Irish Fisheries Investigations Number 16

Population dynamics, age, growth and maturity of lemon sole *Microstomus kitt* (Walbaum 1792) sampled between 2000-2002 off the west coast of Ireland.

By

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Abstract

The age, growth, maturity and population dynamics of lemon sole (*Microstomus kitt*), from commercial catches off the west coast of Ireland (ICES division VIIb), was determined for the period November 2000 to February 2002. The maximum age recorded was 14 years. Males of the population were dominated by 4 year olds, while females were dominated by 5 year olds. Females dominated the sex ratio in the overall sample, by month sampled, by age class and by size (from 22cm in total length onwards, when N > 20). Mature male and female lemon sole were encountered at age 2 and above. Von Bertalanffy growth parameters were estimated using the method of Rafail (1973). In recent years, the lemon sole has exhibited a smaller asymptotic length (L_∞ = 34.47cm), faster growth rate (K = 0.1955) and younger age at first maturity than in the same area in 1978-1979. These changes are indicative of a decrease in population size following exploitation.

1 Introduction

Lemon sole, *Microstomus kitt* (Walbaum 1792) (Pleuronectidae) are distributed from the Bay of Biscay, north-eastwards to Scotland and on all coasts of Iceland (Rae 1965; Wheeler 1969; Nielsen 1986, Jennings *et al* 1993). They are found at depths to 200 m on a variety of bottom types from mud and sand to rock (Rae 1939; Steinersson 1978; Wheeler 1978). Lemon sole reach a maximum of 66cm total length and age 17 years (Wheeler 1969). Over the range of distribution, spawning occurs from January to November, starting earlier in the most southern parts of their range (Russell 1976). Lemon sole were found to be one of the less fecund of the flatfish off the east coast of Scotland, with an estimated 470 eggs per gram of body weight (Newton and Armstrong 1974). Male and female lemon sole sampled from 1978 – 1979 off the west coast of Ireland were found to be 50% mature at 14cm and 2.6 years and 15.2cm and 2.5 years respectively (King *et al.* in press).

Lemon sole is a commercially important demersal species in Europe. However, under the Common Fisheries Policy of the European Union the Total Allowable Catch (TAC) is only set for ICES divisions IIa (Norwegian Sea) and VI (west of Scotland). The TAC for 2003 was 8, 262 tonnes. This has been reduced from 9,720 tonnes in 2002 and 10,800 tonnes in 2001. Landings of witch, *Glyptocephalus cynoglossus* are included in the TAC for lemon sole. The quotas within the TAC allocated were assigned in order of decreasing tonnage to the UK, Denmark, Holland, Belgium, France, Germany and Sweden. There is no quota assigned to Ireland for lemon sole.

Lemon sole are caught as by-catch in the *Nephrops* (prawn) fishery, the whiting fishery or in mixed demersal fisheries off the coast of Ireland. There is no current minimum landing size for lemon sole. In Ireland in 2002, lemon sole had a total landed value of 1.2m Euro (Anon 2004)

Little has been published to date on lemon sole in European waters. Most of the studies have been confined to the findings of Rae (1935 – 1965) in Scottish waters; Jennings *et al* (1993) in the western English Channel, notes on fecundity by Newton and Armstrong (1974) and diet in Icelandic waters (Steinersson 1978). More recently, Allen *et al* (2004) gave an account of the diet of lemon sole in Irish waters.

The latter formed part of a previously unpublished study (1978-79) on the biology of lemon sole off the west coast of Ireland (King 1982).

For the present investigation, samples were taken from commercial catches fished in ICES division VIIb off the west coast of Ireland from November 2000 to February 2002 and landed in Rossaveal, Co. Galway. The purpose of the study was to determine the age, growth, maturity and population dynamics of lemon sole off the west coast of Ireland and to review the latter against a re - interpretation of the 1978-79 data for the same area (King *et al.* in press) and elsewhere in European waters. The data were analysed using standard fisheries statistical methods and the status of the fishery was assessed.

2 Materials and Methods

Lemon sole were taken monthly from commercial landings, from November 2000 to February 2002. The fish were caught off the west coast of Ireland in ICES Divisions VIIb and VIIc (Fig.1), particularly off the Porcupine Bank and in the outer Galway Bay area, just west of the Aran Islands (marked as areas A and B on Fig.1), by fishing trawlers operating out of the fishing port of Rossaveal, Co. Galway. They were caught with twin or single rig otter board trawls (primarily twin-rig). A standard mesh size of 80mm at the cod-end was used.

The fish were weighed (after being gutted i.e. all organs except gonads were removed on board commercial fishing vessels) without surface drying to the nearest 0.1g. A sample of 31 whole fish was also caught in November 2001 and the relationship between gutted body weight and whole body weight calculated. As a number of the samples were stored at -18°C, then defrosted prior to examination, the relationship between fresh weight and defrosted weight was also investigated. This was carried out by initially weighing 40 fresh lemon sole over a range of sizes from a single sample. These fish were then individually bagged, labelled and frozen at -18°C for one month. The fish were then defrosted and reweighed. A defrosted weight correction factor was produced by carrying out liner regression analysis on the two sets of data.

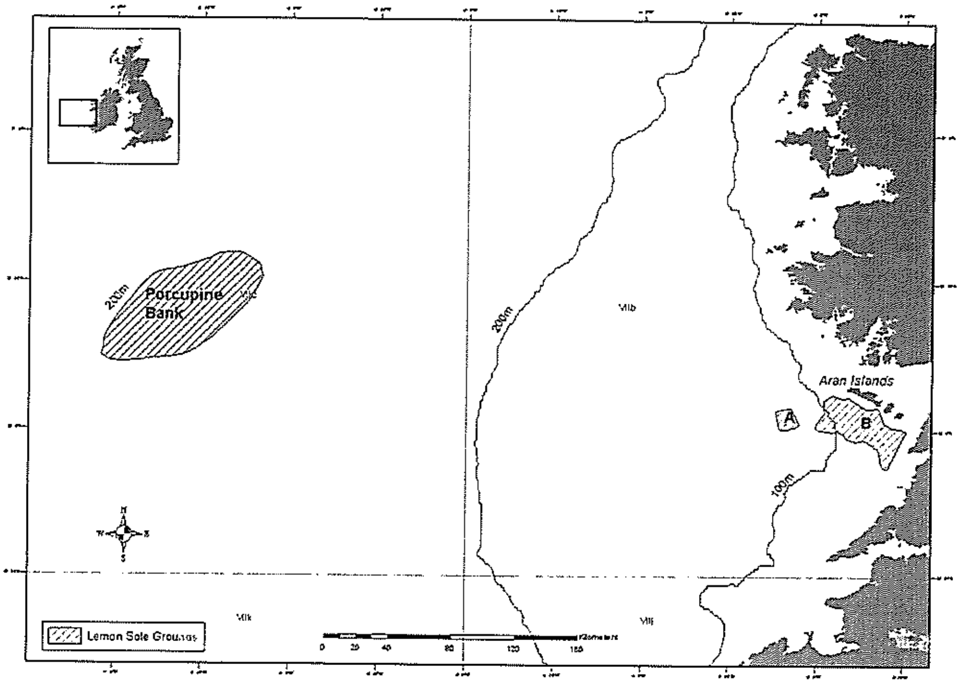


Fig. 1 Fishing grounds for lemon sole off the west coast of Ireland. (A and B indicate sites west of the Aran Islands). (Courtesy of BIM)

Table I (a) Criteria used to macroscopically determine the gonadal stage of female lemon sole *Microstomus kitt* (modified from King, 1982).

I	Immature	Ovaries extremely small and transparent, less than $^1/_3$ of the body length.
II	Maturing virgins or recovering spent	Ovaries flat and dull, greyish-white to very light pink in colour, $^1/_4$ - $^1/_2$ of the body length.
III	Ripening	Ovary not full, blood vessels visible on surface, dark pink in colour, approximately $^1/_3$ – $^1/_4$ of the body length.
IVa	Ripe	Ovaries relatively large, oocytes clearly visible, orange/pink in colour.
IVb	Spawning	Ovaries very swollen, translucent orange, ripe oocytes transparent, ovary wall very thin and translucent, $^2/_3$ of the body length.
V	Spent	Ovaries empty, flat and dull greyish-white, $^1/_2$ - $^1/_3$ of the body length.

(b) Criteria used to macroscopically determine the gonadal stage of male lemon sole, *Microstomus kitt* (modified from King, 1982).

I	Immature	Testes extremely thin transparent cream threads, $^1/_{10}$ body length.
II	Maturing virgins or recovering spent	Testes narrow, cream, tough, $^1/_8$ body length.
III	Ripening/ Ripe	Testes swollen in appearance, cream-white, $^1/_7$ body length.
IV	Spawning	Testes spongy, milky and rather slimy, cream-white, $^1/_6$ body length
V	Spent	Dull, transparent, grey and soft, $^1/_7$ body length.

At the laboratory, each fish was sexed and staged by macroscopic examination of the gonad (Table 1). Samples for histological examination were fixed in 4% buffered formalin for 48 hours then transferred to 70% alcohol. These samples were processed through an alcohol dehydration series, cleared in Histoclear© and embedded in paraffin wax for sectioning. Cross-sections of 5-10μm were stained with haematoxylin and eosin and examined by light microscopy in order to determine the state of gonad development (Table 2).

Table 2 Criteria used to microscopically determine the gonadal stage of male and female lemon sole, *Microstomus kitt* (after Santurtun *et al.* 2000).

	Maturity Stages	Males	Females
I	Immature	Spermatogonia and spermatocyte present, spermatozoids absent	Only oogonia, chromatin nucleolus stage
II	Maturing virgins or recovering spent	Spermatogonia and spermatocyte present, few spermatozoids	Oogonia, chromatin nucleolus stage, perinucleolus stage, early vitellogenesis
III	Ripening/Ripe	Spermatozoids predominant, spermatogonia and spermatocytes present only in the testes cortex	Vitellogenesis, early nucleus migration
IV	Spawning	Spermatozoids predominant	Migratory nucleus stage and oogonia and the other immature stages are also present
V	Spent	Empty seminiferal ducts, residual spermatozoids and few spermatogonia	Post-ovulatory follicles, follicular atresia and atretic oocytes

Fecundity samples were fixed in Gilson's Fluid (glacial acetic acid, chloroform and 60% ethanol) for 2 months and cleaned with distilled water. Oocyte diameters and fecundity counts were recorded by light microscopy using a Sedgwick Rafter counting cell.

Seasonal changes in gonad development were followed by calculating the gonosomatic index for each fish (monthly averages were used), where GSI = gonad weight/gutted body weight x 100 (Htun-Han 1978).

The age of the fish was determined and inter-calibrated (with fisheries biologists/ageing experts at the Irish Marine Institute affiliated to ICES Ageing Working Groups) by visually analysing the opaque and translucent zones on whole sagittal otoliths using a stereoscopic microscope. A complete annual zone was defined at the interface between an inner translucent and outer opaque zone (Cailliet *et al.* 1986), while January 1st was taken as the notional birthday as is usual for demersal species with annual rings (Williams and Bedford 1974).

Standard length (SL) (from the tip of the mouth to a region of the tail which acts as a wrist) and total length (TL) (from the tip of the mouth to the distal end of the tail) measurements were taken for all fish to the nearest 0.1cm below.

The length-weight relationship, represented by the formula $W = qTL^b$ (Beverton and Holt 1957), was log transformed and fitted with linear regression following: ln W = ln q + b (ln TL). W is the weight of the fish in grams, TL is the total length of the fish in centimetres, q is a constant determined empirically and b is the slope of the line.

Growth was determined in the form of the von Bertalanffy equation given below:

$$L_t = L_\infty (1 - e^{-K(t-t_o)})$$

The Rafail (1973) method based on the von Bertalanffy equation was used to determine L_∞.

Catch curves (Beverton and Holt 1957) were constructed by plotting the natural logarithms of the number of fish surviving by age. Total mortality (Z) and the age at full recruitment to the fishery (t_r) was then determined.

The percentage survivorship (% S) was estimated on Z values using the formula (Beverton and Holt 1957): $S = e^{-Z}$

The natural mortality coefficient (M) was estimated using the method of Pauly (1980), based on an empirically defined relationship between M, life history parameters and water temperature.

The fishing mortality coefficient (F) was estimated by substituting M (the natural mortality coefficient) and Z (the total mortality coefficient) into the following formula (Beverton and Holt 1957): $Z = F + M$

3 Results

A total of 1,820 lemon sole was examined during the sampling period. Of these, the sex of only one fish was unidentifiable.

3.1 Sex Ratio

The overall male to female (M: F) sex ratio was 1:3.6, which is highly significantly different from the expected M: F sex ratio of 1:1 (χ^2 = 586.63, $P < 0.001$). The dominance of female lemon sole was statistically very significant ($P < 0.01$) for each month sampled and from three years of age onwards. The relative abundance of both male and female lemon sole in the overall sample decreased with increasing size as shown in Table 3. Only females were present in the largest length category. The excess of females in the length categories was highly significant from 25 –25.99cm upwards ($P < 0.01$). The fish in the upper and lower size limits were grouped for statistical analysis due to small numbers.

Table 3 Numbers of male and female lemon sole at each size captured over the sampling period together with chi square (χ^2) values and significance levels

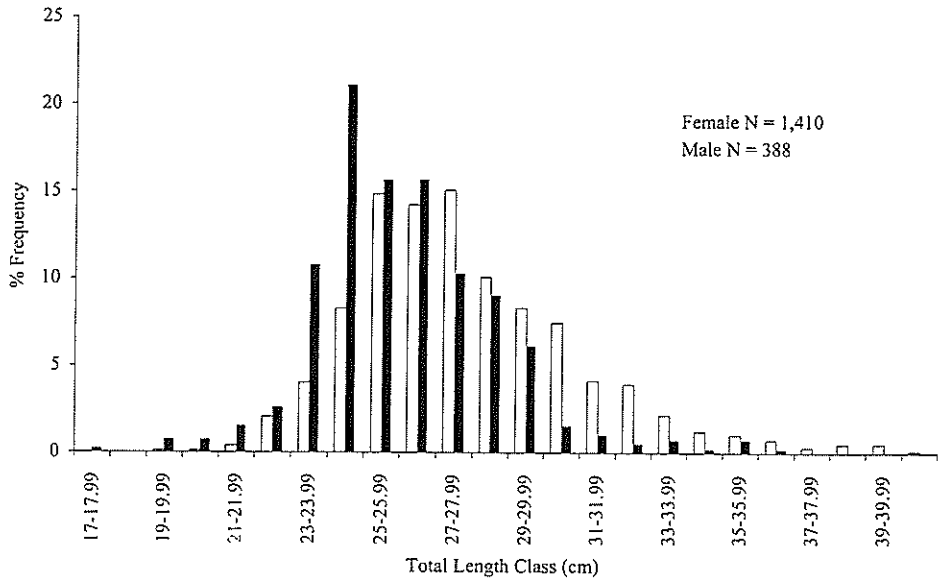
Size Class	Females	Males	Total	Expected	χ^2	Significance
17 – 21.99	9	13	22	11	0.36	NS
22 – 22.99	30	10	40	20	10.00	**
23 – 23.99	57	42	99	49.5	2.27	NS
24 – 24.99	117	82	199	99.5	6.16	*
25 – 25.99	210	61	271	135.5	81.92	***
26 – 26.99	201	61	262	131	74.81	***
27 – 27.99	213	40	253	126.5	118.30	***
28 – 28.99	142	35	177	88.5	64.68	***
29 – 29.99	117	24	141	70.5	61.34	***
30 – 30.99	106	6	112	56	89.29	***
31 – 31.99	59	4	63	31.5	48.02	***
32 – 32.99	56	2	58	29	50.28	***
33 – 33.99	31	3	34	17	23.06	***
34 – 34.99	17	1	18	9	14.22	***
35 – 35.99	15	3	18	9	8	**
36 – 36.99	10	1	11	5.5	7.36	**
37 – 40.99	20	0	20	10	10	**

* = *Significant* ($P < 0.05$), ** = *Highly Significant* ($P < 0.01$), *** = *Very Highly Significant* ($P < 0.001$), *NS* = *Not Significant* ($P > 0.05$)

3.2 Length Frequency Distribution

The overall length distribution for males and females separately is shown on Fig. 2. Males ranged from 17-17.99cm to 36-36.99cm, while females ranged from 19-19.99cm to 40-40.99cm.

Fig 2 Percentage length frequency distribution for male (black) and female (white) lemon sole off the west coast of Ireland as sampled between Nov 2000 - Feb 2002



3.3 Gonad Maturation Stages

Stage I immature fish were not encountered. Five stages of development in the female gonad were observed after macroscopic and microscopic examination (Fig. 3a and Fig. 3b). Ripening females were observed each month sampled particularly from April 2001 – January 2002. Ripe females were most frequently recorded in February (65%) and March (64%) in 2001 and dropped dramatically in April 2001. Spawning females were also most abundant in February (28%) and March (18%). The spent and the recovering spent stages were difficult to assess macroscopically. These stages however, are more accurately identified from histological results. Spent females were found from February to September 2001 and in March 2002. Recovering spent females were captured from April 2001 through to January 2001 and again in March 2002.

Fig 3a Percentage developmental stage from macroscopic observation of the gonad cycle at each month over the sampling period for female lemon sole. (N = 1364)

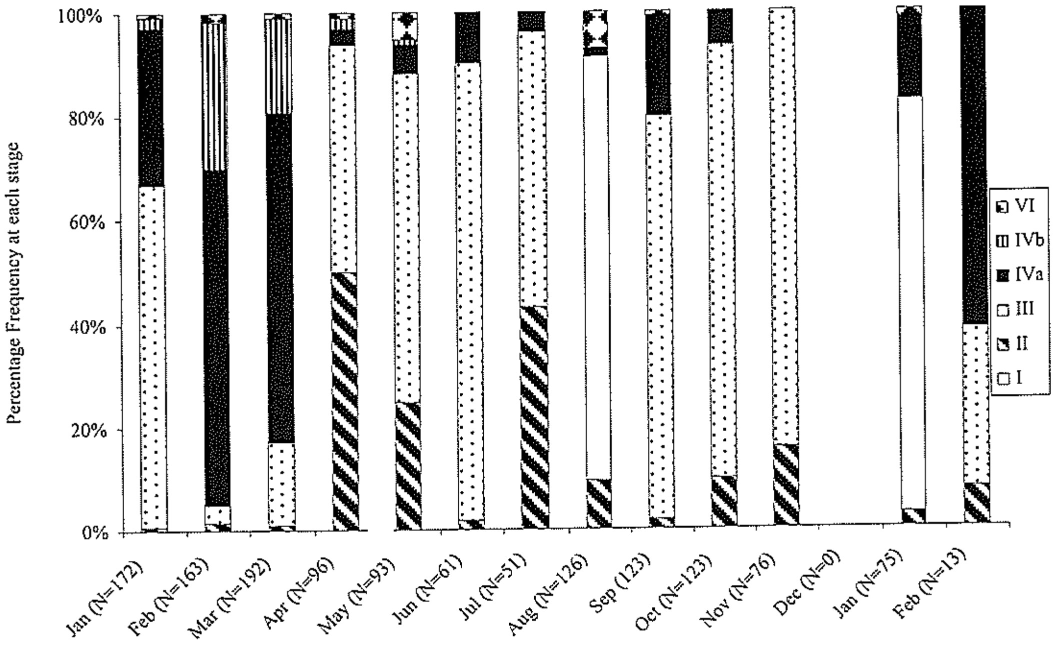
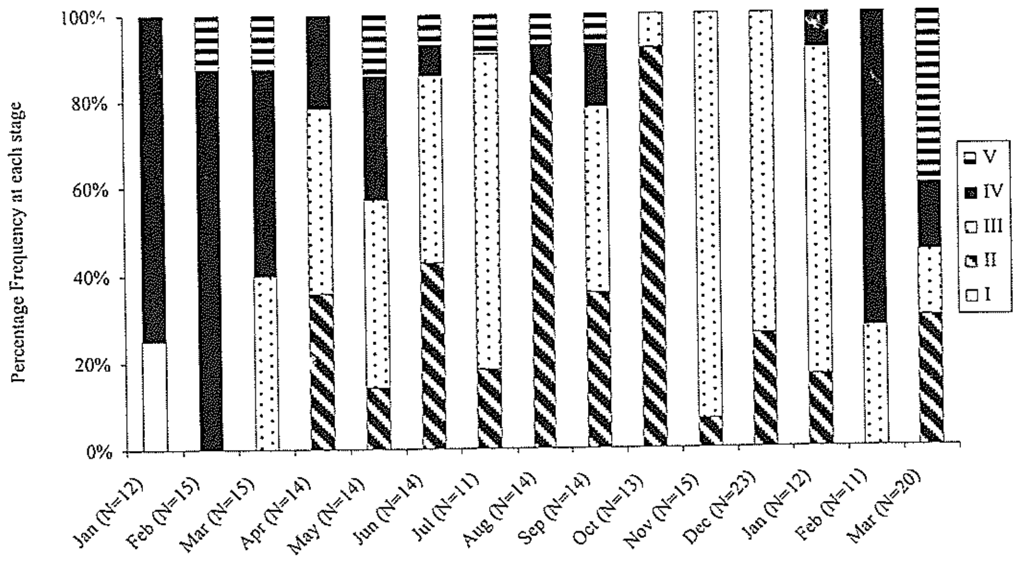


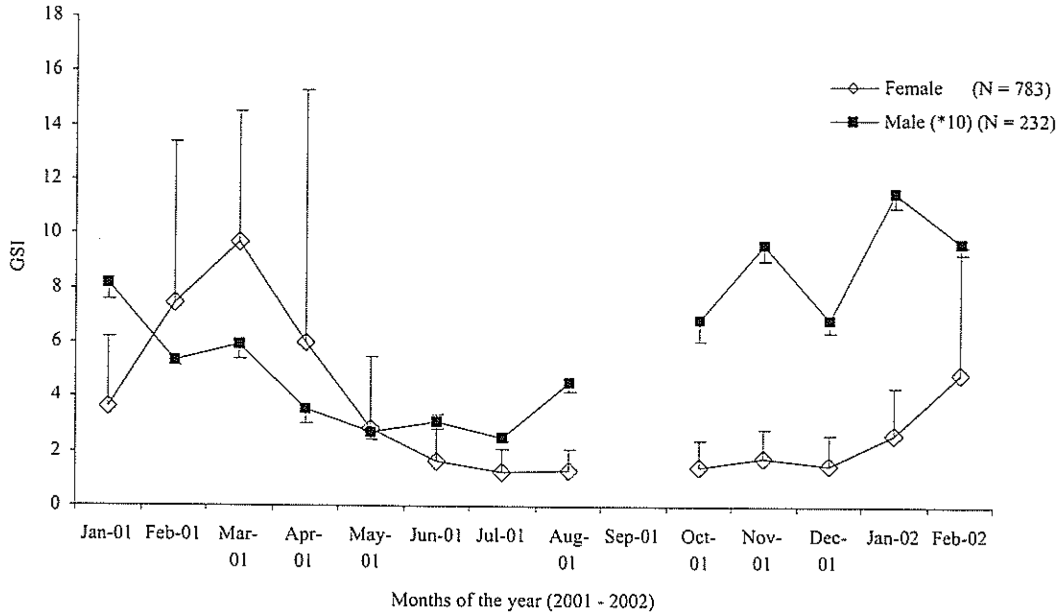
Fig 3b Percentage developmental stage from histological examination of the gonad cycle at each month over the sampling period for female lemon sole. (N = 217)



3.4 Gonosomatic Index

Seasonal changes in the gonosomatic index (GSI) for male and female lemon sole is shown in Fig. 4. An increase in GSI value indicates an increase in the number of ripening fish while a decrease indicates that the fish are spawning. No whole fish were obtained for the month of September 2001 therefore GSI could not be estimated. Female GSI values increased from January 2001 and peaked in March 2001, then decreased over the summer months. Female GSI began to increase again in January 2001 and February 2002. Male GSI values were high in January 2001. The GSI then fell in February and rose slightly in March then fell until May 2001. Male GSI values increased in the autumn of 2001, were highest in January 2002 and fell in February 2002. GSI was estimated on fish at all stages of maturity observed.

Fig. 4 Seasonal changes of the gonosomatic index (GSI) for male and female lemon sole sampled off the west coast of Ireland between 2001 to 2002. Vertical error bars indicate 95% confidence limits.



3.5 Fecundity

Fecundity estimates ranged from 52,515 (4 year old, 26cm TL) to 295,136 (5 year old, 38.5cm TL) for ripe fish. The average fecundity was 150,637.

The fecundity (F) - (gutted) weight relationship was as follows:

$$F=0.2077W^{3.9383} \quad (N = 11, R^2 = 0.7248, P < 0.05).$$

3.6 Total Length versus Standard Length

The Total Length versus Standard Length (SL) relationship was analysed for the 1,755 lemon sole examined. 65 fish were excluded from the analysis as the tail fin was damaged. 1,367 of the 1,755 were female lemon sole while 388 were male. The relationships between TL and SL for all fish sampled and males and females separately are shown in Table 4. The slope of the regression is higher for females (1.013) than for males (0.9987). The mean ratios of SL to TL in males and females were calculated, giving values of 1.22 ±0.002 and 1.21 ±0.001 respectively. These ratios were significantly different ($t = 6.229$, $P < 0.05$), with males having relatively longer tails than females.

Table 4 The relationship between TL and SL for lemon sole sampled off the west coast of Ireland. (All are statistically significant linear relationships ($P < 0.05$))

Sex	Relationship	N	R^2
Combined	$Log_e\ SL = 1.0149 Log_e TL - 0.2404$	1,755	0.98
Male	$Log_e\ SL = 0.9987 Log_e TL - 0.1915$	384	0.97
Female	$Log_e\ SL = 1.013 Log_e TL - 0.2328$	1,347	0.98

3.7 Length-Weight Relationship

The length-weight relationship for males, females and the overall sample was based on the analysis of 1,160 gutted fish as shown on Table 5. 165 fish were examined fresh, the remaining fish were weighed after defrosting from -18°C. A defrosted weight correction factor was calculated using regression analysis, which resulted in the following equation: Log_e Fresh Gutted Weight (g) = [0.1 + Log_e Defrosted Weight (g)]/1.0118. A conversion factor was also calculated for whole fish in relation to gutted fish as follows: Log_e Whole Weight (g) = [0.013 + Log_e Gutted Weight (g)]/1.0019. The mean ratios of weight to total length in males and females were calculated, giving values of 6.70 ±0.239 and 7.75 ±0.168 respectively. These ratios were statistically significantly different ($t = 7.086$, $P < 0.05$), with females heavier than males for their total length at a given length. The values for b in the length-weight relationship for the overall sampled population and for males and females separately were close to 3.

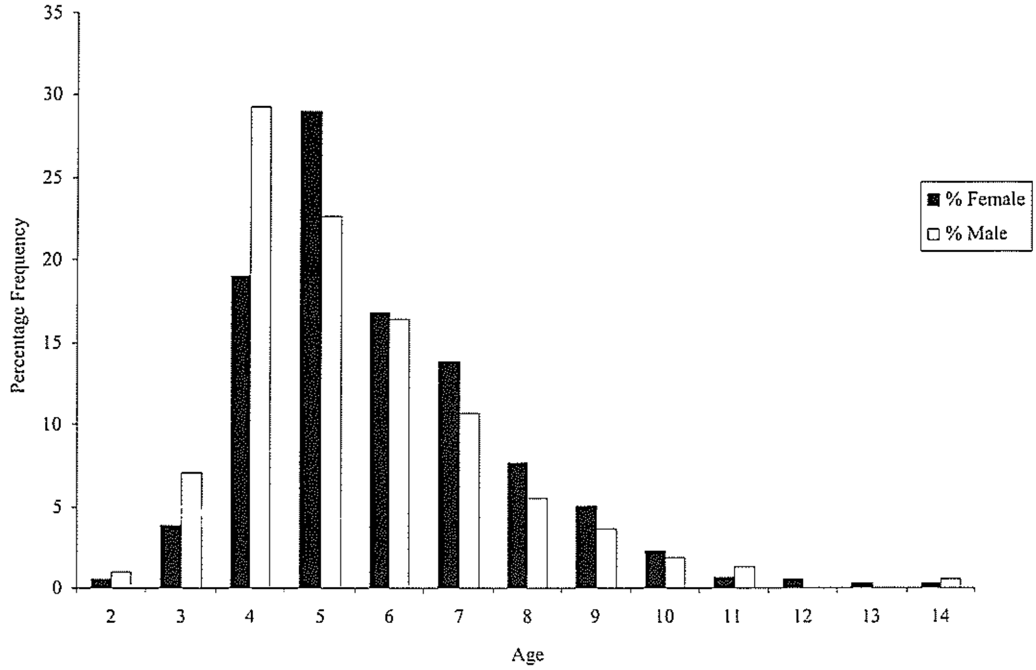
Table 5 The relationship between gutted weight (g) and total length (cm) for lemon sole sampled off the west coast of Ireland. (All are statistically significant linear relationships ($P < 0.001$))

Population	Length-Weight Relationship	N	R^2
Combined	$W = 0.0044L^{3.2495}$	1,160	0.88
Male	$W = 0.0071L^{3.0913}$	265	0.87
Female	$W = 0.0044L^{3.2546}$	894	0.89

3.8 Age Frequency

A total of 1,796 fish were aged. Of these 1,413 were female and 383 were male. Fig. 5 shows the age frequency for males and females separately. Ages ranged from 2 to 14 for both male and female lemon sole. Maximum % frequency (29.2%, N = 112) for male lemon sole occurred in age group 4. No male fish were recorded within the age groups 12 and 13 and few (0.5%, N = 2) were aged 14. Female lemon sole were present in all age groups with maximum numbers (29.0%, N = 410) within age group 5. Lowest percentages (0.3%, N = 4) of female lemon sole were within the oldest age groups of 13 and 14 years. The von Bertalanffy growth parameters were $L_\infty = 34.5$cm, $K = 0.1955$ yr^{-1} and $t_o = -2.20$ yrs.

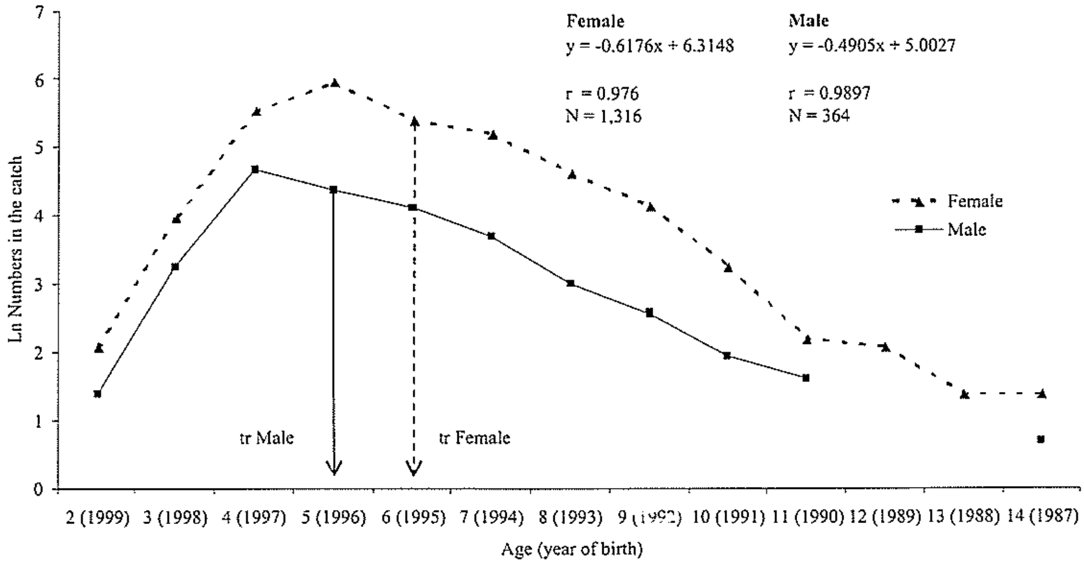
Fig 5 Age frequencies for male and female lemon sole sampled off the west coast of Ireland between November 2000 - February 2002



3.9 Catch Curves

Catch curves representing the age composition of the male and female lemon sole off the west coast of Ireland for the year 2001 are shown on Fig. 6. 5 year old females (i.e. the year class of 1996) and 4 year old males (i.e. the year class of 1997) were most abundant in the catches. The age at full recruitment (t_r) was 6 years for females and 5 years for males. The co-efficient of Total Mortality (Z) was calculated to be 0.61 yr^{-1} for females and 0.49 yr^{-1} for males from the descending leg of the catch curves. Percentage Survivorship was estimated from Z as 61% for females and 54% for males. Natural Mortality (M) of 0.41 was calculated using Pauly's (1980) method for males and females combined based on the results of the von Bertalanffy growth parameters. Fishing Mortality (F) was calculated as F = 0.20 for females and F = 0.08 for males.

Fig. 6 Catch curve for male and female sole sampled off the west coast of Ireland over the year of 2001



4 Discussion

In a previous study on lemon sole, sampled off the west coast of Ireland, over the period March 1978 – September 1979 (King 1982), the male to female sex ratio differed significantly from the expected 1:1 (M:F = 1:1.7) in favour of females. Dominance of females in the lemon sole catches is therefore not a recent phenomenon. In the current study, the dominance of females was observed in each month over the sampling period (2000 – 2002), at each age and from 25cm TL onwards. Bowman and Rae (1935) also found female lemon sole in excess of males at all seasons of the year in Scottish waters. Rae (1965) stated that with the advent of maturity, female lemon sole begin to outnumber males, a feature which became progressively more evident as the fish grew older.

The phenomenon where females outnumber male flatfish is not limited to lemon sole. It has also been observed in *Microchirus variegatus* (King and Fives 1990), *Buglossidium luteum* (King and Fives 1986), *Pleuronectes platessa* (Rijnsdorp 1994) and other species. There are a number of possible explanations for the biased sex ratio. The fishing method may be biased in favour of females, as males are significantly smaller than females ($t = 11.65$, $P < 0.05$) and therefore more likely to escape. The percentage survivorship (S%) estimated from Z (the coefficient of Total Mortality) was lower for males (54%) than for females (61%) in the current study. Higher numbers of males are also discarded, as they are more abundant in the smaller length categories. Another possible reason for the skewed sex ratio is that lemon sole may display differential distribution of the sexes as observed in American plaice (Swain and Morgan 2001) and abyssal grenadier (Merrett and Haedrich 1997).

In the earlier study by King (1982), off the west coast of Ireland lemon sole measured from 11.5cm to 37.4cm in total length. By contrast, fish sampled in 2000 – 2002 ranged in size classes from 17-17.99 to 40-40.99cm in total length. Wheeler (1969) gives a maximum size of 66cm for lemon sole around the British Isles, which is much larger than the maximum length recorded off the west coast of Ireland for the current investigation or that of King (1982). Male lemon sole in the present study and in that of King (1982) were present in an overall smaller size class when compared to that of females. Also, males did not reach as long a total length as females. The mean total length value attained by females in the present investigation exceeded that of males. Sexual dimorphism in lemon sole, where females are larger than males was also noted by Rae (1939) and (King 1982). Rijnsdorp *et al.* (1992) also found this pattern for dab in the south eastern North Sea. It has also been noted in witch (Gutvik *et al.* 1992), plaice (Rijnsdorp 1994) and fringed flounder (Reichert 1998).

Ages for lemon sole captured off the west coast of Ireland during the 2000-2002 sampling period ranged from 2 to 14 years for both males and females. Age groups 12 and 13 were not encountered for male lemon sole during the present investigation. King (1982) found an age range of 1 to 9 years for lemon sole sampled in the Galway Bay area in the period 1978-1979. Rae (1939) found lemon sole within the 1+ and 2+ age groups to be scarce on the fishing grounds. He contrasts this scarcity to numbers of 'baby' plaice and haddock, which were caught in 1000's during the same sampling period using the same gear. There is, therefore, evidence that lemon sole of the smaller length categories are not being caught in the fishing gear. This may be due to a number of factors. One possibility is that the habitat of the young lemon sole is inaccessible to the fishing gear as was assumed by Rae (1965). Alternatively, lemon sole have a better mechanism of escaping through the gear or avoiding being caught, as described by Engas (1994). Becoming vulnerable to fishing gear often coincides with a natural change of habitat, nutrition and behaviour of growing fish (Pitcher and Hart 2001). The most frequently recorded age group for males was age group 4, while for females it was age group 5. King (1982) found the most frequently recorded age group for females was also 5 years, while for males it was 3 years. Female lemon sole were significantly heavier at length than males, a feature found in many flatfish (Santos 1994).

Mature males and females were recorded in the smallest length class and at the youngest age encountered. Mature males were encountered as small as 17cm (TL) and at 2 years of age, while mature females were recorded as small as 20cm (TL) and at 2 years of age. These results agree with the observations of Anon (2004) where lemon sole were said to be mature at a length of 17cm around the Irish coast. In Scottish waters lemon sole began to mature at 2 years of age (Rae 1965). King *et al.* (in review) found that 50% of males were mature at 14cm (TL) and 2.6 years, while 50% of females were mature at 15.5cm (TL) and 2.5 years off the west coast of Ireland in 1978 – 1979. Maturity oogives were not attempted on the data of the present study. This was due to the absence of immature fish.

Rae (1939) found all 4 year old males had spawned at least once, while at least half of the females were still immature at 4 years of age. Most of the females in this study had reached maturity at 5 years of age. 99% of the 4 year old males and 94% of the 4 year old females were mature in the present study. Jennings *et al.* (1999) interpreted data from Rae (1965) and found 50% of lemon sole were mature at 4 years of age and were 27cm in length. Therefore, males and females in the present investigation and that of King (1982) were found to mature at an earlier stage than those examined by Rae (1965) in Scottish waters.

Males maturing at a smaller size class than females have been observed in a number of species of large fish (Froses and Binohlan 2000). Bowering and Brodie (1994) describe this pattern for American plaice (*Hippoglossoides platessoides* F.) on the Flemish Cap. Santos (1995) found that male four spot megrim (*Lepidorhombus boscii* R.) spawned from 19cm whereas the first female to mature was 20cm. Early maturation might put lemon sole in an advantageous position (Heessen and Daan

1996), as the majority of the catch would have reproduced at least once before capture, thus producing a high spawning stock biomass.

Female lemon sole off the west coast of Ireland spawned from January to May. Ripe males were recorded throughout the year excluding March, when females were most ripe. This corresponds with Bowman and Rae (1935), who found ripe males almost all year round, whereas ripe females were only recorded from April to September in Scottish waters. King (1982) recorded ripe males and females from February to August off the west coast of Ireland in 1978 – 1979. Present day results indicate that the females off the west coast of Ireland show similar patterns to the stock of 1978 – 1979.

In the 1978-1979 study (King 1982), the female with 86,200 eggs weighed 102g, which was indicative of a highly fecund lemon sole with 845 eggs per gram. In the present study the female with the greatest number of eggs (295,136) weighed 631.93g, which is equivalent to 467 eggs per gram. The latter is close to that of Newton and Armstrong (1974) who found 470 eggs per gram of lemon sole off the east coast of Scotland.

The present study showed an L_∞ of 34cm for lemon sole, while the stock of the 1978 – 1979 showed an L_∞ of 39cm (King *et al.* in review). K for the present study was 0.1955 $year^{-1}$, while that of the population of 1978 – 1979 was 0.1788 $year^{-1}$. The higher the K value the faster the fish grows towards the asymptotic length. Musick (1999) notes that species with K coefficients below 0.1 are at particular risk to over-fishing. A K value of 0.1955 $year^{-1}$ indicated that lemon sole grow relatively fast in terms of flatfish growth rates. This indicates that the present stock has a faster growth rate, yet they do not reach as great a size as the stock of 1978 –1979.

Jennings *et al.* (1999), who interpreted data from the North Sea after Rae (1965), found that lemon sole in the North Sea had an L_∞ of 37cm. This L_∞ is higher than the L_∞ of 34cm, which was calculated for lemon sole off the west coast of Ireland during the present study. Additionally, K (0.42 $year^{-1}$) for lemon sole in the North Sea (Jennings *et al.* 1999) was greater than that of the present study (0.1955 $year^{-1}$) indicating that lemon sole in the North Sea grew faster than the 2001-2002 fish off the west coast of Ireland. Jennings *et al.* (1999) examined long-term trends in the abundance of species in the North Sea demersal fish community and linked the strategy to the resilience of populations to fishing pressure. They found that between 1925 – 1996 changes in species composition led to an increase in mean growth rates, while mean maximum size, age at maturity and length at maturity decreased. From the present investigation, it is evident that age, length at maturity, and L_∞ have decreased since the late 1970's as shown in King *et al.* (in review), yet the K value increased. Therefore the results of the present investigation agree with the trends seen in Jennings *et al.* (1999). Rae (1951) reported on the stock of lemon sole off Scotland in 1932 – 1937, during a very intensive fishing period. He noted a decrease in the maximum size, yet the survivors showed a faster growth rate. Faster growth, smaller L_∞ and smaller size at first maturity are an indication of a decrease in population size if growth is limited by density-dependence in larger populations (Froese and Binohlan 2000).

The age at full recruitment (t_r) for female lemon sole in the present study was determined to be 6 years, while males were fully recruited at 5 years. A t_r value of 5 or 6 is good for this stock as the fish are mature at 2 years of age. The fish are given 3 to 4 years to contribute to the new recruits before they reach t_r. This could support sustainability in the lemon sole stock off the west coast of Ireland. In the study off the west coast of Ireland in 1978 – 1979 (King 1982), the age at full recruitment was found to be 4 years (King *et al. In press*). Natural mortality for both males and females was higher than fishing mortality, indicating that lemon sole were unlikely to be under any threat from the fishery. However, the study suggests that the population size has decreased and this may be due to the effects of fishing mortality. There is evidence of an observed lower L_∞, higher K and younger age at first maturity when compared to the interpreted data of King *et al.* (in press) for the west coast of Ireland. This may have been influenced by the fact that some of the fish sampled in the 2000-2002 study were from deeper waters off the Porcupine Bank.

Since juvenile lemon sole are not captured in the fishery, maximum ages to 14 years are observed and since they are not fully recruited to the fishery until they are 5 and 6 years (males and females respectively), despite maturing at 2 years or earlier, our data suggests that this stock is not overexploited. However, given that the values for M and F are approximations, it is necessary to conduct long-term investigations to determine the actual state of the stock. It should also be noted that the value of M from the relationship of Pauly (1980) has wide error bars, thus making the resulting F estimate uncertain. Further studies should include data from discard surveys and ground-fish surveys in order to determine t_c and L_c, age and length at first capture.

5 Acknowledgements

Thanks to Dr. Rick Officer, Dr. Colm Lordan, John Molloy, Dr. Paul Connolly and Sara Jane Moore, Fisheries Science Services (FSS), Irish Marine Institute for their advice on fisheries management and to Dr. Deirdre Brophy, Galway-Mayo Institute of Technology, for her constructive criticism in the writing of the paper. Thanks also to Gavin Power for his help in formatting the graphs for the manuscript. Noel Holland and John Holland, Galway Bay Seafoods and Turlough Smith, FSS, Irish Marine Institute are greatly acknowledged for their co-operation in obtaining samples. The co-operation of the Galway and Aran Fishermen's Co-operative in sampling their catch is also greatly appreciated. Sincere thanks to Helen Mc Cormick, FSS, Marine Institute for her advice on aging of lemon sole. The Irish Department of Education, Technological Sector Research programme - Strand I, provided funding for one of the authors (JH) during the investigative period and is greatly acknowledged.

6 References

Allen, B.M., King, P.A. and Fives, J.M. (2004) Diet of lemon sole *Microstomus kitt* (Walbaum 1792) in Galway Bay, on the west coast of Ireland. *Irish Naruralist Journal*, 27, 9, 329-334.

Anon (2004) The Stock Book. Report to the Minister for Communications, Marine and Natural Resources Annual Review of Fish Stocks in 2004 with management advice for 2005. Marine Institute, Ireland, pp 383.

Beverton, R.J.H. and Holt, S.J. (1957) On the dynamics of exploited fish populations. *UK Ministry of Agriculture and Fisheries. Fisheries Investigations*, **2**, (XIX), 533 p.

Browering, W.R. and Brodie, W.B. (1994) Distribution, age and growth, and sexual maturity of American plaice (*Hippoglossoides platessoides* (Fabricius)) on the Flemish Cap (NAFO Division 3M). *Journal of the Northwest Atlantic Fisheries Science*, **16**, 49-61.

Bowman, A. and Rae, B.B. (1935) Lemon soles (*Pleuronectes microcephalus*) marking experiments in Scottish waters during the period 1919-1931. *Fishery Board of Scotland Scientific Investigations*, (1) 42.

Cailliet, G.M., Love, M.S. and Ebeling, A.W. (1986) *Fishes a field and laboratory manual on their structure, identification and natural history.* Wadsworth Publishing Company, Belmont, California.

Engas, A. (1994) The effects of trawl performance and fish behaviour on the catching efficiency of demersal sampling trawls. In Ferno, A. and Olsen, S. (Ed.) *Marine Fish Behaviour in capture and abundance estimation.* Fishing News Books, London.

Froese, R. and Binohlan, C. (2000) Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *Journal of Fish Biology*, **56**, 758-773.

Gutvik, O.K., Hopkins, C.C.E., Nilssen, E.M., Nilsen, R. and Hermannsen, A. (1992) Growth is a many splendid thing: analysis in witch flounder (*Glyptocephalus cynoglossus*), patterns and implications. *International Council for the Exploration of the Seas CM*, G.3 Session P.

Heessen, H.J.L. and Daan, N. (1996) Long-term trends in ten non-target North Sea fish species. *ICES Journal of Marine Science*, **53**, 1063-1078.

Htun-Han, M. (1978) The reproductive biology of the dab *Limanda limanda* (L.) in the North Sea: gonosomatic index, hepatosomatic index and condition factor. *Journal of Fish Biology*, **13**, 377-388.

Jennings, S., Alvsvag, J., Cotter, A.J.R., Ehrich, S., Greenstreet, S.P.R., Jarre-Teichmann, A., Mergardt,N., Rijnsdorp, A.D. and Smedstad,O. (1999) Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure. III. International trwaling effort in the North Sea: an analysis of spatial and temporal trends. *Fisheries Research*, **40**, 125-134.

Jennings, S., Greenstreet, S.P.R. and Reynolds, J. D. (1999) Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology*, **68**, 617-627.

Jennings, S., Howlett, G.J. and Flatman, S. (1993) The distribution, migrations and stock integrity of lemon sole *Microstomus kitt* in the western English Channel. *Fisheries Research*, **18**, 377-388.

King, P.A . (1982) The biology of some commercial and non commercial fish species in the Galway Bay Area, west coast of Ireland. *National University of Ireland, Unpublished Ph.D thesis.*

King, P.A. and Fives, J.M. (1986) Littoral and benthic investigations on the west coast of Ireland-XXI. A contribution to the biology of the solenette *Boglossidium luteum* (Risso) in the Galway bay area. *Proceedings of the Royal Irish Academy, Biological, Geological and Chemical Science*, **86**, (2), 71-80.

King, P.A. and Fives, J.M. (1990) Littoral and benthic investigations on the west coast of Ireland-XXIII. A contribution to the biology of the thickback sole *Microstomus variegatus* (Donovan, 1808) in the Galway bay area. *Proceedings of the Royal Irish Academy, Biological, Geological and Chemical Science*, **90**, (2), 23-31.

King, P. A., Hannan, J. F. and Fives, J.M. (*in press*) Age, growth and reproductive biology of lemon sole *Microstomus kitt* (Pleuronectidae) sampled between 1978 – 1979 off the west coast of Ireland. The *Irish Naturalists' Journal*, **28**, (6).

Merrett, N.R. and Haedrich, R.L. (1997) *Deep – sea demersal fish and fisheries.* Chapman and Hall, London.

Musick, J.A. (1999) Ecology and conservation of long-lived marine animals. In J.A. Musick Life in the slow lane. *American Fisheries Society Symposium*, **23**, 1-7.

Newton, A.W. and Armstrong, D.W. (1974) A note on the fecundity of lemon sole. *International Council for the Exploration of the Sea* CM/F 34.

Nielsen, J.G. (1986) Pleuronectidae Key to genera and species. In Whitehead, P.J.P., Bauchot, M.L., Hureau, J.C., Nielsen, J. and Tortonese, E. (Ed.) *Fishes of the North-eastern Atlantic and the Mediterranean.* Volume III.

Pauly, D. (1980) On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *Journal du Counseil International pour l'Explorations de la Mer,* **39**, 175-192.

Pitcher T.J. and Hart, P.J.B. (2001) *Fisheries Ecology.* Kluwer Academic Publishers, London.

Rae, B.B. (1939) Age and growth of lemon sole in Scottish Waters. *Scientific investigations fish Bulletin Scotland,* **1**, (1) 39.

Rae, B.B. (1951) A comparison of the pre-war stocks of lemon soles at Faroe. *Journal du Counseil International pour l'Explorations de la Mer,* **17**, (3), 242-260.

Rae, B.B. (1965) *The lemon sole.* Fishing News (Books) Ltd., London.

Rafail, S.Z. (1973) A simple and precise method for fitting a von Bertalanffy growth curve. *Marine Biology,* **19**, 354-8. Springer-Verlag.

Reichert, M.J.M. (1998) *Etropus crossotus,* an annual flatfish species; age and growth of the fringed flounder in South Carolina. *Netherlands Journal of Sea Research* **40**, 323-332.

Rijnsdorp, A.D., Vethaak, A.D. and van Leeuwen, P.I. (1992) Population biology of dab *Limanda limanda* in the southeastern North Sea. *Marine Ecology Progress Series,* **91**, 19-35.

Rijnsdorp, A.D.(1994) Population-regulating processes during the adult phase in flatfish. *Netherlands Journal of Sea Research,* **32**, 401-415

Russell, F.S. (1976) *The eggs and planktonic stages of British marine fish.* Academic Press, London.

Santos, P.T. (1994) Growth and reproduction of the population of the four-spot megrim (*Lepidorhombus boscii* Risso) off the Portuguese coast. *Netherlands Journal of Sea Research,* **32**, 3/4, 379-383.

Santos, P. (1995) Growth, mortality and maturation of *Lepidorhombus boscii* in Portuguese waters. *International Council for the Exploration of the Sea CM Demersal Fish Committee CM* 1995/G:38.

Santurtun, M., Lucio P. and Franco, J. (2000) Biology of Megrim in waters off the Bay of Biscay during 1996-1997. *Ozenografika,* **3**, 301-342.

Steinarsson, B. (1978) The food of lemon sole (*Microstomus kitt* Walbaum), megrim (*Lepidorhombus whiffiagonis* Walbaum) and witch (*Glyptocephalus cynglossus* L.) in Icelandic waters. Sonderdruk aus Bd, **27,** 156-171

Swain, D.P. and Morgan, M.J. (2001) Sex-specific temperature distribution in four populations of American plaice (*Hippoglossoides platessoides*).*Marine Ecology Progress Series*, **212**, 233-246.

Wheeler, A. (1969) *The Fishes of the British Isles and North west Europe.* Michigan State University Press, East Lansing.

Wheeler, A. (1978) *Key to the fishes of Northern Europe.* Fredrick Warne and Co. Ltd., England.

Williams, T. and Bedford, B.C. (1974) The use of otoliths for age determination. In T.B. Bagenal (Ed.), *The ageing of Fish.* Unwin Brothers, Surrey, UK.