Age, growth and population dynamics of lemon sole *Microstomus kitt* (Walbaum 1792) sampled off the west coast of Ireland

By

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ABSTRACT

The age, growth, maturity and population dynamics of lemon sole (*Microstomus kitt*), captured off the west coast of Ireland (ICES division VIIb), were 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, each month sampled, at each age and from 22cm in total length onwards (when $N > 20$). Possible reasons for the dominance of females in the sex ratio are discussed. Three models were used to obtain the parameters of the von Bertalanffy growth equation. These were the Ford-Walford plot (Beverton and Holt 1957), the Gulland and Holt plot (1959) and the Rafail (1973) method. Results of the fitted von Bertalanffy growth curves showed that female lemon sole off the west coast of Ireland grew faster than males and attained a greater size. Male and female lemon sole mature from 2 years of age onwards. There is evidence in the population of a smaller asymptotic length ($L_\infty = 34.47$cm), faster growth rate ($K = 0.1955$) and younger age at first maturity, all of which are indicative of a decrease in population size, when present results are compared to data collected in the same area 22 years earlier. Results of the yield per recruit curve indicate that lemon sole are currently being over-fished off the west coast of Ireland. Problems of selectivity within the sampling method, particularly at the discarding stage, may have influenced the outcome of results of the models used in the assessment of this stock. Therefore, additional/future work on this species should include catch data which incorporates discards and not landings data alone.

CONTENTS

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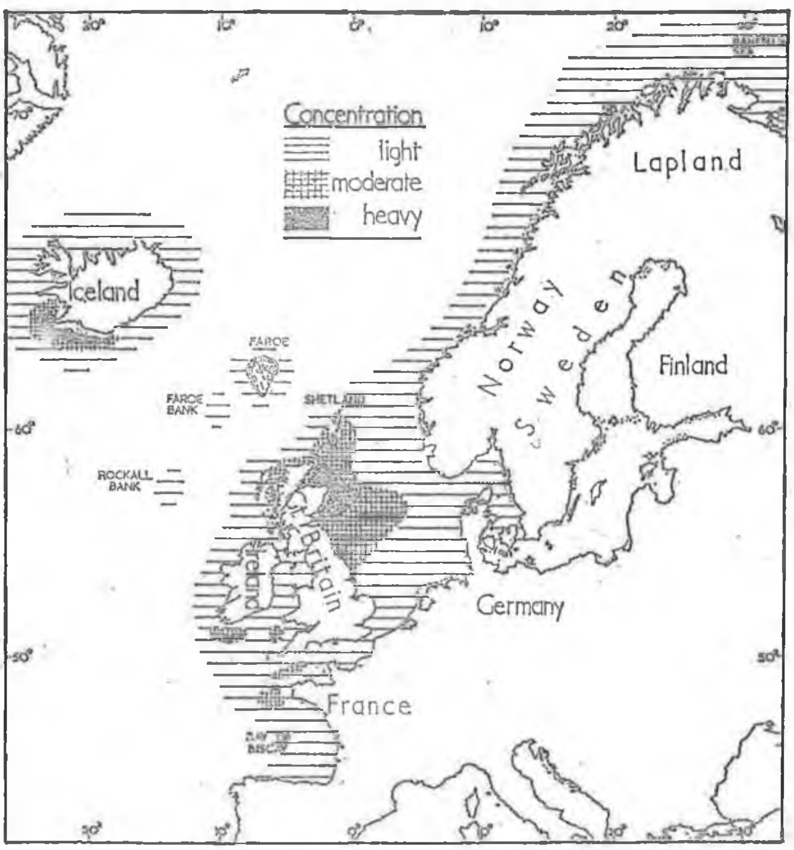
1 INTRODUCTION

Lemon sole, *Microstomus kitt* (Walbaum 1792), is a teleost fish of the Family Pleuronectidae. Synonyms of this species are *Pleuronectes kitt* (Walbaum 1792), *Microstomus microcephalus* (Donovan 1803) and *Pleuronectes microstomus* (Donois 1913). Common names include lemon dab, lemon fish, mary sole, merry sole, smear dab and sole fluke (Rae 1965).

Lemon sole is a demersal flatfish, whose geographical distribution is confined to the north eastern Atlantic (Fig. 1.1). It extends from the Bay of Biscay, north-eastwards to the White Sea, and to the north west to Rockall and Faroe banks, round the Faroe Islands, north east of Scotland in the Atlantic Ocean and on all coasts of Iceland (Rae 1965; Wheeler 1969; Nielsen 1986). The species is found all around the Irish coast (Anon 2001a).

Fig. 1.1 The distribution and main concentrations of lemon sole (after Rae 1965).



Eight other species of the Family Pleuronectidae inhabit the waters off the north-east Atlantic along with *Microstomus kitt*. These are witch (*Glyptocephalus cynoglossus* (Linnaeus 1758)), plaice (*Pleuronectes platessa* (Linnaeus 1758)), dab (*Limanda limanda* (Linnaeus 1758)), flounder (*Platichthys flesus* (Linnaeus 1758)), long rough dab (*Hippoglossoides platessoides* (Fabricius 1780)), halibut (*Hippoglossus hippoglossus* (Linnaeus 1758)), greenland halibut (*Reinharditius hippoglossoides* (Walbaum 1792)) and artic flounder (*Liopsetta glacialis* (Pallas 1776)).

The lemon sole is a small to medium sized oval shaped flatfish with a smooth and slimy thick skin (Rae 1965; Nielsen 1986). It is generally warm brown but with varied and irregularly rounded markings of mahogany, orange, yellow and even green blended into the background colour (Wheeler 1969; 1978). A thin layer of orange flesh is often present on the edge of the operculum (Rae 1965). The fish has a characteristically small mouth and head. The head is one fifth of the body length (Rae 1965; Wheeler 1969). The mouth is positioned in front of the lower eye, to the right of the upper eye (Wheeler 1969). The small mouth of the lemon sole has prominent fleshy thick lips, which are light cream in colour, and are a diagnostic feature of this species. The lateral line is curved above the pectoral fin (Wheeler 1969; 1978).

Lemon sole are found at depths varied between 1 – 200 m (Rae 1939a). The depths most favoured lie between 51 – 125 m in Scottish waters (Rae 1939a), 3 – 200 m round the Faroe Islands (Rae 1939a) and 30 – 140 m in Icelandic waters (Steinersson 1978). Lemon sole have been found on a variety of bottom types from mud and sand to hard rocky substances (Steinersson 1978; Wheeler 1978). They have been caught in places where the strength of the tides prevents the settlement of mud, suggesting that lemon sole favour a hard bottom of rock and shingle (Rae 1939a).

Lemon sole have been known to eat up to 2.6% of their body weight per day (Davenport 1990). This is in the form of small meals (each consisting of several chunks of food) and the stomach is substantially empty 36 hours after a meal (Davenport 1990). The main feeding season of lemon soles lasts from March to September in Scottish waters (Rae 1939a), in the North Sea from April to October, with minimal feeding activity between November to February (Ntiba and Harding 1993), and from May to August off the west coast of Ireland (King 1982). The food of lemon soles consists of five main taxa, Polychaeta, Crustacea, Mollusca, Echinodermata and Coelenterata. Of the five, Polychaeta exceed all others in importance (Rae 1939a; Steinersson 1978; King 1982; Nielsen 1986). Sedentary polychaetes of the family Sabellidae occurred frequently in the diet each month off the west coast of Ireland (King 1982). Polychaetes from the family Terebellidae were most favoured by lemon sole caught off the coast of the British Isles (Rae 1939a) while the family Phyllodocidae were the most favoured Polychaeta off the Icelandic coastline (Steinersson 1978).

In their early years of life, male and female lemon sole appear in the stocks in about equal numbers (Rae 1959). Later, usually with the advent of maturity, the females begin to outnumber the males, a feature which becomes progressively more evident as the fish grow older (Rae 1965).

Maturing and ripe fish appear in increasing numbers in populations of lemon sole of two years of age and older (Rae 1965). Male lemon sole mature earlier than females. By the time they are four years old most males have spawned at least once. At five years of age most females have spawned at least once (Rae 1965). Lemon sole in Irish waters mature at age 2 (King 1982; Anon 2001a) and at a length of 17cm (Anon 2001a). The dividing line between mature and immature lemon sole was set to be 19cm in the North Sea (Heesen and Daan 1996).

Lemon sole are one of the less fecund flatfish with an estimated 470 eggs per gram of body weight (Newton and Armstrong 1974). Fulton (1890) estimated the number of ova in a lemon sole of 32cm in length at over 150,000 and in another of 38cm in length at over 670,000. Fecundity estimates for the stock off the west coast of Ireland varied from 4,453 – 62,828 for fish ranging from 12 to 29cm in standard length (King 1982). Fulton (1890) reported the greatest percentage of ripe females in July off the coast of Scotland. Results of a marking experiment carried out during the period 1919 to 1931 in Scottish waters by Bowman and Rae (1935) found that ripe males were captured almost every month whereas ripe females were not captured until April and ceased to be in the catches after September. Holt (1892) recorded ripe females from March to June and ripe males from March through to July off the west coast of Ireland. Ripe/spawning males and females were recorded from February to August off the west coast of Ireland between 1978 –1979 (King 1982).

Spawning is related to water temperature, with a trigger minimum temperature of 6.5°C (Rae 1953). It is known to take place in deep waters (over 100m) and migratory patterns in connection with habitat change for spawning have been observed (Holt

1892; Hefford 1910; Rae 1953). Spawning occurs progressively later to the north (Rae 1965). Patterns related to spawning vary considerably from place to place (Rae 1953). Over the range of distribution the lemon sole spawns from January to the beginning of November (Russell 1976). Spawning in Scottish waters starts on the west coast at the beginning of April or in some years in the second half of March. The spawning period off the west coast of Ireland extends from January to August (King 1982).

The eggs of lemon sole are pelagic, spherical and 1.13 –1.45mm in diameter. The yolk of the egg is unsegmented and there is no oil globule (Russell 1976). The characteristics of the post-larval stages of lemon sole are described in detail by Kyle (1897) and Russell (1976). Lemon sole eggs were found in the southern North Sea in densities of 0.2 eggs m^{-3}. These eggs were found in the same location as those of common sole (*Solea solea*), Norwegian topknot (*Phrynorhombus norvegicus*), dab and turbot (*Psetta maxima*). However, lemon sole eggs were patchily distributed when compared to the other species (Cameron *et al.* 1992).

Once larvae have hatched out they are carried into the bays by nearby currents (Rae 1953). High densities of lemon sole larvae were observed at depths of 50 m by Rae (1965). Rae (1965) suggested that lemon sole do not drift far from the adult spawning grounds but metamorphose and develop in areas where they are relatively inaccessible to beam and otter trawls (Jennings *et al.* 1993). These areas are likely to be rocky sea beds with patches of sand and gravel (Jennings *et al.* 1993). Lemon sole larvae were found in Galway Bay in April and June of 1972 and in April, May and July of 1973 (Fives and O' Brien 1976). Lemon sole post-larvae (size range 6-9.5mm) were captured off the west coast of Ireland in Killeany Bay off the Aran Islands in April of

1965 indicating that the stock of that year spawned between March - April (Fives 1970).

Reporting of juvenile lemon sole indicates that their occurrence around coastal areas is scarce (Rae 1939b; Jennings *et al.* 1993). However, they have been caught along the UK east coast, particularly in the north western area (Heesen and Daan 1996). Lemon sole begin their demersal life when they are 25 mm in length (Rae 1965). The rough nature of the sea bottom frequented by lemon soles may provide protection against capture by trawls or dredges (Rae 1965).

Lemon sole of up to 48 cm regularly occurred in commercial catches in the waters where lemon sole was distributed in the 1930's (Rae 1965). Wheeler (1969) noted that the largest maximum size lemon sole reached was 66cm, while extra large lemon sole of up to 67 cm were encountered and recorded at the Marine Laboratory of Aberdeen (Rae 1965). Lemon sole were found at a maximum size of 49cm in the Norwegian coasts and fjords (Albert *et al.* 1998). The largest lemon sole recorded off the west coast of Ireland in the late 1970's was 37cm (King 1982), while the largest recorded around Ireland recently was 40cm (Anon 2001a).

Lemon sole of up to fifteen years appeared regularly in the catches in the North Sea (Rae 1939a). Wheeler (1969) noted a maximum age of seventeen years, while ages of up to twenty-three years have been recorded (Rae 1965). The oldest fish recorded off the west coast of Ireland were nine year old females (King 1982).

There are three general methods used to age fish. These include, mark-release-recapture, the Peterson method and the study of seasonal ring formation (Lux 1971; Weatherley and Gill 1987). The mark-release-recapture method requires the recovering of fish of known age, marking it and releasing it. Then when the fish is recaptured the time-lapse is recorded (Cailliet *et al.* 1986). The Peterson method involves comparing length-frequency distribution of fish populations sampled (Ricker 1975). The study of seasonal ring formation involves counting marks that develop periodically in various hard parts of bony fish (Cailliet *et al.* 1986). Several types of hard parts can be used, for example scales, vertebrae, spines, opercula, fin rays and otoliths (Williams and Bedford 1974; Cailliet *et al.* 1986). All ages referred to for lemon sole by Rae (1939a; b; 1951; 1953; 1959; 1965) were estimated by reading scales. However, the most common method used to age lemon sole at present is by reading otoliths.

Otoliths are hard, calcareous bodies in the paired labyrinth systems of teleost fish, located in the cranial bones near the brain (Cailliet *et al.* 1986). Otoliths are composed of needle-shaped crystals of calcium carbonate radiating outwards in three dimensions from a nucleus and passing through a network of organic material (William and Bedford 1974). The size and shape of the crystals may vary within an otolith and the angle at which they lie in relation to one another and to the otolith as a whole may be constant. The organic network is not uniformally distributed either throughout the whole otolith or within similar zones (William and Bedford 1974). There are three types of paired otolith namely lapillus, sagitta and astericus (Pannella 1980). In most teleosts, the sagitta is by far the largest otolith and is usually used in ageing studies (Cailliet *et al.* 1986).

Lemon sole sagittal otoliths are of medium size in relation to fish length. Otoliths from large lemon sole are very different in appearance to those of smaller lemon sole (Harkonen 1986) in terms of overall shape and zone morphology. Correlations were found to exist between otolith length and fish length and also between otolith length and fish weight for lemon sole (Harkonen 1986). Ageing by means of otoliths involves counting the annual zones which are formed throughout the lifespan of the fish (Lux 1971).

Growth in marine fish is related to changes in light, temperature, nutrients, salinity and biological processes. These latter processes, such as spawning or feeding can cause somatic growth checks. Increase in fish length or mass slows with age but never ceases altogether as fish have indeterminate growth (Pitcher and Hart 2000). Growth and recruitment influence the sustainable catch weight that can be taken from a stock (King 1995). Therefore, understanding the growth patterns of a stock of fish is essential in determining the management strategies for that stock. The most common method of assessing the growth patterns of marine fish is by the use of the von Bertalanffy growth equation (Bertalanffy 1938). This assumes that fish grow towards some theoretical maximum length (or weight) and that the closer the length (or weight) gets to the maximum size the slower the rate of change of size. Length and age data are the basic parameters used to calculate the von Bertalanffy growth equation. L_∞, the maximum size that a fish would reach if unaffected by fishing effort, k, the rate at which the fish reaches L_∞, and t_o, the age at which the fish is theoretically zero (Beverton and Holt 1957) can be calculated from the length and age data. There are several methods available for obtaining the parameters of the von Bertalanffy growth curve: using data from length frequency distributions, mark-release-recapture experiments and growth checks.

Historically the Ford-Walford plot (Beverton and Holt 1957) from Ford (1933) and Walford (1946) has been widely used to determine the parameters for the von Bertalanffy growth curve (Beverton and Holt 1957; Ricker 1975; Gulland 1985) and it is still used in fisheries stock assessment (C. Lordan pers. comm.). This method depends on the graphical estimation of L_∞ as the intercept on the 45° line of the graph obtained by plotting length at age against length at age plus one years growth. The method of Gulland and Holt (1959), by where size increments per unit time are plotted against mean length, is also still used in fisheries stock assessment. Allen (1966) introduced a method for obtaining the best least-squares estimates of the parameters of the von Bertalanffy growth equation, while, another method for obtaining the parameters was introduced by Rafail (1973). Rafail's (1973) method was a slightly more complex means of attaining the parameters through a series of calculations and graphical sets of analysis. No one of the above approaches is intrinsically better than another. Each must be fitted to the data and the best one chosen (Pitcher and Hart 2000). This implies that the parameters of the models have no absolute meaning. Comparisons between parameter values can be useful when the same model is fitted to the data from different stocks of the same species (Pitcher and Hart 2000).

Rae (1939b) was the first to study the growth of lemon sole. Rae (1939b; 1965) found variable growth rates within the distribution of lemon sole. A relatively young stock of lemon sole in the north and west of Maggenaes (Faroe), exhibited the fastest rate of growth in the north-east Atlantic (Rae 1965). Rae (1939a) also found the fast growing lemon sole in the Firth of Forth in the western half of the central North Sea adjacent to the Scottish and north-east English coasts. Albert *et al.* (1998) indicated that at Karmoy, Norway, lemon sole grew at a rate that was close to that of the Firth of Forth. However, fish of a larger size were recorded off North Norway. Albert *et al.* (1998) suggest that there may be a northerly migratory pattern governing the size range of lemon sole. The distribution of lemon sole, extended progressively further north and into the fjords with increasing size (Albert *et al.* 1998). Lemon sole is a slow growing flatfish in comparison to other species (Rae 1951; 1965).

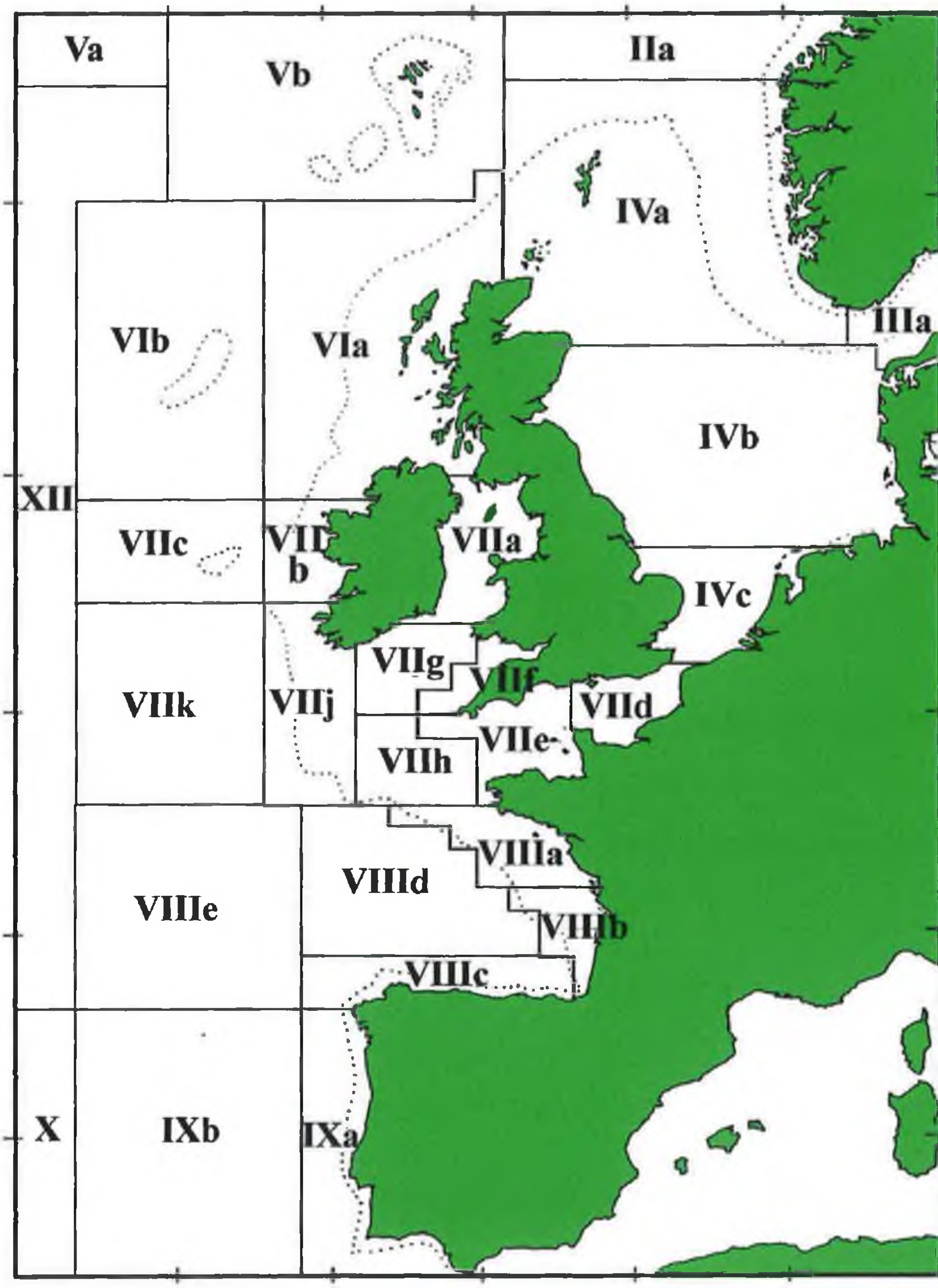
Lemon sole is known to be common in Irish waters (Went and Kennedy 1976). However, little recent information is available on the biology of lemon sole from Irish coasts. The biology of a Galway Bay population of lemon sole was investigated between March 1978 – September 1979 (King 1982), the sample size however, was 472 fish in total. Holt (1891; 1892) reports on some aspects of the biology of lemon sole on the west coast of Ireland, while the seasonal occurrence and distribution of the larval stages off the west coast has been recorded by Fives (1970) and Fives and O' Brien (1976).

Variations in landings have been recorded over the last century from a number of areas. High fishing intensity in Scottish waters between 1932 – 1937 resulted in fewer large specimens being retained in the catches (Rae 1951). Over the 20 year period ranging from 1955 – 1975 lemon sole landings from the Faroes were far from constant (Jones and Jermyn 1976). Landings increased from 1955 to 1963 but dropped dramatically in 1964. From 1964 to 1973 the landings fluctuated without major trend, reaching a peak in 1970. The relatively high level of landings from 1960 to 1963 coincided with a period of relatively high fishing effort. 1964 was the year that the 12 mile limit was redrawn, hence the decrease in landings (Jones and Jermyn 1976). A decline in landings per unit effort from inshore waters from the period 1967 to 1974 was observed for the Scottish lemon sole fishery (Armstrong 1976). This was an indication of a reduction in the sizes of the stocks due to a reduction in the levels of recruitment compared with the mid-1960's (Armstrong 1976). Lemon sole appeared to have increased in abundance in the North Sea from 1970 to 1993 (Heesen and Daan 1996). Rae (1965) stated that the grounds off the south coast of Ireland proved so **highly** a productive region for lemon sole over the period between 1955 to 1960 as to displace the Faroes from the third position of importance, following Iceland at second place and the North Sea at first.

There has been no ongoing analysis of the past fishing history of lemon sole in Irish waters. The Marine Institute have only this year included lemon sole in the stock assessment, under non-quota species (Anon 2001a).

Lemon sole is a commercially important demersal species in Europe. The Total Allowable Catch (TAC) is only set for ICES divisions IIa (west of the north of Norway) and VI (west of Scotland) (Fig. 1.2) under the Common Fisheries Policy of the European Union. The latter was 9,720 tonnes for the year 2002. This is a reduction on the previous year (2001), where a TAC of 10,800 tonnes was allocated to lemon sole. Landings of witch, *Glyptocephalus cynoglossus* are included in the TAC for lemon sole. The quotas for the TAC allocated were assigned in order of tonnage to the UK, Denmark, Holland, Belgium, France, Germany and Sweden. There is no quota assigned to Ireland for lemon sole.

Fig. 1.2 ICES Fishing Divisions (after Anon 2001a)



Many stocks are at present outside safe biological limits in that, they are too heavily exploited, or have low quantities of mature fish, or both (Anon 2001b). Therefore, reference points such as fishing mortality (F) are a key concept in implementing a precautionary approach in management of fish stocks (Anon 1998). The aim of implementing TACs is to control exploitation rates of fish stocks, in addition to the technical measures, such as minimum mesh sizes, closed areas and closed seasons (Anon 2001b).

Lemon sole are caught as a by-catch species of 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 (M. O 'Driscoll pers. comm.). In Ireland in 2000, lemon sole had a total landed weight of 449.9 tonnes, with a value of €798,140.39 (Anon 2002a).

In 2000 5.5% of the total landed value of lemon sole were caught as a by-catch of the *Nephrops* fishery at the port of Rossaveal in the west of Ireland. Rossaveal is Ireland's second most important port with reference to the *Nephrops* fishery, landing 17.5% of the total landed weight value for 2000. There are approximately 21 otter board trawlers fishing out of Rossaveal targeting *Nephrops*. Four out of five of these are twin rig and the remaining trawlers are single rig (T. Smith pers. comm.).

The total landed weight of lemon sole for Rossaveal on the west coast of Ireland in the year 2000 was 23 tonnes. In the same year, Waterford port on the south east coast landed 73.8 tonnes. The latter, was the highest landed weight at any port for lemon sole, totalling 17.6% of the overall landed value. The fishery out of Waterford port is a mixed fishery, with megrim holding the greatest percentage of the catch. 68.3 tonnes of lemon sole were landed at the port of Dunmore East in 2000 as a by-catch of the whiting fishery. This was the second highest tonnage value for lemon sole landed into a single port in Ireland.

The purpose of the present investigation was to determine the age, growth, maturity and population dynamics of the stock of lemon sole off the west coast of Ireland. The stock was sampled 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 data were analysed using standard fisheries statistical methods and the status of the stock was assessed. The results were compared with previous studies on age, growth and maturity of lemon sole from the west coast of Ireland (King 1982) and elsewhere.

2 METHODS AND MATERIALS

2.1 Sampling Method

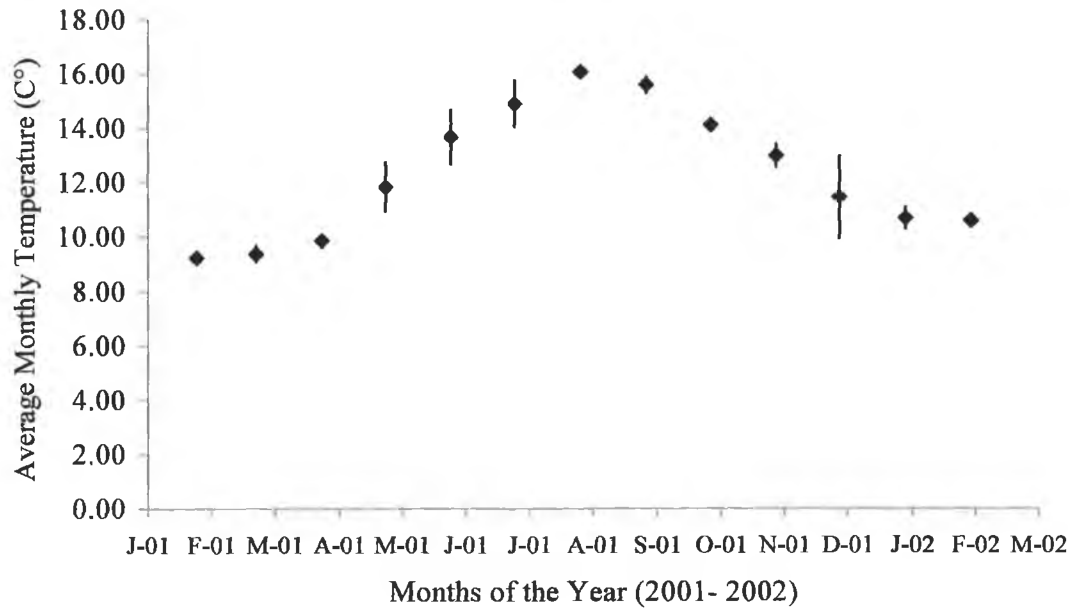
A total of 1,820 lemon sole were examined. The fish were captured monthly, over the period ranging from November 2000 to February 2002. Fishing grounds were off the west coast of Ireland in ICES Divisions VIIb and VIIc (Fig. 1.2), particularly off the Porcupine Bank and in the outer Galway Bay area, just west of the Aran Islands. The fish were caught by commercial fishing trawlers operating out of the fishing port of Rossaveal, Co. Galway. The fishing gear used was twin or single rig otter board trawls (primarily twin-rig). A standard mesh size of 80mm at the cod-end was used. Lemon sole were captured as a by-catch of the prawn (*Nephrops*) fishery or in mixed demersal catches.

All samples were delivered to the laboratory fresh. These would have been caught a few days prior to the dates shown in Table 3.1.1. Samples arriving in the laboratory as whole fish were generally a day or two fresher than those arriving as lemon sole frames (the skeleton and head of filleted fish). Whole fish were landed at Rossaveal, sold in the adjacent auction hall and delivered to the laboratory. Frames arrived at the laboratory from Galway Bay Seafoods. These had been landed at Rossaveal, sold to Galway Bay Seafoods and subsequently filleted. The frames were then provided to GMIT (Galway-Mayo Institute of Technology) as material for examination at the laboratory. A sample of 34 whole fish with guts intact, were provided by the Fisheries Assessment Technician (FAT) at Rossaveal following a *Nephrops* survey in November 2001. This sample contained both discards and commercial size fish. At the laboratory, fish were dissected fresh, where feasible. Otherwise, whole/frame fish were frozen at -18°C until later use.

2.2 Oceanographic Temperatures of the Sampling Area

Since February 2001, the Irish Marine Institute has operated a data buoy (M1), which is located off the west coast of Ireland at 53°07.6'N, 12°12'W. Average monthly sea temperature off the west coast of Ireland for the year Feb 2001 – Feb 2002, calculated from this data buoy is shown in Fig. 2.2.1.

Fig. 2.2.1 Average monthly sea temperature off the west coast of Ireland for the period ranging from Feb 2001 – Feb 2002. (Error bars indicate standard deviation from the mean)



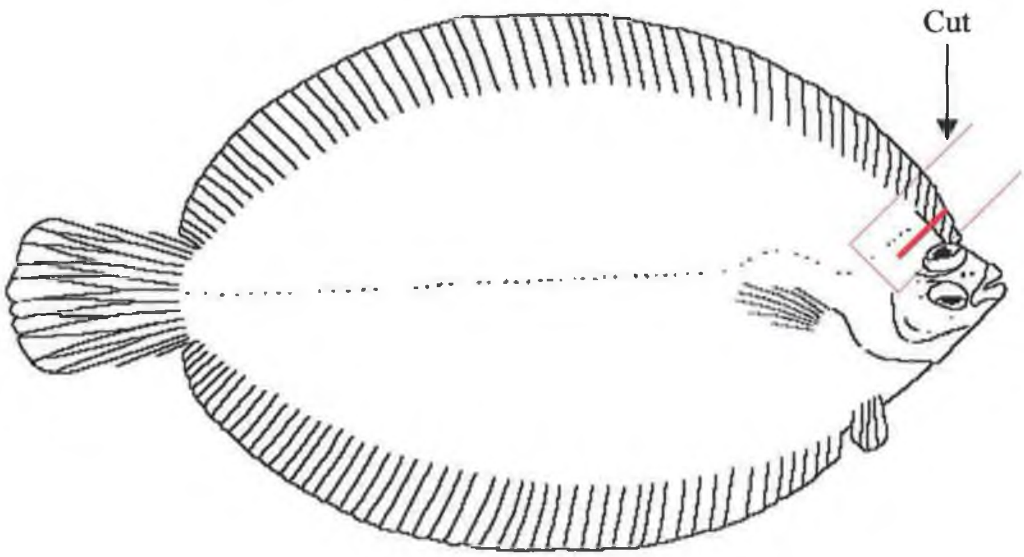
The mean annual water temperature was 12.49°C as calculated from the Marine Institute's data buoy (M1).

2.2 Ageing

<u>Removal and storage of the sagittal otoliths</u>

The sagittal otoliths are located in the cranial bones of the fish, close to the brain. An incision was made directly posterior to the lower right eye as shown on Fig. 2.2.2. The two otoliths were then removed and placed in a petri dish of water to be cleaned of any membranous material and subsequently dried. They were then stored in purpose made otolith boxes. Each box was labelled and stored in a dry, dark container pending further analysis.

Fig. 2.2.2 A lemon sole showing the point of incision of the knife into the head of the fish, in order to remove the otoliths.



Viewing

Each pair of otoliths was placed in a clear glass petri dish on a black plate. They were then viewed using a stereoscopic microscope with 7x to 30x magnifications. A varied combination of reflected overhead and lateral light sources was used to aid in the discrimination of the otolith zones.

Reading

A series of opaque and translucent zones was observed on the outer surfaces of the otoliths (Fig. 3.2.2). The innermost zone of the otolith appeared opaque. This was the nucleus. The next zone was seen as a translucent zone. This indicated a slow period of growth i.e. winter growth (Williams and Bedford 1974). 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 for demersal species with annual rings (Williams and Bedford 1974).

When ageing, the nature of the outermost edge and the date of capture was taken into account. If, for example, the outer edge of the otolith was translucent, it was included in the age count only if the fish was caught after January 1st. If, however, the fish was caught in July, August, September, October, November or December, the outer translucent edge would not be included in the ageing of that fish. Thus, a fish caught in December would be read as 5 years of age, whereas if that fish were caught the following January it would be read as a 6 year old fish.

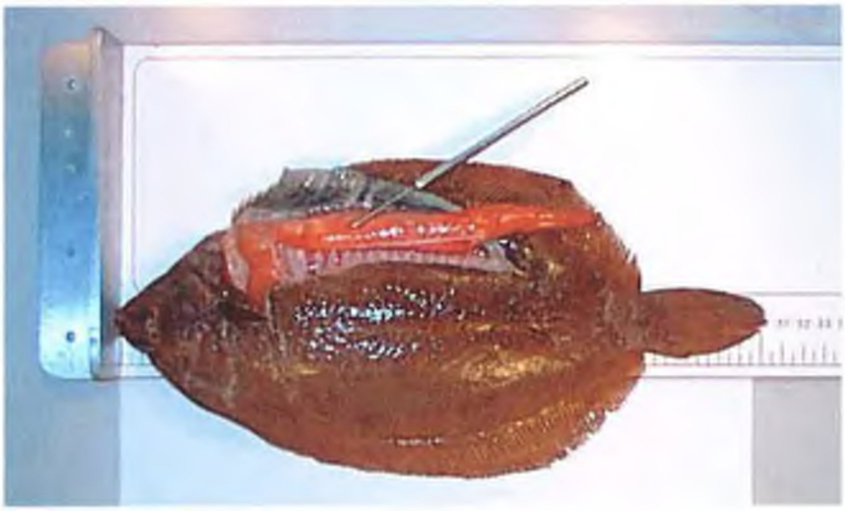
Quality Control

Two inter-calibration exercises in the ageing of otoliths were carried out at the Marine Fisheries Services Division of the Irish Marine Institute with technical staff experts. The latter are also active members of international workshops on ageing. The first inter-calibration exercise was conducted in April 2001 at an early stage in the present investigation while the second was conducted in March 2002, towards the end of the study.

2.3 Sex Ratio, Maturity and Gonosomatic Index (GSI)

At the laboratory, each fish was sexed by macroscopic examination of the gonad (Fig. 2.3.1). The gonads were then removed and weighed (wet weight) to the nearest 0.01g, and stored at –18°C in small freezer bags.

Fig. 2.3.1. Dissection of a lemon sole which was caught off the west coast of Ireland in March 2001, the female gonad is indicated with the teasers.



After initial examination of the lemon sole gonads, and following King (1982), seven maturity stages were defined as follows:

Females

Stage I Immature

Ovaries extremely small and transparent, less than $^{1}/_{3}$ of the body length.

Stage II Maturing virgins or recovering spent

Ovaries flat and dull, greyish-white to very light pink in colour, ¼ - ½ of the body length.

Stage III Ripening

Ovary not full, blood vessels visible on surface, dark pink in colour, approximately $^1/_3$ – ¼ of the body length.

Stage IV Ripe

Ovaries relatively large, oocytes clearly visible, orange/pink in colour, $^2/_3$ the body length.

Stage V/VI Early and Late Spawning

Ovaries very swollen, translucent orange, ripe oocytes transparent, ovary wall very thin and translucent, $^2/_3$ of the body length.

Stage VII Spent

Ovaries empty, flat and dull greyish-white, ½ - $^1/_3$ of the body length.

Males

Stage I Immature

Testes extremely thin transparent cream threads, $^1/_{10}$ body length.

Stage II Developing virgin and recovering spent

Testes narrow, cream, tough, $^1/_8$ body length.

Stage III/ IV Ripening

Testes swollen in appearance, cream-white, $^1/_7$ body length.

Stage V/VI Ripe/Spawning

Testes spongy, milky and rather slimy, cream-white, $^1/_6$ body length

Stage VII Spent

Dull, transparent, grey and soft, $^1/_7$ body length.

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

2.4 Size Relationships

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 fish were weighed (gutted) without surface drying to the nearest 0.1g. 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 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 weighed. A defrosted weight factor was produced by carrying out liner regression analysis on the two sets of data. The 34 fish provided by the FAT were not gutted prior to landing, therefore the guts were removed at the laboratory. The fish were weighed after the guts were removed. The weight values used throughout the investigation were corrected by the defrosted weight factor, where relevant.

The length-weight relationship, represented by the formula $W = qTL^b$ (Ricker 1975), was log transformed into the 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 (Ricker 1975; King 1995).

2.5 Growth

Growth was determined in the form of the von Bertalanffy equation given below (von Bertalanffy 1938, 1949):

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

<u>Growth parameters</u>

L_∞ = The maximum size that the fish would achieve if unaffected by fishing effort, predation, disease and natural mortality.

K = The rate at which the fish reaches the limiting size.

t = age of a fish at time t

t_o = age at which the fish is theoretically 0 mm long

(Beverton and Holt 1957; Ricker 1975).

Three different independent methods were used during the present investigation, to estimate the von Bertalanffy growth parameters (VBGP) for lemon sole, these were:

Method	I	The method of the Ford-Walford plot (Beverton and Holt 1957) from Ford (1933) and Walford (1946) combined,
Method	II	The Gulland and Holt plot (1959) and
Method	III	The Rafail method (Rafail 1973).

<u>Method I</u>

A Ford-Walford Plot (Beverton and Holt 1957) was calculated by plotting mean length at age (L_t) against mean length at age plus one year's growth (L_{t+1}). The straight line fitting these data has a slope of b = exp[-K] and an intercept on the y-axis of $a = L_\infty$ (1 – exp[-K]). These formula were manipulated to estimate K and L_∞ as follows:

$$K = -\ln[b]$$

$$L_\infty = a/(1 - b)$$

Alternatively, L_∞ may be read from the point where the regression line crosses the diagonal line of equality between L_t and L_{t+1} (where there is no growth between one year and the next, or between age t and t + 1) (King 1995).

Method II

A Gulland and Holt (1959) plot was constructed by plotting *y*, the increment per unit time, against *x*, the mid-point of the corresponding length interval. The straight line fitting these data has a slope of $b = \exp[-K]$ and an intercept on the y-axis of $y = bx + a$. These formula were manipulated to estimate K and L_∞ as follows:

$$K = -b$$

$$L_\infty = -a/b$$

t_o was estimated from both the Ford-Walford Plot and the Gulland and Holt Plot using the equation (King 1995):

$$t_o = t + (1/K)(\ln[L_\infty - L_t)/L_\infty])$$

Method III

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

$$L_\infty = \frac{e^K \sum_2^n L_t - \sum_1^{n-1} L_t}{(n-1)(e^K - 1)}$$

The straight line fitting Log_e (dL_t/dt) against age showed $y = bx + a$. This formula was manipulated to estimate K, as K is taken as the slope b. L_∞ was then calculated using the formula as shown above. t_o was estimated from the relationship of Log_e (dLt/dt) against age where a second estimate of K and L_∞ were also estimated. The plot generated a straight line in the form of $y = bx + a$. K was taken as the slope b and t_o was a/b. A second estimate of L_∞ can was then estimated on the second estimate of K. The process was repeated to calculate a second value for t_o and a third value for K and L_∞.

2.6 Catch Curves and Mortality

A catch curve (Edser 1908; Baranov 1918; Ricker 1948) was constructed by plotting the natural logarithms of the number of fish surviving by age. Since the age group at the peak of the dome may or may not be totally vulnerable to the gear, the portion of the descending leg used to estimate Z (the total mortality coefficient) is taken as one age group to the right of the dome (Gulland 1985). The latter age group is then taken to be the age group at which the fish are fully recruited to the fishery (t_r).

The percentage survivorship (% S) was estimated on Z values using the formula (Gulland 1955):

$$S = e^{-Z}$$

Mean life span (t_{max}) (maximum age calculated) is defined as the time required for 95% of the fish species to reach L_∞. This was estimated using the following formula (King 1995):

$$t_{max} = 3/K$$

The Natural Mortality coefficient (M) was estimated using the method of Pauly (1980), using the following formula:

$$\text{Log } M = -0.0066 - 0.279 \text{ Log } L_{\infty} + 0.6543 \text{ Log } K + 0.4634 \text{ Log } T$$

T = Mean annual water temperature where the fish were caught (i.e. 12.49°C as calculated from the Marine Institute's data buoy M1).

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):

$$Z = F + M$$

2.7 Yield Per Recruit

A Yield per recruit model (Beverton and Holt 1957) was constructed for the overall sample of lemon sole using the following equation:

$$Y = \int_{t_r}^{t_L} F_t N_t W_t \, dt$$

Where Y was the yield to the fishery, t_r was the age of full recruitment to the fishery, t_L was the significance of the limiting age or maximum age of fish in the fishery, F_t was the fishing mortality coefficient, which may vary with age, N_t was the number of fish alive at age t and W_t was the average weight of an individual fish of age t.

3 RESULTS

3.1 Sampling

Sample size and source varied throughout the sampling period (Table 3.1.1).

Table 3.1.1. Details of the sampling period, for lemon sole captured off the west coast of Ireland between November 2000 and February 2002 inclusive.

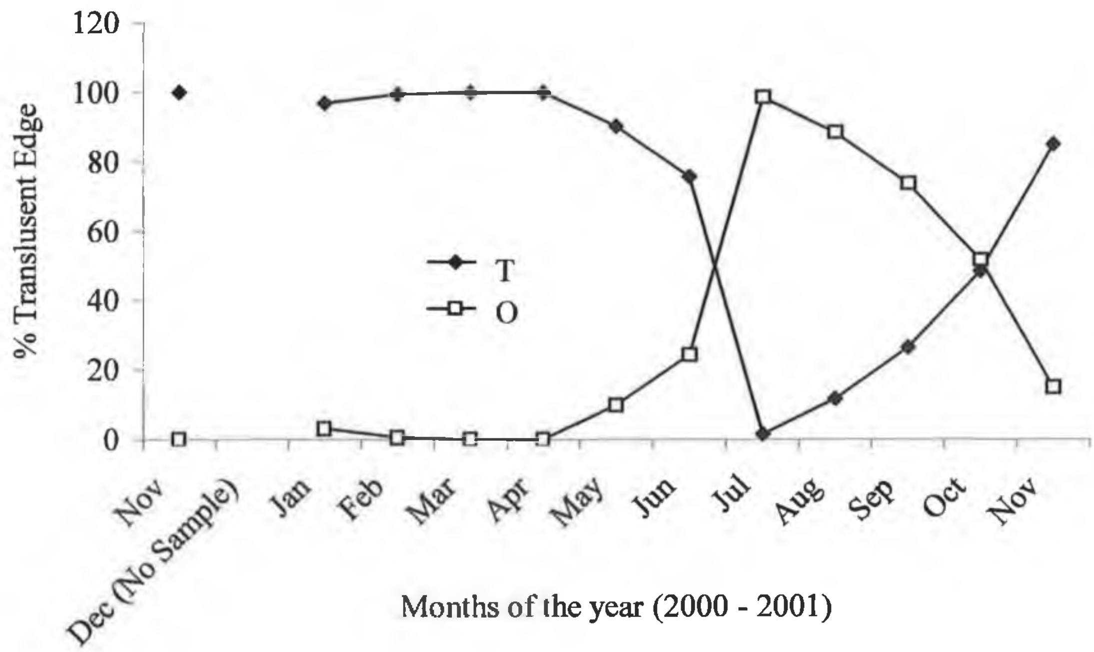
Date	Sample Source	Whole fish	Frames	Totals per Month
November 20th 2000	Galway Bay Seafoods	-	11	**11**
January 9th 2001	Galway Bay Seafoods	-	150	
January 11th 2001	Auction Hall	97	-	**247**
February 13th 2001	Galway Bay Seafoods	-	84	
February 19th 2001	Auction Hall	103	-	**187**
March 20th 2001	Auction Hall	85	-	
March 30th 2001	Galway Bay Seafoods	-	150	**235**
April 23rd 2001	Auction Hall	143	-	**143**
May 11th 2001	Auction Hall	145	-	**145**
June 8th 2001	Galway Bay Seafoods	95	-	**95**
July 11th 2001	Auction Hall	69	-	**69**
August 31st 2001	Galway Bay Seafoods	157	-	**157**
September 28th 2001	Galway Bay Seafoods	-	163	**163**
October 12th 2001	Galway Bay Seafoods	71	-	
October 24th 2001	Galway Bay Seafoods	-	89	**160**
November 27th 2001	Galway Bay Seafoods	68	-	**68**
November/December 2nd 2001	Marine Institute Survey	34	-	**34**
January 14th 2002	Galway Bay Seafoods	90	-	**90**
February 18th 2002	Galway Bay Seafoods	16	-	**16**
Total		**1,173**	**647**	**1,820**

The dates shown on Table 3.1.1 are the dates that the lemon sole samples were delivered to the laboratory.

3.2 Ageing

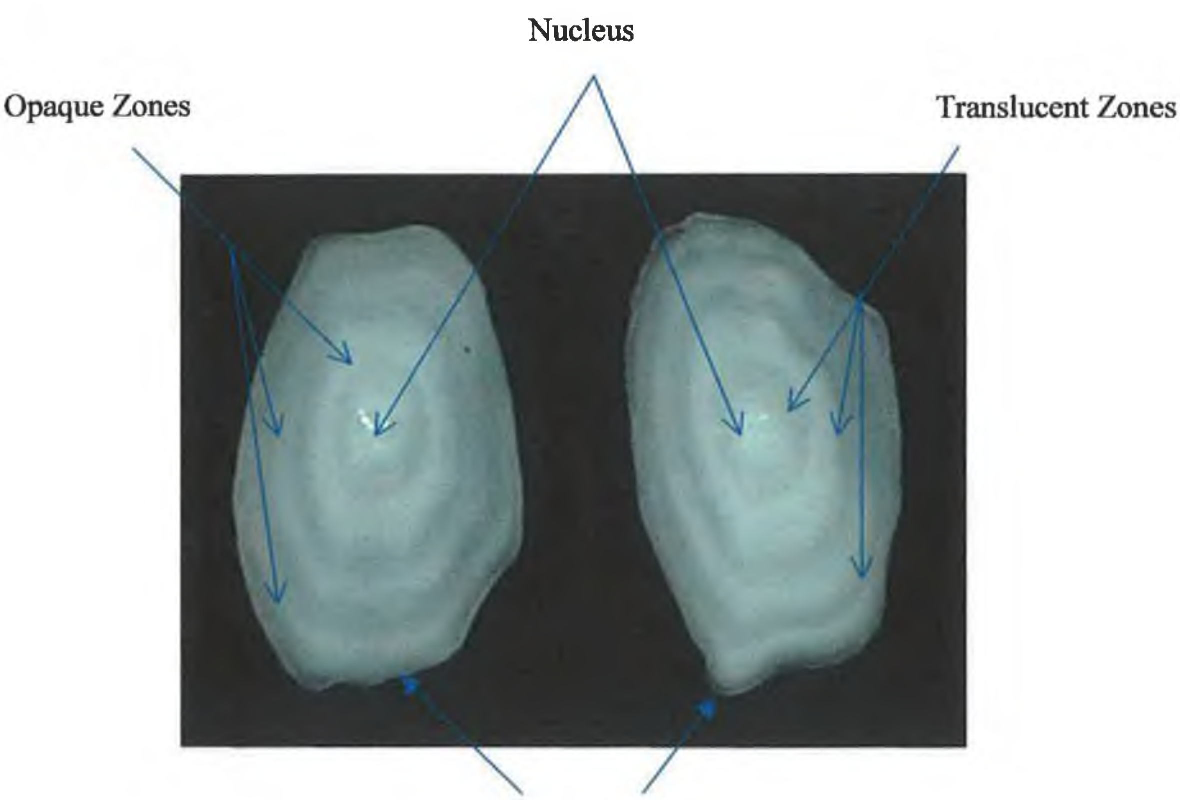
On the examination of the otolith edge, translucent and opaque zones were found to be annular in formation. The otoliths showing percentage translucent and opaque zones at the otolith edge are presented in Fig. 3.2.1. Opaque zone formation begins in April and continues through to November. Translucent zones at the otolith edge were most frequently recorded from November 2000 to March 2001. Maximum values for otoliths with a translucent edge were found in February 2001 (99%). Whilst a certain number of otoliths with a translucent edge were noted each month, minimum values were recorded in July 2001 (1.4%). In August 2001, the number of otoliths with a translucent edge increased once more reaching 85% by November 2001.

Fig. 3.2.1 The percentages of lemon sole otoliths with a translucent (T) or opaque (O) zone at the otolith edge between November 2000 - November 2001 sampled off the west coast of Ireland.



A total of 1,820 paired otoliths were examined. It was not possible to age 24 otolith pairs as they were crystallised, unclear or split rings were present within the zones. Therefore, a total of 1,796 paired otoliths were aged. As there appears to be no published photomicrographs of male or female lemon sole otoliths, a selection are presented here. A pair of sagittal otoliths taken from a male sampled in February 2001 are shown in Fig. 3.2.2. The translucent edge, the nucleus and the three opaque and translucent zones are indicated.

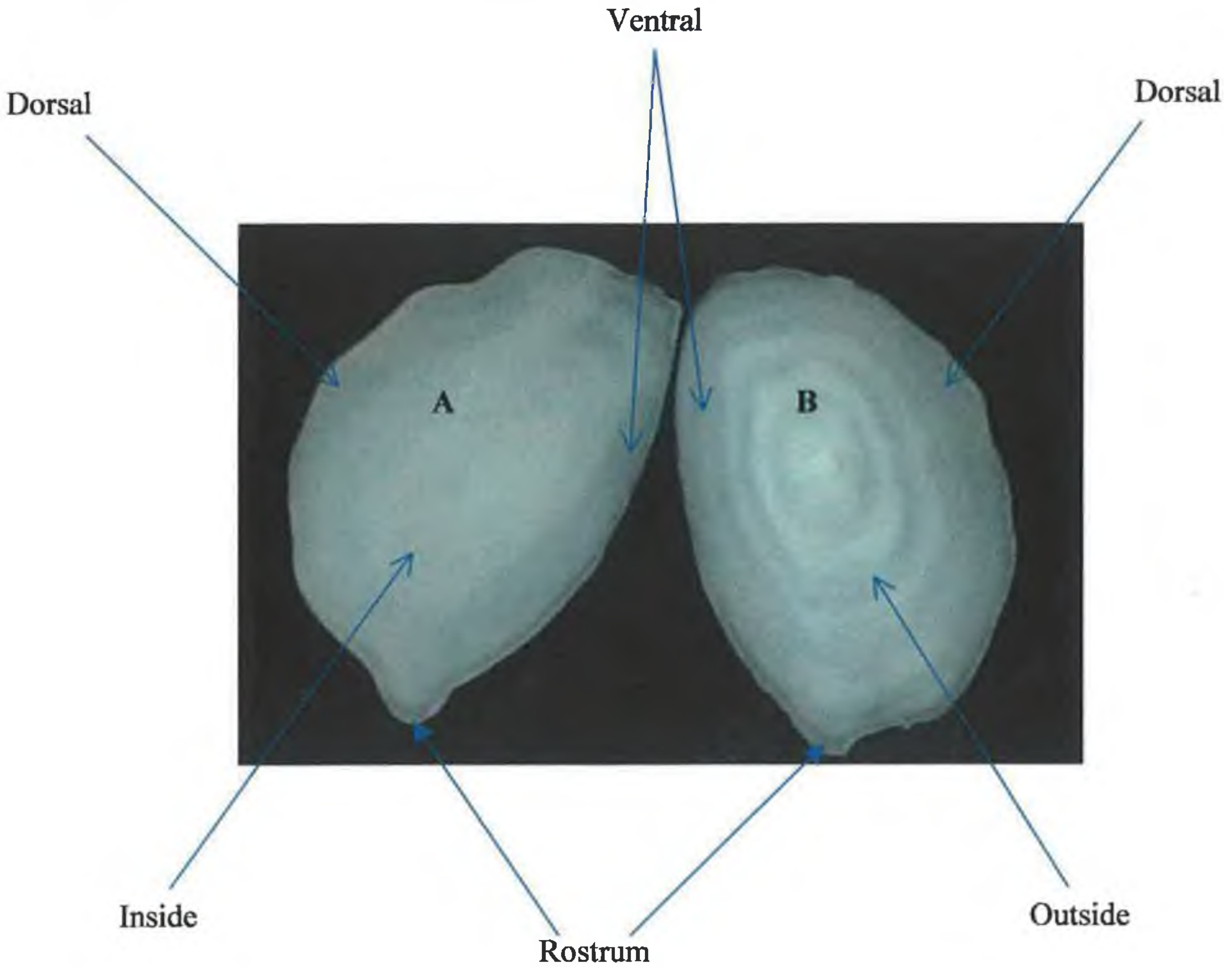
Fig. 3.2.2 A pair of sagittal otoliths taken from a male lemon sole sampled in February 2001, off the west coast of Ireland.



The age of the fish from the pair of otoliths in Fig. 3.2.2 is four years. This was due to the presence of three translucent zones and a developing fourth translucent zone at the otolith edge. As this fish was caught in February the translucent edge was included in the age count.

A pair of otoliths taken from a five year old female in February 2001 is shown in Fig. 3.2.3. Otolith A shows the inner surface of a lemon sole otolith, while B shows the outer surface of a lemon sole otolith on which the ageing process is carried out. The rostrum and dorsal and ventral sides are indicated.

Figure 3.2.3 Otoliths taken from a five year old female in February 2001.



The oldest fish sampled in the overall period were caught in high numbers in July 2001. The otolith of one of the oldest fish sampled is shown in Fig. 3.2.4a and 3.2.4b.

Fig. 3.2.4a Otolith of a 14 year old female lemon sole captured off the west coast of Ireland in July 2001. The otolith shows an opaque edge.

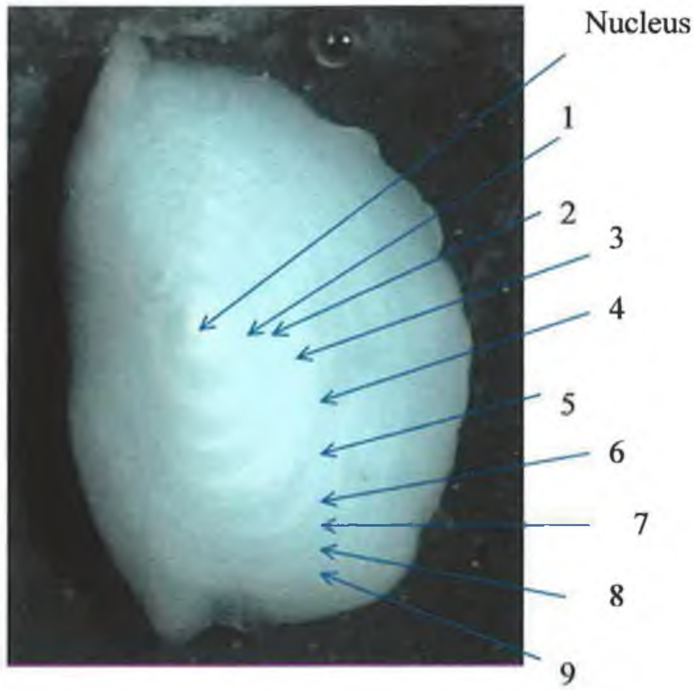
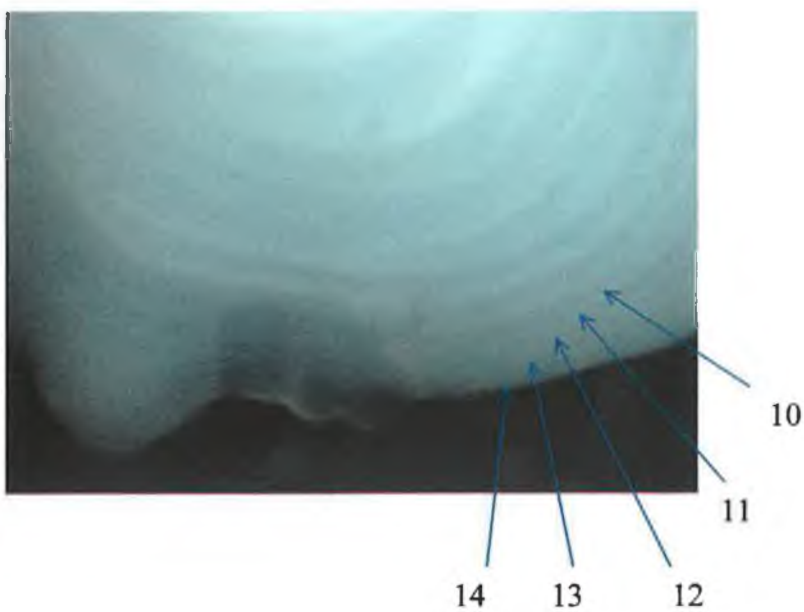


Fig. 3.2.4b Close-up of the otolith in Fig. 3.2.4a showing the intensity of the growth rings in the latter years of the fish life.



3.3 Sex Ratio

A total of 1,820 lemon sole was examined during the sampling period from November 2000 to February 2002. Of these, the sex of only one fish was unidentifiable. 393 male and 1,426 female lemon sole were identified. The overall male to female (M:F) sex ratio for the sampled population is shown in Fig. 3.3.1. 22% of males and 78% of females was recorded and a M:F sex ratio of 1:3.6 was observed. This is very highly significantly different ($\chi^2 = 586.63$, $P < 0.001$) from the expected M:F sex ratio of 1:1.

Fig. 3.3.1. Relative abundance and sex ratio for male and female lemon sole in the overall population sampled off the west coast of Ireland between November 2000 - February 2002 (N = 1,819).

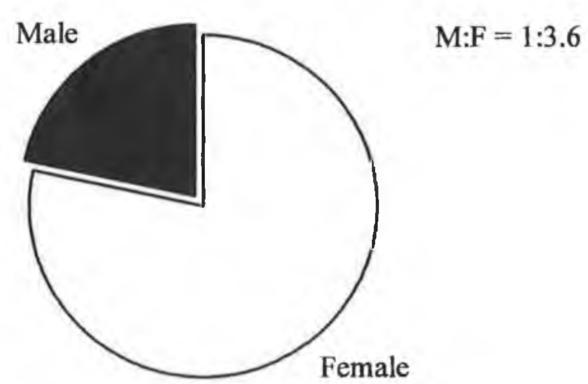


Fig. 3.3.2. and Fig. 3.3.3. show the monthly variation of the M:F sex ratio. A point that reaches 1 on the y-axis of Fig. 3.3.2. indicates a 1:1 M:F sex ratio. This, however, was not observed at any stage over the sampling period. Deviation to $y < 1$ indicates a greater presence of females, while deviation to $y > 1$ indicates greater numbers of males. Females were dominant in the catches of every month (Fig. 3.3.2 and Table 3.3.1). The significance of the result of the sex ratio for each month is shown in Table 3.3.1. The greatest female dominance occurred in November of 2000, with a M:F sex ratio of 1:10 (Fig. 3.3.3). The sample for November 2000 was very small (N = 11) and was therefore omitted from Fig. 3.3.2. The M:F sex ratios calculated for January 2001 to November 2001 were significantly different from the expected M:F sex ratio of 1:1 (Table 3.3.1). January and February 2001 both showed very high numbers of females in the catches (M:F 1:6.7 and 1:6.8 respectively). The relative abundance of male lemon sole in the catches began to increase from February 2001 and remained relatively high until June 2001 where the numbers of females captured was at its lowest, with a M:F sex ratio of 1:1.9. The relative abundance of male fish began to decrease in July 2001. The M:F sex ratio varied between 1:3 and 1:4 from August onward until the female dominance peaked again in January 2002.

Fig. 3.3.2. Monthly male to female sex ratio of the lemon sole caught off the west coast of Ireland over the sampling period.

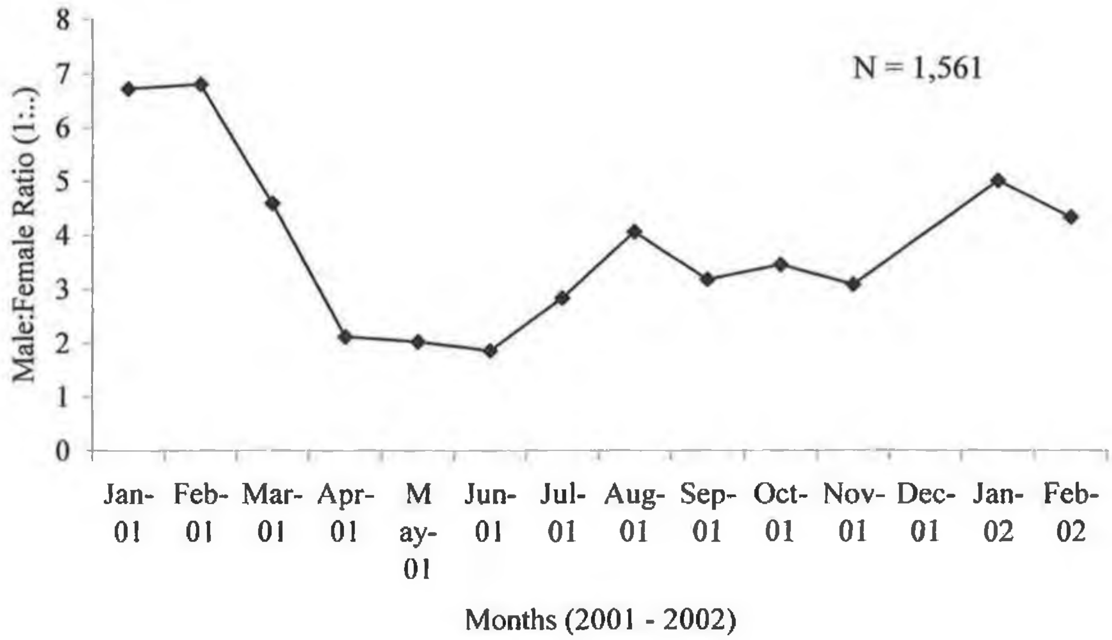


Figure 3.3.3. Monthly male:female sex ratio of the lemon sole sampled off the west coast of Ireland.

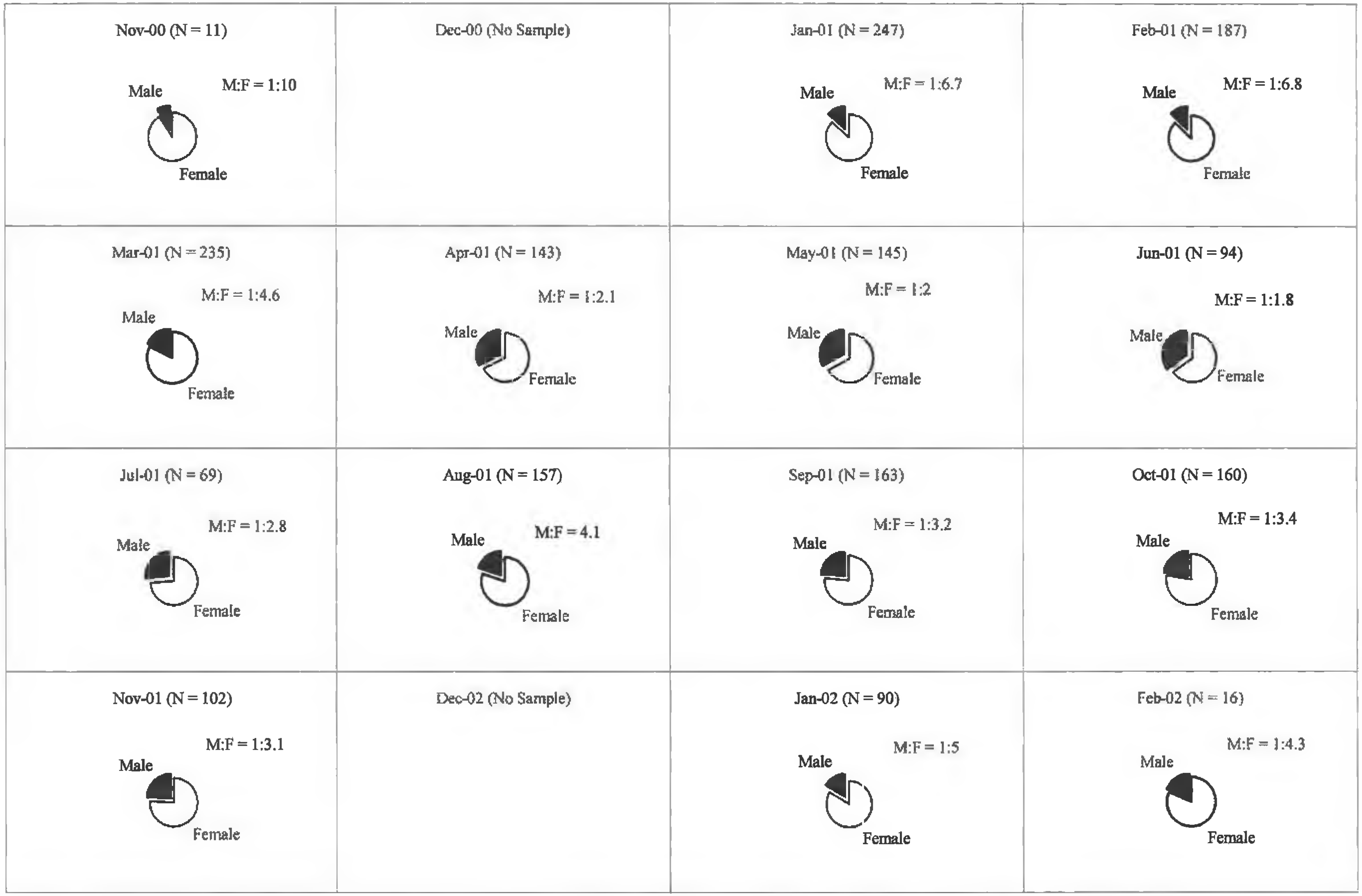


Table 3.3.1. Numbers and percentages of male and female lemon sole in the catches for each month together with chi square (χ^2) values and significance levels.

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

Month	Female	Male	Total	Expected	χ^2	Significance
Nov-00	10	1	11	5.5	7.36	**
Jan-01	215	32	247	123.5	135.58	***
Feb-01	163	24	187	93.5	103.32	***
Mar-01	193	42	235	117.5	97.03	***
Apr-01	97	46	143	71.5	18.9	***
May-01	97	48	145	72.5	16.56	***
Jun-01	61	33	94	47	8.34	**
Jul-01	51	18	69	34.5	15.78	***
Aug-01	126	31	157	78.5	57.48	***
Sep-01	124	39	163	81.5	44.33	***
Oct-01	124	36	160	80	48.40	***
Nov-01	77	25	102	51	26.51	***
Jan-02	75	15	90	45	40	***
Feb-02	13	3	16	8	6.25	*

The percentage of male and female lemon sole in the sampled population at each age is presented in Fig. 3.3.4. The percentage of female lemon sole at all ages exceeded that of males. The χ^2 values (Table 3.3.2) at all ages (excluding age 2 where N = 12) indicate that the relative abundance of females is significantly greater than that of males. The M:F sex ratio was 1:2 at ages two and three. The gap between males and females is slightly wider at age four with a M:F sex ratio of 1:2.4, while a M:F sex ratio of 1:4.7 was recorded at age five. The percentage of males remained low in comparison to females from age group five onwards.

Fig. 3.3.4. Percentage of male and female lemon sole in the sampled population at each age (N at each age > 10). (11+ includes all fish from 11 to 14 years)

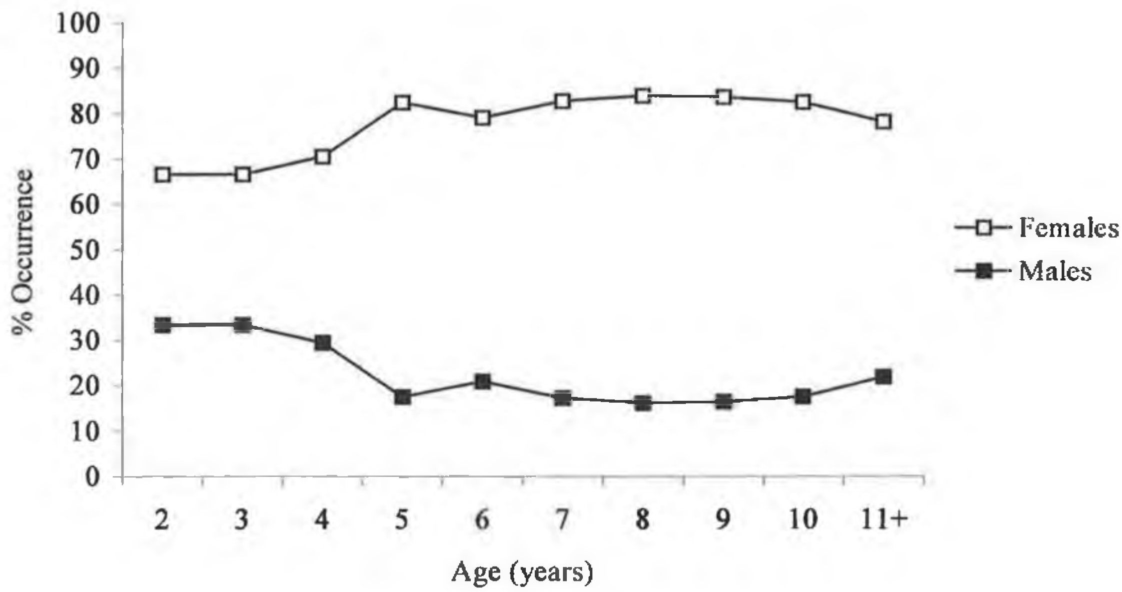


Table 3.3.2. Numbers and percentages of male and female lemon sole at each age captured over the sampling period together with chi square (χ^2) values and significance levels. **(* = *Significant* (P < 0.05), ** = *Highly Significant* (P < 0.01), *** = *Very Highly Significant* (P < 0.001), NS = *Not Significant* (P > 0.05))**

Age	Females	Males	Total	Expected	χ^2	Significance
2	8	4	12	6	1.33	NS
3	54	27	81	40.5	9	**
4	269	112	381	190.5	64.70	***
5	410	87	497	248.5	209.92	***
6	238	63	301	150.5	101.74	***
7	196	41	237	118.5	101.37	***
8	109	21	130	65	59.57	***
9	71	14	85	42.5	38.22	***
10	33	7	40	20	16.90	***
11+	25	7	32	16	10.13	**

The relative abundance of male lemon sole in the overall sample decreased with increasing size as shown in Fig. 3.3.5. Only males were present in the smallest length category, while only females were present in the larger length categories. The dominance of females in the length categories was very highly significant from 25 – 25.99cm to 33 – 33.99cm. The χ^2 values (Table 3.3.3) for all length categories (where N > 20) with the exception of the 23 – 23.99cm length class, indicate that the relative abundance of females is significantly greater than that of males.

Fig. 3.3.5 Percentage occurrence of male and female lemon sole in the sampled population as length increases.

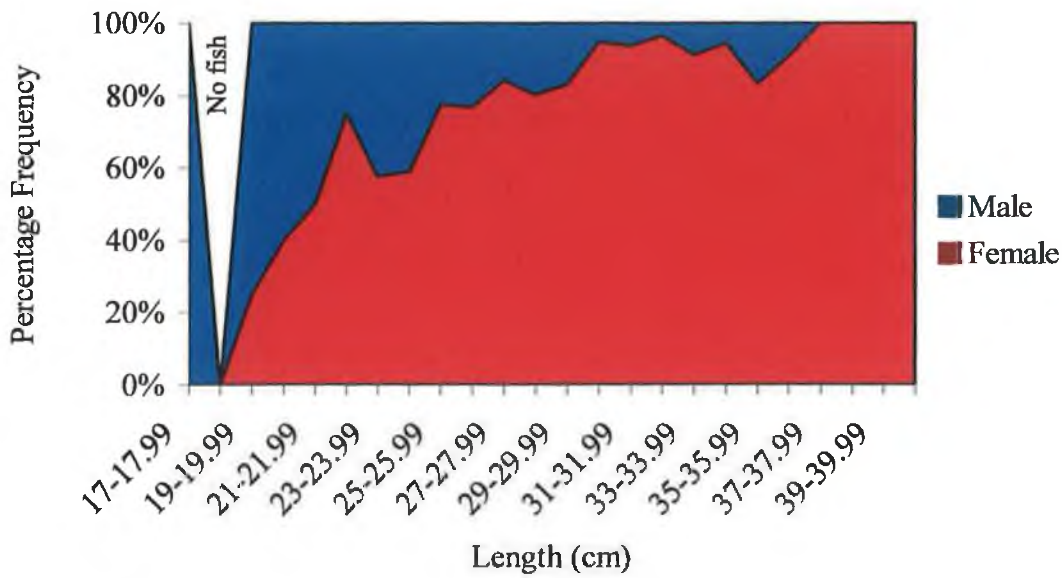


Table 3.3.3. Numbers and percentages of male and female lemon sole at each size captured over the sampling period together with chi square (χ^2) values and significance levels. (* = *Significant* (P < 0.05), ** = *Highly Significant* (P < 0.01), *** = *Very Highly Significant* (P < 0.001), NS = *Not Significant* (P > 0.05), STS = Sample Too Small)

Size Class	Females	Males	Total	Expected	χ^2	Significance
17 – 17.99	0	1	1	STS		
18 – 18.99	No fish in this size class					
19 – 19.99	1	3	4	STS		
20 – 20.99	2	3	5	STS		
21 – 21.99	6	6	12	6	0	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 – 37.99	4	0	4	No Males		
38 – 38.99	7	0	7			
39 – 39.99	7	0	7			
40 – 40.99	2	0	2			

In summary, and excluding those results where sample sizes were very small ($N < 20$), female lemon sole dominated the overall population, at each age, each month sampled and from 22cm in total length onwards.

3.4 Maturity and Gonosomatic Index

Maturity

Each of the seven maturity stages were recorded for female lemon sole while only five of the seven stages were found for males. Male lemon sole gonads were difficult to assess, as the changes were very slight. Stages VI and VII, late spawning and spent respectively, were not recorded for males. Male and female gonads at stage V (ripe/spawning) are shown in Fig. 3.4.1a and Fig. 3.4.1b respectively.

Fig. 3.4.1a Ripe/spawning (stage V) male lemon sole gonads taken from a fish sampled in February 2002.

Fig. 3.4.1b A pair of ripe/spawning (v) female lemon sole gonads taken from a fish sampled in February 2001.

Maturity stages at each length (TL) class for male and female lemon sole separately are shown in Table 3.4.1. Immature fish were found at a length of 24cm for males (N = 2) while immature females (N = 46) ranged from 20cm - 30cm. As numbers of immature fish encountered were very low, due to the absence of small fish, maturity oogives were not attempted on the data. Female fish developing for the first time/recovering spent (II) ranged from 20cm – 40cm in total length, while males measured 20cm - 28cm. The greatest proportion of male and female lemon sole were at maturity stage III (ripening) for the overall catch period, with males ranging from 17cm – 37cm (the entire range of males sampled) and females ranging from 20cm – 40cm. Ripe (IV) males were observed from 20cm – 33cm, while ripe females ranged from 22cm – 39cm. Spawning (V/VI) males ranged in total length from 21cm to 31cm, while spawning females ranged from 23cm – 41cm. Few spent (VII) females were recorded. Those found ranged from 25cm - 32cm in length. No spent males were recorded.

Table 3.4.1 Maturity stages at each total length class for male and female lemon sole separately.

MALE MATURITY STAGES								
TL (cm)	I	II	III	IV	V	VI	VII	Total
17			1					1
18								0
19								0
20		1	3					4
21			2		1			3
22			3	4				7
23		3	9	4	1			17
24	2	3	23	9	3			40
25		5	26	22	1			54
26		4	27	21	2			54
27		2	16	12	2			32
28		2	9	14	1			26
29			6	10	2			18
30			2	2	3			7
31				3	1			4
32								0
33			3	1				4
35			3					3
37			1					1
Total	2	20	134	102	17	0	0	275

FEMALE MATURITY STAGES								
TL (cm)	I	II	III	IV	V	VI	VII	Total
20	1	1	1					3
21								0
22	2	1	11	4				18
23	3	7	24	9	1			44
24	8	4	53	11	4			80
25	6	15	115	37	1		3	177
26	9	11	130	40	4		1	195
27	5	13	128	52	7		9	214
28	5	12	97	39	11		1	165
29	4	7	62	36	12	2	3	126
30	3	4	49	50	9		3	118
31		4	27	26	10		1	68
32		5	22	15	6		1	49
33		1	16	11	5	1		34
34			8	6	3			17
35		3	6	4	3	1		17
36		2	2	3	1			8
37			4	3	1			8
38		1	1		1			3
39			4	2	1			7
40		2	1		1			4
41					1			1
Total	46	93	761	348	83	4	22	1357

Maturity stages at each age for male and female fish separately are shown in Table 3.4.2. Two immature males were found. These were 4 and 6 years of age. Immature females ranged from 3 – 6 years. Stage II males ranged from 4 - 8 years, while females at this stage ranged from 3 – 14 years. Ripening males were recorded in all age groups, while ripening females were found from 2 – 12 years. Ripe and spawning males were recorded at younger ages than females. Ripe males were found from 2 years up to 11 years, while ripe females were not recorded until 3 years onward (excluding 14 years, where N = 4). Spawning males ranged from 3 – 14 years, while spawning females ranged from 4 – 14 years. Spent females ranged from 4 – 9 years and no spent males were found. Mature, ripening (III) males were first encountered at 17cm and at 2 years of age, while mature, ripening females were first recorded at 20cm and 2 years of age.

Table 3.4.2 Maturity stages at each age for male and female fish separately.

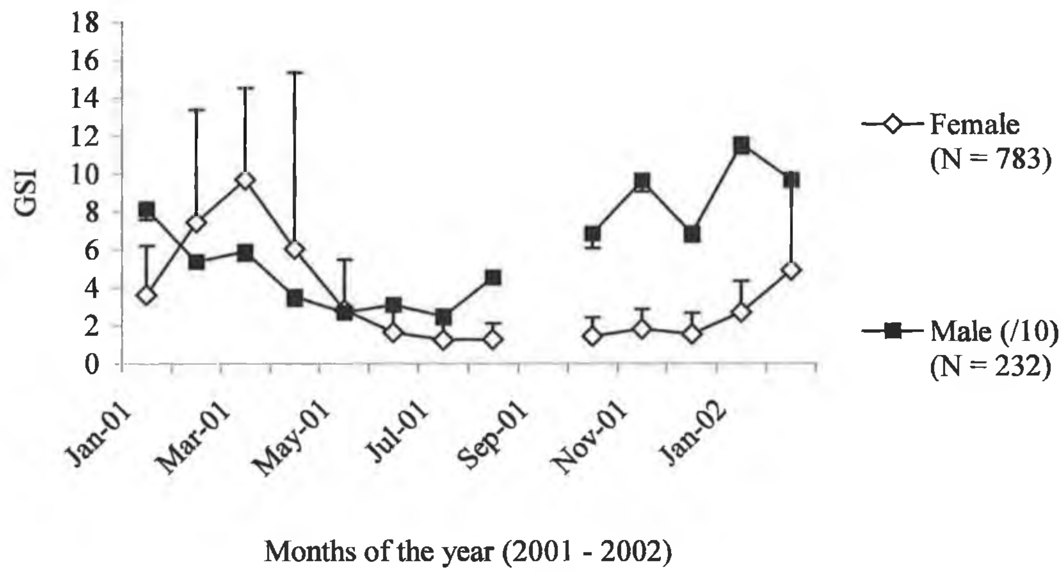
MALE MATURITY STAGES								
Age	I	II	III	IV	V	VI	VII	Total
2			2	2				4
3			12	8	2			22
4	1	5	36	26	4			72
5		6	25	30	3			64
6	1	4	26	14	2			47
7		3	20	8				31
8		2	5	6	2			15
9			3	6	1			10
10			2		1			3
11			2	1				3
14			1		1			2
Total	2	20	134	101	16			273

FEMALE MATURITY STAGES								
Age	I	II	III	IV	V	VI	VII	Total
2			7					7
3	2	8	38	6				54
4	17	13	169	53	9		6	267
5	18	26	237	84	23	2	5	395
6	9	10	113	72	12		3	219
7		10	100	52	17		4	183
8		8	51	41	3	1	3	107
9		10	25	27	6	1	2	71
10		3	19	9	2			33
11		2	5	1	1			9
12		1	3	2	2			8
13		1		1	2			4
14		1			3			4
Total	46	93	767	348	80	4	23	1361

Gonosomatic Index

Seasonal changes in the gonosomatic index (GSI) for male and female lemon sole is shown in Fig. 3.4.2. 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 November 2001 and peaked in 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 and were highest in January 2002.

Fig. 3.4.2 Seasonal changes of the gonosomatic index (GSI) for male (black) and female (white) lemon sole sampled off the west coast of Ireland between 2001 to 2002. Vertical error bars indicate 95% confidence limits. The male GSI values were multiplied by a factor of 10 in order to show a pattern.



The percentage frequency for the seven stages of gonad development for male and female lemon sole are shown in Fig. 3.4.3a and b respectively.

Figure 3.4.3a Percentage developmental stage in the gonad cycle at each month over the sampling period for male lemon sole.

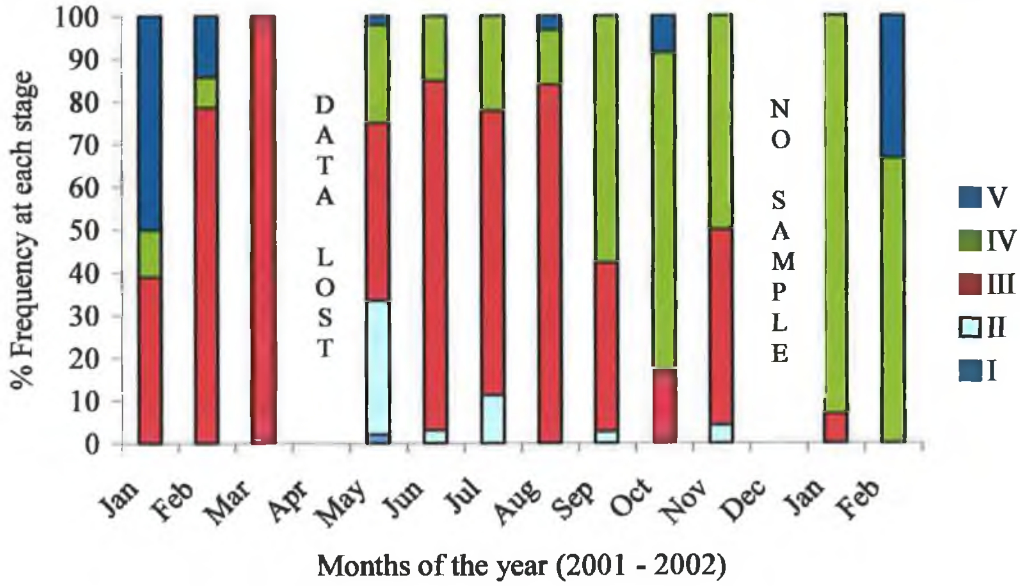
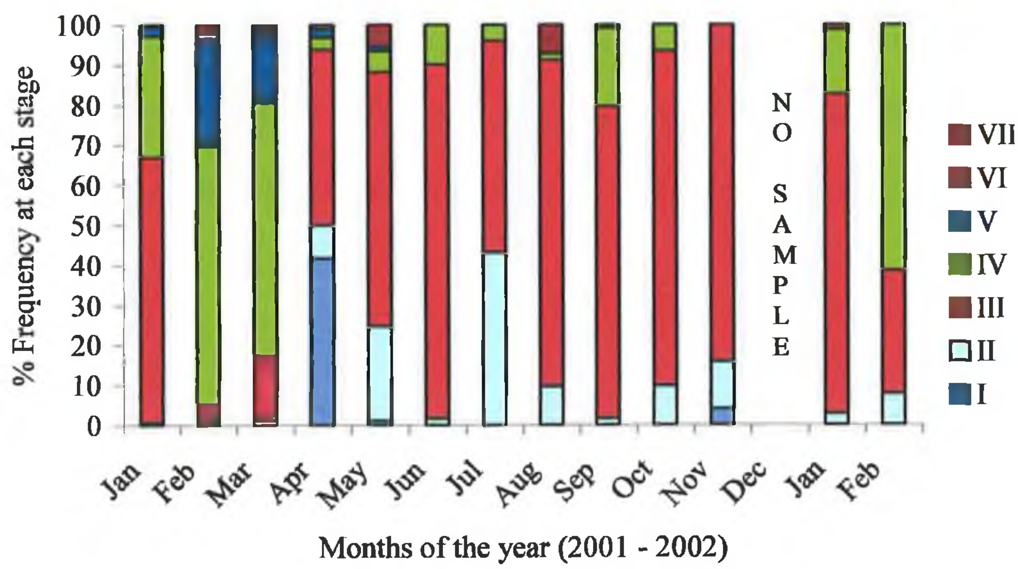


Figure 3.4.3b Percentage developmental stage in the gonad cycle at each month over the sampling period for female lemon sole.

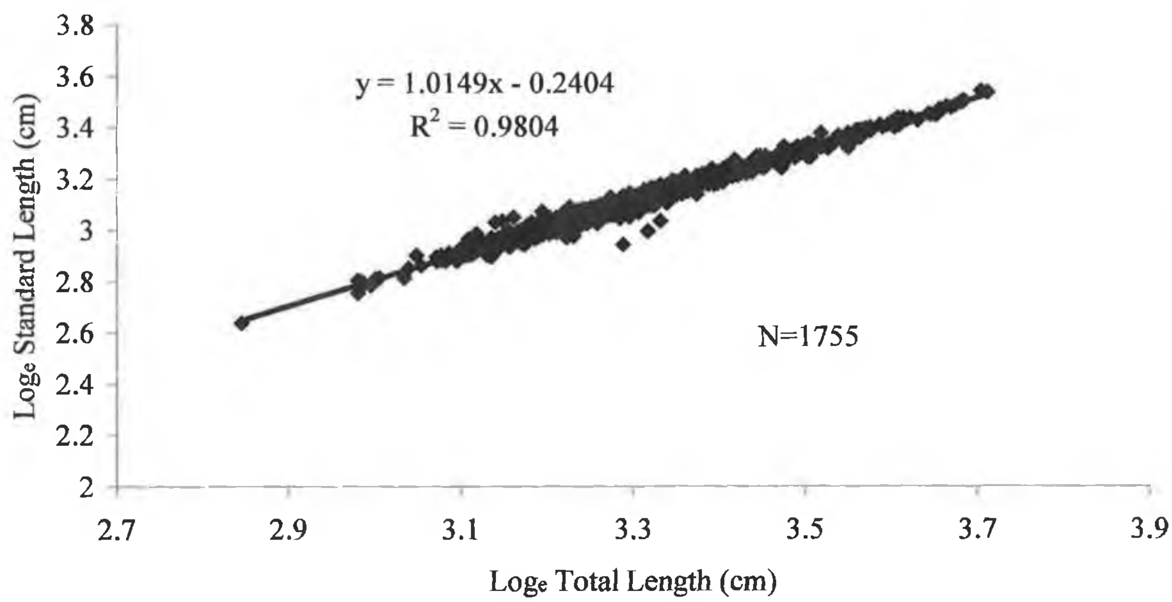


3.5 Size Relationships

Total Length-Standard Length Relationship

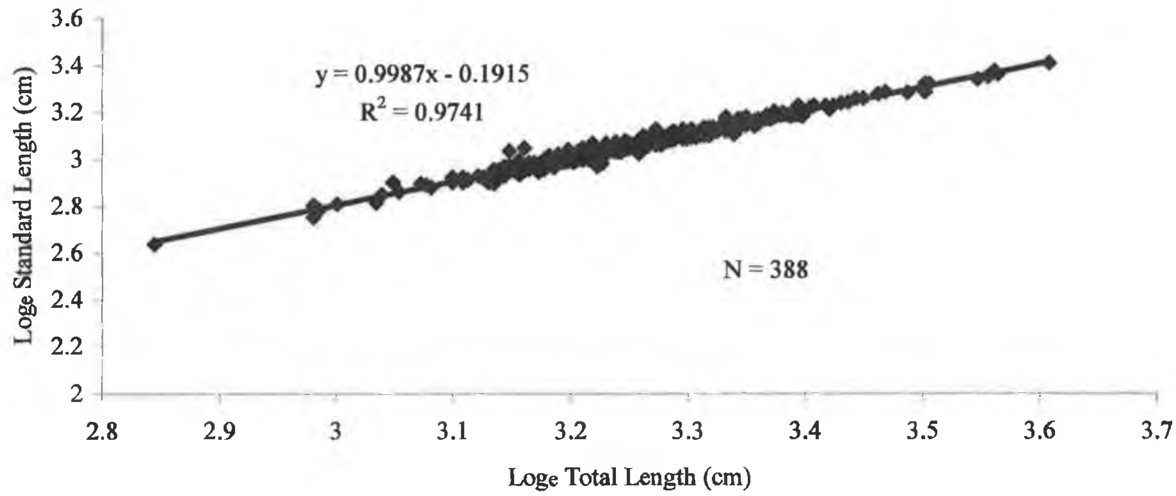
The Total Length (TL) versus Standard Length (SL) relationship was analysed for the 1,755 lemon sole examined. 65 fish were excluded from the analysis as the tail fins were damaged. 1,367 of the 1,755 were female lemon sole while 388 were male. Fig. 3.5.1 illustrates $\log_e$ TL versus $\log_e$ SL for all fish sampled, Fig. 3.5.2 illustrates $\log_e$ TL versus $\log_e$ SL for male fish and Fig. 3.5.3 illustrates $\log_e$ TL versus $\log_e$ SL for female fish. The relationships between TL and SL for all fish sampled and males and females separately are shown in Table 3.5.1.

Fig. 3.5.1 Regression of Log_e SL on Log_e TL for male and female lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



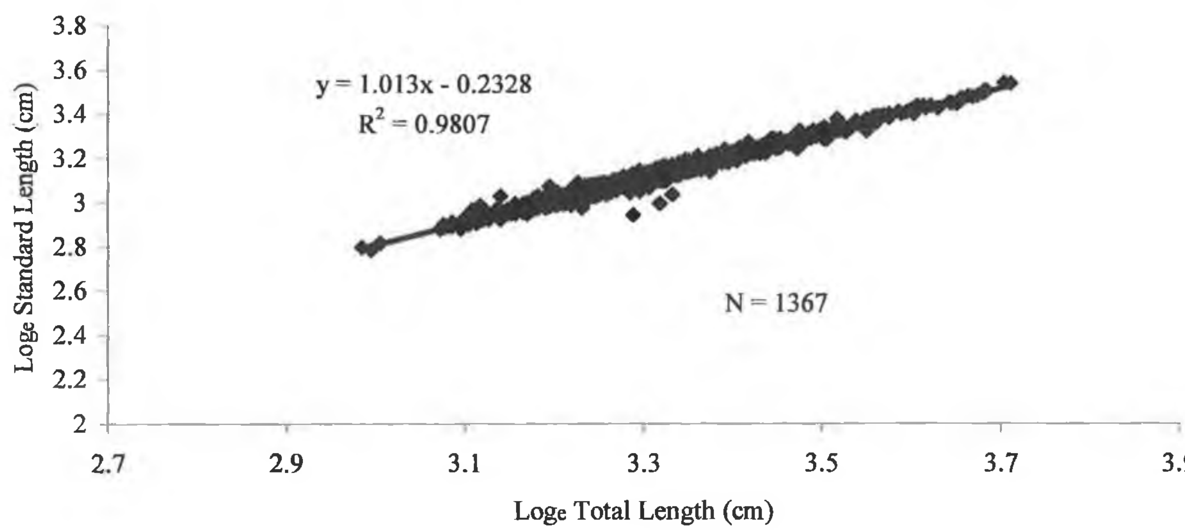
The linear relationship between TL and SL for the overall population sampled is statistically significant ($F_{1,\ 1,754} = 87,842$, $P < 0.05$) with a positive correlation ($R^2 = 0.98$).

Fig. 3.5.2 Regression of Log_e SL on Log_e TL for male lemon sole sampled off the west coast of Ireland between Nov 2000 - Feb 2002.



The relationship between TL and SL for the male population sampled is a statistically significant linear relationship ($F_{1, 387} = 14{,}510$, $P < 0.05$) with a positive correlation ($R^2 = 0.97$).

Fig. 3.5.3 Regression of Log_e SL on Log_e TL for female lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



The relationship between TL and SL for the females within the sampled population is a statistically significant linear relationship ($F_{1,\ 1,366}$ = 69,457, $P < 0.05$) and shows a positive correlation ($R^2 = 0.98$).

Table 3.5.1 The relationship between TL and SL for lemon sole sampled off the west coast of Ireland.

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

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.

Length-Weight Relationship

1,139 lemon sole within the overall sample were gutted fish while 34 fish were whole. The length-weight relationship is therefore based on the analysis of 1,173 gutted fish. 165 fish were examined fresh as shown in Table 3.5.2. The remaining fish were weighed after defrosting from -18°C.

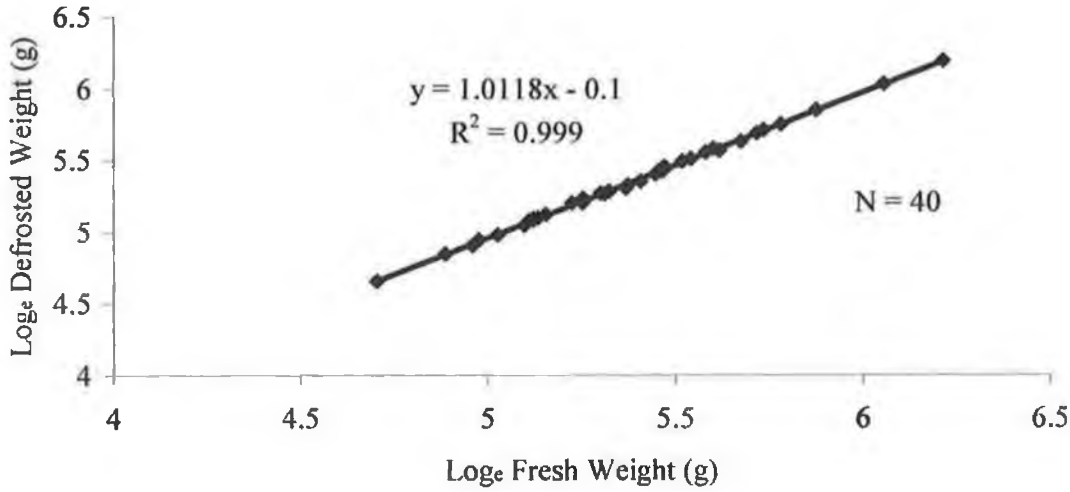
Table 3.5.2 Lemon sole examined as fresh fish.

Month	Numbers of Fish and Fish Codes
February 2001	30 (020185 – 0201114)
March 2001	37 (030101 – 030137)
April 2001	30 (040101 – 040130)
July 2001	12 (070101 – 070112)
January 2002	40 (010201 – 020240)
February 2002	16 (020201 – 020216)

A defrosted weight factor was calculated for 40 fish. The regression of $\log_e$ fresh weight (g) to $\log_e$ defrosted weight (g) is shown in Fig. 3.5.4. The following equation resulted from the regression analysis and this was used to calculated fresh weights from defrosted weights:

$$\text{Log}_e \text{ Fresh Weight (g)} = [0.1 + \text{Log}_e \text{ Defrosted Weight (g)}]/1.0118$$

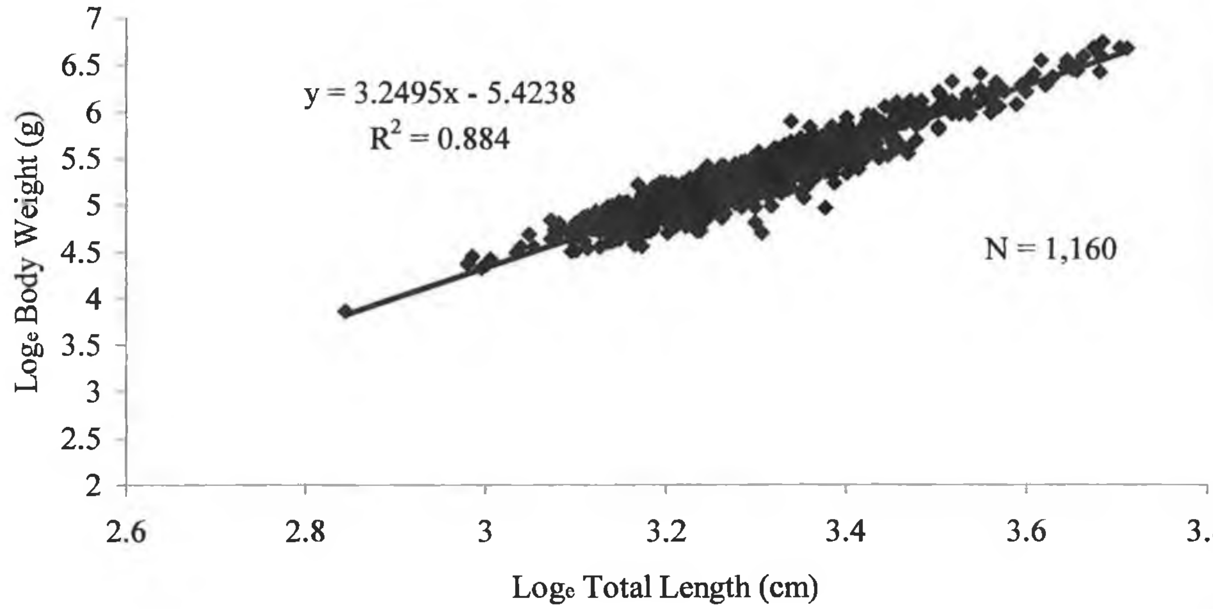
Fig. 3.5.4 Regression of Log_e fresh weight versus Log_e defrosted weight for a selection of the lemon sole sample.



The relationship between fresh and defrosted weight is linear and is very highly statistically significant positive correlation ($F_{1, 39} = 39{,}543$, $P < 0.001$) in that fresh fish are heavier than defrosted fish.

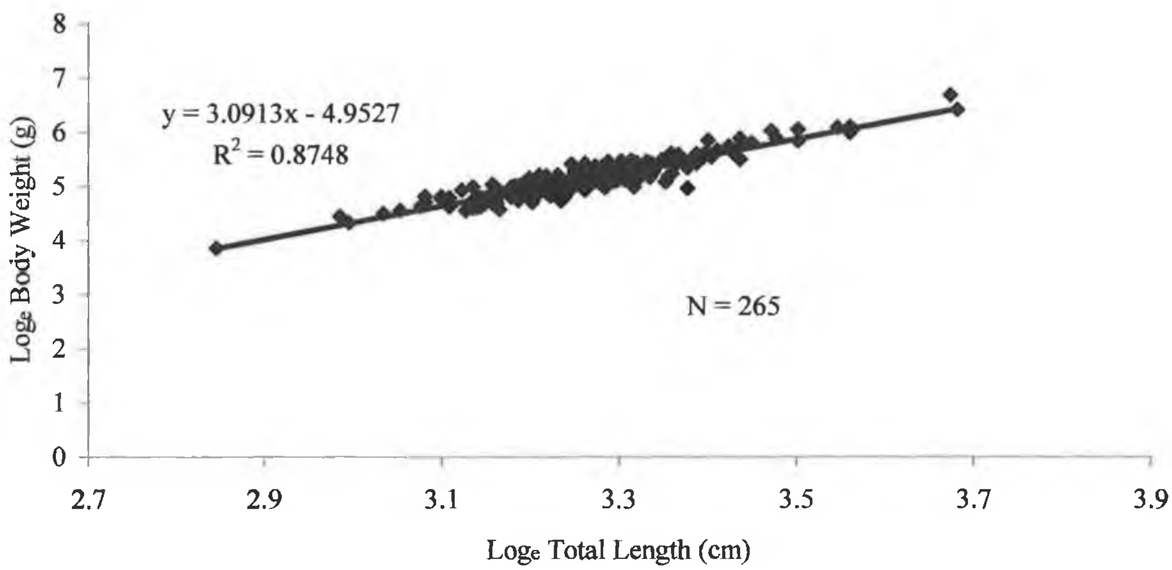
The length-weight relationship for all fish sampled is presented in Fig. 3.5.5. Males are shown in Fig. 3.5.6 and females in Fig. 3.5.7.

Fig. 3.5.5 Regression of Log_e body weight (W) on Log_e TL for all lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



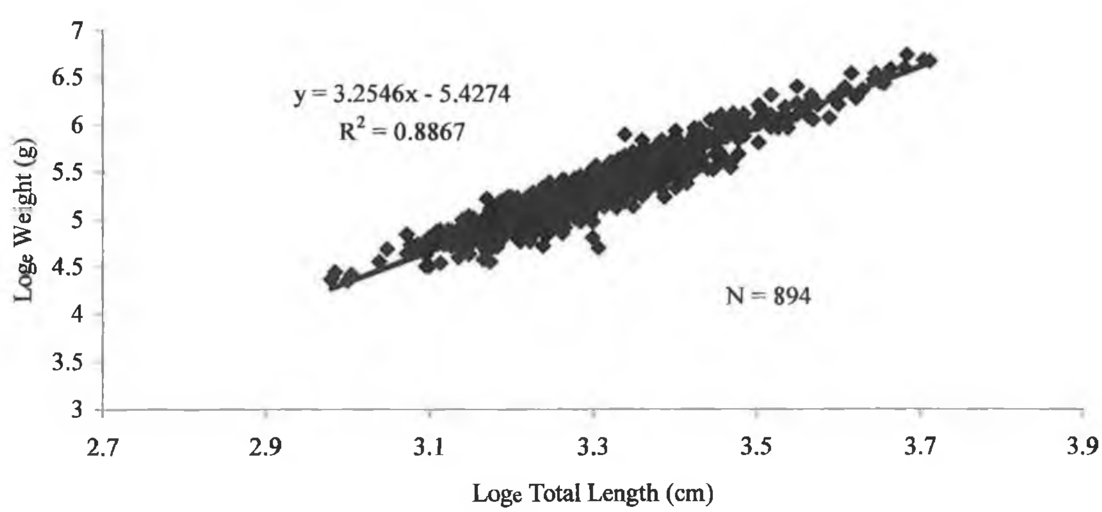
The linear relationship between body weight (W) and total length (TL) is very highly statistically significant for the overall sampled population ($F_{1,\ 1,159}$ = 8,825, $P < 0.001$) and the correlation is positively high (R^2 = 0.88). Lemon sole increase in weight with increasing length.

Fig. 3.5.6 Regression of Log_e W on Log_e TL for male lemon sole sampled off the west coast of Ireland between 2000 - 2002.



The linear relationship between W and TL is very highly significant for the males of the sampled population ($F_{1, 264} = 1{,}837$, $P < 0.001$) and the correlation is positive ($R^2 = 0.87$).

Fig. 3.5.7 Regression of Log_e W on Log_e TL for female lemon sole sampled off the west coast of Ireland between 2000 - 2002.



There is a very highly significant linear relationship between W and TL for the males of the sampled population ($F_{1,\,893}$ = 6,980, $P < 0.001$) and the correlation is positive (R^2 = 0.89).

Table 3.5.2 The relationship between W and TL for lemon sole sampled off the west coast of Ireland.

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

The mean ratios of W to TL 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 TL.

The values for b in the length-weight relationship for the overall sampled population and for males and females separately were close to 3.

3.6 Frequency Analysis

Length Frequency

The percentage length (TL) frequency for the population of lemon sole is presented in Fig. 3.6.1, and for males and females separately in Fig. 3.6.2. Length categories for all fish sampled ranged from 17-17.99cm to 40-40.99cm. Male fish ranged from 17-17.99cm to 36-36.99cm and females ranged from 19-19.99cm to 40-40.99cm. The highest % frequency in the overall sample was 15.1% (N = 271). This was within the 25-25.99cm length category. The lowest % frequency (0.1%, N = 1) was within the 17-17.99cm length category. This consisted of one male, from the sample obtained from the Marine Institute, which contained discards. Males and females had unequal variances ($F = 1.53$, $P < 0.05$), therefore the t-test for samples with unequal variances was carried out on the data (Fowler and Cohen 1995). There was a highly significant difference ($t = 11.65$, $P < 0.01$) between the mean lengths of males and females, with females being significantly longer than males. The highest % occurrence of male fish was (21.1%, N = 82) within the length category 24-24.99cm, while the lowest % (0.25% each, where N = 1) were within the length categories of 17-17.99cm, 34-36.99cm these being the upper and lower limits of the male length frequency distribution. The highest % occurrence of female lemon sole was (15.1%, N = 213) within the length category 27-27.99cm, while the lowest % (0.1%, N = 1) fell within the smallest length category of 19-19.99cm. The descriptive statistics of TL data for all fish sampled and males and females separately are presented in Table 3.6.1.

Figure 3.6.1. Percentage length frequency distribution for all fish sampled off the west coast of Ireland as sampled between Nov 2000 - Feb 2002

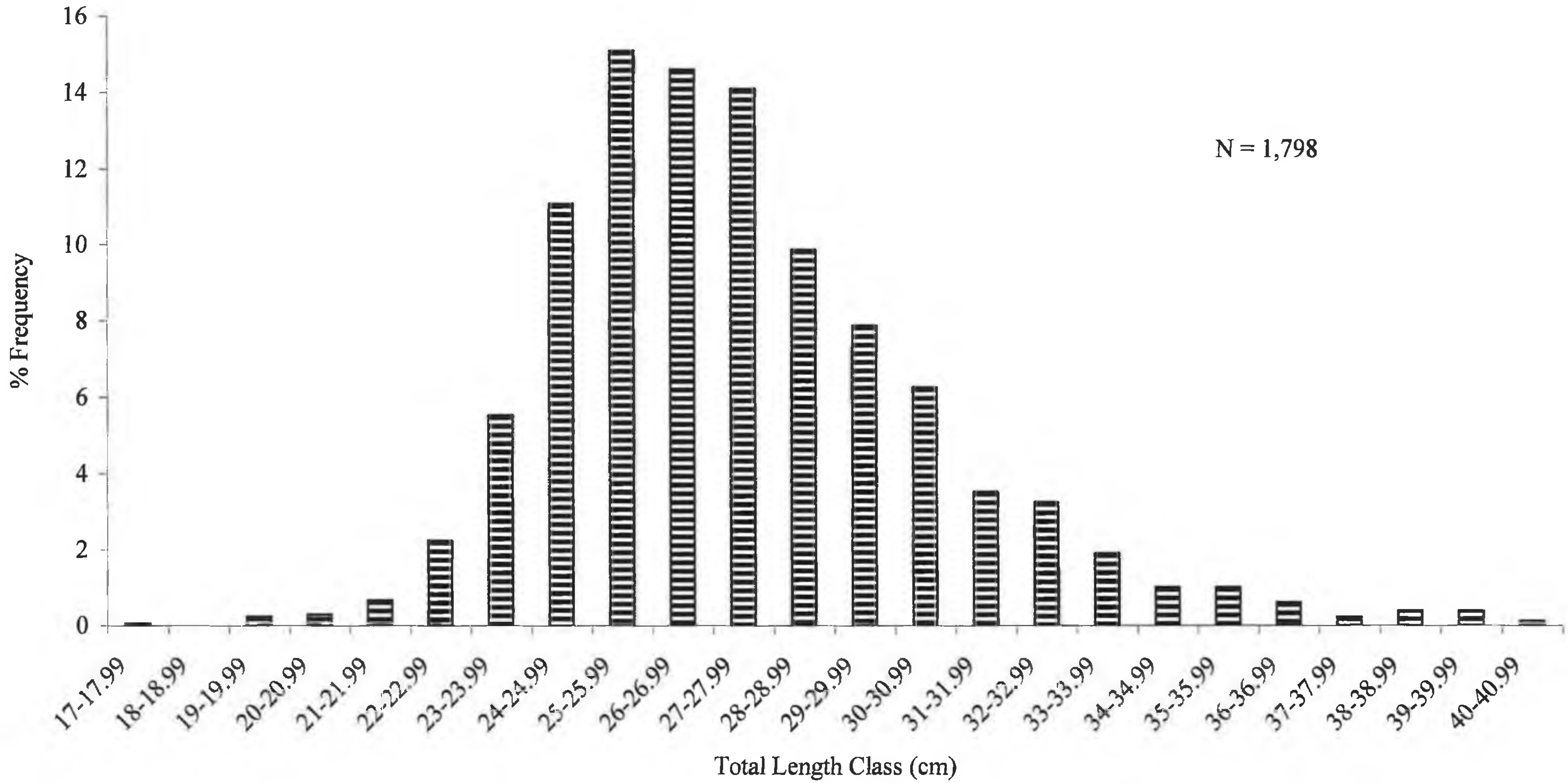


Figure 3.6.2. Percentage length frequency distribution for male and female lemon sole off the west coast of Ireland as sampled between Nov 2000 - Feb 2002

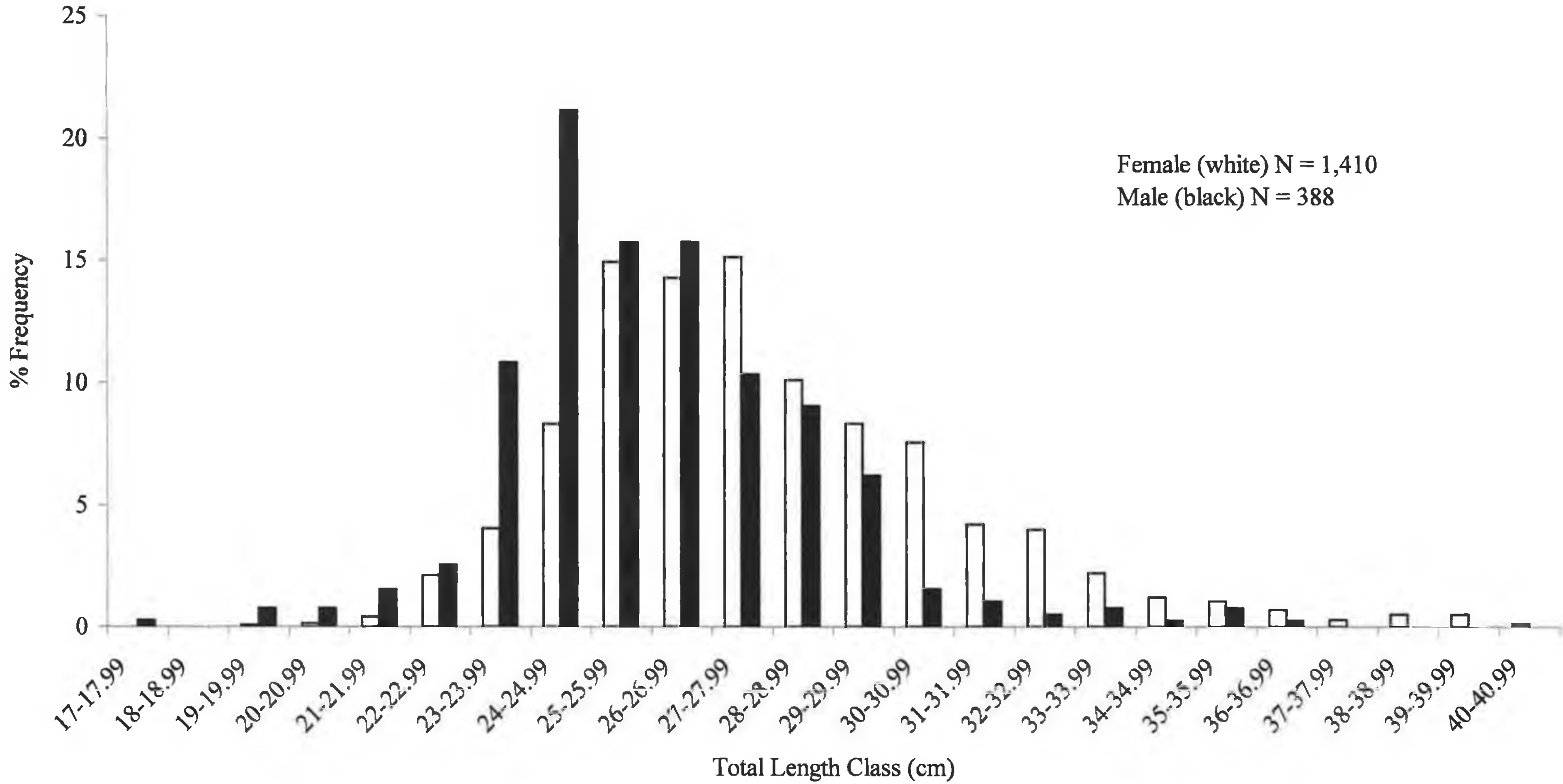


Table 3.6.1 Descriptive statistics for size in total length of lemon sole sampled off the west coast of Ireland.

Description	All	Male	Female
N	1,798	388	1,410
Mean (cm)	27	26	28
Median (cm)	27	26	27
Standard Deviation	3.13	2.55	3.16
Minimum (cm)	17.2	17.2	19.8
Maximum (cm)	40.9	36.9	40.9

The largest fish sampled was a female measuring 40.9cm TL, while the smallest fish sampled was a male measuring 17.2cm TL. The largest male within the sample was 36.9cm TL and the smallest female was 19.8cm TL.

Age Frequency

A total of 1,796 fish were aged. Of these 1,413 were female and 383 were male. Fig. 3.6.3 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 minimum numbers (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.

Length at Age Frequency

Percentage length frequency at each age is presented in Fig. 3.6.4 for male lemon sole and Fig. 3.6.5 for females. The numbers of fish at each length at each age for the overall population are presented in Table 3.6.2, while Tables 3.6.3 and 3.6.4 show numbers of fish at each age at each length for males and females respectively. There was a large variation in length in all age groups for males and females sampled. For example, 3 year old males ranged from 17 – 29cm TL and 10 year old males ranged from 23 – 35cm TL. 3 year old females ranged from 20 – 31cm TL and 10 year olds ranged from 25 – 39cm TL. It was not possible to recognise cohorts in the length frequency distribution.

Figure 3.6.3. Age frequencies for male and female lemon sole sampled off the west coast of Ireland between November 2000 - February 2002

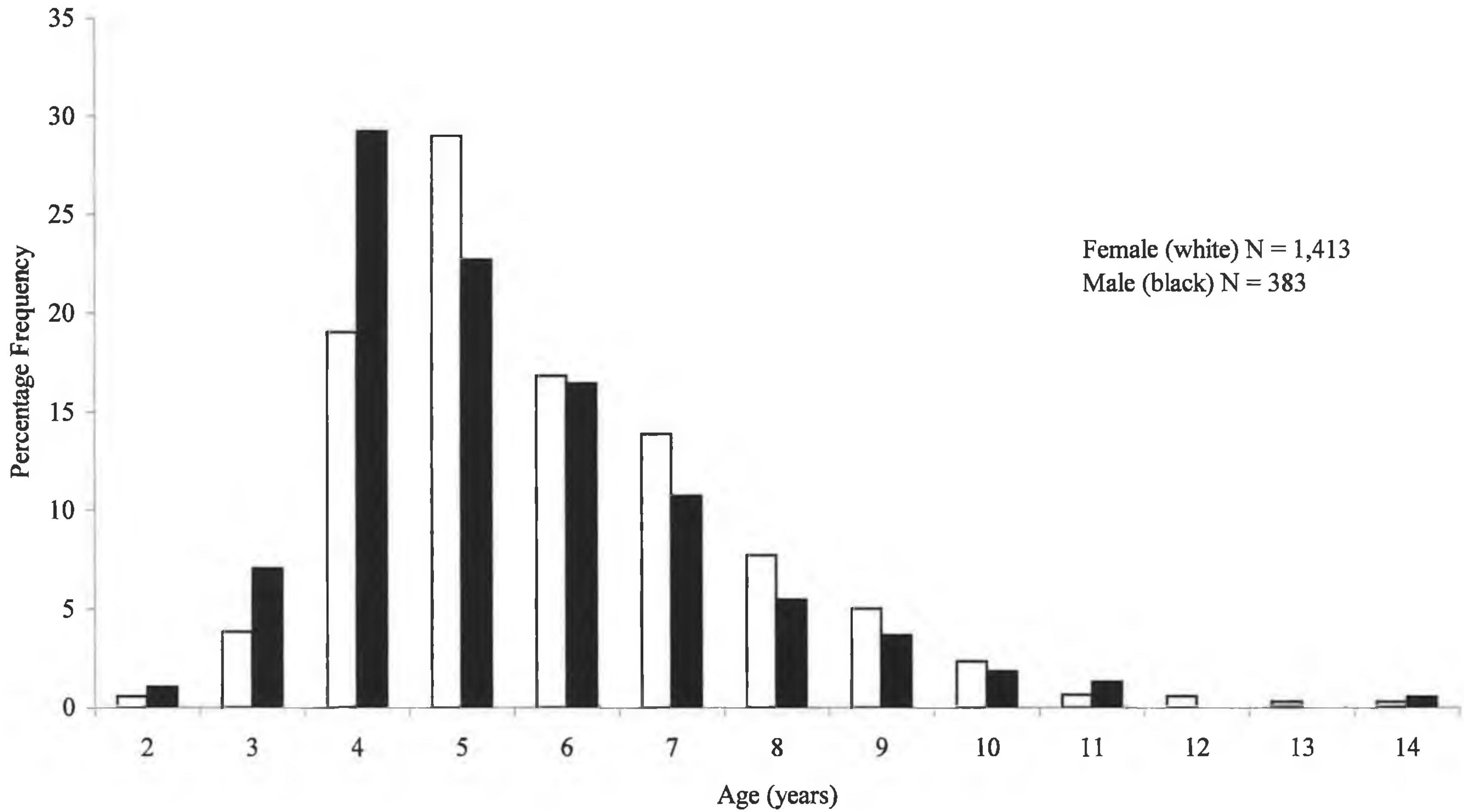


Fig. 3.6.4. Percentage length frequency for male lemon sole at each age sampled off the west coast between Nov 2000 - Feb 2002 (no 12 or 13 year old males were caught).

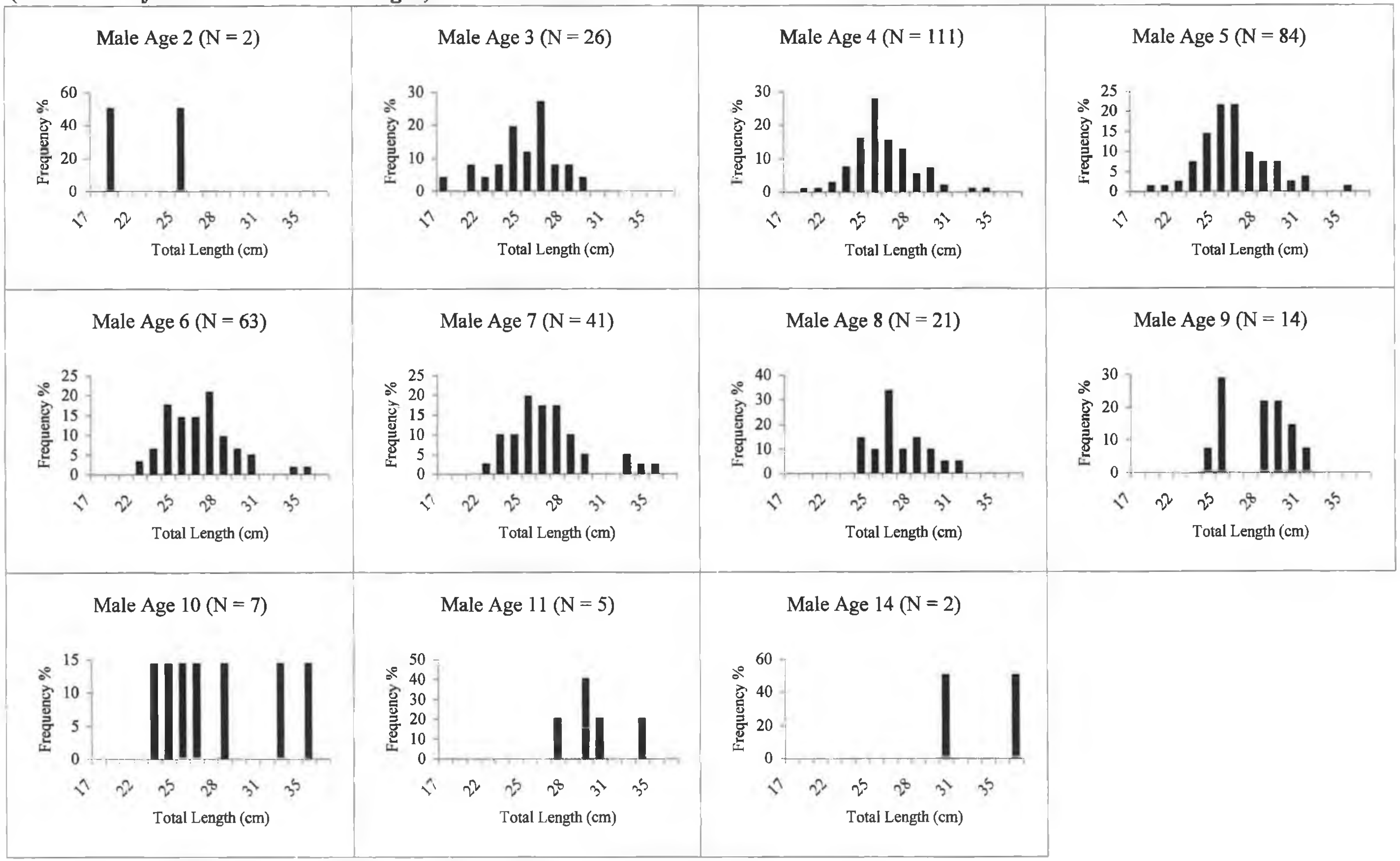


Fig. 3.6.5. Percentage length frequency for female lemon sole at each age sampled off the west coast of Ireland between Nov 2000 - Feb 2002.

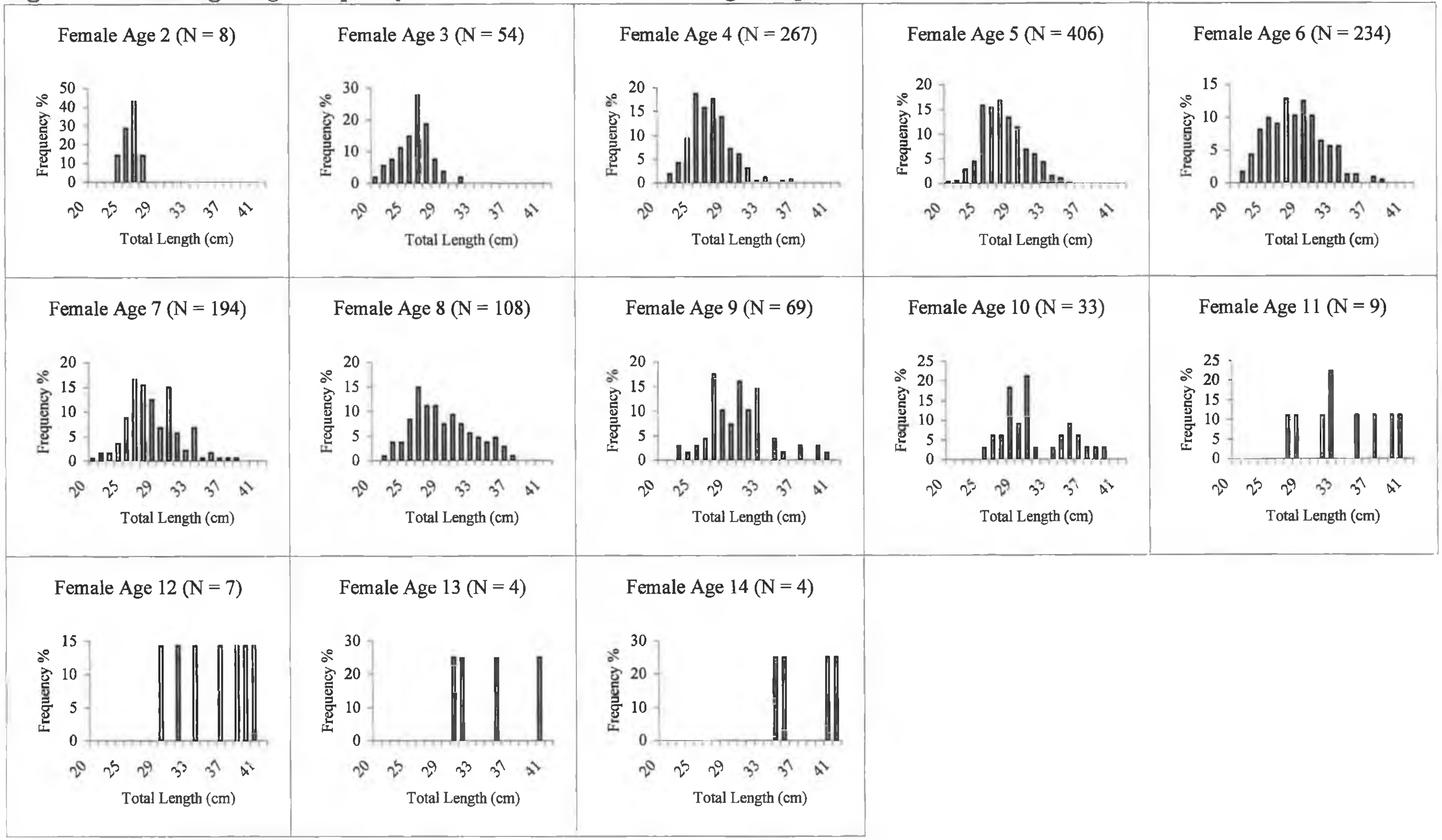


Table 3.6.2 Numbers of lemon sole at each age in each TL groups for the overall population.

	Age (years)													
Total Length (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
17		1												1
20	2	1	1	2		1								7
21		2	1	1										4
22		4	8	4	6	4	1							27
23		6	19	17	14	7	4	2	1					70
24	2	11	43	30	30	11	7	2	1					137
25	4	11	81	82	32	25	11	6	2					254
26	3	22	59	80	30	39	23	3	3					262
27	1	12	61	76	43	37	14	12	2	2				260
28		6	43	60	30	28	15	10	7	1				200
29		3	27	52	33	15	10	8	3	2	1			154
30			18	30	27	29	11	13	7	1		1	1	138
31		1	8	27	15	11	9	8	1	1	1	1		83
32			2	17	13	6	6	10	1	2				57
33			4	6	14	14	5		1	1	1			46
34				4	3	1	4	3	2				1	18
35			1	2	4	4	5	1	4	1		1	1	24
36			2			1	3		2		1			9
37					2	1	1	2	1	1			1	9
38					1	1			1		1			4
39								2	1	1	1			5
40								1		1	1	1	1	5
41													1	1
Total	12	80	378	490	297	235	129	83	40	14	7	4	6	1775
Mean	24	25	26	27	28	28	28	29	30	32	35	34	36	27.4552

Table 3.6.3 Numbers of male lemon sole at each age in each TL groups.

	Age (years)												
Total Length (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
17		1												1
20	2		1	1										4
21		2	1	1										4
22		1	3	2	2	1								9
23		2	8	6	4	4			1					25
24		5	18	12	11	4	3	1	1					55
25	2	3	31	18	9	8	2	4	1					78
26		7	17	18	9	7	7		1					66
27		2	14	8	13	7	2			1				47
28		2	6	6	6	4	3	3	1					31
29		1	8	6	4	2	2	3		2				28
30			2	2	3		1	2		1			1	12
31				3			1	1						5
32			1			2			1					4
33			1		1	1				1				4
35				1	1	1			1					4
37													1	1
N	4	26	111	84	63	41	21	14	7	5	0	0	2	378
Mean TL	22.5	24.7	25.6	25.9	26.2	26.4	26.7	27.6	27.6	29.6			33.5	

Table 3.6.4 Numbers of female lemon sole at each age in each TL groups.

	Age (years)													
Total Length (cm)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Total**
20		1		1		1								3
22		3	5	2	4	3	1							18
23		4	11	11	10	3	4	2						45
24	2	6	25	18	19	7	4	1						81
25	2	8	50	64	23	17	9	2	1					176
26	3	15	42	62	21	32	16	3	2					196
27	1	10	47	68	30	30	12	12	2	1				213
28		4	37	54	24	24	12	7	6	1				169
29		2	19	46	29	13	8	5	3		1			126
30			16	28	24	29	10	11	7			1		126
31		1	8	24	15	11	8	7	1	1	1	1		78
32			1	17	13	4	6	10		2				53
33			3	6	13	13	5		1		1			42
34				4	3	1	4	3	2				1	19
35			1	1	3	3	5	1	3	1		1	1	20
36			2			1	3		2		1			9
37					2	1	1	2	1	1				8
38					1	1			1		1			4
39								2	1	1	1			5
40								1		1	1	1	1	5
41													1	1
N	8	54	267	406	234	194	108	69	33	9	7	4	4	1397
Mean TL	25.4	25.6	26.7	27.4	28.1	28.1	28.7	29.8	30.9	33.4	35.1	34.0	37.5	

Mean TL values for male and female lemon sole plotted against age are shown in Fig. 3.6.6. This shows a very gradual increase in mean length at age for male and female fish. Mean values for males are smaller than females at all ages. The difference between mean lengths at age for males and females is not significant ($P < 0.05$) from 3 years of age and onwards (with the exception of age group 10), i.e. the confidence intervals (CI) overlap. There is a significant difference ($P < 0.05$) at age groups 2 and 10, however, as the CI values do not overlap, females showing a higher value for mean length. The mean length at age values for the four quarters of 2001 are shown in Fig. 3.6.7. Fish reaching the maximum age recorded for the present study were only present in the 1st (January 2001 – March 2001) and 3rd (July 2001 – September 2001) quarters.

Fig. 3.6.6 Length at age for Male (blue) and Female (red) lemon sole sampled between Nov 2000 - Feb 2002. (Error bars indicate 95% confidence intervals)

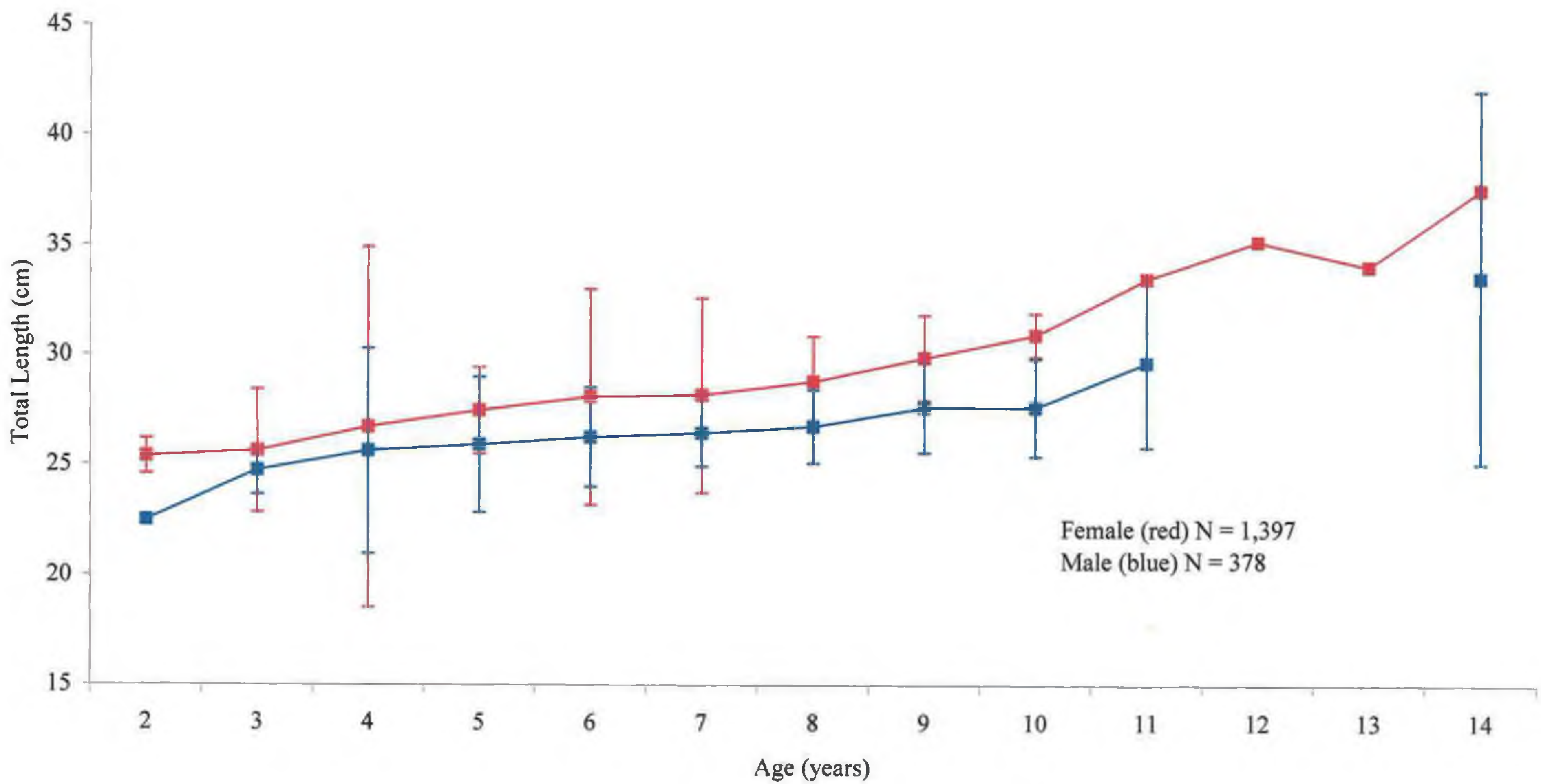
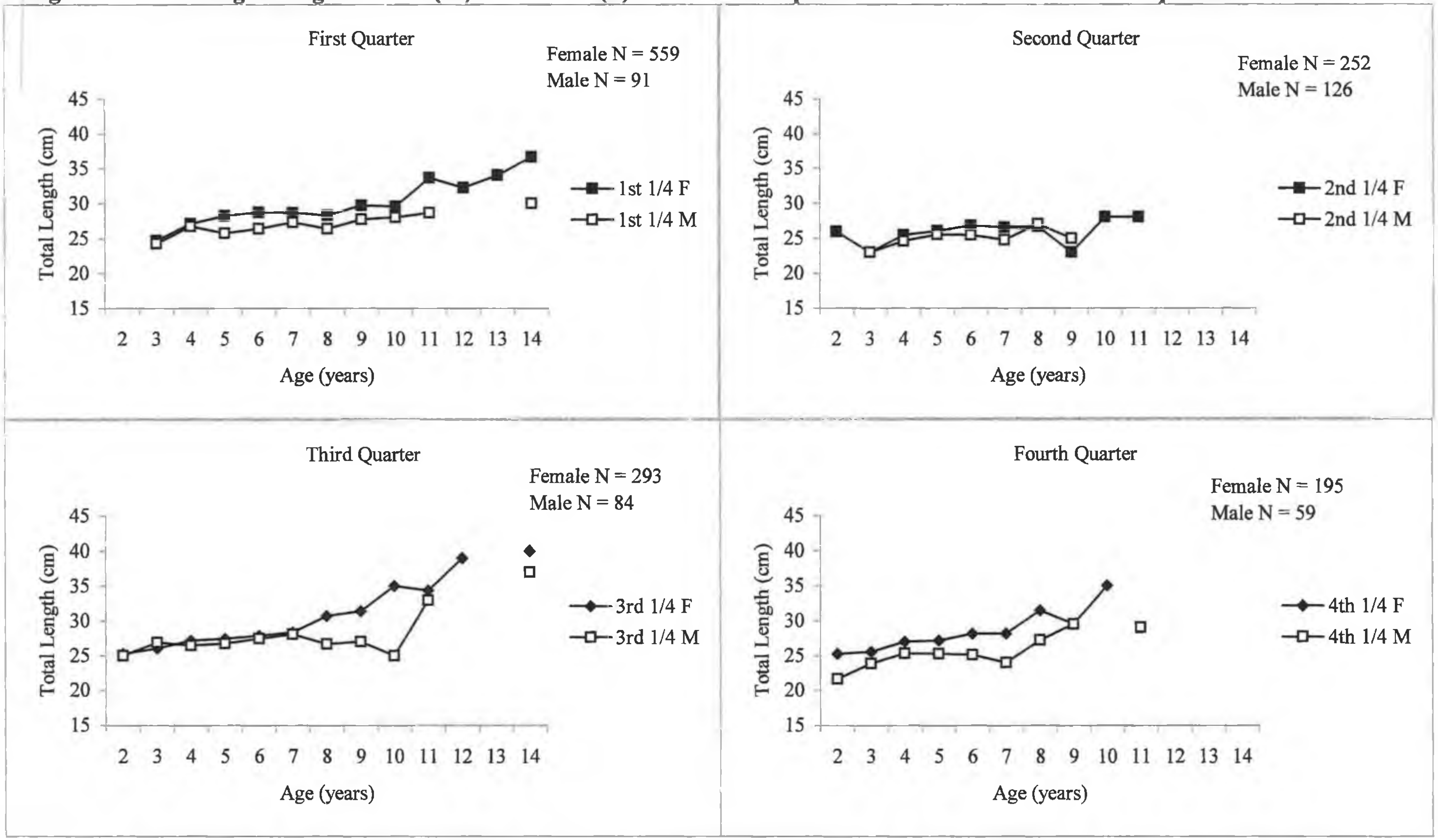


Fig. 3.6.7 Mean length at age for male (M) and female (F) lemon sole sampled off the west coast for the four quarters of 2001



Weight at age

Mean weights at age with standard deviation of the mean together with maximum and minimum values are given for male and female lemon sole in Tables 3.6.5 and 3.6.7 respectively. Mean weights at age for male and female lemon sole are shown on Fig. 3.6.8 with 95% CI values indicated. Weight increase is apparent for males and females with increasing age. A large variation in the weight (very high standard deviation values) was observed for the females within the sample, particularly with increasing age. Mean values indicated that females were heavier than males at all ages, however the difference is not significant ($P < 0.05$) as CI values overlap.

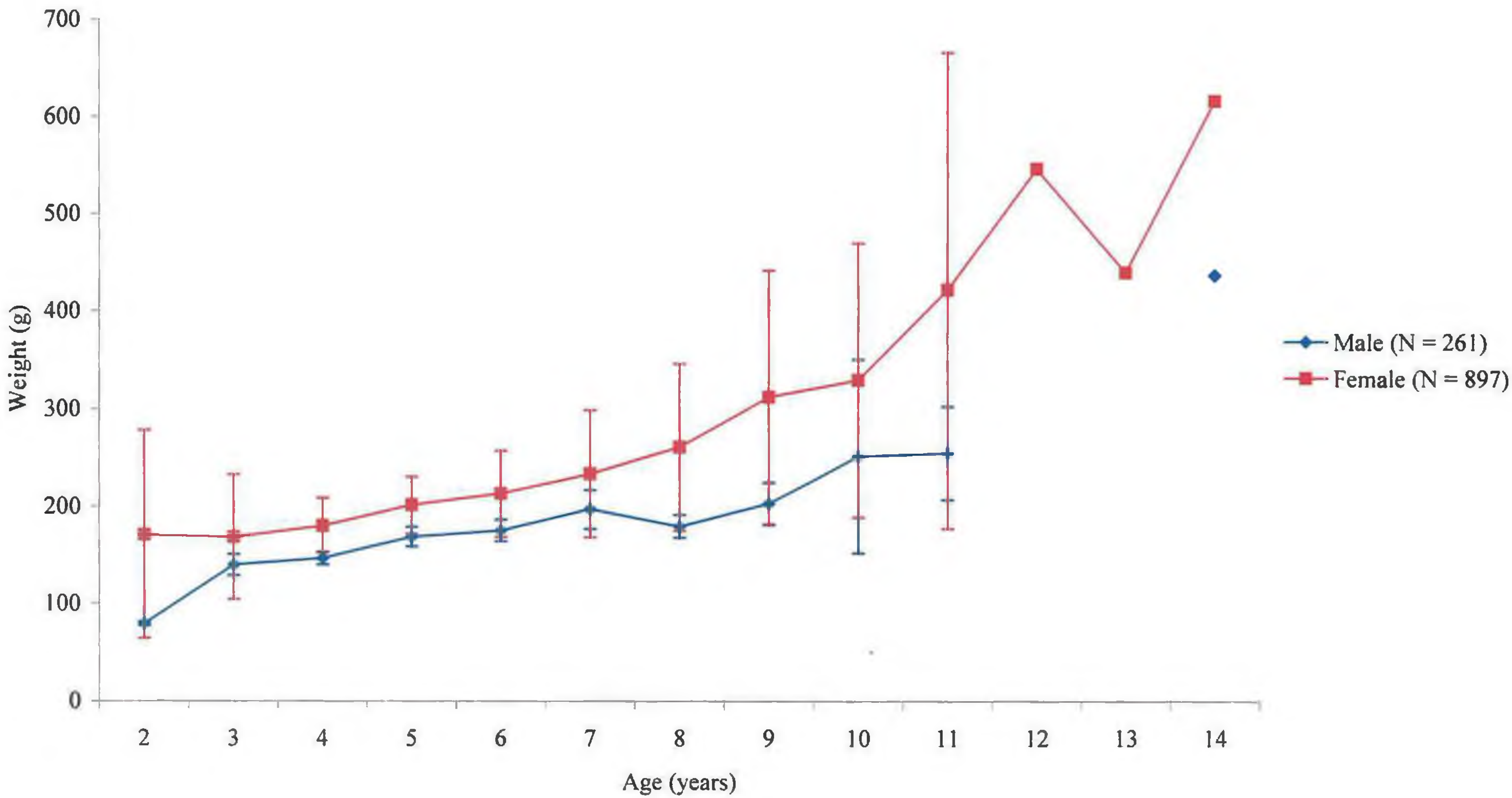
Table 3.6.5 Weight at age for male lemon sole sampled off the west coast of Ireland from November 2000 – February 2002.

Age (years)	2	3	4	5	6	7	8	9	10	11	12	13	14
N	2	18	78	59	47	27	13	9	3	3			2
Mean (g)	79	140	146	169	175	197	179	202	251	254			436
Std dev	0.2	37	41	64	63	93	35	59	169	80			232
Max (g)	79	204	331	477	426	439	253	280	438	343			600
Min (g)	79	48	78	86	110	103	136	140	112	188			273

Table 3.6.6 Weight at age for female lemon sole sampled off the west coast of Ireland from November 2000 – February 2002.

Age (years)	2	3	4	5	6	7	8	9	10	11	12	13	14
N	4	33	188	268	146	120	52	39	25	7	7	4	4
Mean (g)	171	168	180	201	213	233	260	312	329	421	546	439	616
Std dev	210	358	361	448	508	693	602	798	693	642	846	737	798
Max (g)	140	83	100	76	99	85	115	114	146	180	285	243	422
Min (g)	29	51	54	64	80	102	122	149	144	182	178	213	178

Fig. 3.6.8 Mean weights at age for male and female lemon sole (error bars indicate 95% confidence intervals)



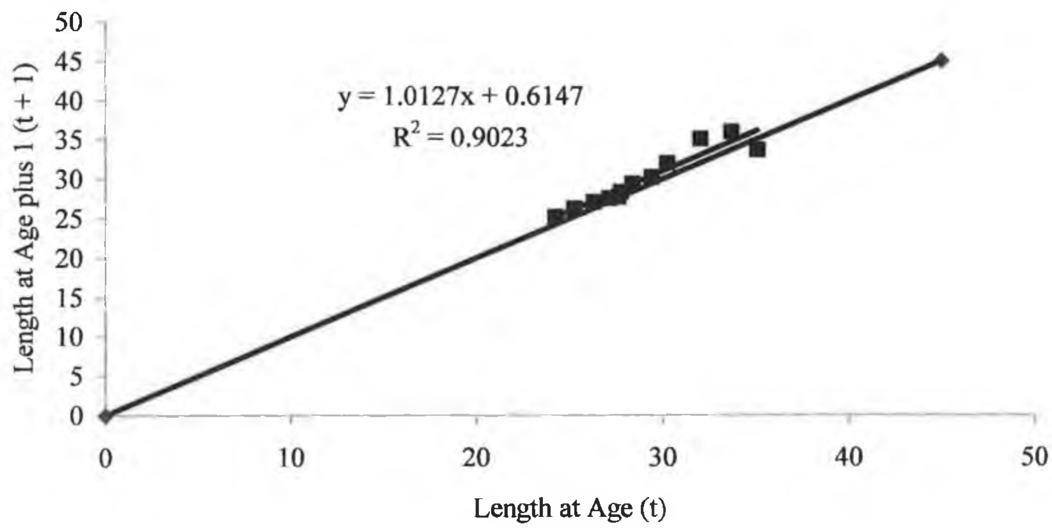
3.7 Growth

Three separate methods were selected to determine the parameters for the von Bertalanffy growth equation (Bertalanffy 1938, 1949). These were the Ford-Walford Plot (Beverton and Holt 1957), the Gulland and Holt Plot (1959) and the method of Rafail (1973). The von Bertalanffy growth parameters (VBGP) derived from each method (Table 3.7.1), if appropriate, were then used to plot von Bertalanffy growth curves.

The Ford-Walford Plot (Beverton and Holt 1957)

The Ford-Walford Plot is shown for the all fish sampled in Fig. 3.7.1.

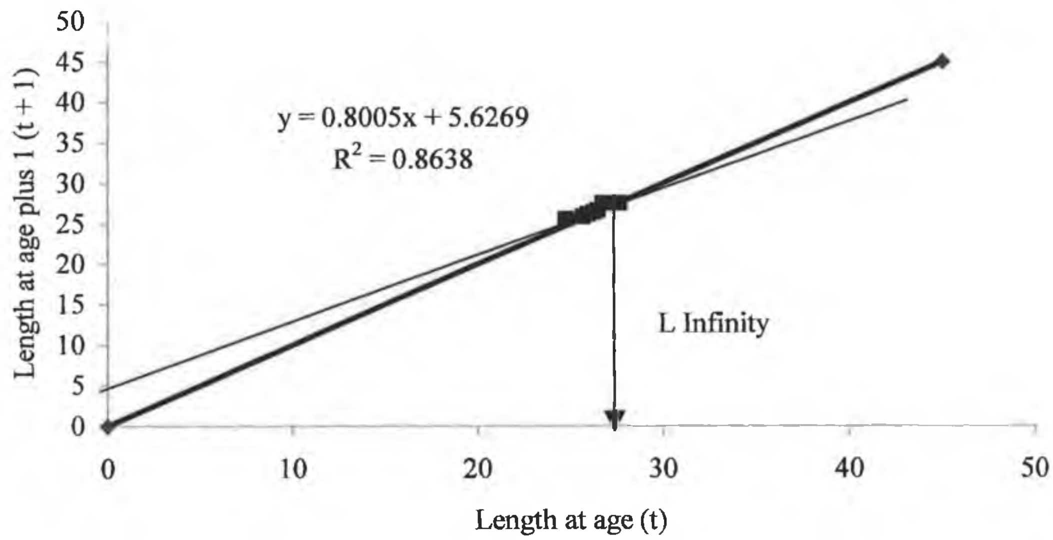
Fig. 3.7.1 Ford-Walford plot for all fish sampled between Nov 2000 to Feb 2002 off the west coast of Ireland.



The VBGPs estimated from the regression equation were: $L_\infty = 48.4$cm, $K = 0.1262$ yr^{-1} and t_o = -0.6997 yrs. All age groups were included in the analysis of the data. The intercept is not shown on the graph. The parameters estimated from this plot were used to plot a von Bertalanffy growth curve for the overall sample.

The Ford-Walford plot for male lemon sole is shown in Fig. 3.7.2.

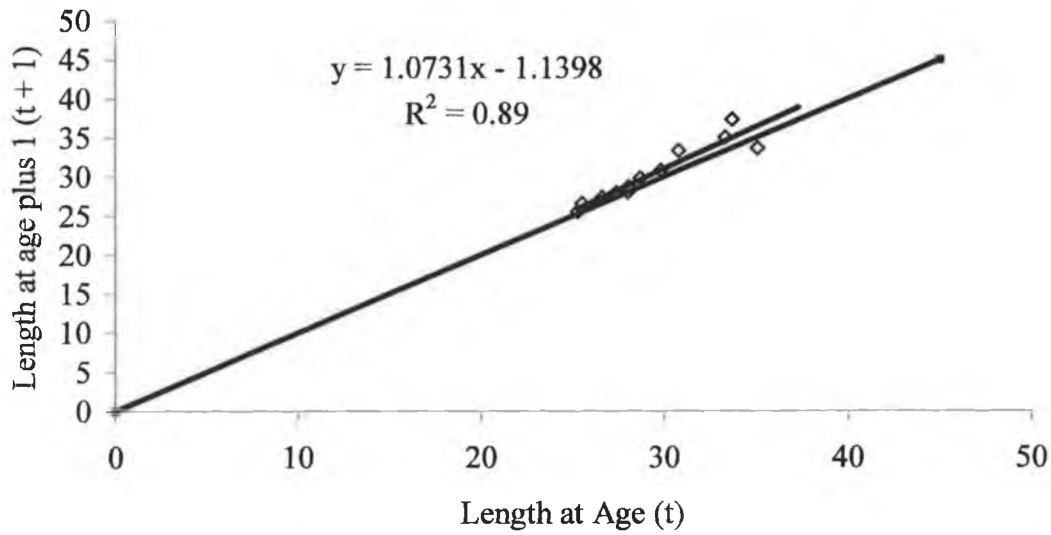
Fig. 3.7.2 Ford-Walford Plot for Male fish sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



The VBGPs were estimated from the regression equation giving rise to: L_∞ = 28.21cm, K = 0.2225 yr^{-1} and t_0 = -6.355 yrs. Fish in age groups 2 (N = 2), 10 (N = 7), 11 (N = 5) and 14 (N = 2) were omitted from the analysis. The intercept is shown on the graph. The values for L_∞ and K are feasible. However the t_0 value is unlikely to be representative. These parameters were however, used to plot a von Bertalanffy growth curve.

The Ford-Walford plot for female lemon sole is shown on Fig. 3.7.3.

Fig. 3.7.3 Ford Walford Plot for Female lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.

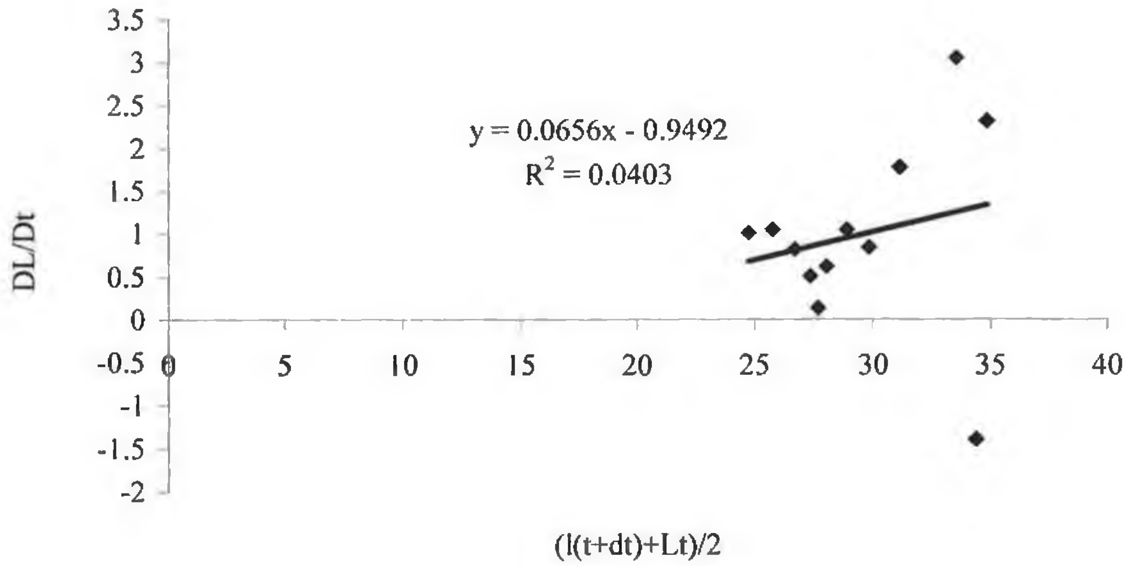


The VBGPs were estimated from the regression equation giving rise to: $L_\infty = 15.59$cm, $K = 0.0706$ yr^{-1} and t_0 = N/A. These estimates are not feasible. All age groups were included in the analysis of the data. The L_∞ value indicates that the maximum length female lemon sole grow to is 15.59cm (the smallest female in the sample was 20cm TL). The K value indicates very slow growth and it was not possible to estimate the t_0 value. These values cannot be used to plot the von Bertalanffy growth curve for female lemon sole.

Gulland and Holt (1959)

The Gulland and Holt plot is shown for all the fish sampled in Fig. 3.7.4.

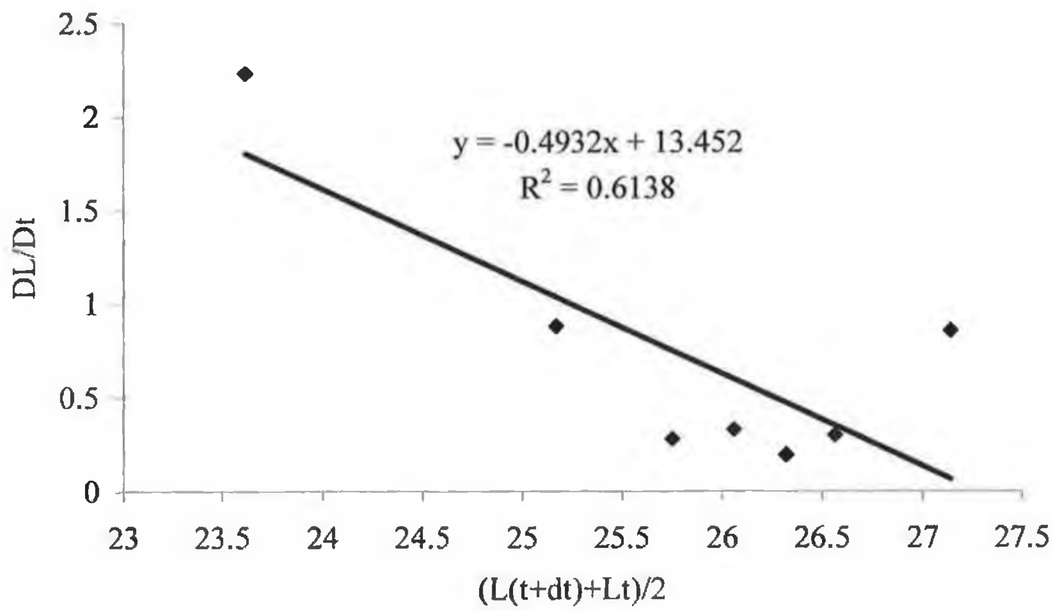
Fig. 3.7.4. Gulland and Holt Plot for all lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



The VBGPs were estimated from the regression equation giving rise to: L_∞ = 14.47cm, K = -0.0656 yr^{-1} and t_o = N/A. L_∞ is smaller than the smallest fish, K indicates negative growth and it was not possible to calculate t_o. This is due to the fact that the data did not fit the model, as can be seen from the scatter of points on Fig. 3.7.4. These parameters were not be used to plot a von Bertalanffy growth curve.

The Gulland and Holt plot for male lemon sole is shown in Fig. 3.7.5.

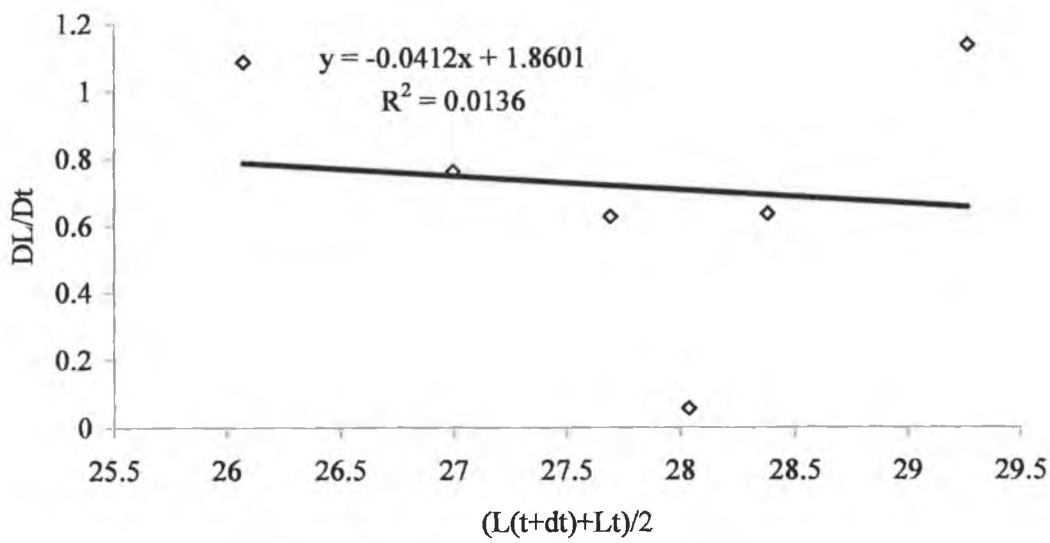
Fig. 3.7.5. Gulland and Holt Plot for male lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



The VBGPs were estimated from the regression equation giving rise to: L_∞ = 27.27cm, K = 0.4932 yr^{-1} and t_0 = -1.1584 yrs. These results are reasonable estimates of the VBGPs and were used to plot a von Bertalanffy growth curve.

The Gulland and Holt plot for female lemon sole is shown in Fig. 3.7.6.

Fig. 3.7.6 Gulland and Holt plot for female lemon sole sampled off the west coast of Ireland between Nov 2000 – Feb 2002.



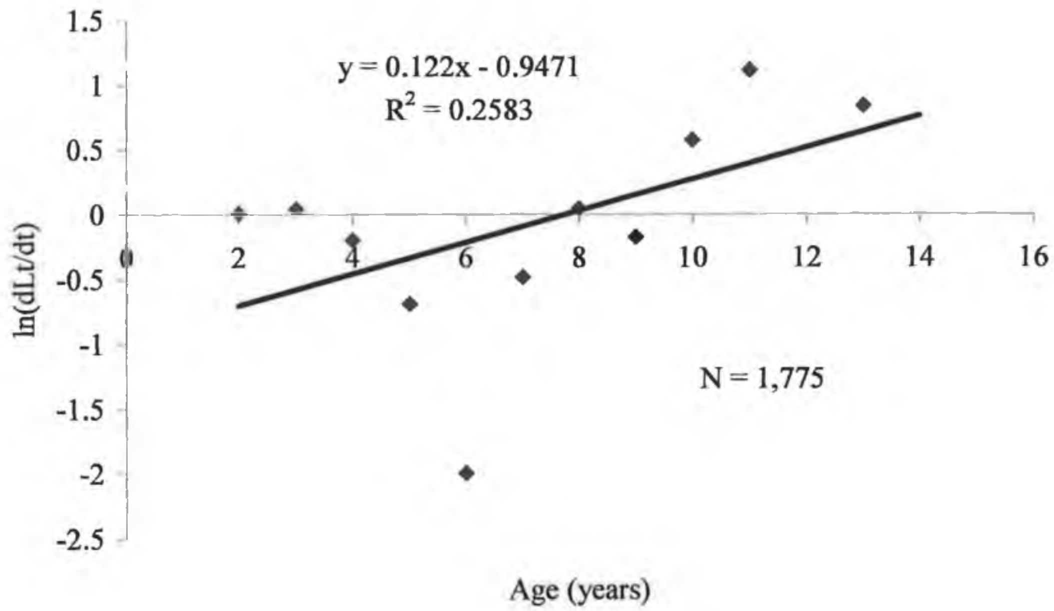
The VBGPs were estimated from the regression equation giving rise to: $L_\infty = 45.15$cm, $K = 0.0412$ yr^{-1} and $t_o = -16.96$ yrs. The value for L_∞ is a realistic estimate. However the plot gives inconsistent results for K and t_o. Nonetheless the values were used to plot a von Bertalanffy growth curve.

Rafail (1973)

A series of 3 Rafail plots give rise to 3 estimates of L_∞ and K and two estimates of t_0.

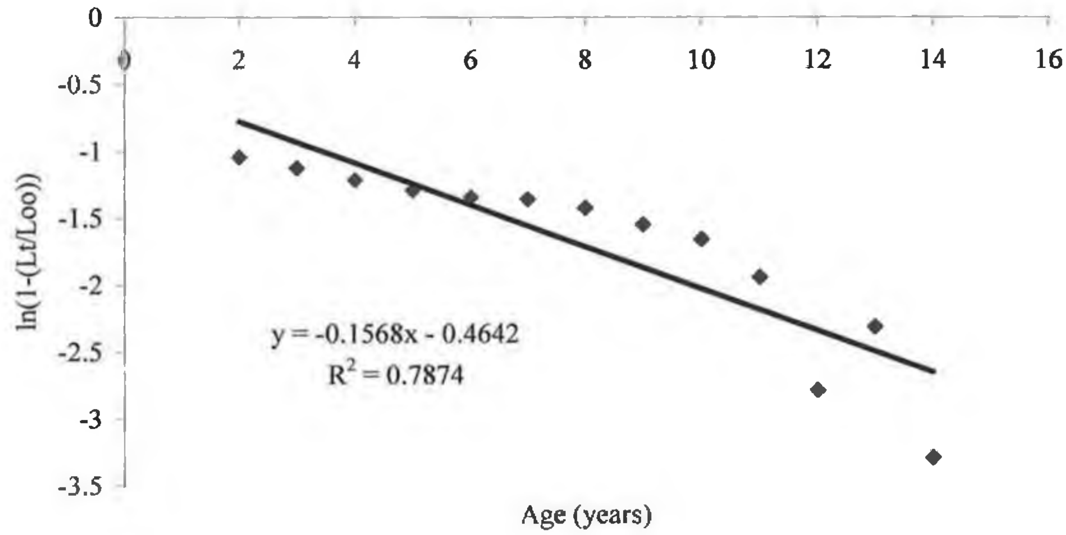
Rafail Plots for all fish sampled are shown in Fig. 3.7.7a, b and c

Fig. 3.7.7a Rafail - Plot No 1 for all fish sampled (Ln (dLt / dt) versus Age)



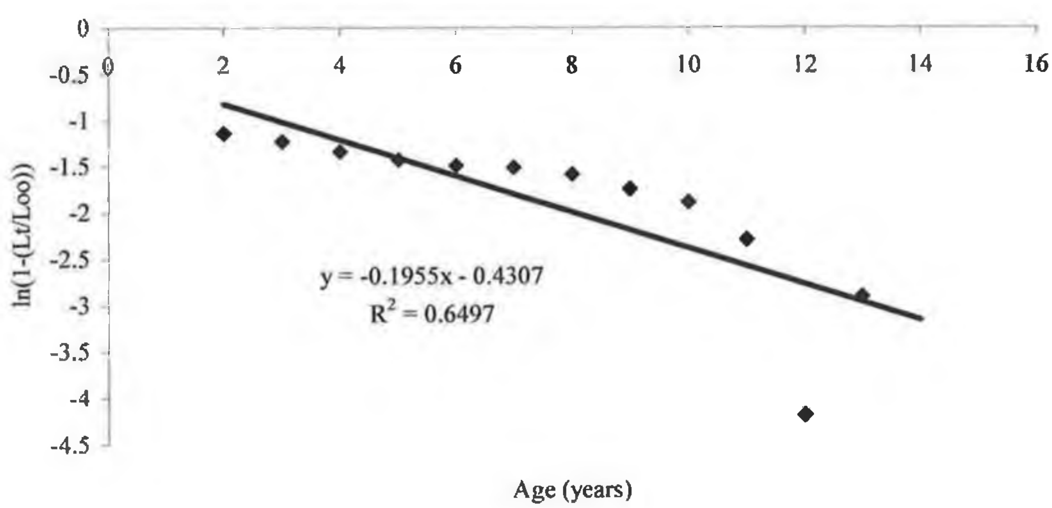
The first estimates of L_∞ and K are derived from this plot. L_∞ 1 = 37.4cm and K 1 = 0.122 yr^{-1} . These values were then used to plot Rafail – Plot No 2.

Fig. 3.7.7b Rafail - Plot No 2 for all fish sampled (Ln (1-Lt / L_∞) versus Age using 1[st] L_∞ value)



The second estimates of L_∞ and K and the first estimate of t_0 are derived from this plot. L_∞ 2 = 35.64cm, K 2 = 0.1568 yr^{-1} and t_0 1 = -2.96 yrs. These values were then used to plot Rafail – Plot No 3.

Fig. 3.7.7c Rafail - Plot No 3 for all fish sampled (Ln (1-Lt/L_∞) versus Age using 2[nd] L_∞ value)

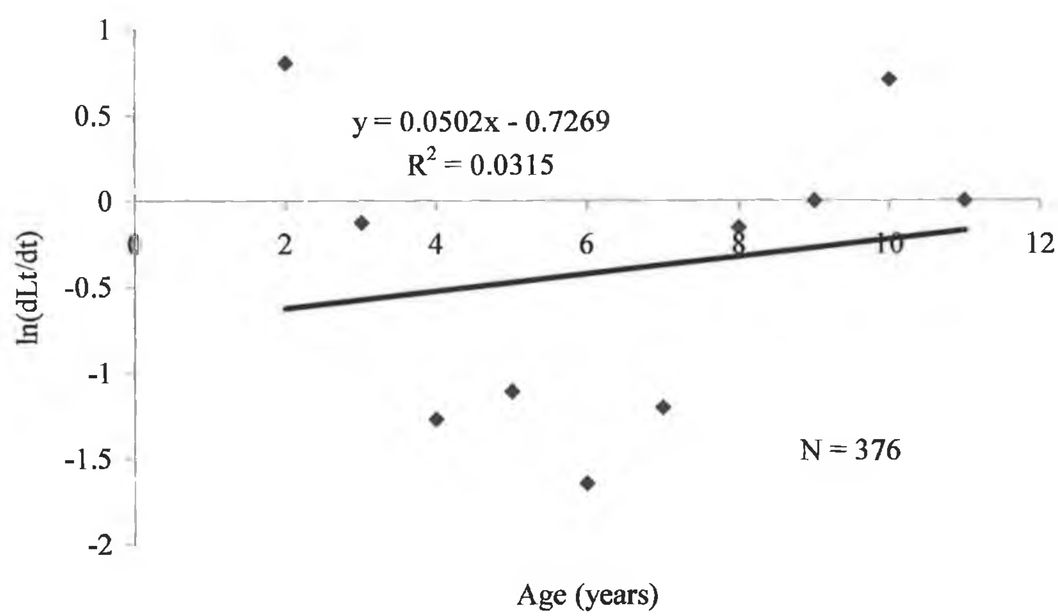


The third estimates of L_∞ and K and the second estimate of t_0 are derived from this plot. L_∞ 3 = 34.47cm, K 3 = 0.1955 yr^{-1} and t_0 2 = -2.2031 yrs.

The estimates of L_∞ appear to slightly underestimate the maximum size that the lemon sole off the west coast of Ireland reach, however the estimates of K indicate that the growth rate is good and the estimate of t_0 show a low value that may not be entirely accurate. These estimates were used to plot a von Bertalanffy growth curve for all fish sampled.

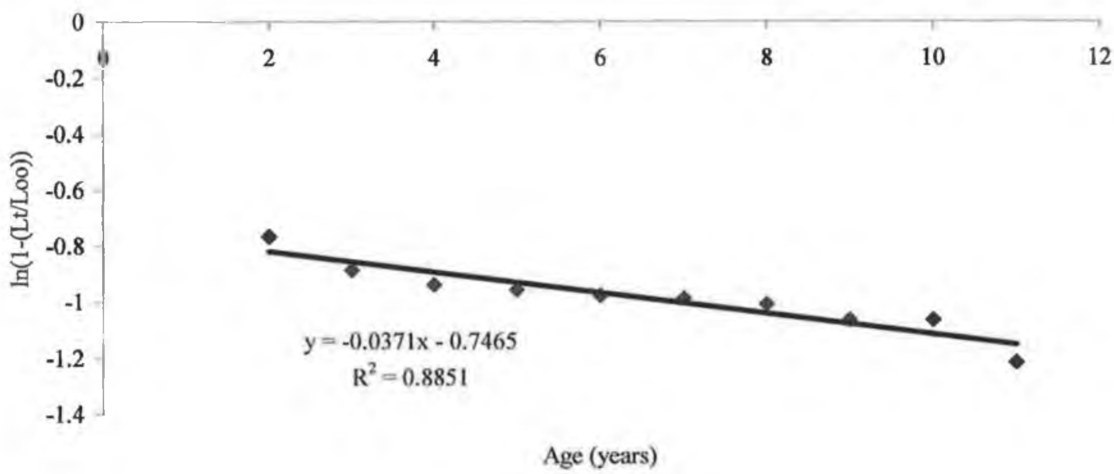
Rafail Plots are shown for male lemon sole in Fig. 3.7.8a, b and c.

Fig. 3.7.8a Rafail - Plot No 1 for males (Ln (dLt / dt) versus Age)



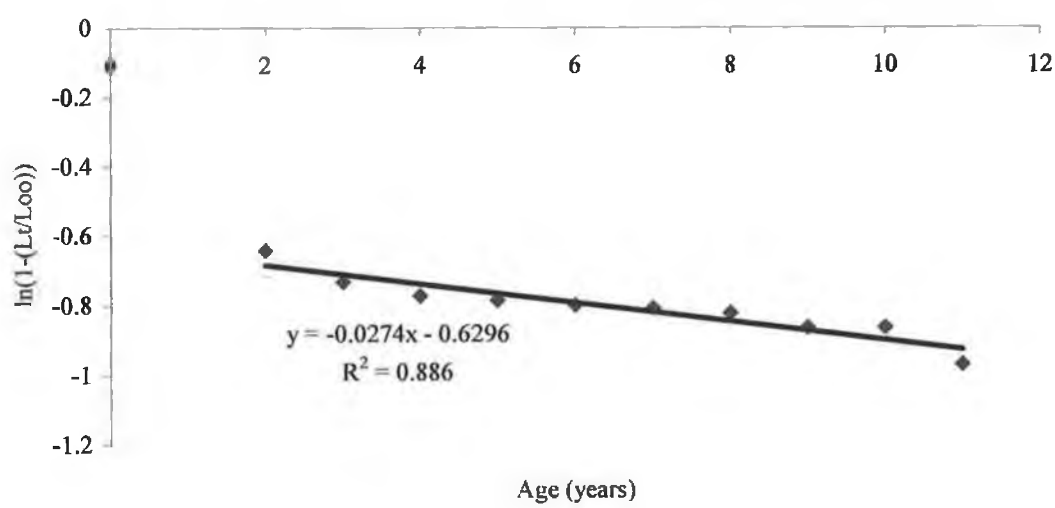
The first estimates of L_∞ and K are derived from this plot. L_∞ 1 = 42.04cm and K 1 = 0.0371 yr^{-1}. These values were then used to plot Rafail – Plot No 2.

Fig. 3.7.8b Rafail - Plot No 2 for males (Ln (1-Lt / L_∞) versus Age using 1st L_∞ value)



The second estimates of L_∞ and K and the first estimate of t_o are derived from this plot. L_∞ 2 = 47.57cm, K 2 = 0.0371 yr^{-1} and t_o 1 = -20.12 yrs. These values were then used to plot Rafail – Plot No 3.

Fig. 3.7.8c Rafail - Plot No 3 for males (Ln (1-Lt/L_∞) versus Age using 2nd L_∞ value)

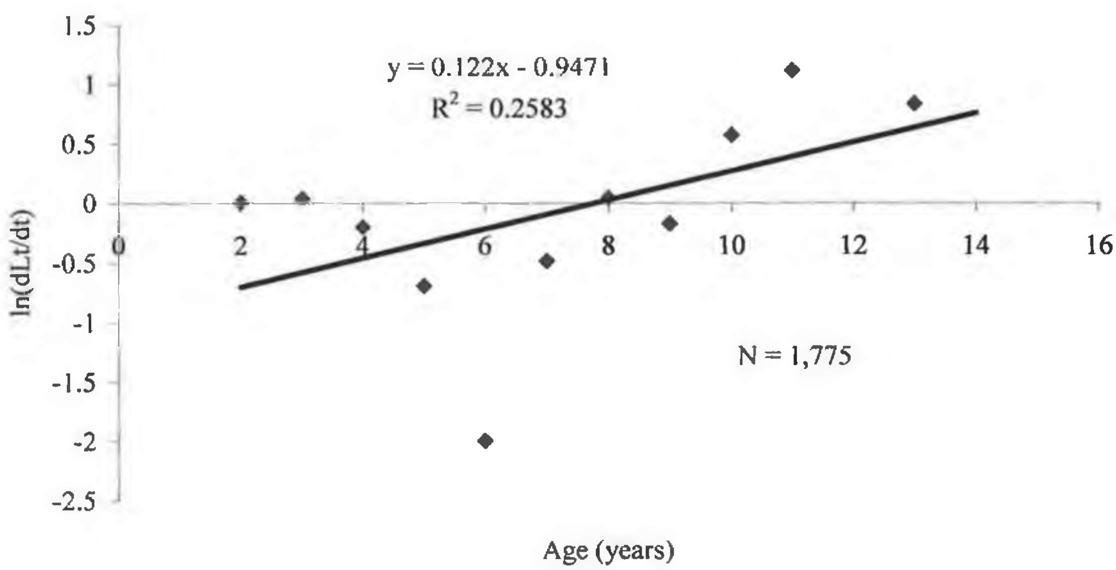


The third estimates of L_∞ and K and the second estimate of t_0 are derived from this plot. L_∞ 3 = 55.12cm, K 3 = 0.0247 yr^{-1} and t_0 2 = -22.98 yrs.

The estimates of L_∞ became larger, yet the growth rate K reduced with each plot. The high t_0 value is unrealistic therefore these values were not used to plot a von Bertalanffy growth curve.

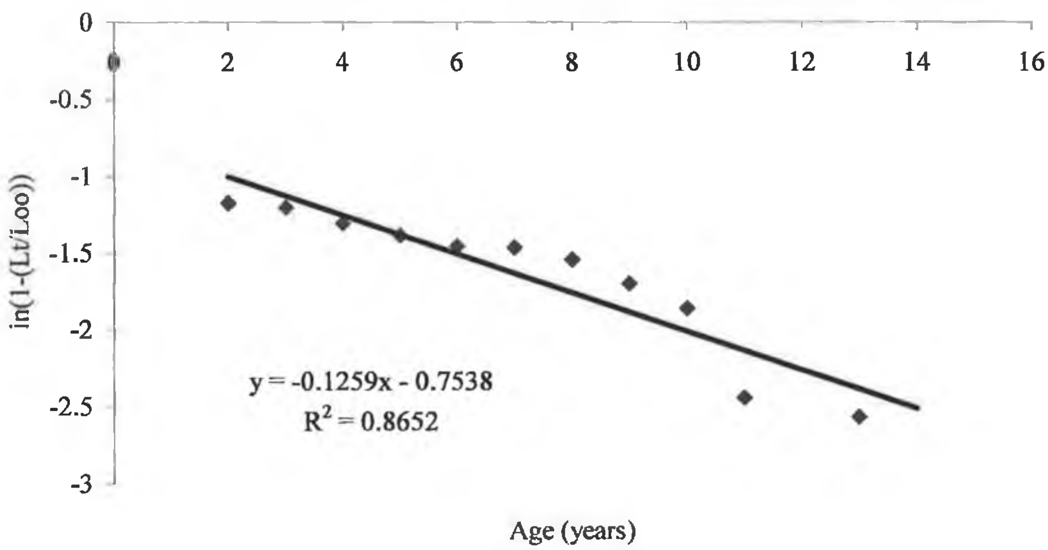
Rafail plots for female lemon sole are shown in Fig. 3.7.9a, b and c.

Fig. 3.7.9a Rafail - Plot No 1 for females (Ln (dLt / dt) versus Age)



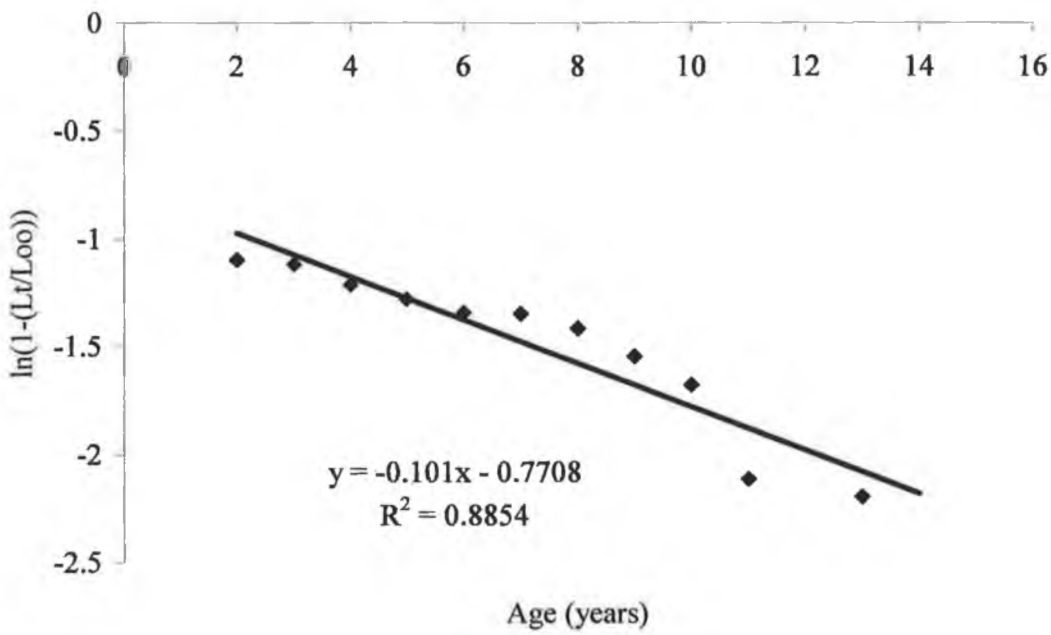
The first estimates of L_∞ and K are derived from this plot. L_∞ 1 = 36.5cm and K 1 = 0.1523 yr^{-1}. These values were then used to plot Rafail – Plot No 2.

Fig. 3.7.9b Rafail - Plot No 2 for females (Ln (1-Lt / L_∞) versus Age using 1st Loo value)



The second estimates of L_∞ and K and the first estimate of t_0 are derived from this plot. L_∞ 2 = 37.9cm, K 2 = 0.1259 yr^{-1} and t_0 1 = -5.99 yrs. These values were then used to plot Rafail – Plot No 3.

Fig. 3.7.9c Rafail - Plot No 3 for females (Ln (1-Lt/L_∞) versus Age using 2^{nd} L_∞ value)



The third estimates of L_∞ and K and the second estimate of t_0 are derived from this plot. L_∞ 3 = 39.9cm, K 3 = 0.101 yr^{-1} and t_0 2 = -7.63 yrs.

The estimates of L_∞ became larger yet the growth rate K reduced with each plot as seen for the males above. The t_0 value was high, however, these estimates were used to plot a von Bertalanffy growth curve for females.

Table 3.7.1 VBGPs for the sexes combined and males and females separately.

	Sex	Combined	Female	Male
Ford-Walford Plot	N	1,775	1,389	376
	Age Range (yrs)	2 – 14	2 – 14	3 – 9
	K (yr^{-1})	0.1262	0.0706	0.2225
	L∞ (cm)	48.40	15.59	28.21
	t_o (yrs)	-0.6997	N/A	-6.355
Gulland and Holt Plot	Sex	Combined	Female	Male
	N	1,775	1,389	376
	Age Range (yrs)	2 – 14	2 – 14	3 – 9
	K (yr^{-1})	-0.0656	0.0412	0.4932
	L∞ (cm)	14.47	45.15	27.27
	t_o (yrs)	N/A	-16.96	-1.1584
Rafail	Sex	Combined	Female	Male
	N	1,775	1,389	376
	Age Range (yrs)	2 – 14	2 – 14	2 – 11
	K 1 (yr^{-1})	0.122	0.1523	0.0502
	L∞ 1 (cm)	37.4	36.5	42.04
	K 2 (yr^{-1})	0.1568	0.1259	0.0371
	t_o 1 (yrs)	-2.96	-5.99	-20.12
	L∞ 2 (cm)	35.64	37.9	47.57
	K 3 (yr^{-1})	0.1955	0.101	0.0274
	t_o 2 (yrs)	-2.2031	-7.63	-22.98
	L∞ 3 (cm)	34.47	39.9	55.12

von Bertalanffy (1938, 1949)

The fitted von Bertalanffy growth models (VBGM) are shown for all fish in Fig. 3.7.10 and for males and females separately in Fig. 3.7.11, using the VBGPs presented in Table 3.7.1. The fitting of the VBGM, however, were only viable using the following methods for the overall sample and males and females separately:

All Fish Sampled	-	VBGMs were plotted using the parameters estimated from Rafail's Method and the Ford-Walford Plot for all lemon sole sampled.
Males	-	VBGMs were plotted using the parameters estimated from the Gulland and Holt Plot and the Ford-Walford Plot for males.
Females	-	VBGMs were plotted using the parameters estimated from the Gulland and Holt Plot and Rafail's Method for females.

Changes in values for L_{∞}, K and t_0 show very different patterns of fitted growth. The VBGMs fitted using the Rafail method showed a very gradual increase in growth. The two models fitted (for all fish sampled and females) incorporate all the data points indicating the observed length at age.

The model fitted using the estimates of the Ford-Walford plot for all fish sampled showed a relatively fast growth pattern, with the end point at the maximum size and the starting point below minimum size as seen from the observed data. This indicated that the parameters estimated from the Ford-Walford plot give rise to fitted models, which are heavily biased. In contrast the Ford-Walford estimates for males, fit a model that indicates that males showed a very slight growth increase with increasing years.

The model fitted using the parameter estimates from the Gulland and Holt plot for males showed a very similar result to that of the Ford-Walford plot parameter estimates. For females the parameters estimated from the Gulland and Holt model showed a slower increase in predicted growth, reaching a maximum size at age 14. This was lower than the smallest female observed in this age category.

Figure 3.7.10. von Bertalanffy growth curve plotted for lemon sole off the west coast of Ireland. Parameters estimated using the Rafail method (green) and the Ford-Walford Polt (blue), data points show the observed length at age.

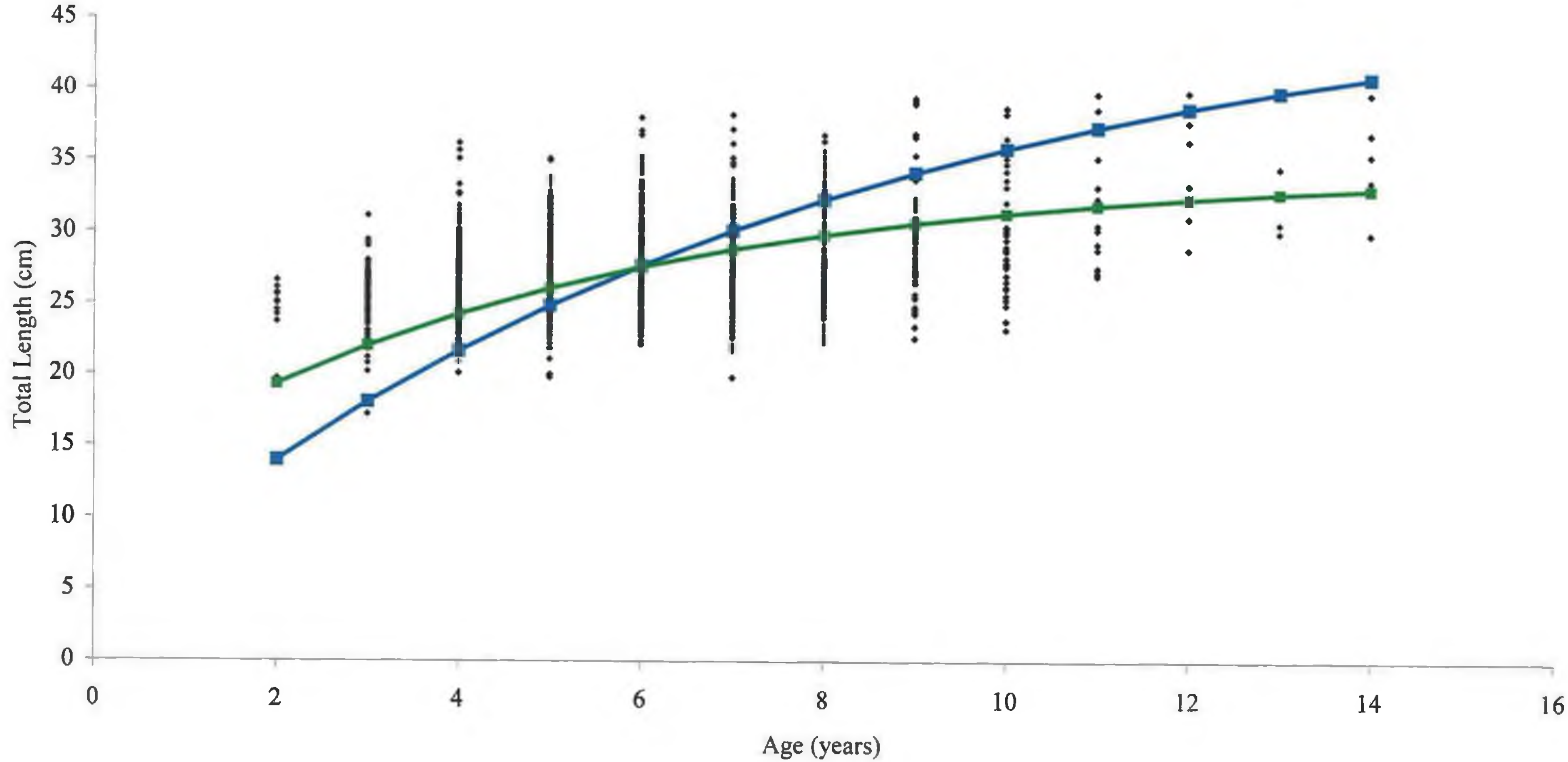
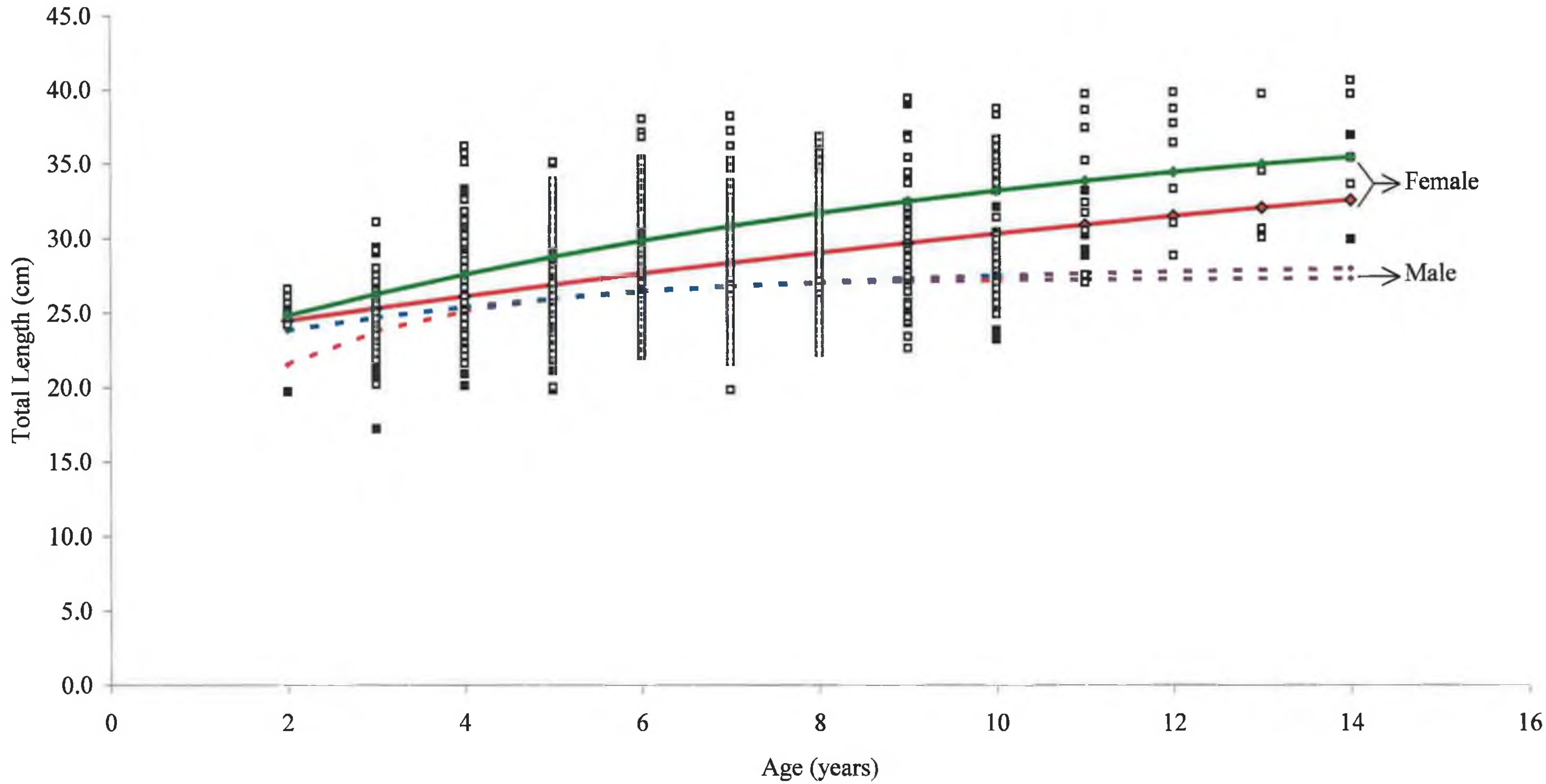


Fig. 3.7.11. von Bertalanffy growth curve for male and female lemon sole. Rafail (green), Gulland and Holt (red) Ford-Walford (blue), data points show the observed length at age.



3.8 Catch Curves, Survivorship and Mortality

A catch curve representing the age composition of the overall sample of lemon sole off the west coast of Ireland for the year 2001 is shown on Fig. 3.8.1. Catch curves representing the males and females of the sampled population separately are shown on Fig. 3.8.2. 5 year olds (i.e. the year class of 1996) were most abundant in the catches as an overall sample and in the female sample, while 4 year olds (year class of 1997) were most abundant in the males. Relatively high numbers of 4 year olds were present in the overall catch figures, due to the high numbers of males at this age. The age at full recruitment (t_r) for the overall sample was 6 (year class of 1995), females showed the same t_r, while males were fully recruited at age group 5.

Catch curves representing the length composition of males and females of the sampled population separately are shown on Fig. 3.8.3. The length at full recruitment (l_r) for males was 25cm (TL), while females were not fully recruited until they were 28cm (TL).

The co-efficient of Total Mortality (Z) was calculated from the descending leg of the age based catch curves for all three elements of the population examined. Z for the overall sample was 0.64 yr^{-1}, for the males 0.49 yr^{-1} and for the females 0.61 yr^{-1}.

Percentage Survivorship (% S) was estimated from Z for each element of the population examined. The overall population showed 53% S, males showed 61% S and females showed 54% S.

The mean life span (t_{max}) is shown in Table 3.8.1 for the overall population and males and females separately.

Natural Mortality (M) was calculated using Pauly's (1980) method for all three elements of the population examined. M was calculated for the overall sample using the growth parameters determined by the Rafail method and the Ford-Walford plot. M was calculated for males using the growth parameters of the Gulland and Holt plot and of the Ford-Walford plot. M was calculated for females using the growth parameters determined by the Rafail method and the Gulland and Holt plot. Thus, two values for M were generated for each element of the stock. The reasons for the choice of methods used to calculate the M values will be described later in the discussion. The average water temperature for the year of 2001 (12.49°C) off the west coast of Ireland was used for the calculation of all M values. Natural Mortality estimates are shown on Table 3.8.1 for all elements of the population examined.

Three values for Fishing Mortality (F) were calculated for all elements of the population examined. The first two sets of F values as shown on Table 3.8.1 were attained by subtracting M values (described above) from Z values (of the catch curves). The third set of F values were attained by subtracting the arbitrary M value of 0.12 as assigned by ICES for plaice and common sole off the west coast of Ireland from Z values (of the catch curves). Results are shown in Table 3.8.1.

Fig. 3.8.1. Catch curve for all lemon sole sampled off the west coast of Ireland over the year of 2001.

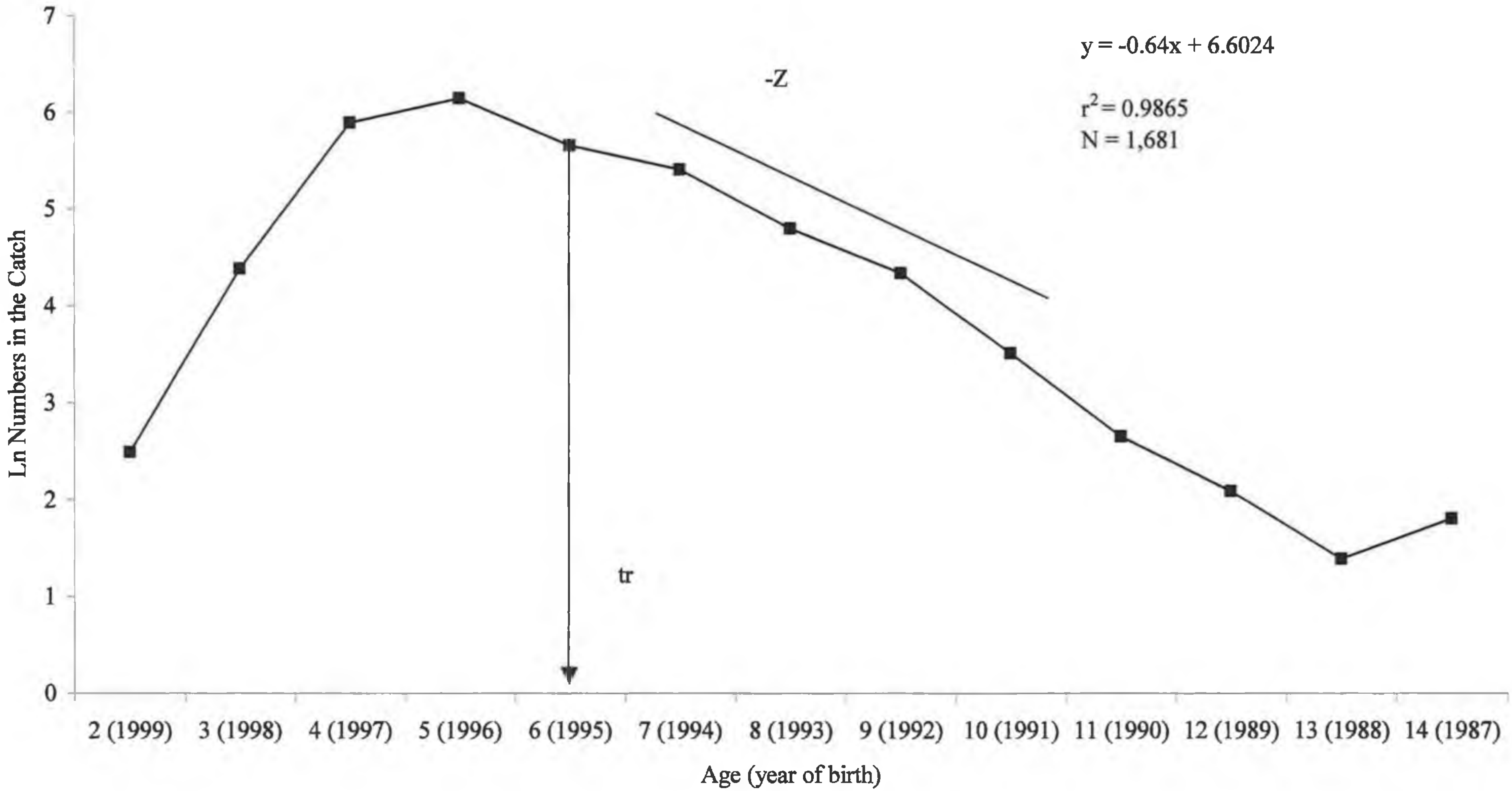


Fig. 3.8.2. Catch curve (age) for male and female sole sampled off the west coast of Ireland over the year of 2001.

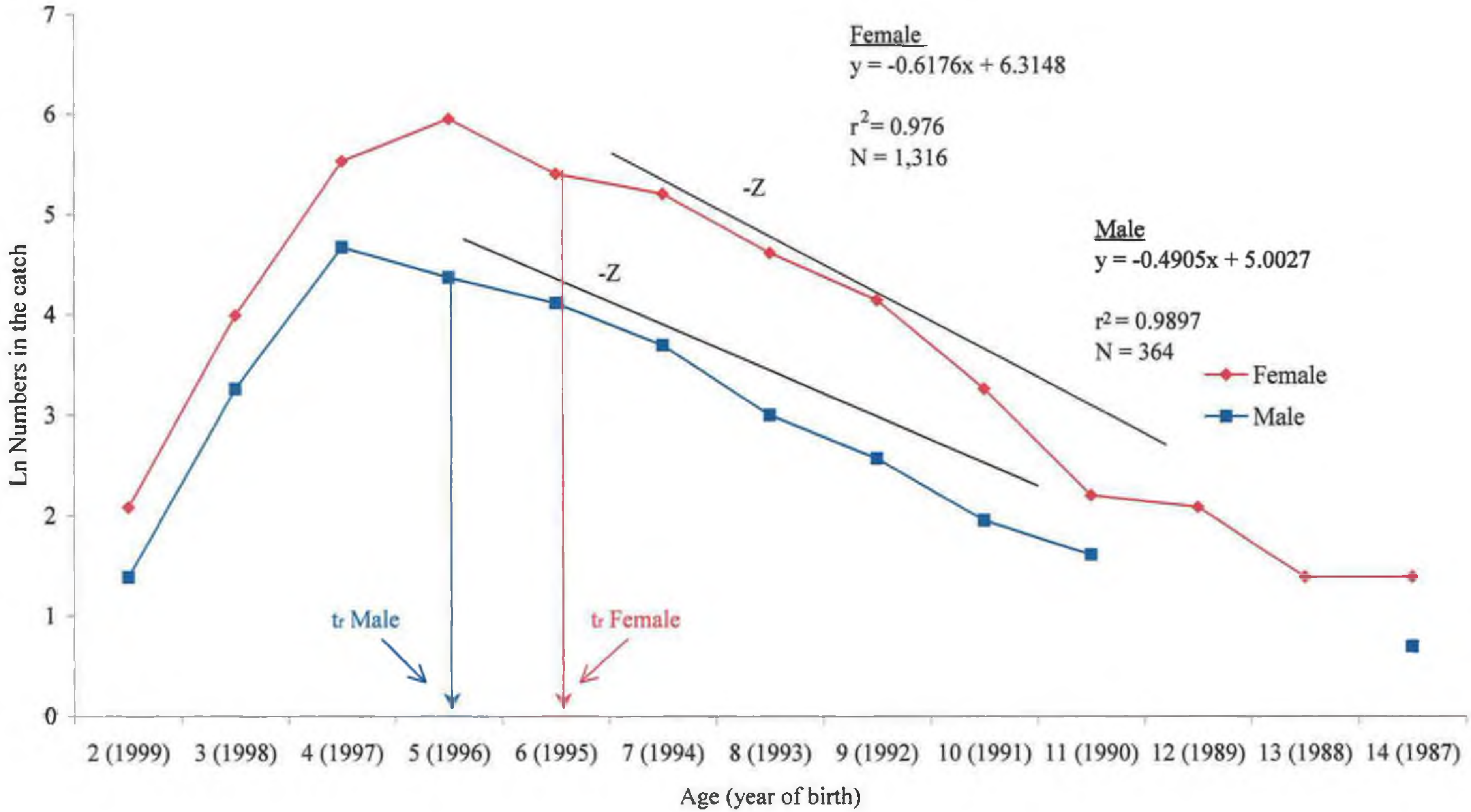


Fig. 3.8.3. Catch curve (length) for male and female sole sampled off the west coast of Ireland over the year of 2001.

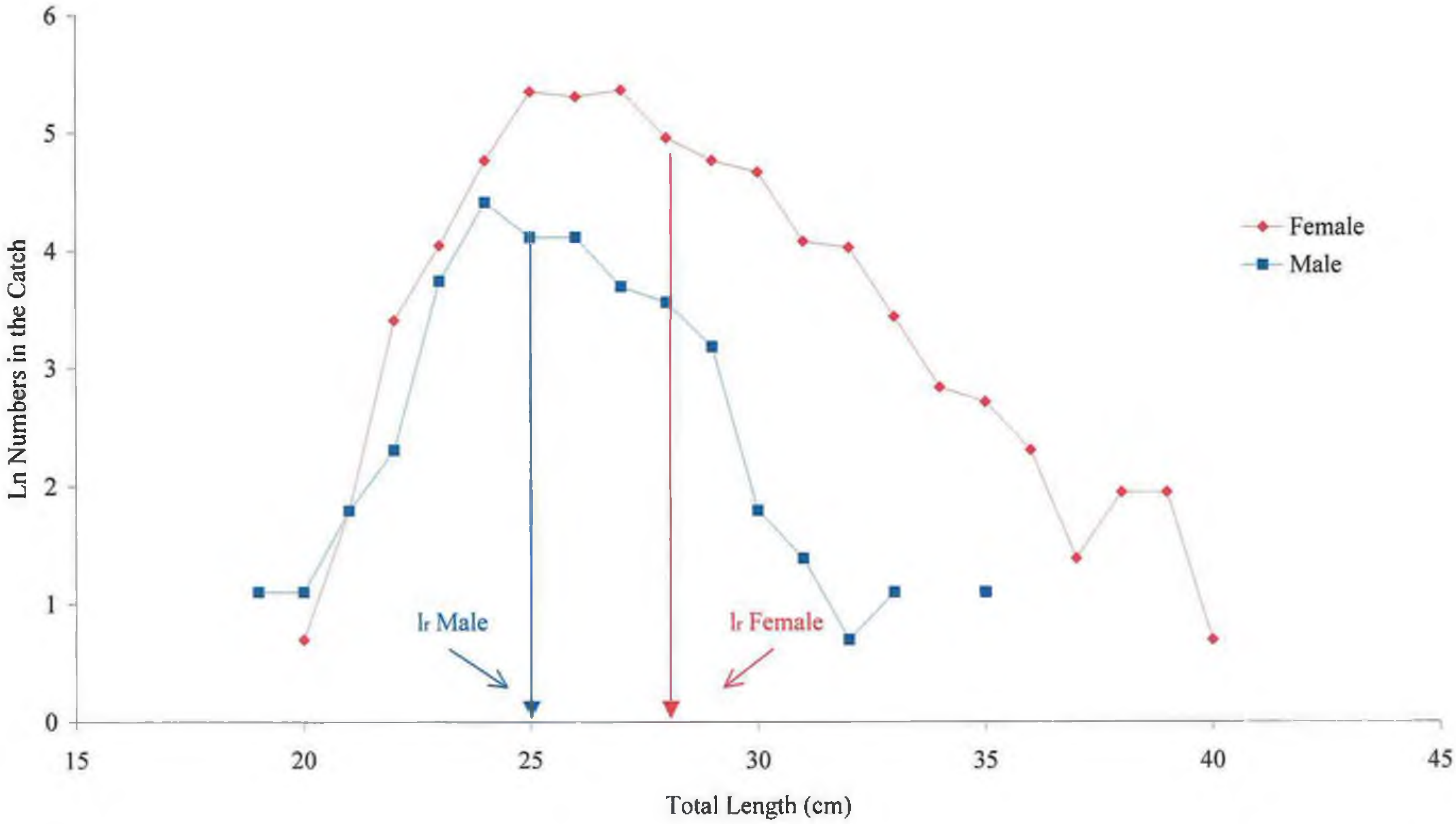


Table 3.8.1. Mortality and Survivorship for lemon sole as combined (male and female), male and female stocks off the west coast of Ireland for the year 2001.

Element of the Sampled Population	Combined	Male	Female
Z	0.64 yr^{-1}	0.49 yr^{-1}	0.61 yr^{-1}
% Survivorship	53	61	54
Average Water Temperature	12.49°C	12.49°C	12.49°C
Method of obtaining Growth Parameters	Rafail	Ford-Walford	Rafail
M (Natural Mortality)	0.4063	0.4675	0.2531
F (Fishing Mortality)	0.2337	0.0225	0.3569
t_{max} (years)	15.3	13.5	29.7
Method of attaining Growth Parameters	Ford-Walford	Gulland & Holt	Gulland & Holt
M	0.2775	0.7944	0.1360
F	0.3625	-0.3044	0.4740
t_{max} (years)	23.8	250	6.1
M (ICES)	0.12	0.12	0.12
F	0.52	0.37	0.49

Male lemon sole show a lower total mortality co-efficient and a higher % survival than females. M estimates vary throughout the various methods of analysis of the VBGP. The ICES M is the lowest for the overall sampled population and for males and females separately. The M value calculated from the Rafail VBGP for the overall sample was higher than that of the Ford-Walford VBGP. The lowest F value was calculated from that of the Rafail VBGP M value, while the highest F value was calculated from the ICES M for the overall sample. Estimates of M and F for males using the VBGP of the Gulland and Holt plot were not applicable as the M value was greater than the Z value.

The estimate of M using the VBGP of the Ford-Walford plot was almost as high as Z for males indicating that the F was very low. F for female lemon sole was higher than M for all three estimates, indicating that fishing takes greater numbers of females annually than natural causes of death.

3.9 Yield Per Recruit

Yield Per Recruit (YPR) is shown on Fig. 3.9.1 for the overall sample of lemon sole. Three different Natural Mortality (M) values were used for the computation of the YPR model. These are shown on Table 3.9.1. M1 and M2 were generated by the empirical equation of Pauly (1980) using the VBGP from the Rafail method and the Ford-Walford plot, while M3 is an arbitrary value assigned by the ICES.

F_{max} is the value of Fishing Mortality (F) associated with the highest yield per recruit (Y/R) value that is possible and $F_{0.1}$ is the value of F at which the slope of the Y/R is $^{1}/_{10}$ of its value at the origin. Reference points for F_{max} are shown on Fig. 3.9.1 while reference points for $F_{0.1}$ are shown on Fig. 3.9.2. Results of the two models are shown in Table 3.9.1. The highest rate of Natural Mortality (M2) gave rise to the highest yield per recruit for both reference points, while the lowest rate of Natural Mortality (M3) produced the lowest yield per recruit for both reference points. F_{max} produced higher MSY values than the $F_{0.1}$ for all three M values.

Table 3.9.1 Results of the Yield Per Recruit Model for lemon sole off the west coast of Ireland.

	M1	**M2**	**M3**
M	0.28 (Ford-Walford plot)	0.41 (Rafail)	0.12 (ICES)
F_{max}	0.95	1.2	0.42
MSY (F_{max}) (g)	1950	2960	1230
$F_{0.1}$ Slope	0.45	0.65	0.25
MSY ($F_{0.1}$) (g)	1700	2650	1160

Fig. 3.9.1 Yield Per Recruit for lemon sole sampled off the west coast of Ireland between Nov 2000 - Feb 2002, using 3 values for M (from Table 3.8.1).

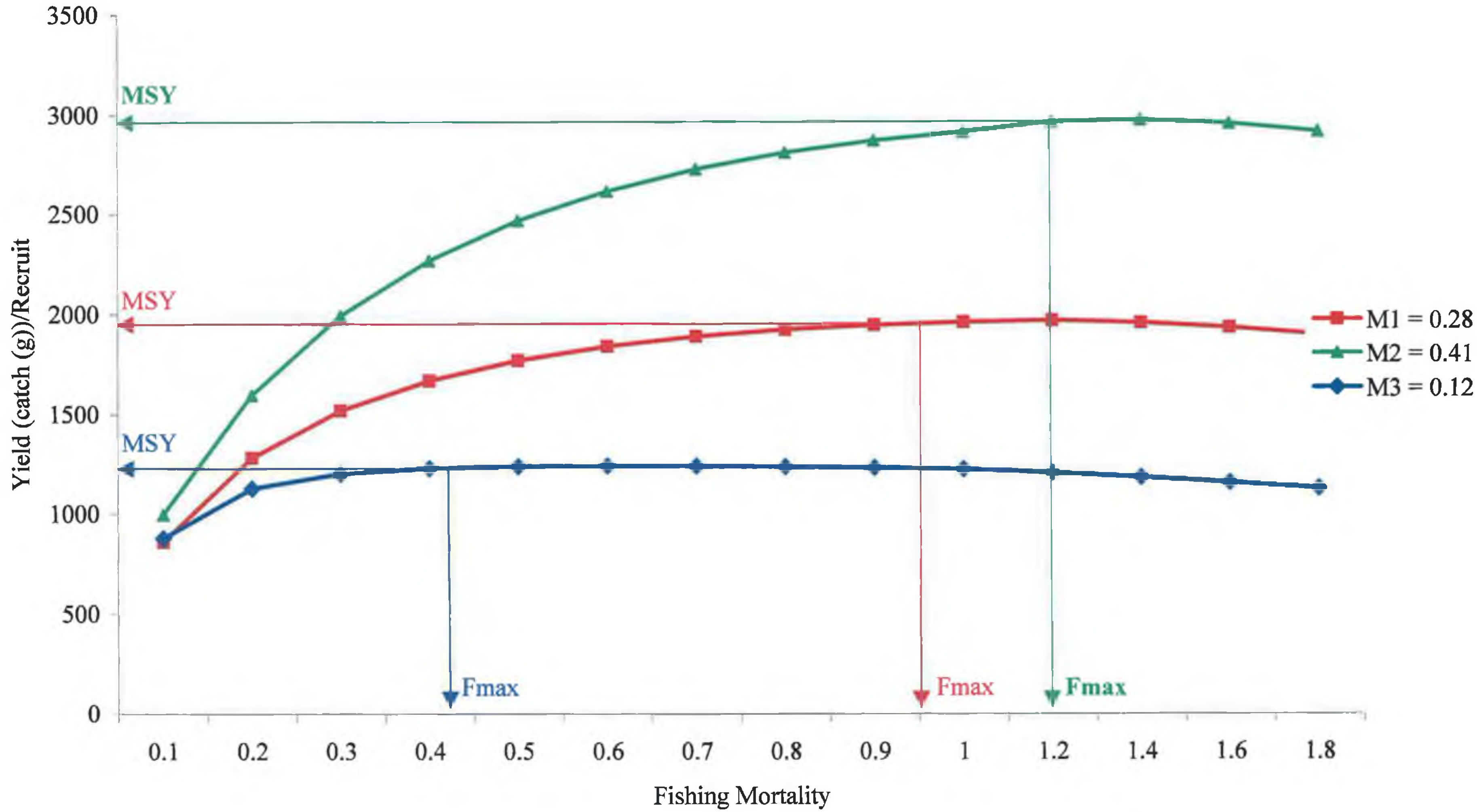
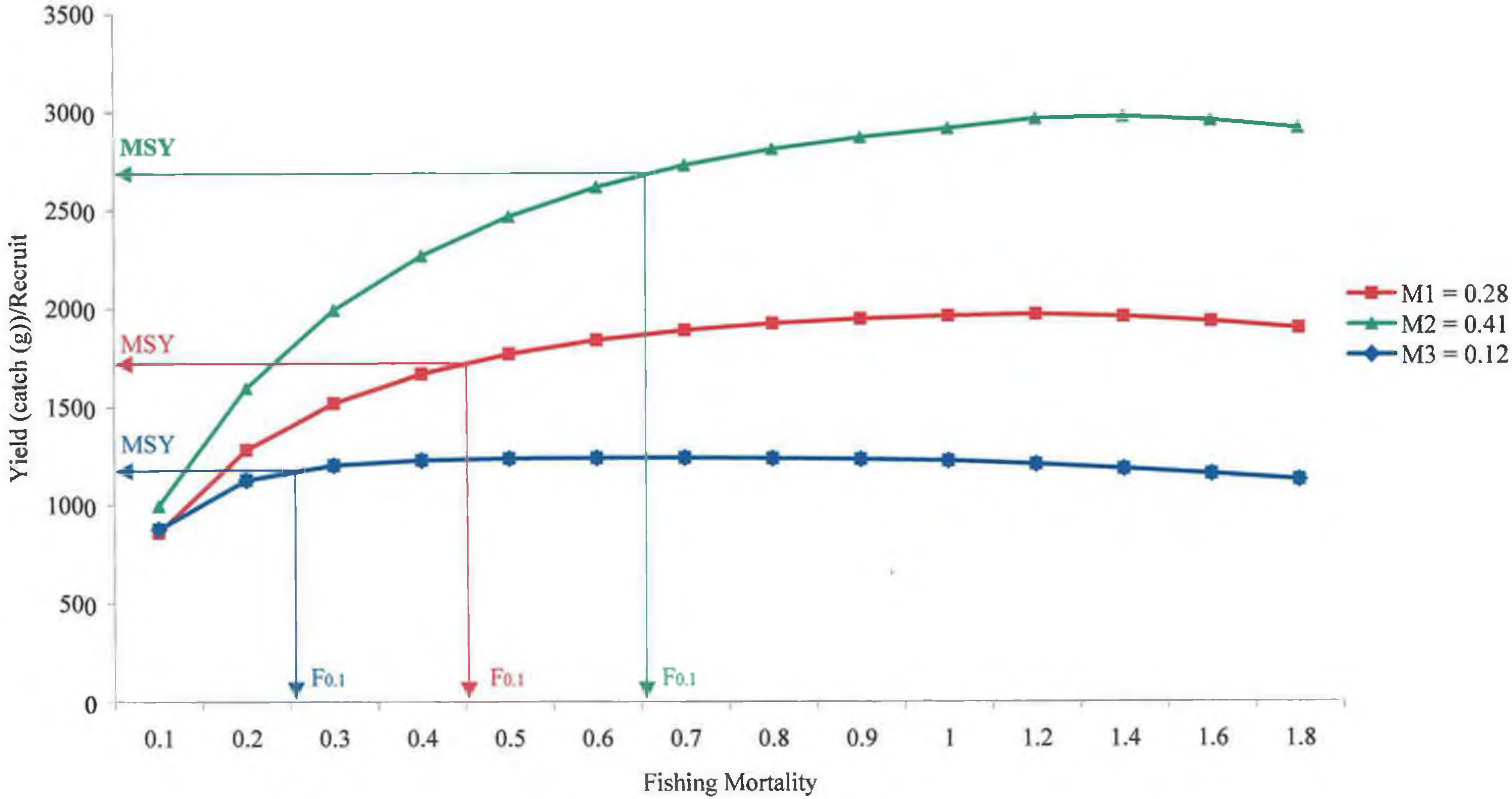


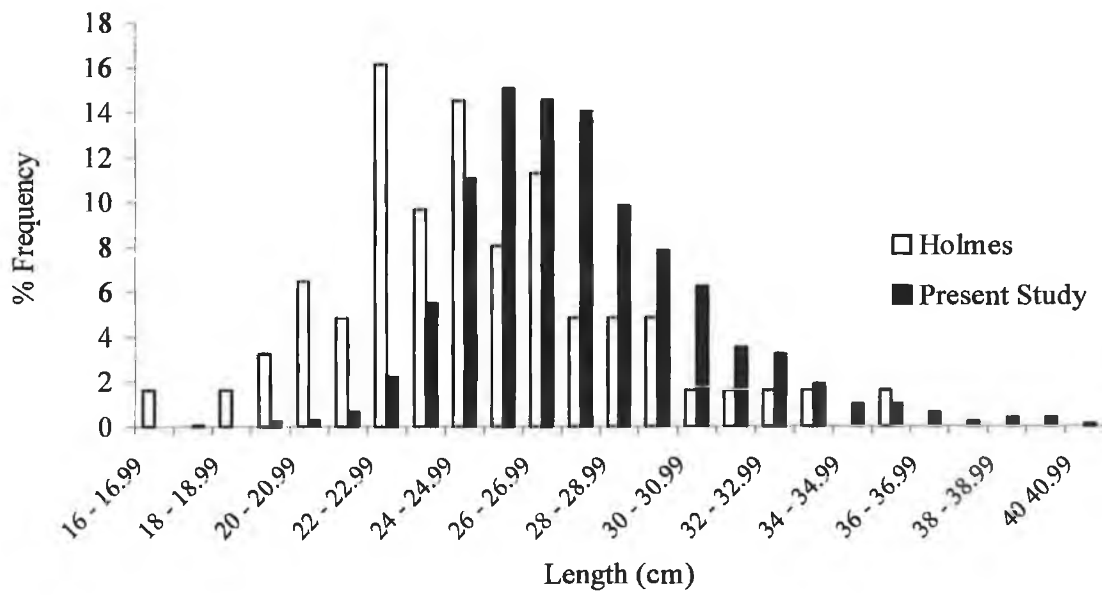
Fig. 3.9.2 Yield Per Recruit for lemon sole sampled off the west coast of Ireland between Nov 2000 - Feb 2002, using 3 values for M (from Table 3.8.1).



3.10 Discards

The percentage length frequency for a discard sample (N = 62) of lemon sole (data sourced from T. Holmes) off the south west of Ireland is shown with the percentage length frequency for the data of the present study in Fig. 10.1. Lemon sole discards from the south west coast ranged from 16cm to 35.99cm, while the commercial catch on the west coast ranged from 17cm to 40.99cm, (the 17 – 17.99cm class fish for the west coast was from a commercial sample which included discards). The highest percentage of lemon sole discards off the south west coast of Ireland were 22 – 22.99cm, while the highest percentage of commercial fish landed on the west coast ranged from 25 – 27.99cm.

Fig. 3.10.1 Percentage Length Frequency for lemon sole discards sampled in Dingle Bay off the south west coast of Ireland from Oct 2001 to Jan 2002 (Data sourced from Tony Holmes) and for the lemon sole sampled off the west coast of Ireland from Nov 2000 – Feb 2002.



4 DISCUSSION

Fish used for this project were sampled from commercial fish at the point of sale. These fish arrived at the point of sale after a series of steps where size selection was likely to have occurred. These were net selectivity, discard selectivity, on board box selectivity and selection at the point of sale.

Net selectivity is inevitable. The nets used off the west coast of Ireland to target *Nephrops* or mixed demersal fisheries have a minimum diamond shape mesh size of 80mm at the cod end. Mesh size regulations have to take into account differences in selectivity, due to the mixed nature of fisheries (Daan 1997). Fish smaller than L_c (mean length at first capture) should not be retained within the net unless the cod end is tightly packed with the catch thereby blocking the exit. L_c was not determined for lemon sole during the present investigation. The length-width ratio of lemon sole taken from Wheeler (1969) suggests that fish greater than 14cm would not be caught by an 80mm mesh. The smallest fish recorded by Smith (pers. comm.) caught off the west coast of Ireland was 15cm.

Fishermen discard any lemon sole smaller than marketable size. This method of selection is by eye. The practices of discarding depends on catch rates and total allowable catch (TAC) constraints but vary on all spatial and temporal scales (Daan 1997). Minimum landing size for lemon sole was 25cm in total length. However, following new EU legislation produced in 1998, there is no current minimum landing size for lemon sole off the west coast of Ireland. However, the length data presented suggests that a size of approximately 25cm is still used by the fishermen. A comparison of the length frequency of discards with that of the landed samples points to this. Lemon sole discards off the west coast of Ireland range from 15cm upward (T.

Smith pers. comm.), while off the south west coast discards ranged from 16cm to 35cm (T. Holmes pers comm.). A number of surveys have been carried out on the impacts of discarding fish. Evans *et al.* (1994) reviewed the *Nephrops* fishery of the Farne Deep, within the North Sea. He found that for every 52kg of lemon sole caught 39kg were discarded. The survival rate of discarded lemon sole is thought to be zero as all those caught were dead within 15 minutes (Evans *et al.* 1994). Lemon sole were among the five highest discards of non-commercial species in the Danish and Scottish North sea fleet (Clucas 1997).

If space is limited on board, fishermen tend to discard even the marketable lemon sole as they are not the most commercially valuable species landed. Then space is available on board for the more valuable species, such as *Nephrops*. This on board sorting could have a very significant effect on the results of the project and is an area of study which needs further investigation. A report on discards and by-catch information has recently (March 2002) been produced by ICES Advisory committee on Fishery Management (Anon 2002b). This report does not include lemon sole discard information, however, as it is a non-quota species. Daan (1997) stipulates that it is unknown to what extent variable discard rates have at present undermined the scientific evaluation of the state of the flatfish stocks.

Following discarding of non commercial sized fish, sorting of the marketable fish begins on board. Most fish retained are then sorted into boxes containing small, medium and large categories depending on the preference of the fish merchants (S. J. Moore pers. comm.). However, as quantities of lemon sole caught are small, they are usually landed unsorted (T. Smith pers comm.). Therefore this form of sorting is not relevant to the analysis of lemon sole during the present investigation. The fish are simply thrown haphazardly (see Krebs (1989) for a definition of the word haphazard in ecological methodologies) into boxes to be sold at the auction hall.

During the present study, a box of lemon sole was haphazardly selected from the auction hall floor. At various times, this selection was made by the author or the fisheries assessment technician (FAT) at Rossaveal. Alternatively, boxes were bought by the manager of Galway Bay Seafoods (GBS) fish processing plant and one of these was made available to the author. On consultation with the manager of GBS, the author was informed that no further sorting of the box occurred.

All fish delivered to the laboratory were used for the present investigation therefore no further sorting took place after purchase. In summary, size selectivity undoubtedly occurred at the net and discarding stage. The scale of the effects of these selectivity measures is as yet unknown.

No 0 group or 1 year old fish were captured during the investigation. Juveniles are thought to occupy rough grounds inaccessible to fishing trawlers (Rae 1965). Older juvenile fish either may have escaped through the net or they may have been discarded. Therefore, it is likely that the size structure of the sampled population is very likely changed by the disproportionate removal of the smaller specimens, thus artificially increasing the observed mean length at age for younger fish in the sample. This would produce a bias in favour of larger fish and caused a skew in the length frequency distribution. Possible additional impacts of the sampling method will be reviewed throughout the discussion.

During the investigation, the departure from a 1:1 ratio in favour of females in the overall catch was very highly significant (χ^2 = 586.63, P < 0.001), with a male to female sex ratio of 1:3.6. The male to female sex ratio for lemon sole sampled off the west coast of Ireland between March 1978 – September 1979 also gave a statistically significant departure from a 1:1 sex ratio (M:F – 1:1.7) in favour of females (King 1982) indicating that the dominance of female lemon sole in this area is not a recent phenomenon. The dominance of females was observed each month over the sampling period and at each age in the present study. 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 becomes progressively more evident as the fish grows older. By contrast, King (1982) found males dominated the catches of June, July, August and September, whereas females dominated all other months sampled (with the exception of February 1979 which gave a M:F sex ratio of 1:1). The sampling method used for the investigation by King (1982) differed from that of the present study. King (1982) included discards. Therefore, the sex ratio may have been influenced by the presence of smaller fish, as the present study has shown that the small fish are dominated numerically by males.

There are five hypotheses which might explain this consistent departure from a 1:1 male to female sex ratio.

I There are not as many male lemon sole as there are females in the stock.

II Lemon sole display differential distribution among the sexes.

III The fishing method is biased in favour of females.

IV Lemon sole change sex at some point in their life cycle and males become females.

V The discarded fish are predominantly males.

The first hypothesis presented here can only be accepted if all the others are rejected.

Differential distribution of sexes is seen in a number of fish species. Swain and Morgan (2001) found female American plaice (*Hippoglossoides platessoides*) in the southern Gulf of St. Lawrence and off Newfoundland generally occupied warmer waters than males. Merrett and Haedrich (1997) found a differential distribution in that female abyssal grenadier (*Coryphaenoides armatus*) dominated significantly in the deeper waters over the distribution of the species. It is not known whether lemon sole show differential distribution. It is interesting to note that males were most abundant from April to July 2001 and least abundant in January and February 2001. The greatest abundance of males does not, however, correspond with the peak spawning season. Jennings *et al.* (1993) state that lemon sole remain in the same area of the western Channel throughout the year, suggesting that they do not display migratory patterns.

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 from the nets. Additionally, lemon sole show sexual dimorphism in that males have a relatively longer tail length than females. This sexual dimorphism might have an influence on swimming speed or manoeuvrability thus allowing males to escape from the nets in greater numbers than females. Male lemon sole may also display better tactics of avoidance of the fishing nets. Reactions of fish to gear during trawling operations have been described by Engas (1994). Since fish have well developed visual and auditory senses and many species have remarkable swimming capabilities, they are often able to detect an approaching trawl and attempt to avoid capture (Engas 1994). Sexual dimorphism, where females are larger than males has also been noted in witch off the Norwegian fjords (Gutvik *et al.* 1992).

It is possible that lemon sole change sex as they reach a certain length. The relative abundance of male lemon sole was at its highest in the smallest length categories in the present investigation, while females showed the opposite pattern (Fig. 3.3.5). Lemon sole in this study present the possibility of protandry, as males mature at a slightly earlier stage than females. The advantage of such a sex change as proposed by Warner (1974) is that less energetically demanding sperm are produced by small animals, while the more energetically demanding eggs are produced by the largest members of the population. The female lemon sole of the present investigation were found to attain a greater size than the males. Sex change from female to male has been recorded in honeycomb grouper at 4 to 6 years of age (*Epinephelus merra*) as a natural occurrence (Kobayashi *et al.* 2000). Naturally occurring sex reversal has also been observed in ballan wrasse (*Labrus berggylta*) (Elofsson *et al.* 1999). Hendry *et al.* (2001) have used steroids to change the sex of Atlantic halibut (*Hippoglossus hippoglossus*) and found a 97 – 100% success rate.

Mean lengths for male lemon sole sampled were significantly less than that of females, with females attaining greater lengths than males. Only males were recorded in the smaller length categories. It is possible that high numbers of male lemon sole were discarded as the males were more abundant in the smaller length categories.

It is not possible at this stage of research to determine the validity of any of the above hypotheses. This feature, where females outnumber males, is not limited to lemon sole off the west coast of Ireland. Sex ratios observed for several other flatfish off the west coast of Ireland are presented in Table 4.1. The dominance of females was significant in all cases (where N > 20) except one. Plaice (*Pleuronectes platessa*), which were sampled during the plaice spawning season, showed no significant departure from the expected 1:1 M:F sex ratio. An overwhelming dominance of females among megrim (*Lepidorhombus whiffiagonis*) has been determined (Robson pers. comm.) off the west coast of Ireland. All samples for the Robson study have been landed from commercial fishing trawlers. Molloy (2002) examined a sample of megrim discards obtained from the same area as Robson's commercial samples. The difference in the sex ratio observed shows that among the smaller megrim a 1:5 M:F sex ratio was observed, while in the larger fish a 1:39 M:F sex ratio was observed. Both showed that females dominated. However, the dominance was seven times greater in the commercial samples when compared to the discards. This is an indication as to the extent of the bias effect of limiting samples to commercially landed individuals.

Table 4.1 Male to Female Sex ratio for several flatfish species together with chi square (χ^2) values and significance levels.

(= Significant, ** = Highly Significant, *** = Very Highly Significant,* NS = *Not Significant)*

Species	Location	N	M:F Sex Ratio	χ^2	Significance	Source
Glyptocephalus cynoglossus	West coast of Ireland	332	1:3.6	106.46	***	O Dwyer (2000)
Lepidorhombus boscii	West coast of Ireland	150	1:3.4	44.82	***	Robson *et al.* (2000)
Pleuronectes platessa	West coast of Ireland	239	1:0.8	2.32	NS	Byrnes (2002)
Solea solea	West coast of Ireland	1,117	1:1.4	28.68	***	King (1982)
Microchirus variegatus	West coast of Ireland	605	1:4.5	207.6	***	King and Fives (1990)
Buglossidium luteum	West coast of Ireland	268	1:5.5	129.1	***	King and Fives (1986)
Pegusa lascaris	West coast of Ireland	18	1:1.25	0.22	NS	King (1982)
Lepidorhombus whiffiagonis	West coast of Ireland	5,472	1:39.1	5066	***	Robson (pers. comm.)
Lepidorhombus whiffiagonis (discards)	West coast of Ireland	69	1:2.1	69.0	***	Molloy (2002)
Lepidorhombus whiffiagonis (discards)	South west coast of Ireland	121	1:5.4	121.0	***	Molloy (2002)
Limanda limanda (discards)	West coast of Ireland	290	1:1.6	16.9	***	Walsh (2001)

Lemon sole sampled from the west coast of Ireland ranged in size classes from 17-17.99 to 40-40.99cm in total length. The smallest fish in the overall sample was a 17cm male. The latter fish was from a sample which included discards. The youngest and smallest lemon sole sampled in the Galway Bay area between March 1978 – September 1979 was a one year old male of 11.5cm in total length (King 1982). This specimen was caught using commercial trawlers fishing for *Nephrops*. Discards were included in the landed sample. The smallest fish found in a beam trawl survey on lemon sole off the western English Channel was 18cm in total length (Jennings *et al.* 1993). The largest fish of the present sampling period was a female measuring 40.9cm in total length. The largest and oldest lemon sole sampled in the Galway Bay area between March 1978 – September 1979 was a nine year old female measuring 37.4cm in total length (King 1982). 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 this investigation or that of King (1982). The most frequently recorded total length class for male lemon sole off the west coast of Ireland from 1978 – 1979 was 15-16.99cm, while for females it was 17-18.99cm (King 1982). Males ranged from 11cm to 33cm, while females ranged from 13cm to 39cm. The results of the current study are not directly comparable to that of King's (1982) as the latter included discards. The most frequently recorded size class recorded in the present investigation is biased by the discarding activities of the fishermen. Male lemon sole in the present investigation 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. This feature was also noted by Rae (1939a) and King (1982). Rijnsdorp *et al.* (1992) also found this pattern with dab, where female dab were found to attain a mean greater length than males in the south eastern North Sea.

Ages for lemon sole captured off the west coast of Ireland during the 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 one to nine years for lemon sole sampled in the Galway Bay area. The limited age range reported by King (1982) when compared to the present study may be due to the smaller numbers analysed (N = 472). 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. Low numbers of small lemon sole have also been noted by Holmes (pers. comm.) in a study of discards from Dingle Bay off the south west coast of Ireland. The smallest lemon sole encountered by Holmes was a 16cm fish, and numbers at this length were rarely encountered. This contrasts with dab, which are caught in very high numbers at 16cm within the same sampling area, using the same gear. The smallest dab encountered were 12cm in total length (Holmes pers. comm.). 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 2000). Male and female lemon sole in the present investigation attained 14 years of age. The most frequently recorded age group for the overall sampling period was age group 5. 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, again this may have been due to the presence of the discards in the samples. Bimodal distribution was observed in King (1982) for the females at age group 5, with modal classes at 19-20.99cm and 29-30.99cm. This was not apparent from the present results.

The length-weight relationship gave rise to 'b' values (3.250 for the overall sample, 3.091 for males and 3.255 for females) which were close to 3, indicating that lemon sole grow isometrically, i.e. increases in all dimensions at the same rate (King 1995). For comparative purposes, the length-weight relationship for the overall sample of the current study is shown in Table 4.2 with that of lemon sole in the North East Atlantic as estimated by Coull *et al.* (1989) and that of the west coast of Ireland between 1978 - 1979 as estimated from the data of King (1982).

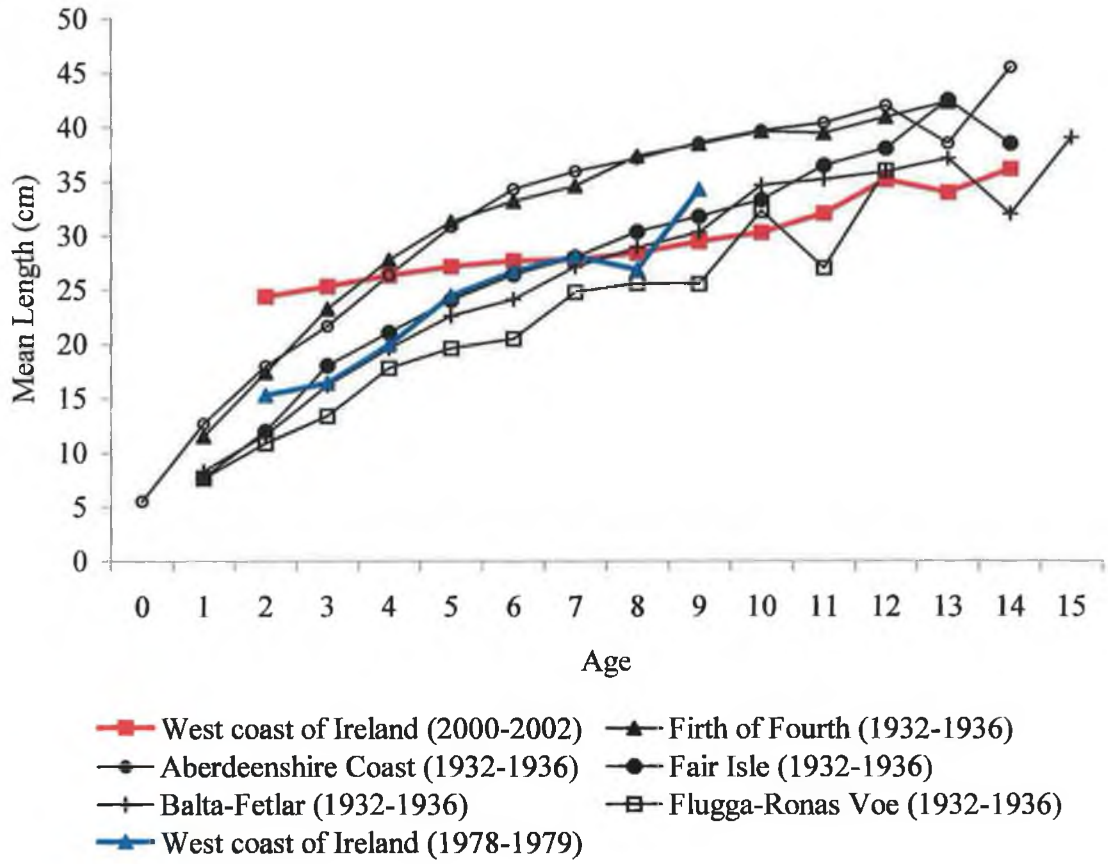
Table 4.2 Length-weight relationships for lemon sole, with weight estimates at 20cm and 40cm length classes.

Source	Length-Weight Relationship	Weight Calculated 20cm Length Class	Weight Calculated 40cm Length Class
Present Study	$W = 0.0044L^{3.250}$	74g	708g
King (1982)	$W = 0.0067L^{3.158}$	86g	768g
Coull *et al.* (1989)	$W = 0.0255L^{2.7643}$	101g	684g

Female lemon sole were significantly heavier than males, a feature found in many flatfish (Santos 1994). The parameters estimated from the data of King (1982) yield a higher weight for the length of the lemon sole at all lengths when compared to the 'a' and 'b' values attained from the present investigation. This suggests that the lemon sole off the west coast of Ireland do not grow as well as they did during the 1978 – 1979 investigation by King (1982). The parameters of Coull *et al.* (1989) yield a weight that is higher than that of King (1982) or those attained from the present investigation at the lower length class of lemon sole. However, the parameters of Coull *et al.* (1989) yield a lower weight for length at the upper length class.

Females at all ages showed a larger mean length than males. However the difference was not significant as confidence intervals overlapped. For comparative purposes mean length at age for the sample of lemon sole off the west coast of Ireland for the present investigation and that of King (1982) were plotted with results of Rae (1939) for Scottish waters in Fig. 4.1.

Fig. 4.1 Mean length at age for lemon sole sampled in a number of areas in 1932-1936 (Rae 1939a), 1978-1979 (King 1982) and 2000 - 2002 (present study).



Lemon sole in all areas studied by Rae (1939) and King (1982) showed greatest growth (increase in mean length at age) in the early years of life. In many species of fish, growth decreases in both sexes with the onset of maturity (Roff 1983). This pattern whereby growth was at its fastest at the early years of life was not apparent from the data in the present investigation. As discussed previously, the sampling method was biased in favour of larger fish and the smaller fish within the younger age categories were not caught or else were discarded. This would explain the observed pattern. The maximum age recorded by King (1982) was 9 years. The mean length at age 9 for the fish sampled between 1978 – 1979 (King 1982) was greater than that of the 9 year olds of the present investigation, suggesting that the lemon sole off the west coast of Ireland today do not reach as large a size at age 9 as they did in the late 1970's.

The areas of fastest growth identified by Rae (1939) were the Firth of Fourth and the Aberdeenshire Coast, while growth was not as good in the Flugga-Ronas Voe and the Balta-Fetlar areas. Lemon sole off the west coast of Ireland in the present investigation were found to reach similar ages to those sampled between 1932 – 1936 off Scotland (Rae 1939a). However, the mean length at ages 12, 13 and 14 were closer to those of the areas identified as slow growth areas by Rae (1939a) than the areas identified as fast growing areas, indicating that the west coast of Ireland supports a slow growing stock of lemon sole.

Mature males and females were recorded in the smallest length class recorded 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 (2001) where lemon sole were said to be mature at a length of 17cm around the Irish coast. Data analysed by the author from King (1982) indicates 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 between 1978 – 1979. Maturity oogives were not attempted on the data of the present study. This was due to the low numbers of small, and therefore immature fish encountered.

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 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 (Heesen 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 March to July, while, males spawned from January onwards. 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, wheras 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 between 1978 – 1979. Present day results indicate that the females off the west coast of Ireland show similar patterns to the stock of 1978 – 1979.

Numbers of lemon sole otoliths showing an opaque edge were highest in the warmest months of the year (July, August and September 2001). This is an indication at to the period of fastest growth and peak feeding intensity (Cailliet *et al.* 1986). King (1982) found the peak opaque edge for lemon sole occurred from June to August off the west coast of Ireland between 1978 – 1979.

The von Bertalanffy growth model was chosen to describe the growth of the population of lemon sole off the west coast of Ireland. Three methods of calculating the von Bertalanffy growth parameters (VBGP) were used (i.e. the Ford-Walford plot, the Gulland and Holt plot and the method of Rafail). The three methods of calculating the VBGPs provide different results. All three methods were attempted on each component of the stock, males and females combined, males only and females only. However some of the results obtained were invalid. The problems of selectivity in the sampling method can be seen in the VBGPs calculated. Fish numbers in the extreme upper and lower age groups were low and those in the younger age groups were biased towards the larger fish of that age. These biases have a major impact on the von Bertalanffy growth curve and it is for this reason that three separate methods of attaining the VBGPs were used in the assessment of the stock.

L_∞ calculated (48.4cm) from the Ford-Walford plot for the males and females combined is reasonable as is greater than the largest fish in the population, yet within the size range known elsewhere for lemon sole. The growth rate (K) of 0.1262 year $^{-1}$ was also reasonable from the Ford-Walford plot when compared with that of the Gulland and Holt plot (K –0.0656 year $^{-1}$) which is inappropriate. The latter would indicate negative growth. The L_∞ value attained for the overall sample from the

Gulland and Holt plot of 14.5cm is an unrealistic value as it is smaller than the smallest fish in the sample. The three L_∞ values calculated using the Rafail method are realistic as they are similar to values observed within the larger fish sampled within this stock (1st L_∞ = 37.4cm, 2nd L_∞ = 35.6cm and 3rd L_∞ = 34.5cm). K values obtained using Rafail's method were also reasonable. Values estimated for t_0, for the overall sampled population is valid only from the Ford-Walford plot as the lemon sole may have been 0.7 of a year upon release from the egg.

VBGPs obtained for the males of the population from the Rafail method were poor, t_0 values were inappropriate. K values were very low, yet L_∞ values were very high. The high L_∞ values can be attributed to the inappropriate t_0 values. In contrast, values attained using the Ford-Walford plot and the Gulland and Holt plot were realistic. L_∞, and K were within the ranges expected. L_∞ values were similar 28.21 (Ford-Walford) and 27.27 (Gulland and Holt) for the two assessments. Observed lengths for males did, however, exceed these values. K values differed between the two models. Male lemon sole appear to grow over twice as fast using the Gulland and Holt plot than those from the assessment of the Ford-Walford plot. t_0 values differ by almost five times, with the Gulland and Holt Plot result being the more likely value.

VBGPs obtained from the Ford-Walford plot for the females of the population were inappropriate. L_∞ indicated a maximum size which was smaller than any fish sampled, the K value was very low and it was not possible to calculate t_0. However the Gulland and Holt plot provided a reasonable value for L_∞ as it was larger than the largest female lemon sole sampled, yet the t_0 and K values observed were highly unlikely.

Rafail's method showed values most appropriate for L_∞, as they were within the size category of the largest females sampled. K values were low, yet reasonable, and t_0, while inappropriate was not as high as that calculated from the Gulland and Holt plot.

Numbers of males in the sample were low (N = 360). This may have contributed to the wide variation of VBGPs in males resulting from the different methods used. The results of the Ford-Walford plot and that of the Gulland and Holt plot combined produced the most appropriate results. VBGPs calculated from the Rafail method were most suitable for the females. Results were most appropriate when the population was assessed as an overall population using the method of Rafail to calculate the VBGPs.

L_∞ for the present study using the method of Rafail (1973) can be compared to the L_∞ value for lemon sole sampled between 1978 – 1979 (King 1982). VBGPs were calculated on the 1978 – 1979 data by the author in the present investigation using the method of Rafail (1973). The 2000 – 2002 stock (present study) showed an L_∞ of 34cm, while the stock of the 1978 – 1979 (King 1982) showed an L_∞ of 39cm. K values can also be compared for the two periods. K for the present stock was calculated as 0.1955 year^{-1}, while that of the stock of 1978 – 1979 was 0.1788 year^{-1}. The higher the K value the faster the fish grows. 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) interpreted data from the North Sea from Rae (1965). He found lemon sole in the North Sea had an L_∞ of 37cm. This L_∞ is higher than the L_∞ of 34cm which was calculated for the present stock off the west coast of Ireland. 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 of the North Sea grew better than the present stock 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. Life-history strategy has been linked to the resilience of populations to fishing pressure in the North Sea (Jennings *et al.* 1999). Jennings *et al.* (1999) 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 and length at maturity have decreased with time and the L_∞ has also shown to have decreased since the late 1970's as shown from King's (1982) data, yet the K value has increased from that of King (1982). Therefore the results of the present investigation agree with the trends seen in Jennings *et al.* (1999). Rae (1951) reports on the stock of lemon sole off Scotland between 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 (Froese and Binohlan 2000).

Variations in VBGPs within a stock have been reviewed in a number of papers. K values for the long rough dab varied considerably in a study from Stratoudakis *et al.* (1997) from 0.08 in the Central North Sea to 0.17 in the Northern North Sea. In a study conducted by Rijnsdorp *et al.* (1992) values for L_∞ were lower for male dab in the south eastern North Sea when compared to females. Yet K values were not always lower for males. Male K values in Rijnsdorp *et al*'s (1992) study ranged from 0.26 to 0.39 while female K values ranged from 0.19 to 0.28.

The growth models plotted using the VBGPs calculated show different patterns for males, females and the overall population. The parameters of the Ford-Walford plot produce a moderately increasing growth curve for the overall population whereas the growth curve resulting from the Rafail VBGPs show a slower growth pattern. The Ford-Walford plot growth curve underestimates the mean age at the younger end of the curve and overestimates the mean age at the older end of the curve. The growth curve of Rafail shows faster growth at the early ages than in later years of life. The method of Rafail (1973) accounts for the fact that numbers are low in the upper and lower extremes of the population and therefore it does not distort the growth curve. This method puts emphasis on the high numbers in the midrange of the age groups and goes through the centre of these points. The model is therefore inclusive of all fish. In addition the calculated maximum age, t_{max}, of 15.3 years estimated from the VBGP K of the Rafail method, was closest among the models to the actual maximum age observed. If a lemon sole off the west coast of Ireland lives to an age near its maximum age of 15.3 years, it will have lived 87% of its life-span after sexual maturation. This enables lemon sole to invest energy and time in reproduction over many spawning years.

The growth curves produced from the Gulland and Holt model showed slower growth patterns than that of the Ford-Walford plot or the Rafail method, for males and females respectively. Females grew at a faster rate than males particularly in later years. Rae (1965) states that after maturity female lemon sole grow at a faster rate when compared to males. Lemon sole around the Irish coast were found to be mature at 2 years of age according to the present study, Anon (2001) and at 2.5 years King (1982). The growth curves show females are growing faster than males from 2 years of age and this difference in growth rate between males and females increases with increasing age off the west coast of Ireland. In fish, fecundity generally increases with size and hence, all other things being equal, there are selective pressures for continued growth of females. There is no such pressure on males (Roff 1983). Faster growth in females has also been observed in Amercian plaice on the Flemish Cap in a study by Bowering and Brodie (1994). In this study growth rates were similar between the sexes up to age 3, however beyond age 3, females grew faster. Male American plaice in Bowering and Brodie's (1994) study were found to be mature at age 3, while females were found to be mature at 4 years of age. Santos (1994) found female megrim growing faster than males off the Portuguese coast. Gutvik *et al.* (1992) reports that female witch become longer than males after 4 years of age.

Newer growth models have attempted to incorporate factors contributing to growth. Roff (1983) for example, presented a model of growth and reproduction in fish, which incorporates the trade-offs between the two. Schnute and Richards (1990) present a unified approach to the analysis of fish growth, maturity and survivorship. Pauly *et al.* (1992) introduced a new model which modifies the von Bertalanffy growth function and accounts for seasonal cessation of growth in fishes. All these models, however, require additional data, such as, more intensive reproductive work and historical information on the species.

The age at full recruitment (t_r) for males in the present study was determined to be 5 years. This was one year younger than that of females, while the overall t_r was 6 years. A t_r value of 5 or 6 is good for this stock as the fish are mature at 2 years of age. Females are given 4 years initially to contribute to the new recruits and males are given three years to contribute to recruitment before they reach t_r and so are fully recruited to the fishery. This could support sustainability in the lemon sole stock off the west coast of Ireland. In the study off the west coast of Ireland between 1978 – 1979 (King 1982), the age at full recruitment was found to be 4 years.

The catch curve depicting the length at full recruitment (l_r) for males and females indicates that males are smaller than females when fully recruited to the fishery. Male lemon sole were found to be fully recruited at 25cm (TL), while females were not full recruited until they were 28cm (TL). Mean length at age data for male and female lemon sole highlights the pattern that male lemon sole at age 5 are smaller than females at the same age as was evident at all ages. This indicates that males are being caught in greatest numbers at a smaller length category than females. Numbers of males in the older age groups of this study were less than that of the numbers of females in the greater age groups.

The absence of the discards in the present investigation, as discussed earlier, may have had a significant impact on the results of the catch curves. Fish at the length of l_r and upward are more marketable than smaller individuals, therefore discard selectivity by the fishermen could be distorting the shape of the catch curves. If discards were included the t_r and l_r values would probably shift to the left of the curve giving rise to a result similar to that of King (1982), indicating a smaller and younger size and age at full recruitment to the fishery for both male and female lemon sole. This highlights the impact of the discard selectivity in fishery assessments which use only commercial samples.

Total mortality co-efficients (Z) were estimated on the age based catch curves. These estimates should be accurate as the absence of the discards would be expected to impact on the left side of the curve not the descending leg where Z is estimated. Z was lower for male lemon sole than for female lemon sole. The estimates of the co-efficients of Natural Mortality (M) varied among the components of the populations examined and the methods of attaining VBGP (which were used in the calculation of M coefficients). Estimates of M for males were higher than for females, a feature which has been noted for megrim in Santos (1994) and was said to be a common occurrence in fish stocks (Cardador 1988). Estimates of M and the Fishing Mortality co-efficient (F) for the males indicated that fishing effort impacted only very slightly or not at all on the males. However, when the arbitrary M as set by ICES for plaice and common sole off the west coast of Ireland was applied to the male population, there was an indication that males were three times more likely to die from the effects of fishing than from natural causes.

Estimates of M for females provided results which were more realistic than those for males. The first estimate of M calculated based on the VBGP of the Rafail method gave an F value of 0.36. This indicated that females were 1.4 times more likely to die from fishing effort than from natural causes. The second estimate of M calculated based on the VBGP of the Gulland and Holt plot lead to an F value which indicated that females were 3.5 times more likely to die from the efforts of the fishing industry when compared to dying from natural causes. The M value calculated in the latter case was 0.14. The arbitrary M value as assigned by ICES for common sole and plaice off the west coast of Ireland is 0.12. This is close to the estimate of 0.14 as described above. An M value of 0.12 applied to the females would indicate that lemon sole were four times more likely to die from fishing effort than from natural causes. In fisheries it is best to err on the side of caution. It is for this reason that ICES have set the arbitrary value of M so low.

The stock was finally reviewed considering males and females combined. Again a range of estimates for mortality was obtained. The M estimated on the VBGP calculated from the Rafail method (0.41) indicated that lemon sole were not under any threat from the fishery as the fish were more likely to die naturally. The second estimate of M using the VBGP calculated from the Ford-Walford plot (0.28) indicated that lemon sole off the west coast of Ireland were 1.3 times more likely to die from fishing effort than from natural causes.

As plaice are a member of the same family as lemon sole it is possible to draw some comparisons on the sustainability of the stock. When the F values estimated (on the catch curve) for the lemon sole stock (0.23 (Rafail), 0.36 (Ford-Walford) and 0.52 (ICES)) are compared to that of the plaice stock off the west coast of Ireland (ICES division VIIb) it is obvious that fishing mortality is much lower for lemon sole. Plaice off the west coast of Ireland currently have an F value reaching almost 0.8 and this is expected to rise (Anon 2001a). In addition to this high F value, landings of plaice from the west coast of Ireland mainly comprise of 3 and 4 year old fish which make up 72% of the total landings. Lemon sole landings are made up of 5 year old fish primarily and the age groups are more evenly distributed throughout the catch. Lemon sole also reach much greater ages than that of plaice off the west coast of Ireland. Therefore the M value is most likely higher for lemon sole than for plaice off the west coast of Ireland.

There are no concerns about the state of the stock of common sole off the west coast of Ireland, as recruitment is high and the maximum age recorded off the west coast is 15 years. The landings are made up of 4 year olds primarily. Fishing mortality is currently 0.21 and it is decreasing (Anon 2001a). This is lower than the three current estimates for lemon sole from the catch curve of the present study. This indicates that fishing mortality is higher on the stock of lemon sole off the west coast than that of common sole.

The state of the stock of lemon sole off the west coast of Ireland has not been addressed in detail prior to this study. M, F and Z values given here are the first estimates obtained. It is therefore necessary to conduct long-term investigations to determine the actual state of the stock. Further studies should include data from discard surveys and surveys to determine t_c and L_c, age and length at first capture.

The M values estimated for the overall stock were applied to a Yield Per Recruit (YPR) curve (Beverton and Holt 1959) and plotted against increasing F values. This is a slightly outdated method of assessing stocks (Pitcher and Hart 2000). However, it is still in use today and thus used here for comparative purposes. Jones and Wells (2001) used this model to assess the state of the stock of black drum (*Pogonias cromis*) off the east coast of the United States. They state that these models are typically used in management to regulate fishing mortality in order to obtain sustainable harvests of the stock. Jones and Wells (2001) found that the black drum were not under threat. The YPR method in the past has, however, lead to collapse of fisheries giving rise to incorrect reference points. Therefore it should always be used with caution.

A slight increase in the M value has considerable effects on the maximum sustainable yield (MSY) as shown on Fig. 3.9.1 and Fig. 3.9.2. Allowing for an M of 0.41 (calculated using the VBGP of the Rafail method) would give rise to a very intensive maximum fishing mortality (F_{max}) of 1.2. Otherwise, using the slightly more cautious reference point $F_{0.1}$, M (0.41), would lead to a fishing mortality of 0.65. These reference points are very different yet both may be used to calculate the MSY, which could be applied to the stock of lemon sole off the west coast of Ireland to maintain a sustainable stock. F_{max} and $F_{0.1}$ are greater than F (0.23) calculated from the catch curve (using M = 0.41), indicating that lemon sole are not currently being fished to the MSY (using the VBGP of the Rafail method).

The lower M of 0.28 (calculated using the VBGP of the Ford-Walford plot) when applied to the overall stock, indicated that an F_{max} of 0.95 or an $F_{0.1}$ of 0.45 could be applied to reach the MSY without causing collapse of the fishery. F_{max} and $F_{0.1}$ are greater than F (0.36) calculated from the catch curve (using M = 0.28), indicating that lemon sole are not currently being fished to the MSY (using the VBGP of the Ford-Walford plot).

The two M coefficients calculated from the lemon sole data of the present study are higher than the arbitrary M value of 0.12 as set for plaice and common sole off the west coast of Ireland (ICES). When the arbitrary value was applied to the data an F_{max} value of 0.42 and an $F_{0.1}$ of 0.25 were found to reach the MSY for lemon sole off the west coast of Ireland. F_{max} and $F_{0.1}$ are lower than F (0.52) calculated from the catch curve (using M = 0.12), indicating that lemon sole are currently being fished to a level above the MSY (ICES arbitrary M). Plaice in the North Sea have been reviewed by Daan (1997), who indicates that plaice are growth-overfished in the North Sea as F is higher than required for the MSY.

The YPR method, as mentioned earlier, is not always reliable. Other factors should be taken into account to determine biological reference points (Pitcher and Hart 2000). Recruitment, the idea of virtual population analysis (VPA) (Pope 1972) multiple stocks analysis (Pope and Knight 1982), and the incorporation of randomness and oceanographic and meteorological changes and events (Pitcher and Hart 2000) are included in newer models. However, the requirements for data are high for these methods of analysis. The advantage of the more traditional Beverton and Holt (1957) YPR method is its limited data requirements. The problems of fitting YPR models are discussed in detail in Pitcher and Hart (2000). They indicate that the standard methods of fitting Surplus Yield models to data are always subject to the danger that the data employed in fitting the model did not come from a fishery in equilibrium. Newer, more complex models, try to incorporate all the additional factors and the past history of the fishery in question. Francis (1991) provides a means of evaluating fishery management rules, where only two-thirds of the MSY should be targeted, although the question of what is an acceptable level of risk is as yet undetermined.

This study indicates that lemon sole off the west coast of Ireland have been subjected to over-fishing. There is evidence, of an observed lower L_∞, higher K and younger age at first maturity when compared to the data of King (1982) for the west coast of Ireland and Rae (1965 interpreted in Jennings *et al.* 1999) off the North Sea. Supporting the arbitrary M from ICES as set for plaice and common sole, a fishing intensity reaching a $F_{0.1}$ of 0.25 should be applied to maintain a sustainable stock of lemon sole off the west coast of Ireland. Therefore, fishing effort should be reduced. The idea behind TAC management is that future catches can be predicted on the basis of percentage changes in exploitation rate from the status quo level and, conversely that limiting future catches might be expected to control fishing mortality (Daan 1997). The TAC for lemon sole in ICES divisions IIa and VI has been reduced since 2001. This indicates that there is some awareness as to the state of the stock in these divisions. However, Daan (1997) argues that the TAC management approach has failed to maintain sustainable stocks. This was due to a number of factors. In particular as it is based on commercial landings and not catches, which include discards.

Little information is available on the past history of lemon sole off the west coast of Ireland. Also, there are problems associated with the use of different sampling methods, as highlighted earlier. Of particular concern, is the possible impact of discarding on stock assessment and also the wide variation in results obtained from the various models used to describe the stock. Further assessment of the state of the stock of lemon sole off the west coast of Ireland is necessary in order to determine long-term management strategies.

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