and made no mention of hatch checks or accessory primordia and thus larval duration. The developmental sequence of laboratory reared flounder was reported by Hutchinson and Hawkins (2004). Hutchinson and Hawkins' (2004) observed metamorphosed flounder at 45 days after fertilisation. Given that the eggs hatched at 6-7 days (Hutchinson and Hawkins, 2004) this would give a larval duration of 38-39 days.

A particular aspect of otolith microstucture analysis is the use of daily increment width as a growth index (Reichert et al., 2000), although it is not certain that increments formed within the accessory growth centres (accessory primordia) represent daily growth (Nash & Geffen, 2005). Otolith increment widths (µm) have been used as an index of growth in 0-group flatfish (Karakiri *et al.* 1991; Gilliers *et al.* 2004; Allard, 2007). Among these studies several used otolith increment widths as an index of larval growth. Karakiri *et al* (1991) used daily increment width as an index of larval growth of 0-group plaice. In Galway Bay, increment widths from day 20-25 after hatching were used as an index of larval growth in plaice (Allard, 2007). There are no studies on the use of daily increment widths as a growth index in flounder.

Following the larval period, metamorphosis takes place. Sagittal otoliths of newly metamorphosed and settled flatfishes display distinct secondary growth centres (accessory primordia) at the circumference of the larval otolith (e.g. Campana, 1984; Al-Hossaini, 1989; Karakiri *et al.*, 1989; Sogard, 1992; Modin *et al.*, 1996). The coincidence of the accessory primordia and metamorphosis in flatfish has been evaluated for winter flounder (Sogard, 1992), for plaice (Modin *et al.*, 1996) and for dover sole (Toole *et al.*, 1993). However, no information is available as to whether the accessory primordia in flounder otoliths coincide with metamorphosis or settlement. Campana (1983) found outer nucleii (probable accessory primordia) formed around the periphery of starry flounder otoliths and suggested they were formed at or shortly after metamorphosis. Sogard (1992) found that accessory primordia on winter flounder (*pseudopeuronects americanus*) otoliths appeared midway through eye migration. Toole *et al.*, (1993) found that in dover sole, accessory primordia may form over a period of 70 days suggesting that the structures do not form in response to a single event. Modin *et al.* (1996) showed that the accessory primordia on plaice otoliths were formed at early metamorphosis when the pupil of the asymmetrical left eye had migrated beyond the edge of the dorsal ridge. Although it has been shown that different flatfish species deposit accessory primordia at differerent life stages, the influence of habitat or abiotic factors on the deposition of accessory primordia is unknown.

Given that the deposition of the accessory primordia generally coincides with metamorphosis, increments deposited after the accessory primordia may be considered as post-larval. Post-larval duration can be calculated by counting the number of daily increments from the first accessory primordium to the edge of the otolith. There are no studies on the post-larval ageing of flounder

There are only two known studies on ageing of flounder from otolith microstructure. Bos (1999a, b) aged larval flounder from the river Elbe from daily increment counts using light microscopy. Otoliths greater than 250 μm could not be aged as they did not allow sufficient light to pass through Bos (1999a, b). Flounder larvae ranged in age from 10 – 60 days and were of ontogenetic stage IIIc - V (Bos, 1999a, b). He also found that daily increment counts were significantly higher upstream than at the entrance of the estuary and significantly higher from May samples than for April samples (Bos, 1999a, b).

The aims of the following chapter are to address some of the deficits in our knowledge of flounder otolith microstructure and early life history discussed above. Specifically:

- Determining whether hatch checks and accessory primordia are laid on flounder otoliths.
- Estimate the hatch dates and settlement dates for west of Ireland flounder.
- Calculating larval duration and the age of flounder.
- Estimate larval growth rates.
- To determine scales of temporal, spatial and between habitat variability in these parameters.

Materials and Methods

Study Area and Sampling Procedure

0-group flounder were sampled on two beaches and three tidal rivers in Galway Bay. Ballyloughaun, (54° 15.2`N, 09° 01.6`W) is a sandy beach approximately 500 meters in length (at low water) and 400 meters wide located approximately 2 kilometres east of Galway City centre. There is a strong freshwater influence at the site due to its close proximity to the river Corrib outflow and several small fresh water outflows. . A second sandy beach site was located at Murrogh House (53° 16.01`N, 08° 59.59`W) in mid-April of 2005 with juvenile flounder found at the site. This is a sheltered shore located behind several islands within 1km distance from Ballyloughaun and with a similar freshwater influence from the Corrib and Roscam stream. Three tidal river sites were sampled for 0-group flounder. Oranmore river (53° 16.16`N, 08° 55.46`W) is a small tidal river approximately 15 meters wide at the mouth located in the north eastern corner of Galway Bay. A 200m long tidally influenced section was sampled near the mouth. The Corrib (53° 16.04`N, 09° 02.5`W) is one of the largest systems in Ireland. A 200m long tidally influenced section was sampled on the western shore close to the mouth at Nimmos Pier). Roscam (53° 16.06`N, 08° 59.51`W) is a small stream, approximately 3 meters wide at the mouth which feeds into the beach at Murrogh house. Due to its relatively narrow channel compared with the Corrib and Oranmore a longer section of 400m from the mouth was sampled. A detailed description of the sampling procedure and methods is described in chapter 3.

Laboratory Analysis

In the laboratory all fish were identified to species and coded. The fish were placed in vials which were labelled according to sampling replicates. Each flounder was measured (total and standard length) to the nearest 0.1mm using callipers. Damage was observed on the fin rays of many of the caudal fins in which case only the standard length was measured. It was therefore decided to take only the standard lengths for analysis.

A sub-sample of fish from each sample was randomly picked for otolith microstructure analysis. The sagittal otoliths were removed from the head using pins and placed in labelled vial lids for storage and processing.

Otolith preparation

In order to carry out otolith microstructure analysis, the 0-group flounder 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) and Allard (2007) 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, 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.

Otolith microstructure analysis

Otolith microstructure analysis allowed for the determination of hatch checks, daily increments and accessory primordia (Fig 1, 2). It has been established that flounder deposit daily growth rings from the marginal increment technique (Bos, 1999a, b). Validation of daily increment reading was carried by reading the same otoliths on three separate occasions.

Many flatfish species lay down distinctive checks associated with hatching. Plaice otoliths are 10 μm in length when hatched (Hovenkamp, 1990) and are characterised by a dark band at about 10μm from the otolith core, (Brophy, 2006 pers. comm.). In the absence of validation of hatch checks for flounder otoliths, it was decided that, similar to plaice, a heavy dark band which appeared as the first daily increment (Fig 1) would be considered as a hatch check. 0-group flounder otoliths from Galway Bay were observed for hatch checks and their presence was quantified in both tidal river and beach habitats. 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 the hatch date.

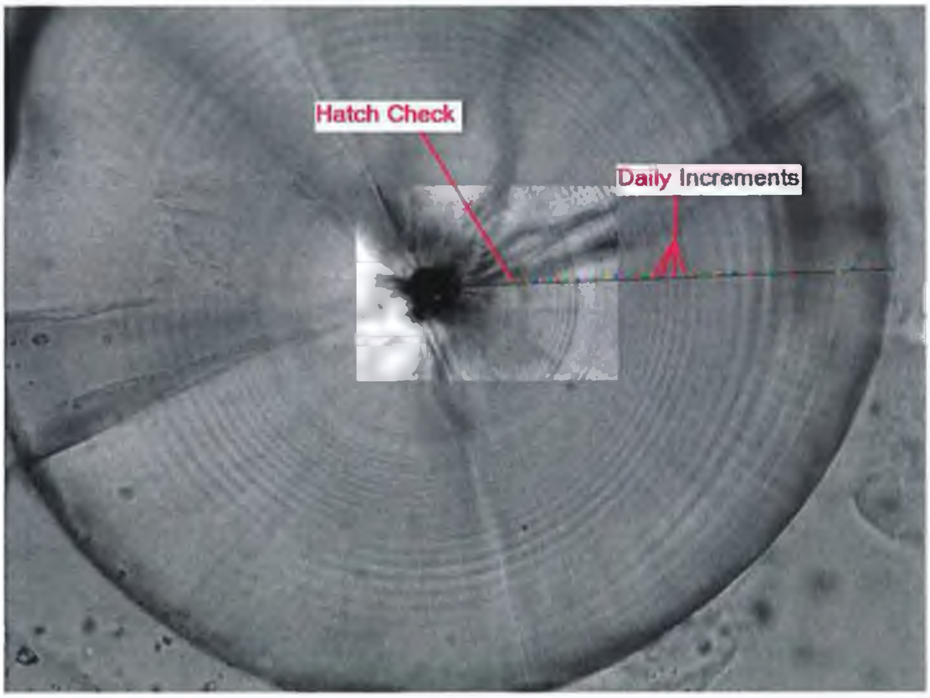

Fig 1. Picture of a 0-group flounder otolith taken under X1000 magnification. Hatch checks and daily growth increments are visible.

From the hatch check larval duration (age in days) can be calculated by counting the daily growth rings up to the edge of the first accessory primordium (Fig 2). 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).

Sagittal otoliths of newly metamorphosed and settled flatfishes display distinct secondary growth centres (accessory primordia) (Fig 2) at the circumference of the larval otolith. The accessory primordia generally coincide with metamorphosis in other flatfish species. Flounder otoliths from sandy beaches and tidal rivers were examined to determine if the accessory primordia were present in both habitats.

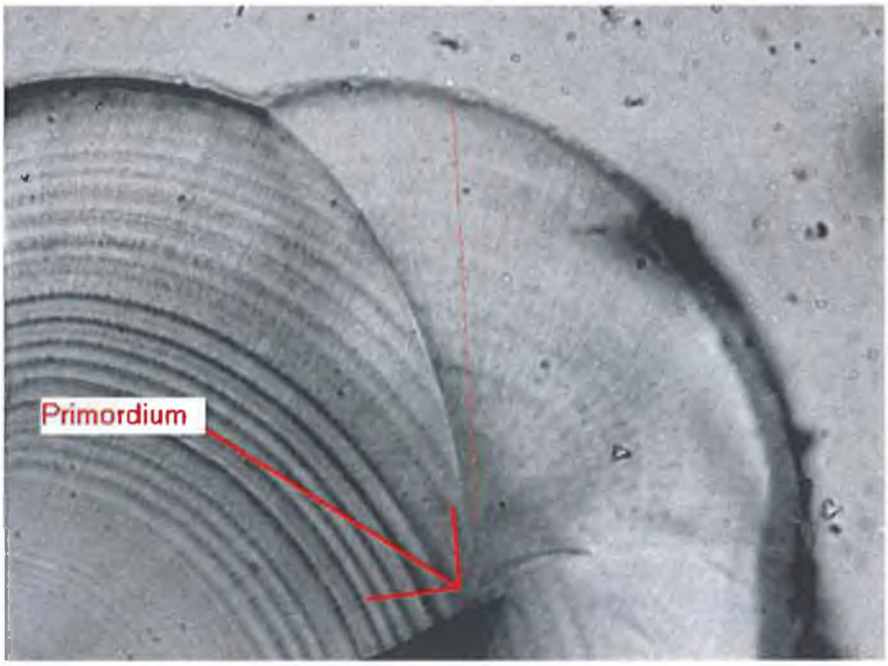

Fig 2. Picture of a 0-group flounder otolith at X1000 showing the accessory primordium.

The age of flounder (in days) was calculated by counting the total number of daily increments (larval and postlarval) on 0-group flounder otoliths. The age was used for comparisons between beach and river habitats.

Otolith increment width (μm) can be used as an index of larval growth (Karakiri *et al.* 1991, Gilliers *et al.* 2004). Otolith increment widths 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 were taken from day 20 to 25, from the hatch check, for the 73 fish sampled. This was to compare with another study from Galway Bay where increment widths from day 20-25 were measured for 0-group plaice (Allard, 2007). Increment widths 20-25 are easier to measure than earlier in the life history, probably have less error, and all fish share this larval period. Friel (2007) has shown for plaice that there is a statistically significant correlation between the growth rate over the 20 -25 day period than that of the entire larval phase.

Data Analysis

The data were coded and inputted into excel before being transferred to Minitab for further analysis. All data were subjected to Ryan-Joiner normality tests and checked for homogeneity of variance using Cochran's test. If the data was found to be non-normal, non-parametric tests were used. When the data were found to be normal parametric tests (ANOVA) were carried out.

Otoliths were extracted from 0-group flounder on two beaches and two rivers sampled over a two week period from the 8th – 20th of April 2005. This was the only time where there was sufficient data for comparison between the two habitats. This period also coincided with peak settlement on sandy beaches and tidal rivers in 2005 (see Chapter 3). Comparisons of hatch dates, larval duration, larval growth, settlement dates, and age (days) were made between habitats and sites. Comparisons were also made between otoliths from beach and river habitats to see if accessory primordia were present and the size at which they were deposited. In cases where accessory primordia were not deposited on the otoliths it was not possible to calculate larval and post-larval durations, and settlement dates. The experimental design is shown in Fig 3.

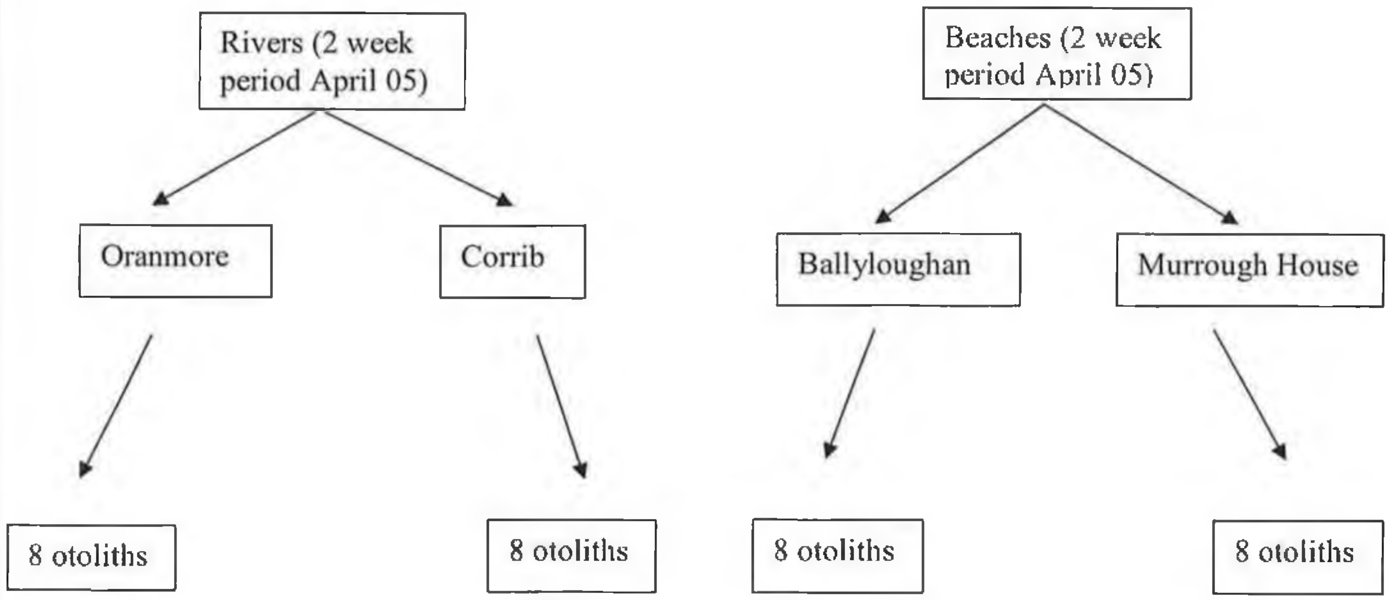

Fig 3. The experimental design to compare otoliths between beach and river habitats.

The hatch dates, larval growth and age of 0-group flounder on one sandy beach (Ballyloughaun) was compared over a two year period on comparative dates (7/4/04 and 8/4/05) to see if there was any difference between the years. Given the lack of accessory primordia on beaches (see below) it was not possible to calculate parameters such as larval duration. The experimental design is shown in Fig 4.

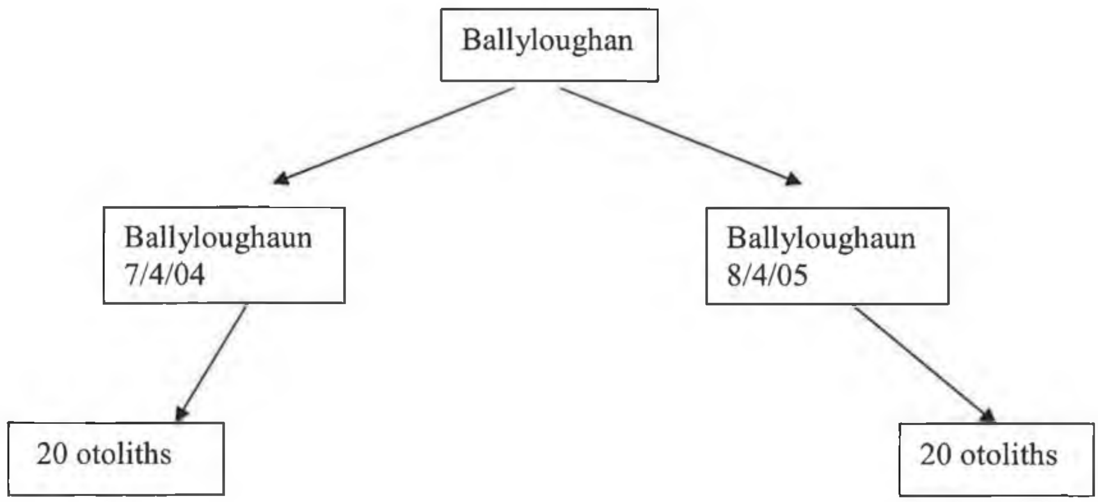

Fig 4. The experimental design to compare otoliths between years on Ballyloughaun.

Larval duration of flounder was compared over a three year period. The results of the present study in 2005 (Reader 1), were compared with flounder larval durations from 2002 and 2003 (Reader 2). The samples were independent of one another with the reader 1 sample taken from the present flounder tidal river sampling in 2005. Reader 2 data were taken from information from beach seine samples from May and September of 2002 and 2003 on Ballyloughaun. All of the otoliths used in the comparison had accessory primordia and only the larval (hatch check to accessory primordium) information was analysed.

Results

Hatching times

There is no published information available as to whether flounder lay down hatch checks. The hatch check for plaice is situated approximately 10 μm from the otolith core (Hovenkamp 1990). While reading flounder otoliths, a heavy dark band was observed around 10 μm from all of the otoliths, this was also the first increment observed, so this was assumed to be the hatch check (see Fig 1).

Hatching times for all flounder from beaches and rivers from April 2004 and 2005 in Galway Bay are shown in Fig 5. Hatching times in Galway bay ranged from 9th of February to the 18th of March (Fig 5). The peak hatching time occurred in late February.

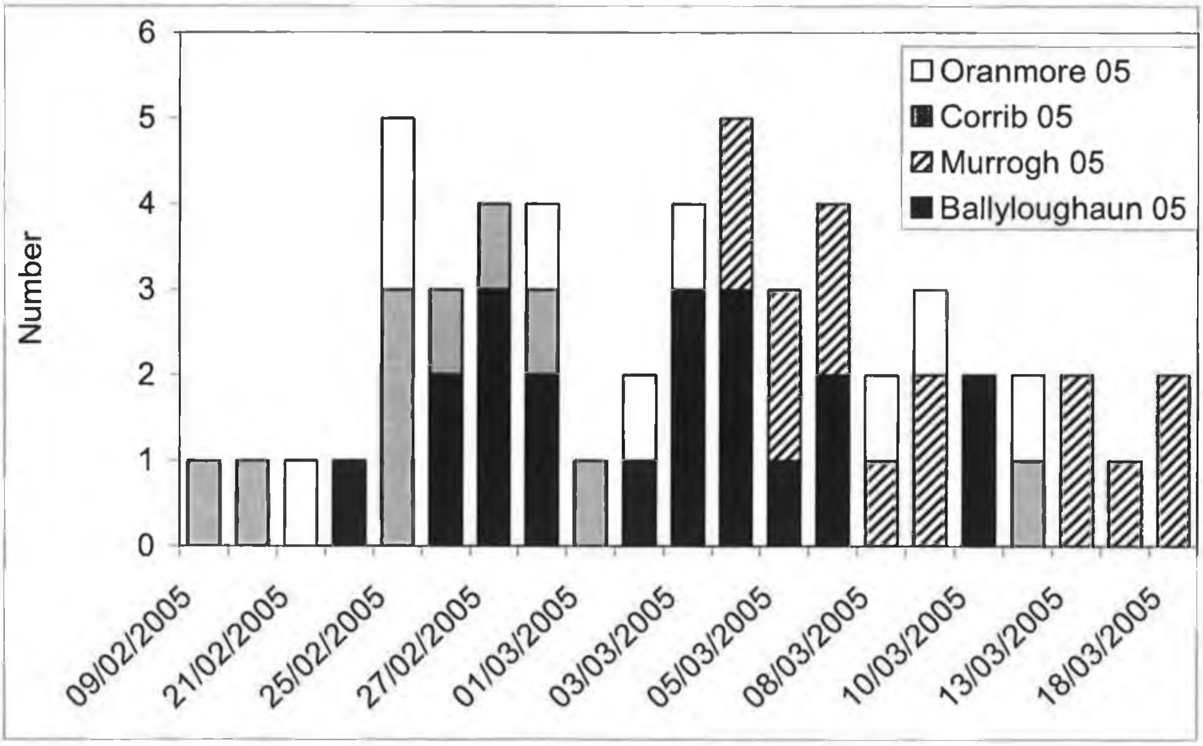

Fig 5. Hatch dates for 0-group flounder from Galway Bay in 2005 shown by site (Ballyloughaun 05, Murrogh 05, Corrib 05 and Oranmore 05) sampled in April.

Table 2 shows the mean and range of hatch dates of flounder from beach and river sites in Galway bay in 2004 and 2005: Hatching started around the same time in late February for flounder sampled on Ballyloughaun in 2004 and 2005, however hatching extended slightly later for flounder sampled on Ballylounghaun in 2005.

Flounder from Murrogh had the latest hatching period of any site ranging from the 4th – 18th of March in 2005. The hatching period and mean hatch dates were similar for flounder sampled in Oranmore and the Corrib in 2005 with mean hatch dates occurring on the 2nd of March. Flounder sampled from the Corrib had the earliest recorded hatch date on the 9th of February and the longest hatching period.

Table 2. The mean hatch date and standard deviation (± SD) and range of hatch dates for otoliths from beach and river sites in 2004 and 2005.

Habitat	Site	Mean	SD	Range
Beach	Ballyloughaun 04	26-Feb-04	5	23rd Feb – 5th Mar
Beach	Ballyloughaun 05	2-Mar-05	4	23rd Feb - 10th Mar
Beach	Murrogh 05	9-Mar-05	5	4th Mar - 18th Mar
River	Corrib 05	25-Feb-05	7	9th Feb – 11th Mar
River	Oranmore 05	2-Mar-05	7	25th Feb - 11th Mar

Analysis of variance for hatch dates

All hatch dates were transformed into Julian days using Microsoft EXCEL spreadsheets. This allowed further statistical analysis. The sampling design described in the methods was used to test the data statistically. A random sub-sample of hatch dates was used from beaches in order to balance the design. There were three null hypotheses: There was no difference in hatch dates between habitats. There was no difference in hatch dates between sites. There was no difference in hatch dates between years for flounder sampled on Ballyloughaun. The data were normally distributed so a nested ANOVA was used to test the variance between habitats and sites. A one way ANOVA was used to test the variance between years.

There was no significant difference in hatch dates between habitats ($p = 0.310$), thus accepting the null hypothesis. There was a significant difference was between sites ($p = 0.014$), thus rejecting the null. Fishers pairwise post hoc analysis showed that flounder sampled from Murrogh hatched later than any other site (Table 2). The null hypothesis C was accepted as there was no significant difference between years ($p = 0.107$).

Larval duration

Larval duration was taken as the number of increments between the hatch check and the first accessory primordium. There were 15 otoliths with at least one accessory primordium from which the larval duration could be calculated. The larval duration ranged from 32-47 days with a mean of 38 ± 5 days (Table 3). There were 8 otoliths with at least one accessory primordium on Oranmore. Larval duration for flounder sampled on Oranmore ranged from 33-46 days with a mean of 37 ± 5 days (Table 3). There were 6 otoliths with at least one accessory primordium in the Corrib. Larval duration for flounder sampled in the Corrib ranged from 32-47 days with a mean of 38 ± 5 days (Table 3). There was found to be no significant difference in larval duration between flounder sampled in Oranmore and the Corrrib in 2005 (Mann Whitney, p=0.9).

Table 3. Mean larval duration (days), standard deviation (± SD) and ranges for 0-group flounder in April in the Corrib and Oranmore in April 2005.

Site	Mean larval age (SD)	Range of larval age (days)
Corrib	38(5)	32 to 47
Oranmore	37(5)	33 to 46
Total	38(5)	32 to 47

There were 57 otoliths observed without accessory primoria. The mean age of flounder without accessory primordia was 37 days ± 4. There was no significant difference in age (in days) between those flounder without accessory primordia and the larval duration of those with accessory primordia (Mann Whitney, p=0.93).

Difference in larval duration between years

Larval duration of flounder was compared over a three year period. The results of the present study from tidal rivers in 2005 (Reader 1), were compared with flounder larval durations from 2002 and 2003 for flounder sampled on Ballyloughaun (Reader 2). The mean larval duration was and 41 ± 4 days in 2002, 40 ± 4 days in 2003 and 38 ± 5 days in 2005 (Fig 6). There was no significant difference in larval duration between years (Kruskal-Wallis, $p = 0.153$).

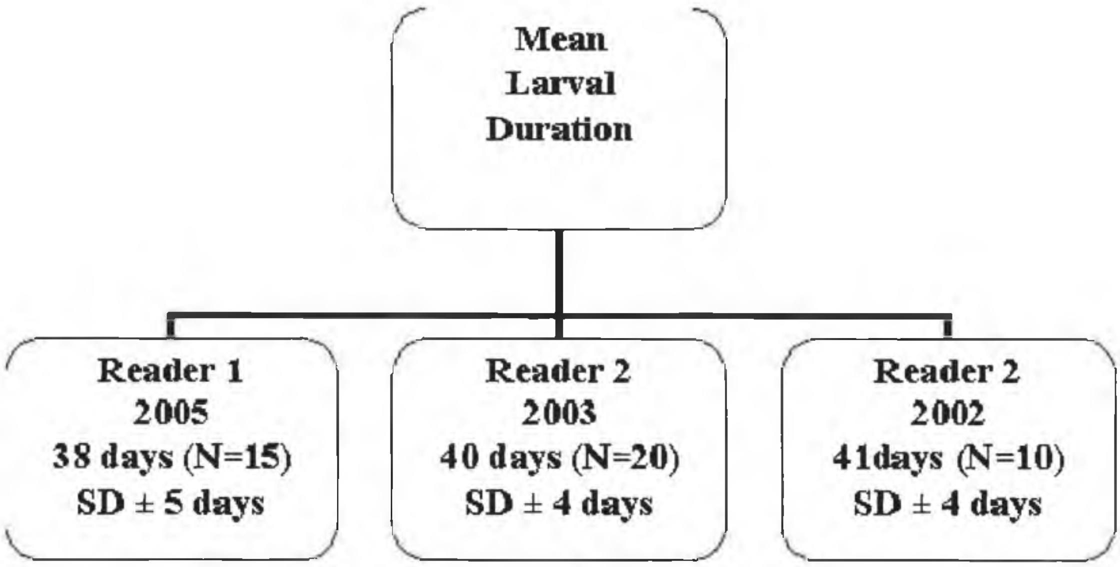

Fig 6. The mean larval duration (± SD) of 0-group flounder for two readers from independent samples taken in three separate years. Reader 1 = Breen, D. Reader 2 = Keirse, G.

Growth

Otolith increment width (µm) can be used as an index of larval growth (Karakiri *et al.* 1991, Gilliers *et al.* 2004). Increment widths were taken from day 20 to 25, from the hatch check, for the 73 fish sampled. The daily increment widths from day 20 to 25 from hatching, for the two beach and two rivers sampled in April, ranged from 0.73 to 3.98 µm with a mean of 1.74 µm. For flounder sampled at Ballyloughaun, the mean increment width was 1.44 ± 0.35 µm in 2004, and 1.61 ± 0.49 µm in 2005 (Fig 7). For flounder sampled on Murrogh, the mean increment width was 1.95 ± 0.53 µm in 2005 (Fig 7). Flounder sampled on Oranmore had a mean increment width of 2.1 ± 0.6 µm in 2005 (Fig 7). Flounder sampled in the Corrib had a mean increment width of 1.92 ± 0.7 µm in 2005 (Fig 7).

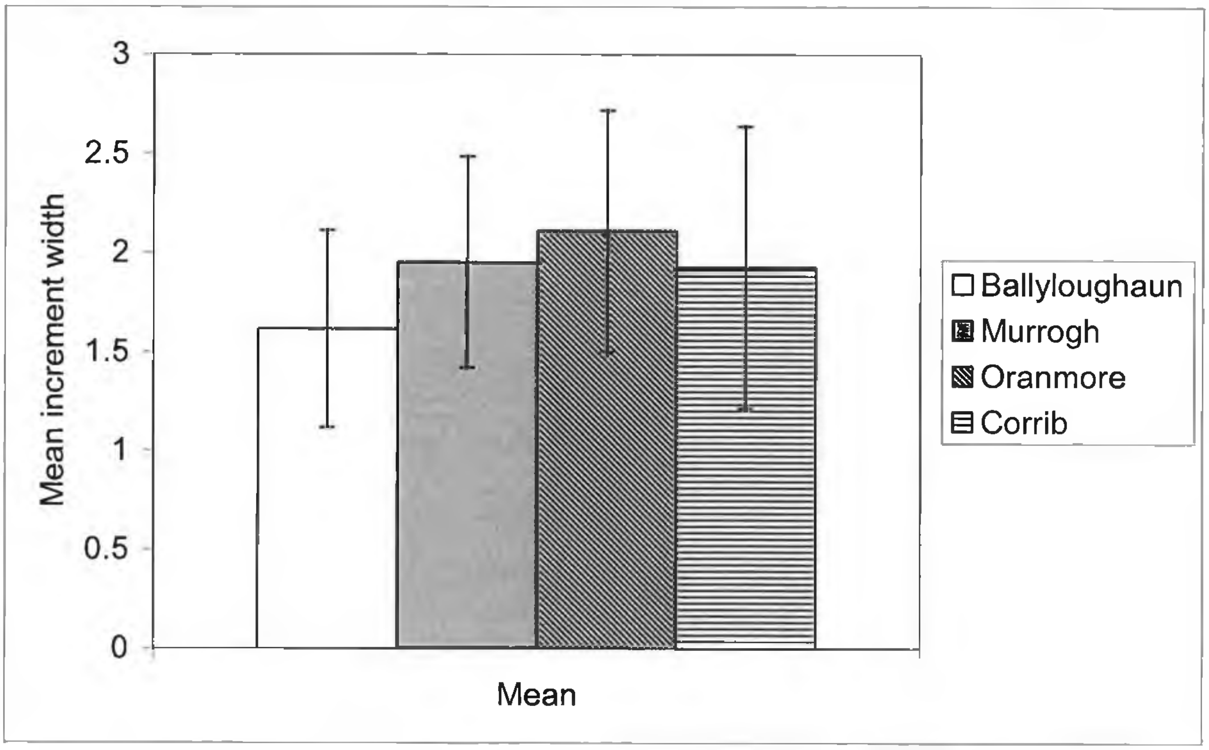

Fig 7. Mean daily growth increment widths (µm) ± S.D for 0-group flounder, sampled from Ballyloughaun, Murrogh, the Corrib and Oranmore from day 20 to 25 from the hatch check, in April of 2005.

Analysis of variance for growth

Analysis of variance was carried out to determine if there was any difference in increment width from day 20 to 25 from hatching between sites in 2005 and between 2004 and 2005 for flounder sampled on Ballyloughaun during the peak settlement period. The data were non normal so non-parametric tests were used. There was found to be a significant difference in increment widths between sites in 2005 (Kruskal-Wallis $p=0.001$). A Mann Whitney ($p=0.000$) revealed increment widths were significantly larger for flounder sampled on Oranmore than Ballyloughaun. Increment widths were significantly larger for flounder sampled on Ballyloughaun in 2004 than 2005 (Mann Whitney, $p=0.012$). In summary significant differences in increment widths between sites and years were noted pointing to differing spatial and temporal patterns in larval growth.

Accessory primordia

The extent to which accessory primordia were present on flounder otoliths on beach and river habitats was evaluated. A total of 54 otoliths was analysed from beaches. Of the 54 otoliths, only one was observed to have at least one accessory primordium. The flounder sampled on beaches exhibited a benthic form with the left eye crossing the dorsal ridge and appeared to be metamorphosing (Fig 8). None of the flounder from sandy beaches who's otoliths were observed had completed eye migration (i.e the eye was beyond the edge of the dorsal ridge). It thus appears that flounder on beaches are not completely metamorphosed and do not have the accessory primordia often associated with metamorphosis.

Fig 8. A typical newly settled flounder from sandy beaches in Galway Bay in April of 2005. The left eye has not fully crossed the dorsal ridge.

Otoliths of 19 flounder from tidal rivers were analysed. Of these, 14 had deposited at least one accessory primordium. Of the flounder from tidal rivers without accessory primordia, four were from the Corrib with one from Oranmore. Most of the flounder observed from rivers appear to have fully metamorphosed with the left eye having migrated beyond the dorsal ridge (e.g. Fig 9).

Fig 9. A typical newly settled flounder sampled from tidal rivers in Galway Bay in April of 2005. The left eye has fully crossed the dorsal ridge.

Length / Habitat vs. Deposition of Accessory Primordia

The flounder sampled for otoliths from Galway Bay ranged in size from 6 - 15mm. There were no flounder below 9mm with accessory primordia (Table 4). On beaches the flounder sampled ranged from 6-10mm. All lacked accessory primordia except a single individual at 9mm long (Table 4). In tidal rivers, primordia were recorded on those of length range 9-15mm (Table 4). Those flounder without accessory primordia in tidal rivers were within the range 10-12mm (Table 4). As there was little overlap in the length range of flounder between habitats it was difficult to ascertain the effect of habitat on the deposition of accessory primordia.

Table 4. The number of flounder which had accessory primordia in relation to standard length (mm) from newly settled flounder sampled in rivers and beaches in Galway Bay in April of 2004 and 2005.

	Beach		River	
St. Length (mm)	no primordia	primordia	no primordia	primordia
6	3	0	-	-
7	9	0	-	-
8	16	0	-	-
9	20	1	0	3
10	5	0	1	3
11	-	-	3	5
12	-	-	1	2
15	-	-	0	1

Settlement dates

Settlement dates for 0-group flounder sampled in tidal rivers in Galway Bay are shown in Fig 10. Settlement dates were calculated 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 dates for 0-group flounder in Galway Bay ranged from the 28th of March to the 14th of April (Fig 10).

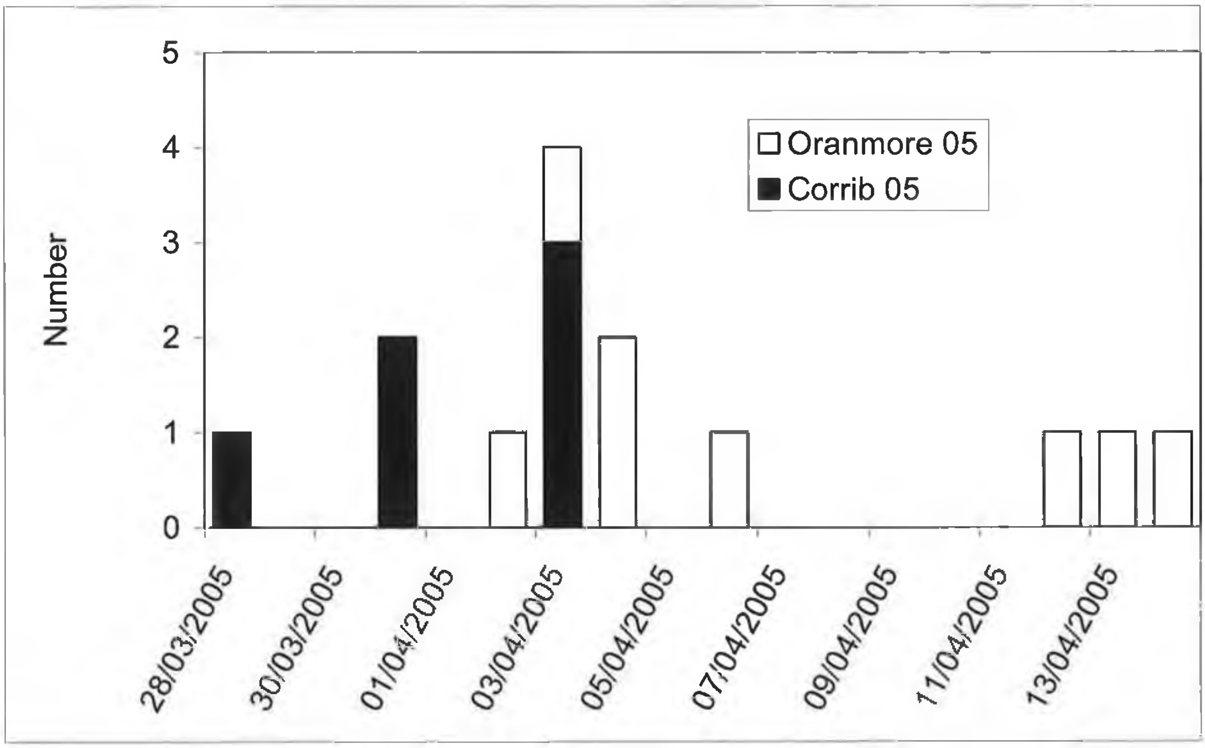

Fig 10. Settlement dates for 0-group flounder from Galway Bay in 2005 shown by site (Corrib 05 and Oranmore 05) sampled in April.

The only settlement date recorded on beaches was on the 28th of March on Ballyloughaun in 2004 (Table 5). Settlement dates for the Corrib ranged from the 28th of March to the 3rd of April with a mean on the 1st of April (Table 5). Settlement dates for Oranmore ranged from the 2nd to the 14th of April with a mean on the 7th of April (Table 5).

Table 5. Mean settlement times and ranges for 0-group flounder from Ballyloughaun in 2004 and the Corrib and Oranmore in 2005. Note n=1 for Ballyloughaun.

Habitat	Site	Mean	SD	Range
Beach	Ballyloughaun 04	28-Mar-04	N/A	N/A
River	Corrib 05	1-Apr-05	2	28th Mar - 3rd Apr
River	Oranmore 05	7-Apr-05	5	2nd Apr - 14th Apr

Analysis of variance for settlement dates

Settlement date was then transformed into Julian days using Microsoft EXCEL spreadsheets in order to carry out statistical tests. Given the low sample size from beaches only rivers could be compared. Flounder were found to settle significantly earlier in the Corrib than Oranmore in 2005 (Mann Whitney, p=0.024).

Age

Given that most of the flounder on beaches did not have accessory primodia the total age was used for comparative purposes between habitats and sites. The total age of flounder includes all of the daily increments present on the otolith (both pre and post larval).

Flounder sampled from Galway Bay ranged from 27 – 59 days old with a mean of 40 ± 5 days (Table 6). Flounder from Ballyloughaun ranged from 33-54 days old in 2004 and 29-44 days old in 2005 with a mean age of 40 and 37 days respectively (Table 6). Murrogh also had a similar mean age to Ballyloughaun in 2005 of 35 days with a range of 27-41 (Table 6). Older flounder were present in rivers than on beaches. Flounder from the Corrib sampled in 2005 ranged from 29-59 with a mean age of 43 days (Table 6). Flounder from Oranmore sampled in 2005 ranged of 39-57 days with a mean age of 48 days (Table 6).

Table 6. Mean age (days), standard deviation (± SD) and ranges for 0-group flounder in April on Ballyloughaun in 2004 and 2005, Murrogh, the Corrib and Oranmore in 2005.

Habitat	Sitecode	Mean age (days)	SD	Range of age (days)
Beach	Ballyloughaun 04	40	5	33-54
Beach	Ballyloughaun 05	37	4	29-44
Beach	Murrogh 05	35	5	27-41
River	Corrib 05	43	7	29-59
River	Oranmore 05	48	6	39-57

Analysis of variance for age

The null hypotheses were that there was no difference in age (days) between sites and habitats (rivers and beaches). The data were non normally distributed so non-parametric tests were chosen. There was a significant difference in age between the four sites (Kruskal-Wallis, $p<0.001$) thus the null was rejected. A Moods – Median test ($p=0.001$) revealed that 0-group flounder on Oranmore were significantly older than those on Ballyloughaun or Murrogh. However, there was no difference between Ballyloughaun and Murrogh, or the Corrib and the other three sites. Thus there was no consistent difference between habitats and the null hypothesis was accepted.

The age of 0-group flounder on one sandy beach (Ballyloughaun) was compared over a two year period on comparative dates (7/4/04 and 8/4/05) to see if there was any difference between the years. The null hypothesis was that there was no difference in flounder age between years. The data were non-normal so a non-parametric Mann Whitney U-test was used. The null hypothesis was rejected as flounder were found to be significantly older in 2004 than 2005 (Mann Whitney $p = 0.012$).

Discussion

Given that all of the flounder otoliths observed were shown to have a dark band at about 10µm from the core, it appears reasonable to assume that, similar to plaice (Hovenkamp, 1990), flounder deposit hatch checks on their otoliths. However, the hatch check requires validation, as was done for plaice by Hovenkamp (1990). This could be done by validating the hatch check formation on the otoliths of laboratory reared flounder of known age.

Hatching times in Galway Bay ranged from early of February to mid March with peak hatching occurring in late February to early March. In 2005, there was no significant difference in hatch dates between beach and river habitats. However a significant difference in hatch dates was found between sites. Flounder sampled from Murrogh hatched later than any other site. There was no significant difference in hatching between years for flounder sampled on Ballyloughaun.

As pelagic flounder eggs drift with the water currents (Campos *et al.* 1994), earlier spawned eggs may have drifted inshore earlier. Pulsed production of eggs is a common feature in marine fish populations. This may account for differences in hatching periods between sites and lead to hatching cohorts. A similar phenomenon was observed in the Wadden Sea where differences in hatching periods between sampling stations were found from daily increment counts on plaice otoliths (Karakiri *et al.*, 1991).

There are no other studies to compare hatch dates for flounder. However flounder are known to spawn in spring (Wheeler, 1969; Russell, 1976, Harding, 1978; Dando & Ling, 1980; Johnson 1981). Given the hatching period of the present study, and the 6-7 days egg life found by Hutchinson and Hawkins (2004), it appears that flounder would spawn from February – March in Irish waters. Sims *et al.* (2004) found that spawning aggregation of flounder at sea lasts about one month. It also appears from the hatching period, that spawning would last about one month in Irish waters.

The mean larval duration of the flounder sampled was 38 ± 5 and ranged from 32-47 days. There was found to be no significant difference in larval duration between flounder sampled on Oranmore and the Corrib in 2005. The lower limit of larval durations observed in the present study were greater than those observed by Bos (1999a, b) (10 – 60 days) due to the absence of larvae from the Galway Bay samples. Hutchinson and Hawkins (2004) found the larval duration from time of hatching to metamorphosis of laboratory reared flounder to be 38-39 days. This is similar to the larval durations in the present study. This lends support to Bos' (1999 a,b) validation of daily increments in flounder. Allen (2004) reviewed findings of larval age of plaice 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. Thus, the longer larval duration for flounder of Bos (1999 a, b) probably reflects the temperatures being lower in the Elbe. The larval duration for plaice in Galway Bay in 2005, ranged from 21 to 45 days with a mean of 30 ± 4 days (Allard, 2007). Thus flounder appeared to have a longer larval duration than plaice in Galway Bay in 2005. Larval flounder migrate into estuaries (Hutchinson & Hawkins, 1993; Jager, 1998, 1999, 2001; Bos, 1999a,b) and plaice are more of a coastal species. The longer larval duration in flounder may be necessary to facilitate migration into estuaries by selective tidal transport (as observed by Jager, 1999, 2001; Bos, 1999a, b).

Otolith growth from increment widths (µm) has been used as an index of growth in 0-group flatfish (e.g. Karakiri *et al.* 1991, Gilliers *et al.* 2004). The daily larval growth rates, for Galway Bay in 2004 and 2005, ranged from 0.73 to 3.98 µm with a mean of 1.74 µm. There was found to be a significant difference in larval growth rates between sites and years. Flounder larval growth rates were significantly higher for flounder sampled from Oranmore than Ballyloughaun. This suggests that the larvae delivered to Oranmore may have a different pelagic life history. Flounder on Ballyloughaun also appear to have been subjected to differing pelagic conditions between years.

There are no studies on the use of daily increment widths as a growth index in flounder. Growth rates for 0-group flounder were generally less than those recorded for other flatfish species although most of the studies recorded increment widths at a different stage of development than the present study. The only direct comparison of growth for the same life history stage is Allard (2007). Allard (2007) reported otolith growth rates for 0-group plaice from day 20 to 25 ranging from 0.7 μm to 9.7 μm. Mean larval growth rates ranged from 2.62 – 3.09 μm for plaice sampled on beaches in April and May 2005 in Galway Bay (Allard, 2007). The results suggest that plaice larvae have faster growth rates than flounder larvae in Galway Bay. This may explain the relatively small size of flounder post-larvae as compared with plaice at a similar stage of development observed in Galway Bay. Growth rates at about 90 days after hatching were recorded for three flatfish species by Gilliers *et al.* (2004). Growth rates of 3.47 μm to 8.24 μm were recorded for sole, 3.54 μm to 8.11 μm for dab and 6.6 μm to 11.57 μm for plaice (Gilliers *et al.,* 2004). Growth rates in 0-group plaice were also reported by Karakiri et al. (1991), who described the otolith microstructure of 0-group plaice caught in the Dutch Wadden Sea in 1988. Growth rates just after hatching were found to range in width from 0.2 to 0.8μm depending on location (Karakiri *et al.*, 1991). This suggests that early larval growth is slower than late larval growth. The above results suggest that the maximum value for growth attained for flounder in Galway Bay is generally less than the values for other species.

There was no significant difference in age (in days) between those flounder without accessory primordia and the larval duration of those with accessory primordia. This suggests that that flounder settlement in tidal rivers and beaches takes place at around the same age and those animals without accessory primordia must have been within a short period of its development.

The evidence from the present study points to the fact that flounder do not generally deposit accessory primordia and are not fully metamorphosed on sandy beaches in Galway Bay. All but one of the 54 0-group flounder from beaches that had their otoliths observed had no accessory primordia. In contrast, 14 of the 19 newly settled flounder that had their otoliths observed from tidal rivers had deposited accessory primordia. Therefore, it would appear that accessory primordia are not deposited until arrival in tidal rivers and settlement is delayed until low salinity areas are reached.

0-group flounder from beaches exhibited a benthic form but the left eye had not fully crossed the dorsal ridge. This is evidence that flounder do not fully metamorphose in this habitat. Fully metamorphosed flounder were observed from those sampled from tidal rivers, with the left eye having fully traversed the dorsal ridge. Different flatfish species deposit accessory primordia at different stages of metamorphosis. Campana (1983) found evidence to suggest that starry flounder deposit outer nuclei (probably accessory primordia) at the edge of sagittal otoliths shortly after metamorphosis. Sogard and Able (1992) found that accessory primordia on winter flounder (*pseudopeuronects americanus*) otoliths appeared midway through eye migration. In dover sole, completion of eye migration occurs between the formation of the first and last accessory primordia, which encompasses a period of 70 days in some individuals (Toole *et al.*, 1993). In plaice, accessory primordia are formed at early metamorphosis when the pupil of the asymmetrical left eye had migrated beyond the edge of the dorsum Modin *et al.* (1996). However, there are no studies ascertaining what stage of metamorphosis flounder deposit the accessory primordia. The location of the eye in relation to accessory primordia deposition was not quantified for flounder in either rivers or beaches so it is difficult to ascertain at what stage of metamorphosis it is deposited. It is however, apparent that accessory primordia are not generally deposited during early metamorphosis on beaches in Galway Bay.

Flounder are different sizes on beaches and in rivers so it is possible that the deposition of accessory primordia is size dependent. There were no flounder below 11mm (total length converted from standard length using Fig 1 in Appendix) with accessory primordia. It may be that case that flounder don't deposit accessory primordia until they are above 10mm (TL) however this is difficult to prove in the present study given the lack of overlap between sizes in the habitats. In the laboratory, once 0-group flounder reach a critical length (8.14 ± 0.61mm TL), the onset of metamorphosis is immediate once the flounder are transferred to reduced salinity (Hutchinson and Hawkins, 2004). This, and the evidence discussed above, suggests that the lower salinity present in tidal rivers (see Chapter 3) may cause flounder to metamorphose fully and deposit accessory primordia.

Settlement dates for 0-group flounder in Galway Bay ranged from the 28th of March to the 14th of April. This range should be treated with some caution given the very small number of flounder with accessory primordia. Flounder were found to settle significantly earlier in the Corrib than Oranmore in 2005, this despite the fact that neither the hatch dates or larval duration differed significantly between these two sites. Oranmore is the most distant site (over 4 km from the nearest site) and hydrographic processes may have favoured the earlier delivery of larvae to the Corrib on this occasion. Flounder post-larval durations ranged from 5 -17 days with a mean of 10 ± 4 days. This reflects the fact that flounder were sampled early in the settlement season.

There are no known studies on settlement dates and post-larval age of 0-group flounder from otolith microstructure. Flounder settlement timing has been observed from the first appearance of newly settled flounder elsewhere. Settlement of flounder in Galway Bay in March is earlier than any other known study. Settlement timing in April was similar to that recorded in the southern part of the UK (Russel, 1980 in Claridge *et al* 1986; Claridge *et al* 1986; Hutchinson and Hawkins, 1993) and northern France (Robin, 1991).

Flounder in Galway Bay ranged from 27 – 59 days old with a mean of 40 ± 5 days old. In 2005, there was no significant difference in age between beach and river habitats. However, in 2005, there was a significant difference in age of 0-group flounder between sites. The results reveal that the three closest sites, Ballyloughaun, the Corrib and Murrogh, had no significant difference in age. The greater age of flounder on Oranmore compared with Ballyloughaun and Murrogh may reflect the tendency of flounder to stay on the site longer than the two beach habitats (see Chapter 3). Flounder were significantly older on Ballyloughaun in 2004 than 2005.

The results of the present study suggest complex factors determining the life history of 0-group flounder in Galway Bay. Hatching, larval duration, larval growth and settlement are part of the pelagic life stage. Allard (2007) found no spatial or temporal effect for 0-group plaice in any of the pelagic lifecycle stages over the two years or over the three beaches in Galway Bay in 2005. In, contrast, the results from the present study suggest complex spatial and temporal patterns in the pelagic life stages with significant differences noted in hatching, larval growth and settlement. The results suggest flounder may form distinctive stocks or sub-populations in the area with different spawning times and larval transport processes. Evidence from spawning habits, suggest four distinct flounder stocks in the Baltic (Nissling *et al.,* 2002). Sims *et al.*, (2004) found that flounder arrived on the spawning grounds over a shorter time period when cooler than normal conditions prevailed in the estuary. The timing of migration was earlier when the largest differences in temperatures between near shore and offshore environments occurred (Sims et al., 2004). Therefore, given that there are a number of estuaries in the Galway Bay area, different temperatures within some estuaries may cause the timing of spawning migrations to be altered and thus cause distinct spawning cohorts. Alternatively, flounder in Galway Bay may be from the same stock with pulsed production of eggs accounting for the differences in hatching and settlement timing found in Galway Bay. Pulsed production of eggs is a common feature of marine fish populations.

Chapter 5: General Discussion

The present study has shown the economic value of flounder as a contributor to angling tourism in Ireland. Flounder was found to be the most caught shore angling species in competitions around Ireland constituting roughly one third of the shore angling competition catch although this did vary by area. A total value of flounder from shore angling tourism was estimated to be in the order of €8.4 million. A conservative estimate for the value of flounder from shore angling, classifying the species as "non-preference", was €2.79 million. The indications are that flounder are worth more to the Irish economy than many commercial species. Yet there are no official management or conservation measures in place for this species in Irish waters. There is also little research done on this or other non commercial species that are important for recreational angling tourism

The value for flounder is based on the percentage flounder caught in shore angling tournaments around Ireland. These percentages were then related to tourism income for overseas and domestic angling tourism to calculate a value for the species. This approach constitutes a new and innovative way of estimating the value of an angling species has not been adopted previously. Many other studies quantifying the value of a species were based on expenditure of anglers from recreational fishers' surveys (e.g. O'Conner 1975; Radford et al., 1991; O'Bara, 1999; Rusedski, 2002; Indecon 2003; Nautilus Consultants, 2005; Kelch et al., 2006). The advantage of the method used in the present study over angling surveys is that angling tournament data tends to be more accurate than anglers' opinions. Lawrence (2005) states that anglers would pay only a third as much for increased catches of non favorite species. There is no information on angler preferences for shore angling species in Ireland. The indications are that using both survey and tournament data may be the best approach to determining the value of a species. Angling surveys could also be used to find out the extent to which the angling tournament catch reflects the overall shore angling catch.

Flounder were shown to be a sustainable shore angling resource in Ireland. There was no evidence for a decline in catch per unit effort of flounder from shore angling tournaments. There was also no evidence that flounder specimens were getting smaller. This contrasts to the UK, where declines in numbers and sizes of shore angling species including flounder have occurred in recent years (eg. Nautilus Consultants, 2005; Richardson *et al.*, 2006). Several authors have used methods similar to those in the present study to give an indication of stock health (e.g. Fitzmaurice *et al.*, 2005; Richardson *et al.*, 2006). However, the accuracy of these metrics as a stock assessment method for recreational species is uncertain.

The present study covers the population dynamics of 0-group flounder from hatching through the larval life and metamorphosis to the early benthic stage. The study addresses some of the deficits in our knowledge about the early phases of flounder life history. It also reports on previously unknown aspects of flounder otolith microstructure.

Hatching, larval duration, larval growth and settlement are part of the pelagic life stage. Information on the early life history of flounder, such as hatching and larval life was obtained from otolith microstructure. There is no known published information on the above parameters in flounder from otolith microstructure. However, other information on the biology of flounder and various flatfish species can be used for comparative purposes.

Flounder are known to spawn in spring (Wheeler, 1969; Russell, 1976, Harding, 1978; Dando & Ling, 1980; Johnson 1981). Hatching times of flounder in Galway Bay ranged from early February to mid March. Given this hatching period, and the 6-7 days egg life found by Hutchinson and Hawkins (2004), it appears that flounder would spawn from February to March in Irish waters. Spatial variability was found, with flounder from Murrogh hatching significantly later than any other site. This may be related to pulsed production of eggs, which is common in marine fish species. There may also may be different stocks or sub-populations spawning at different times in the area. The timing of flounder spawning migrations may be altered according to the thermal conditions in the local estuary and open sea (Sims *et al.*, 2004). Given the number of estuaries in the Galway Bay area, the period of spawning migrations may vary between estuaries.

There were no spatial or temporal differences in larval durations from flounder in Galway Bay. The mean larval duration in Galway Bay was similar to that of laboratory reared flounder Hutchinson and Hawkins (2004). This and the validation of increments by Bos (1999 a, b), lends support to increments on flounder otoliths being daily in nature.

Significant spatial differences in larval growth and settlement dates were found between Oranmore and various other sites. This points to a different pelagic life history of flounder on Oranmore. Oranmore is the most distant site (over 4 Km from the nearest site) and hydrographic processes may have favored the earlier delivery of larvae to the Corrib than Oranmore in 2005. Peak densities on Oranmore were about a month later on Oranmore in following year (2006) suggesting that later settlement on Oranmore may be a particular feature of the site. Indeed, length frequency distributions show that newly settled flounder are present in Oranmore later than the Corrib suggesting that a larval supply continues later in the season than the Corrib. Allard (2007) found no significant spatial difference in 0-group plaice pelagic life history events from otolith microstucture in Galway Bay in 2005. This suggests that plaice were spawned from the same stock (Allard, 2007). In contrast, significant spatial differences were found for flounder pelagic history in Galway Bay suggesting flounder form distinct stocks or sub-populations in the area. Significant differences in larval growth rates between years on Ballyloughaun point to differing conditions at sea between years. These differences may be related to temperature, with faster growth rates during years with warmer sea temperatures.

Post-larval duration, total age and the dynamics of post settled flounder are part of the 0-group flounder benthic stage. There is more published information on the benthic stage than pelagic stage and much of the information in this study supports the findings of other studies on 0-group flounder (e.g. Kersten, 1991; Hutchinson and Hawkins, 2004; Bos 1999 a, b, 2006). However, many of the studies deal with 0-group flounder at a later stage of development than the present study. There are few studies dealing with the early benthic stage of 0-group flounder and processes such as the settlement dynamics. Many of the studies that deal with the early benthic stage, are confined to laboratory environments (e.g. Hutchinson and Hawkins, 2004; Bos, 2006).

Significant spatial and temporal patterns were also found for the early benthic stage. Similar to the pelagic life history, the most common difference was between Oranmore and other sites. During the two week period of peak settlement in 2005, flounder were significantly older and larger in Oranmore than the two sandy beach sites. This probably reflects the retention of flounder in Oranmore, with its weirs, and the departure of flounder within weeks on the beach sites. No significant inter-annual variability in abundance of flounder was found in the present study. In contrast Allard (2007) found significant inter-annual variability in abundance for 0-group plaice in Galway Bay. 0-group flounder were found in dense aggregations as opposed to 0-group plaice being more evenly spread on sandy beaches in Galway Bay. This suggests that the spatial scales of sampling were inadequate for sampling 0-group flounder on sandy beaches in Galway Bay. The patchy distribution of 0-group flounder observed in the present study makes firm conclusions on abundance for the species difficult.

Habitat utilisation of 0-group flounder at different stages of metamorphosis and length ranges has not previously been described in the wild. Flounder were not fully metamorphosed on sandy beaches in Galway Bay. The accessory primordia often associated with metamorphosis in many flatfish species were not deposited on sandy beaches. Eye migration was also not completed in the newly settled beach-caught specimens. 0-group flounder disappeared from sandy beaches within a matter of weeks after first sampling and were significantly smaller than those in the more upstream sections of tidal rivers. The onset of metamorphosis in flounder is size dependant occurring at 8.14 ± 0.61mm (TL) (Hutchinson and Hawkins, 2004). Flounder were generally in the size range 10-12 mm (TL) on sandy beaches. Thus most of the flounder on sandy beaches are above the critical length for metamorphosis but yet have not fully metamorphosed. There was no significant difference in age of those flounder without primordia and the larval duration of those with primordia. This suggests that those flounder without primordia are within a matter of days of depositing them on their otoliths.

Flounder were observed to fully metamorphose and deposit accessory primordia in tidal rivers in Galway Bay. Eye migration in flounder was completed in tidal rivers. Similar to sandy beaches, 0-group flounder became absent or in insignificant numbers in the lower section of tidal rivers near the mouth in a matter of weeks. Larger 0-group flounder 14-32mm (TL) were found in the middle and upper sections of tidal rivers. The difference in length ranges between areas and the fact that 0-group flounder were generally present later in tidal rivers strongly suggests migration of 0-group flounder to the upper and middle sections of tidal rivers.

Given the results discussed above, there appears to be another critical factor besides length or age in determining flounder metamorphosis and the deposition of the accessory primordia. This factor is likely to be salinity. Hutchinson and Hawkins, (2004) found from laboratory studies that once a critical length was reached, flounder would metamorphose when transferred to a salinity of 8 ppt and would not generally metamorphose if kept in sea water. This would explain why flounder do not fully metamorphose on polyhaline sandy beaches. Indeed high salinity areas such as Silverstrand, with a mean of salinity of 29ppt, had very few (<2) 0-group flounder present. Thus high salinity polyhaline areas are unsuitable nursery areas for 0-group flounder. In contrast, 0-group flounder were observed fully metamorphosed in mesohaline and oligohaline areas in tidal rivers.

Post-larval and juvenile flounder were shown in the laboratory to have a preference for freshwater (0.5ppt) over salinities of 5, 10, 15 and 20ppt by Bos (2006). This preference for fresh water is borne out in the current study with highest densities in limnetic and oligohlaine areas. Kersten (1991) also found highest densities in the limnetic and oligohaline areas of the Elbe. Bos' (2006) flounder ranged from 7.5-21mm, with preference for a salinity of 0.5ppt as opposed to salinities of 5, 10, 15 and 20 ppt strongest in flounder of 15 and 13mm (TL). Bos (1999 b) also observed post-metamorphosed flounders invading the fresh water section of the tidal river Elbe at the end of May 1996 and beginning of June 1997. Length frequencies show that flounder above 14mm (TL) moved into oligohaline areas of tidal rivers in May and June in Galway Bay. 0-group flounder were then observed to become absent from oligohaline areas at about 30mm. It appears from the present study and Bos (2006) that as flounder grow above 15mm (TL) their preference for oligohaline areas wanes. Thus flounder utilise oligohaline areas in a certain length range in the early benthic stage of life. The evidence from this and numerous other studies is that larger 0-group flounder later in the year have a preference for mesohaline areas (e.g. Jager at al., 1995 Vinagre *et al.* 2005). Kersten (1991) observed that 0-group flounder reached peak densities at approximately 50mm in June at the earliest in the limnetic section of tidal rivers, thereafter departing with those who lagged behind in growth remaining in the limnetic section over winter. This would explain the retention of the slower growing flounder later in the year in the oligohaline sections of Oranmore. In contrast, faster growing flounder on the Corrib can depart the oligohaline section earlier. The evidence from this and other studies show that 0-group flounders utilise different salinity habitats at different length ranges. Given that most of the salinity values in the present study are taken around low water, future experimental work could focus on the behavior of 0-group flounder in relation to changes in salinity and tidal conditions.

The present study has contributed to our overall knowledge of flounder biology and established the species as a valuable and sustainable angling resource in Ireland. The dynamics of flounder settlement was largely unknown prior to this study. Issues in this study such as the value of a species from angling tournaments, the length cohorts of newly settled flounder in relation to habitat, observations of hatch checks, larval durations, larval growth and accessory primordia deposition, have not have not previously been addressed for this species. The study has also pointed towards future research possibilities for the species. These include an analysis of the angling data on a regional basis, particularly in relation to specimen numbers and catch levels. Also, an expansion of temporal datasets from the other regions of Ireland (outside Munster) to expand our knowledge on long term trends in anglers' catches. Little is known about the adult population dynamics in European waters and this deficit should be addressed. Personal observations indicate a different size structure of adult populations among Irish estuaries. Commercial exploitation levels of this species need to be determined as these fisheries are largely unregulated in Irish waters. A recruitment index for the species could be established with yearly sampling of tidal rivers. In terms of otolith microstructure future research might be directed at determining the stage of metamorphosis when accessory primordia are deposited and the influence of abiotic factors such as salinity on their deposition. The hatch check on flounder otoliths also needs to be validated.

Appendix

Table 1. Salinity and temperature values taken at beach and river sites in Galway Bay from 2005-2006. Note, where more than one value was taken on a sampling visit, an average was shown.

Site	Year	Date	Salinity	Temp
Murrogh	2005	Early April	25	6
		Late April	19	8
		Early May	28	9
		Late May	22	
		Early June	33	16
	2006	Early April	28	
		Early May	22	
		Late May	14	
Ballyloughaun	2005	Early February	12	10.5
		Late February	25	10
		Early March	28	9
		Late March	17	
		Early April	30	6
		Late April	7	11
		Late May	29	
		Early June	16	
	2006	Early February	14	
		Late April	26	
		Early May	26	
		Late May	22	
Corrib	2005	Early April	2	
		Late April	3	7
		Early May	4	9
		Late May	3	15
		Early June	2	17
	2006	Late March	0	
		Early April	2	9
		Late April	4	14
		Early May	0	
		Late May	0	11
		Early June	2	
		Late June	6	
Roscam	2005	Late April	3	7
		Early May	4	7
		Late May	8	13
		Early June	0	19
Oranmore	2005	Late April	0	
		Early May	2	7
		Late May	0	
		Early June	3	
		Late June	0	
		Early July	0	13
		Late July	0	12
	2006	Late March	0	
		Early April	0	9
		Late April	0	11
		Early May	0	11
		Late May	0	
		Early June	0	14
		Late June	0	

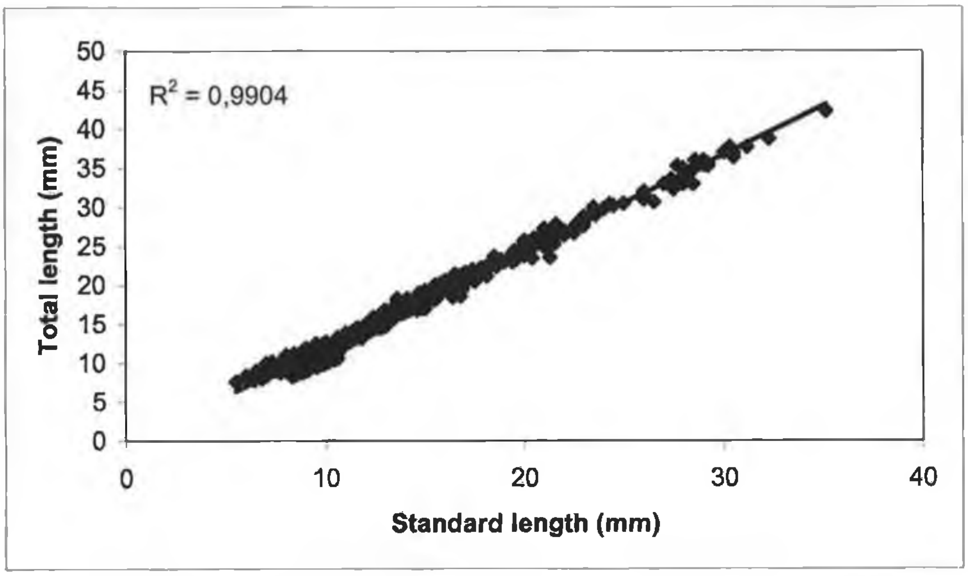

Fig 1. The standard length vs. total length relationship for measured 0-group flounder in Galway Bay.

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URL 1: http://www.fao.org/fi/website/FIRetrieveAction.do?dom=species&fid=2550

URL 2: http://www.nfsa.org.uk. Website of the National Federation of Sea Anglers, UK.

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