Age, growth and reproductive biology of whiting *Merlangius merlangus* (Linnaeus 1758) in the Celtic Sea

By

Imelda Hehir

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Galway-Mayo Institute of Technology and The Marine Institute

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

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ABSTRACT

Age, growth and reproductive biology were investigated for whiting (*Merlangius merlangus*) captured from the Celtic Sea (ICES division VIIg), for the period January 2001 to January 2002. Females dominated the sex ratio of 1 : 2.25. The relative abundance of females exceeded the number of males in all length classes. The relationship between weight (g) and total length (cm) was the same for male and female whiting. A total of 973 fish were aged and the maximum age recorded was 11 years. Results from an intercalibration exercise showed 87% agreement in age readings between the author and an expert in ageing whiting at the Marine Institute. Females were dominated by 2 year olds, while males were dominated by 3 year olds. L_∞ was estimated as 38cm and a growth rate was calculated K = 0.3769 year^{-1}. Females were fully recruited to the fishery at 3 years of age, while the age at full recruitment (t_r) for males was 4 years. Female whiting spawned from late February to June 2001 and matured at a total length of 23 cm in their first year. Female whiting reached L_{50} at a total length of 28 cm and 2.7 years of age. Male whiting spawned from February to June 2001. They matured at a total length of 21 cm and in their first year. Male whiting reached L_{50} at a total length of 30.4 cm and 3.6 years of age. The following critical points should be taken into account in the management of the Celtic Sea whiting stock: An F_{pa} should be established in order to assess the current level of fishing mortality; The maturity ogives need further study; The extent of gutting of large fish before landing by fishers in the fleet should be investigated and the apparent decline in size of 4 – 7 year old fish in the Celtic Sea between 1996 and 2001 needs to be assessed.

CONTENTS Page

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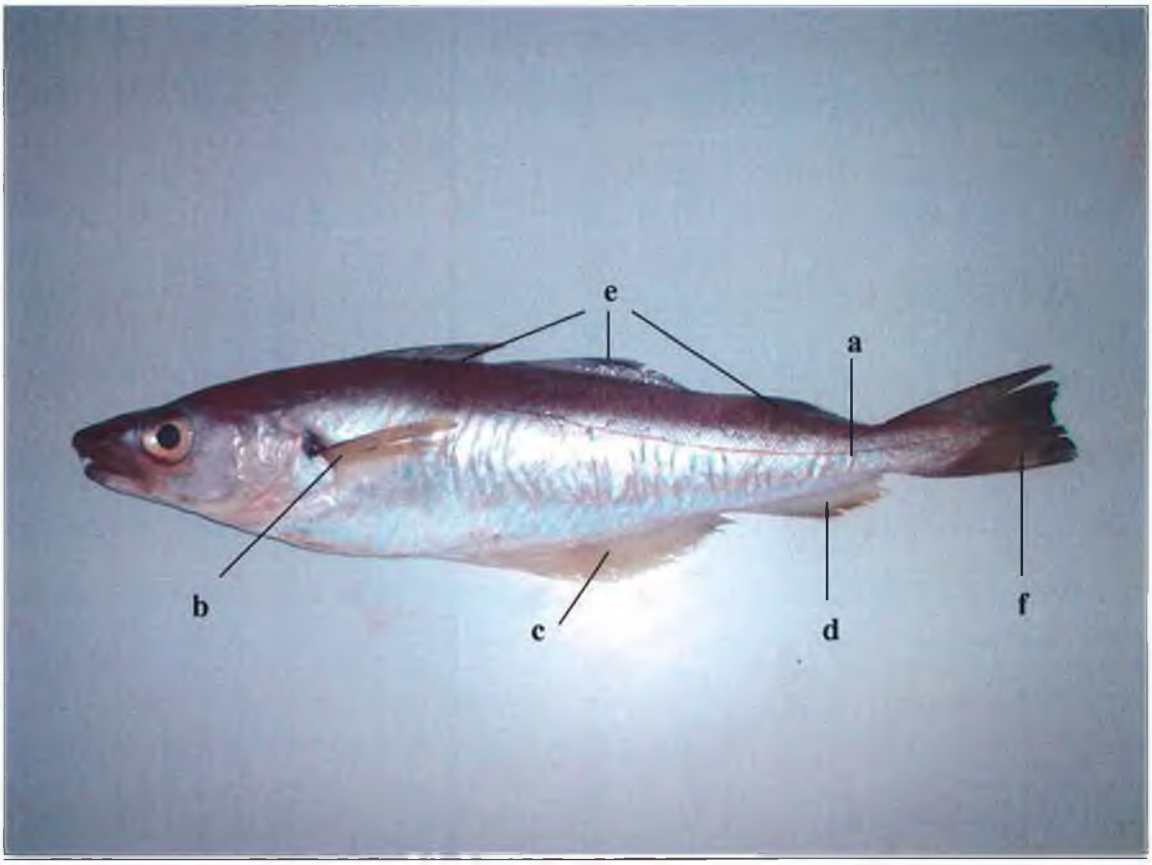
1.0 Introduction

Whiting, *Merlangius merlangus* (Linnaeus, 1758), a round demersal fish is a member of the family Gadidae. A large number of species in the family occur in British and Irish waters. All species have pelagic eggs. These species are as follows, Cod (*Gadus morhua* (Linnaeus, 1758)), Haddock (*Melanogrammus aeglefinus* ((Linnaeus, 1758)), Poor-cod (*Trisopterus minutes* ((Linnaeus, 1758)), Norway pout (*Trisopterus esmarkii* Nilsson, 1855)), Blue whiting (*Micromesistius poutassou* (Risso, 1827)), Saithe (*Pollachius virens* ((Linnaeus, 1758)), Pollack (*Pollachius pollachius* ((Linnaeus, 1758)), Torsk (*Brosme brosme* (Ascanius, 1772)), Greater Fork-beard (*Phycis blennoides* (Brunnich, 1768)), Ling (*Molva molva* ((Linnaeus, 1758)) and Tadpole-fish (*Raniceps raninus* ((Linnaeus, 1758)) (Russell, 1976). The rocklings are also members of this family (Wheeler, 1969).

The shape of the whiting body is streamlined so as to offer as little resistance as possible to its progress through the water. The skin is covered with small cycloid scales (Saunders and Manton, 1965) (see Fig. 1.1). Colour is variable, often dark blue or green on the back, sometimes sandy, but always having strikingly white or silvery sides and belly. There is a distinctive dark spot at the pectoral fin base. The snout is long and rather pointed, the upper jaw distinctly longer. The upper jaw extends backwards to the front edge of the pupil. A small barbel is present, but is inconspicuous or even absent in larger specimens (Wheeler, 1969). Running from the operculum back to the tail, a pigmented line formed of modified scales can be seen. In these scales sensory pits are lodged to form the lateral line system (Saunders and Manton, 1965). The origin of the first anal fin is under the midpoint of the first dorsal fin (Wheeler, 1969). The median fins consist of three dorsal and two ventral fins, and lying between them is the caudal fin. The pectoral fins are situated in the anterior part of the body on either side behind the operculum. The skeleton of all the fins consists of bony fin rays. A few centimetres behind the pelvic fin, there are two openings lying close together. The most anterior and larger of these two openings is the anus, the posterior opening receives the opening of the gonoduct in front and the ureter behind (Saunders and Manton, 1965).

Fig. 1.1. Whiting (*Merlangius merlangus* Linnaeus, 1758*)*

(a) Lateral line, (b) Pectoral fin, (c) 1st Anal Fin, (d) 2nd Anal Fin, (e) Dorsal Fin (1st, 2nd and 3rd) and (f) Caudal Fin



The geographical distribution of whiting in the northeastern Atlantic ranges from the Barents Sea down to the North Sea; from Iceland to Portugal and the north coast of the western Mediterranean. It is also present in the Black Sea, and adjacent areas of Adriatic Sea, Aegean Sea, Sea of Marmara and Azov Sea (Whitehead *et al.*, 1986) (see Fig. 1.1).

Because they have a relatively prolonged pelagic larval life, whiting are very widely dispersed by means of ocean currents (Wheeler, 1969). Whiting are an important European commercial fish, which use inshore marine waters, sea lochs, and estuaries as nursery areas (Nagabhushanam, 1964; Arntz & Weber, 1972 and Gordon, 1977). Whiting are fished throughout their range.

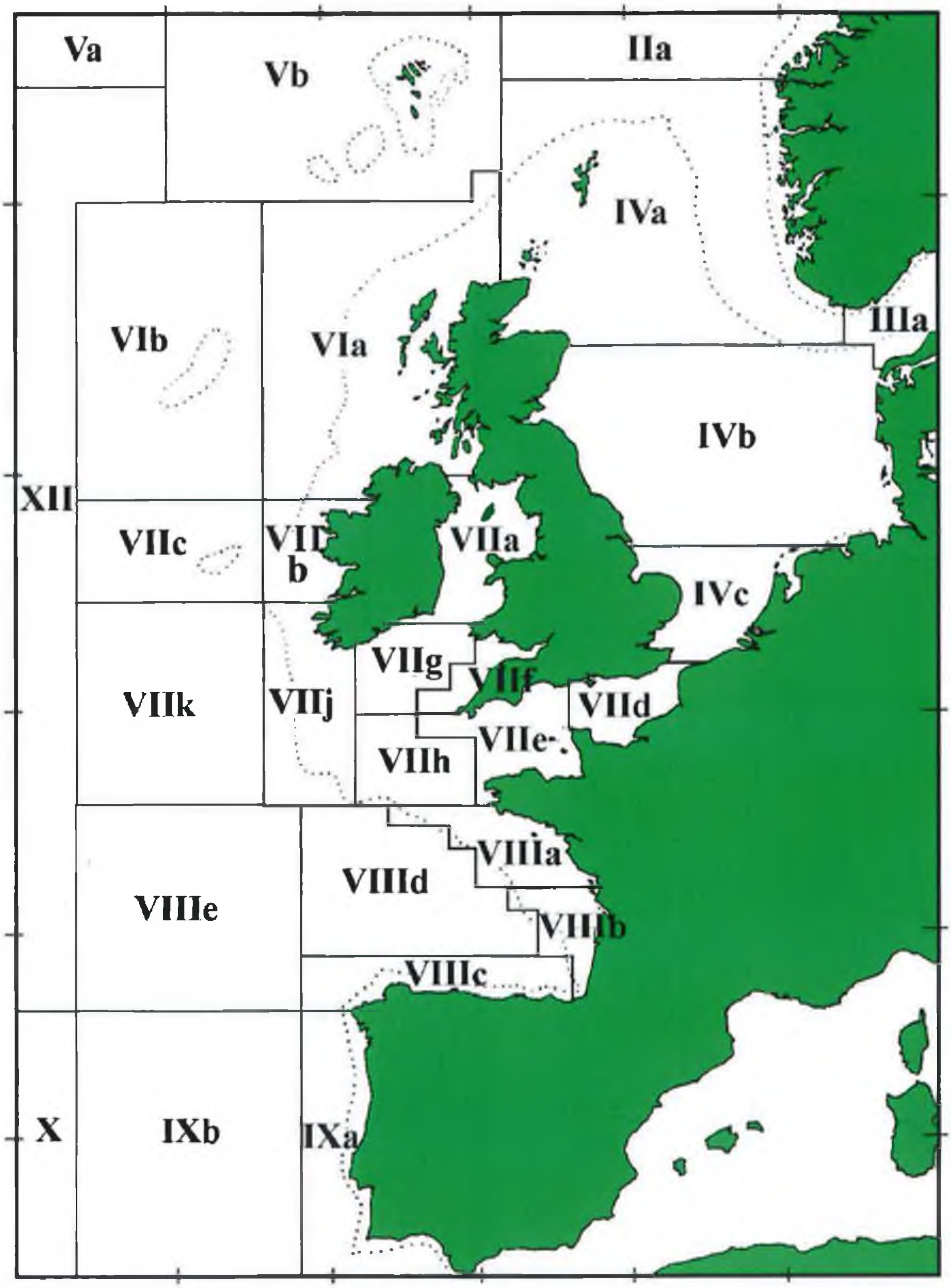
The adult whiting is a shallow water species, ranging from a minimum depth of 20 meters (although numbers at this depth were rarely encountered), to a maximum depth of 100 metres. The more common range of depths is from 30 - 100 m (Wheeler, 1969). Adult whiting inhabit shallow, sandy waters (Wheeler, 1969). Adult whiting occur at a greater range of depths than juveniles. Immature whiting are found close inshore (5 – 30 metres). For 1 year old whiting, the winter distribution corresponds with the shallow, cold and less saline areas while the 2 year olds stay in deeper water (Daan *et al.*, 1990). Zheng *et al.* (2001) sampling Scottish waters reported lower abundance and younger whiting being found in shallower waters, in a depth range 100-200m. Very young whiting up to 3 cm in length associate with the common jellyfishes *Cyanea lamarcki* and *Chrysaora isosceles*, swimming in small shoals just in front of the medusa but seeking the shelter of its tentacles and possibly possessing a certain immunity from its stings (Wheeler, 1969). Juveniles tend to be found over sandy and muddy sediments in coastal areas and estuaries (Gerritsen *et al.* 2003).

The UK Celtic sea groundfish survey conducted in ICES division VIIe-j indicated that whiting occurs over the whole of the ICES division VIIe-j but does not extend into deeper waters >100 m (Warnes and Jones, 1995). ICES fishing divisions around the Irish coast are illustrated in Fig. 1.2. Whiting are widely distributed throughout the Irish

Sea (Garrod and Gambell, 1965; Gerritsen *et al.*, 2003). For Irish waters, the main demersal fisheries can be divided into four general groups (Anon., 2002a) as follows;

- The Irish Sea Fishery (Division VIIa),
- The Donegal/Rockall Fishery (Divisions VIb, VIa),
- The Celtic Sea Fishery (Divisions VIIf,g,h), and,
- The West and Southwest of Ireland Fishery (Divisions VIIb,c, VIIj,k).

Fig. 1.2. ICES fishing divisions around the Irish coast (taken from Anon., 2002a).



Many fished species migrate and this may allow individuals to remain in optimal conditions for feeding, growth or reproduction for the longest possible period. Cooper (1983) assumed that larger whiting migrate to deeper water. Gordon (1977) stated that O-group whiting became established in inshore waters off the west coast of Scotland during the summer and autumn and remained there during their first winter. Thereafter, there was a gradual movement of a proportion of the whiting to the open sea. Spawning migrations have been observed in several areas, e.g. Kiel Bay (Arntz and Weber, 1972); the Skagerrak (Knudsen, 1964) and in the Firth of Clyde (Garrod and Gambell, 1965) where an origin from planktonic stocks from the northwest coast of Ireland was inferred (Cooper, 1983). Gerritsen *et al.* (2003), explained how spawning grounds could not be located during the investigation off the west coast of Scotland and assumed whiting migrate.

Conventional tagging, using sequential coded tags attached to fishes, suggests the general migrations of fished species (Jennings *et al.*, 2001). Some whiting tagged in the western Irish Sea have been recaptured as far as the west coast of Scotland and the Celtic Sea, distances in order of 200 km (Garrod and Gambell, 1965). Gerritsen *et al.* (2003) found that the bulk of whiting recaptures (tagged also in the Irish Sea) came from within the Irish Sea, suggesting only limited interchange with surrounding areas. Also, tagging studies conducted off the west coast of Scotland indicated that large scale movements of whiting do not occur, most of the movements observed by Newton (1986) being of less than 60 miles. Returns of adult whiting tagged in the Western Channel indicated more movement into the Celtic Sea than between the Western Channel and Eastern Channel. Whiting released in the Bristol Channel moved south and west towards the two spawning grounds off Trevose Head and southeast of Ireland.

There was no evidence of migration out of the Celtic Sea area. The results of a tagging whiting programme in the County Down spawning area showed that a greater proportion of Irish Sea whiting moved south into the Celtic Sea rather than north towards the west of Scotland (Anon., 2002a).

Investigations of a limited vertical migration in O-group whiting concluded that only the large O-group fish migrated whereas the smaller O-group fish remained in mid-water (Gordon, 1977).

The study of how fish reproduce forms a basic part of the biology of fishes, especially those that support important fisheries. Knowledge of the sex ratio and the state of maturity of individuals in a population is useful, and estimates of fecundity are important in studies of population dynamics, productivity, or population estimates (Cailliet *et al.*, 1986). The probability of being mature varies with space and time (Rochet, 2000). Knowledge of the proportion mature at size or age is necessary for estimation of spawning stock biomass (SSB). The latter is central to the management of any fishery (Trippel and Harvey, 1991).

The length or age at which 50% of females or males attain maturity (L_{50}) is usually estimated by fitting a logistic curve to the relationship between proportion mature and length or age. These are referred to as ogives. Ogives are important in fisheries management. Calculation of L_{50} is partly used in the determination of the legal minimum landing size so as to allow fish to contribute to the stock before capture. When fish are congregated during spawning, it is possible to obtain more representative samples of the whole population to enable maturity ogives to be established (Anon., 2002b).

The eggs and larvae of whiting are pelagic, as mentioned earlier. In whiting, the yolk of the egg is unsegmented, the eggs have no oil globule and the embryo has black and yellow pigment. The eggs of whiting are spherical and 0.97 – 1.32 mm in diameter (Russell, 1976).

Eggs spawned in one year develop from a reservoir of resting, non vitellogenic oocytes, sometimes termed primary oocytes. Through hormonal triggers, some of the eggs start to take up yolk (vitellogenin) and grow in size. It is only these vitellogenic eggs that are visible to the naked eye. Eventually the eggs reach a maximum size and, at an appropriate time, they hydrate and are extruded from the follicle into the lumen of the ovary, before being liberated into the sea for fertilization (Horwood, 1993). In whiting, the size and length distribution of oocytes bifurcates just after spawning has started (Hislop and Hall, 1974). Seasonal changes in gonad condition and growth of whiting was described for Isle of Man waters by Bowers (1954) and Nagabhushanam (1964). Different methods are used in the identification of maturity stages in fish. Sylva and Breder (1997) reported that histological studies are expensive and time consuming but perhaps yield the most reliable, objective information on spawning cycles.

Whiting mature at around 25.5 cm for males and 27.5 cm for females, most fish spawning for the first time in the 2-group, although a small number of males and females spawn in the 1-group (Cooper, 1983). Zheng *et al.* (2001) reported that at around 2 years of age, the majority of whiting are mature, and able to spawn. Spawning takes place throughout the range of distribution, with the possible exception of the more extreme northern areas. The peak of spawning intensity varies from January off the Biscay coast, to late May off Iceland (Wheeler, 1969). The peak of spawning principally takes place in April to May around British and Irish waters. Hislop and Hall (1974) reported that spawning season varies with latitude.

The high fecundity of whiting, together with the fact that there is such a large range of sizes of maturing eggs in a ripe ovary, suggests that the spawning period of an individual fish may be very long. A prolonged spawning season might be expected to reduce the extent of annual fluctuations in the year class strength of a species. Chances of a large proportion of the spawning products of a population being liberated during a particularly favourable or unfavourable period of environmental conditions should be less than when spawning is restricted to a short period (Hislop and Hall, 1974).

Spawning takes place in 50-150 meters of water, mostly within the 100 meter line, although in some localities spawning occurs in only 20 meters. Hislop and Hall (1974) reported that adult whiting spawning grounds are generally in shallow waters (<100m) and 1-year-old whiting also occur in shallow waters (<100m). Knudsen (1950) found that in Danish waters the principal spawning places are found in the southern North Sea at depths of 20-60 m.

The main spawning areas of whiting in the Western Channel and Celtic Sea are off Start Point (VIIe), off Trevose Head (VIIf), and the southeast coast of Ireland (VIIg) (Anon., 2002a). The only spawning ground reported for the west coast of Scotland was in the deep upper basin in Loch Etive (Gordon, 1977). Cooper (1983) reported that the physiological strain of spawning causes greater mortalities amongst males. The long spawning season for whiting has been widely noted (Fulton, 1890; Desbrosses, 1945).

The spawning period for whiting in Irish waters has been investigated by Bowers (1954), Elkin (1955) and Nagabhushanam (1964).

Fecundity has been defined as the number of ripening eggs in the female just prior to the next spawning period (Bagenal, 1957). A biological parameter, needed for the estimation of the absolute size of a spawning population from total egg production data, is the average fecundity of a representative female in the population (Hislop and Hall, 1974). The whiting is a very fecund fish (Bromley *et al.*, 1997). Fulton (1890), from the examination of a small number of ovaries taken from the Firth of Forth, concluded that a whiting produced on average 200,000 – 300,000 eggs per annum. Messtorff (1959) estimated fecundity of 37 whiting from the southern North Sea as ranging between 120,400 and 1,150,000 female eggs. Messtorff (1959) also noted a tendency for older whiting to be more fecund than younger ones of the same length. Although the fecundity/length relationship of the whiting from Iceland differed significantly from those of the North Sea and the Minch, it seems unlikely that the study of fecundity could be used to distinguish between stocks of whiting in British waters (Hislop and Hall, 1974).

Recruitment is defined as the number of individuals that reach a specified stage of the life cycle (e.g. metamorphosis, settlement or joining the fishery). When scientists developed techniques for ageing fishes and looked at the age structure of their populations they showed that only a few year classes accounted for most of the biomass even though many year classes were present. Fish in the abundant year classes would often dominate catches for many years before new abundant year classes recruited to the fishery (Jennings *et al.*, 2001). The whiting stock in the Celtic Sea (VIIe-k) appears to exhibit periods of good recruitment followed by periods of very poor recruitment (Anon., 2002b).

Different methods of determining the age of whiting have been used. Scales were used in the past (Saemundsson, 1925; Knudson, 1950). Petersen's method has been used to determine ages in the 0 and 1 groups (Knudson, 1950). The Petersen method involves analysing length-frequency distribution of fish populations sampled (Ricker, 1975). Saemundsson (1925) found that age could be determined for whiting by structures in certain parts of the skeleton i.e. the basal bones of the paired fins and the vertebrae. Messtorff (1959) found that such determinations gave unreliable results. In elasmobranches and some other bony fishes, rings or bands in the vertebrae have been studied also.

Otoliths and scales are the hard parts most often used in the study of age in bony fishes (Knudson, 1950; Desbrosses, 1948; Bowers, 1954; Messtorff, 1959; Gambell & Messtorff, 1964). Ageing by means of otoliths involves counting the annual zones, which are formed throughout the life span of the fish (Lux, 1971). An annulus is a concentric zone, band, or mark that is a ridge, valley, or translucent or opaque zone (Cailliet *et al.*, 1986). In many species, these marks represent seasonal variations (usually winter, summer) in somatic growth rates. In general, the more extreme the temperature difference between summer and winter, the greater the differences will be in seasonal growth rates and hence the more obvious the annual marks will be.

Elkin (1955) determined age for whiting by counting the number of opaque zones showing on the otolith, with the first opaque zone occuping the centre of the otolith.

Otoliths are hard, calcareous bodies in the paired labyrinth systems of teleosts, located in the cranial bones near the brain. In most teleosts, the sagitta is by far the largest otolith and is usually used in ageing studies. Otoliths are composed of calcium carbonate crystals embedded in an organic matrix. The organic material consists of layers of concentric shells. There is evidence that the variations in the amount and thickness of shells are responsible for ring formation. With some exceptions, opaque zones are laid down during the summer, and translucent (hyaline) zones are formed during winter (Cailliet *et al.*, 1986). Otoliths are usually examined on dark backgrounds with reflected light in an aqueous medium and exhibit a series of dark and light rings. In whiting, the otoliths require that a section be removed across the nucleus in order to produce readable growth zones. This technique is further explained by Cailliet *et al.* (1986). A description of the whiting otolith is given by Bowers (1954).

The average size at each age, and hence growth, is difficult to determine in most marine fish populations (Jennings *et al.,* 2001). Most data are obtained from the analysis of commercial landings where the size of fish caught depends upon the mesh used and only fish above the legal minimum landing size are usually recorded (Horwood, 1993). The growth rate varies with populations of whiting, but first year fish average about 15cm, second year fish up to 22cm and third year fish up to 30cm (Wheeler, 1969). Females, which are bigger on average, live for seven or eight years and reach a length of 49 -53cm at this age. Whiting attains a maximum length of 70 cm (Wheeler, 1969). Whiting in the northern North Sea usually grow faster than their more southern counterparts (Anon., 2000b).

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, 2001). 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 (von Bertalanffy, 1938). The Ford-Walford plot (Beverton and Holt, 1957) has been widely used to determine the parameters for the von Bertalanffy growth curve (Beverton and Holt, 1957; Ricker, 1975).

During the pelagic phase all gadoids have very similar diets with an overlap in the range of prey consumed by the various gadoid species (Bromley *et al.*, 1997). Early post larvae are between 4.5 – 16.5 mm and they mainly feed on small planktonic copepods (Nagabhushanam, 1965). Late post larvae between 17 and 53 mm, found during May, June and July feed on adult *Calanus finmarchicus* and the furcilia larvae of *Meganyctiphanes norvegica*. The post larvae remain pelagic until they are between 53 and 70 mm in length when they become demersal. By the end of the first growth season, juvenile whiting reach 17 cm in standard length (SL), and the instantaneous mortality is 0.76% per day^{-1} (Hamerlynck and Hostens, 1993). Juvenile whiting (less than 22 cm) begin feeding on the nektonic organisms such as Euphausids, mysids and amphipods. Epifauna such as polychaetes and crustaceans are also eaten, but plankton still makes up 10% of the whitings diet (Nagabhushanam, 1965). An active predator, whiting probably feed most intensively during daylight and mostly in mid-water or just off the bottom. Young whiting, which mainly live inshore, eat pink and brown shrimps, young shore crabs, amphipods, gobies and sand eels. With increasing size, they include more fish in their diet. Large whiting eat sand eels, sprats, younger whiting, poor-cod, Norway pout, brown and pink shrimps, swimming-crabs and hermit crabs. Less important items in their regular diet are the masked crab (*Corystes*), polychaete worms (including *Aphrodite* – the seamouse), cuttlefish and small squids and, occasionally, gastropod molluscs. Of the fish eaten, sand eels and sprat are the most important but others such as plaice, soles, scald fishes, and even red-band fish, occur in the diet (Wheeler, 1969). Whiting is one of the most important predators on fish of commercial importance in the North Sea (Hislop *et al.*, 1991).

Whiting have a low market value but the volume landed means that it is the most economically valuable component of mixed demersal fisheries in the Celtic Sea. In 2001, the Irish fleet reported total Irish landings of 42,378 tonnes (live weight) of demersal fish species. This represented a small reduction on the 2000 landings, of 37,416 tonnes. The total value of demersal fish landed in 2001 was €89.6 million, an increase of 34% on the 2000 value of €66.8 million. Landings for whiting alone were 6,582 tonnes with a value of €6.9m (Anon., 2002a). Irish landings in 2000 showed that young fish dominated, with 57% of the landings consisting of between 2 and 3 year olds. Whiting are of major commercial importance as a fishery resource, being the third most important demersal fish category in Scotland (Zheng *et al.*, 2001). They are extremely common, particularly in the North Sea, which provides more than 50% of European whiting landings.

In the North Sea, along with other gadoid species, whiting reached a peak of abundance in the 1960s and 1970s, but stock abundance has generally declined since the late 1970s

(Hislop, 1996). It is increasingly recognised that spatial and temporal trends in fish stock abundance and distribution may be related, at least in part, to environmental variation (Zheng *et al.*, 2001). Stocks of cod and whiting in the Irish Sea declined substantially in abundance during the 1990's due to high fishing mortality (Anon., 2001b).

A "stock" is a population of a species living in a defined geographical area with similar biological parameters (e.g. growth, size at maturity, fecundity etc.) and a shared mortality rate. A thorough understanding of the fisheries biology of any species is needed to define these biological parameters (Anon., 2002a). Whiting stocks are subject to total allowable catches (TACs) and quotas, which are based on average reported catches in preceding years. TACs are limits on the total catch, to be taken from a specified stock. Such TACs are agreed by the EU Council of Ministers (on the basis of proposals by the European Commission). There are no concerns about the state of the Celtic Sea (VIIe-k) whiting stock, although the Fisheries Science Services (FSS) of the marine Institute agrees with the ICES recommendation that fishing mortality should not increase (Anon., 2002a). Irish landings in 1999 and 2001 were 5,807 t and 4,942 t respectively. The 2002 TAC was 31,700 t with an associated Irish quota of 8,814 t. In contrast, the 2000 TAC was 22,500 t with an associated Irish quota of 6,260 t (Anon., 2000a). Misreporting is not considered to be a problem in this fishery. France took 60% of the 2001 landings, mostly by the Lorient – based gadoid fleet. Ireland account for about 30%, UK 7%, while Belgium take less than 1% of the catches (Anon., 2002a). In contrast there are serious concerns about the state of the whiting stocks in the Irish Sea and West of Scotland. The 2001 total international catch for West of Scotland whiting was estimated to be 4,000 t of which 1,600 t was discarded. Landings for Irish Sea whiting have declined since 1985, and the proportion of the catch discarded has increased.

Fisheries are managed because the consequences of uncontrolled fishing are seen as undesirable. These consequences could include fishery collapse, economic inefficiency, loss of employment, habitat loss or decreases in the abundance of rare species. Management is intended to maximize some specified biological, social or economic benefits from the fishery while minimising costs (Jennings *et al.*, 2001). Historically, the main objective of fisheries management has been the conservation of fish stocks. The broad objectives of fisheries management may therefore include the aims of maximizing yield (weight or revenue), maintaining a particular level of stock in order to provide a buffer against poor recruitment years or maintain a minimum spawning stock (Anon., 2002a). In Ireland, whiting are managed in different ICES areas. These are as follows: Celtic Sea and Western Channel (Division VIIe-k); West of Scotland (Division VIa); Rockall (Division VIb); Irish Sea whiting (Division VIIa) and West of Ireland (Division VIIb,c). In 1993, Ireland initiated a stock monitoring programme in VIIb,c and VIIj,k with the aim of providing an adequate time series of biological data for a full analytical assessment of gadoid stocks (Wheatley *et al.*, 1999).

There are no clear management objectives for the Celtic Sea (VIIe-k) stock. Management objectives should be to maintain spawning stock biomass (SSB) above B_{pa}. B_{pa} is the Spawning Stock Biomass (SSB) level above which the stock should be maintained to ensure that recruitment is not impaired. In stocks where there has been no evidence of reduced recruitment below a certain SSB size, B_{pa} is calculated by multiplying B_{loss} (the lowest observed SSB) by an uncertainty factor ($e^{-1.645}$) to take into account assessment uncertainty (Anon., 2002a). Successful levels of recruitment are dependent, among other things, on the production of large numbers of good quality eggs (Kjesbu *et al.*, 1991).

Since 2000, Bord Iasce Mhaire (BIM) has undertaken a major Technical Conservation Measures (TCM's) work programme. Preparatory work commenced in relation to the likely introduction of further conservation regulations from the EU which will not only affect fisheries for cod and hake but also potentially other stocks including whiting. In 2002, a comprehensive work programme was carried out in the southwest, west and north of Ireland, including trials assessing selective trawl designs, twine thickness, square mesh and separator panels. In the southwest, work to assess the economic and biological effects of increasing codend mesh size and also using materials of different twine thickness have been completed. Comparison of standard 80 mm mesh codend with 90 mm, 100 mm and 110 mm were carried out. Results from the boats showed losses in catch and value in the region of 25% and 40% with the 100 mm and 110 mm codends, respectively, and 15-20% with the 90 mm (Anon., 2003a). A major Stock Recovery/TCM programme for the Northwest area commenced in 2002. The initial results from these trials, which are continuing this year (2003), show that an increase in mesh size to 100 mm significantly reduced discards of all species but lead to loses in revenue of up to 70%. This gave rise to recommendations from the participating fishers of testing 90 mm mesh panels, and subsequent trials have shown this mesh size to be more appropriate, particularly when a square mesh panel is also fitted. There was a general level of interest in the TCM work from fishers around the coast, therefore, work promoting selective gears is continuing this year. The development of recovery programmes through the use of selective gears have also been promoted in other localised areas this year, where Irish fishers predominantly exploit the fisheries (Anon., 2003a).

Information about whiting has been collected for over one hundred years. For example, Matthews (1887) examined stomach contents of whiting off the east coast of Scotland. Other studies have also been conducted in other areas for whiting. Spatial patterns of whiting abundance and relationships with environmental variables in Scottish waters have been investigated (Zheng *et al.*, 2001). Studies were carried out on diet comparison between pelagic and demersal whiting in the North Sea (Pedersen, 1999). Age composition, growth, movements, meristics and parasites of whiting have also been studied in the Severn Estuary and Bristol Channel (Potter *et al.*, 1988). Diet has also been investigated by Andersen (2001); Pedersen (1999) and Bromley *et al.* (1999). Knudsen (1950) reported on the importance of whiting in Danish waters and reviewed distribution, age composition and growth.

There is, however, little published information available on the biology of whiting from Irish coasts. Studies on whiting from the east and west coasts of Ireland have summarised research of food on large whiting (Elkin, 1955 and Jones, 1954). Elkin (1955) compared spawning, growth, feeding and parasitology and population structure between east and west coasts stocks of whiting. Fives (1970) reported on the occurrence of whiting larvae and post larvae (during May-June) from surveys of plankton on the west coast. More recent work includes a study on species distribution observed during the English Celtic Sea groundfish surveys (Warnes and Jones, 1995). The south and west young fish survey covers ICES Divisions VIa, VIIb, VIIg, and VIIj and commenced in 1994. This survey was primarily designed to map inshore nursery areas over a 3 year period (1995 – 1997). It was hoped that this survey would provide information on spawning and nursery grounds off the west coast of Ireland. Tagging experiments in the Irish Sea have been carried out (Garrod and Gambell, 1965). There has been little scientific work carried out in the Celtic Sea.

This project presents information on age, growth and reproductive biology of whiting (*Merlangius merlangus*) during the period January 2001 to January 2002 in the Celtic Sea area (ICES Division VIIg) on the Southeast coast of Ireland. The work described will contribute to and compliment other research at the Marine Institute on whiting age and growth and will also provide fisheries scientists with a new and quantitative analysis of the reproductive cycle of whiting stocks in the Celtic Sea. Results of the study will improve understanding of the life cycle of this species and help fisheries scientists at the Marine Institute to better predict the effect of fishing effort on whiting stocks in the Celtic Sea.

Visual information is minimal in helping fisheries scientists to identify sexual maturity by macroscopic assessment of the gonads, especially male gonads. One of the areas of crucial importance to objective management of fisheries is information on the reproductive biology of the stock. This is lacking for the Celtic Sea stock. Therefore a detailed assessment of female and male reproductive cycles was undertaken using both macroscopic and histological methods of assessment. In particular, the value of using a descriptive key to assess reproductive stages, by visual assessment of the whole gonad, was assessed by comparing the stages so defined (macroscopically) with detailed histological preparations of the same gonad. Strategies for the future management of the Celtic Sea fishery are discussed.

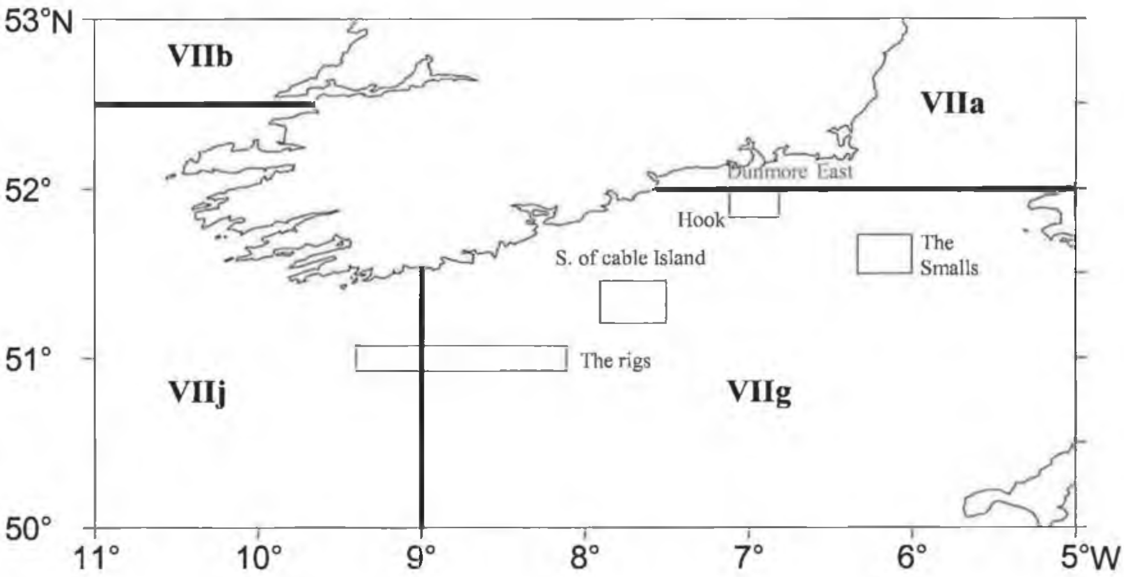
2.0 Materials and Methods

2.1 Sampling Procedure

The Celtic Sea population of whiting was investigated from February 2001 to January 2002 inclusive.

The fish were caught by commercial vessels, fishing off the Southeast coast of Ireland in the vicinity of Dunmore East at 52.14° N, 6.99° W. Whiting were taken from four possible fishing grounds, the Smalls, the Rigs, the Hook and South of Cable Island (Fig. 2.1.1). The main trawlers that target whiting when in season in Dunmore East are the Wilhelmina (22 m), the Stellimar (19 m), the Crest (24 m), the Loradon (20 m), the Una Alan (20 m) and the Celtic Fisher (18 m). A seiner, the Caronia I (24 m) also fished for whiting. The provenence of the samples could not be determined.

Fig. 2.1.1. ICES Fishing Divisions indicating the fishing areas in the Celtic Sea (VIIg).

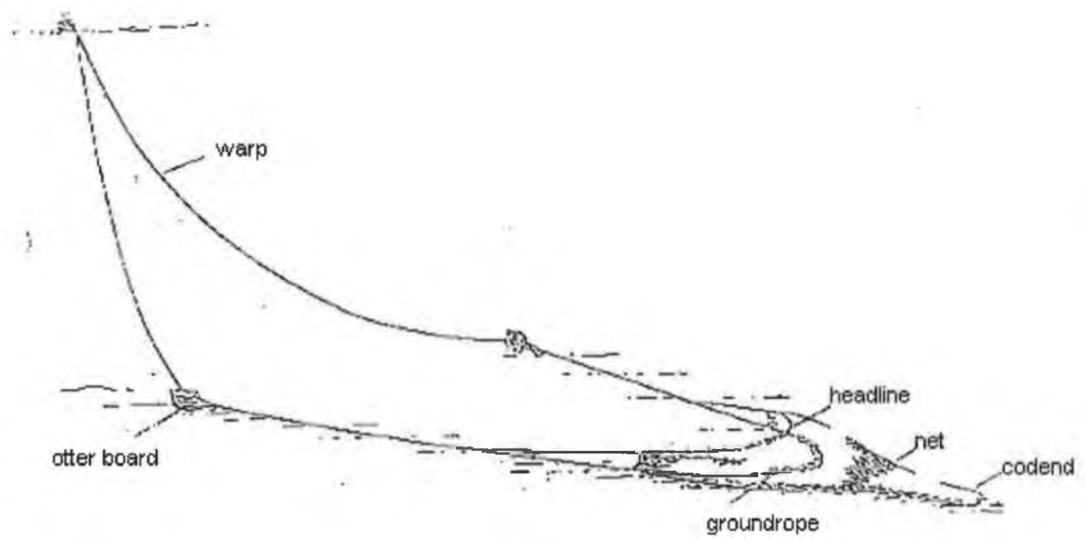


Whiting, *Merlangius merlangus*, are taken as a by-catch in the Celtic Sea and Irish Sea. Danish Seining and Mid-water Trawling directly target this commercially important species, while valuable quantities are taken as by-catch in the otter-board trawl fishery. There follows a brief description of these fishing methods:

Otter-board Trawling

An otter trawl consists of a conical or funnel-shaped net leading into a bag or cod-end in which the fish are retained (Fig. 2.1.2). The net may be extended laterally by panels of netting (wings) at its opening and long cables (sweeps) which help to herd the fish into the mouth of the net. Otter trawls derive their name from the otter-boards, or doors, which act as paravanes to hold open the mouth of the net when towed. During towing, the sweeps and the clouds of sand swept up by the doors help to herd individuals into the path of the approaching net. Demersal otter trawls are designed for bottom trawling, in which the target species differ depending on variations of the design and modifications (King, 1995). Whiting can be successfully captured when the headline height of the trawl is large enough so that fish are unable to escape over the top of the mouth of the net before being captured by the moving net.

Fig. 2.1.2. Demersal otterboard Trawling (taken from Von Brandt, 1984)



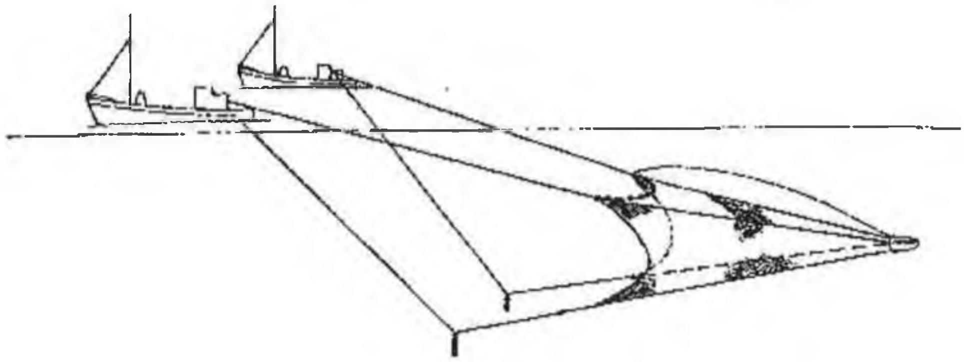
Danish Seining

The seine net is of similar design to the bottom trawl but has differences in the footrope weight, wing length and head rope height. The net is set out from a 'Dhan' or marker buoy. Firstly one dragline or 'rope' is put into the water as the boat moves forward, then one net wing follows and while the fishing boat swings round in an arc or circle back to the buoy, the bag net and the other wing and dragline are set. Thus a big area is encircled by the time the boat comes back to the 'Dhan' buoy from which it started out. The draglines are negatively buoyant and sink to the bottom rapidly. The boat hauls the net by hauling the two draglines simultaneously with the help of the rope coiling machine or 'coils', until the bag with the catch can be taken on board the vessel. The success of this method depends on the contact of the draglines on the bottom allowing frightened fish to be herded into the mouth of the moving net. This assumes clear water and good sighting conditions otherwise the frightening affect does not work. The seining process follows the tide so that the current is flowing into the net opening while the gear is hauled. Seining is a daytime fishery for the reasons mentioned before. Four to ten sets or 'rings' can be made in a day in summertime. This fishing method can also be carried out in wind forces Beaufort seven to eight (Von Brandt, 1984).

Mid-water Trawling

This fishing method can involve just one vessel using otter-boards to achieve the opening of the net in mid-water, or can involve two vessels, of similar size and power, using just one large mid water net at any one time. Double towing power is available in the latter allowing the net, the area of coverage and the possible yield to be made substantially larger. Mid-water trawls are made as four-seam nets with two equal top and bottom panels and two equal, usually smaller, side panels (Fig. 2.1.3), to get an optimal size of trawl opening. These nets have a low resistance when towed, due to a large mesh size at the opening of the net, and are made from polyamide fibres or nylon with a high breaking strain (Von Brandt, 1984). Schools of fish are located by fishing vessels at mid-water or near the seabed using sonar equipment. The net is 'shot' by one vessel, cod-end first, until both sets of wing bridles are trailing behind one boat. The wing-ends of one vessel are passed across and attaches to the ends of the steel fishing warps. The footrope bridles are attached to a large weight or 'ball of chain' which is attached to the warp. This weight helps to sink the footrope and thus opening the mouth of the net. The head-rope bridles are attached to another warp in each vessel. It is by making changes to the length of warp attached to both the head-rope and foot-rope that the vessels can manipulate the depth at which the net fishes and can open and close the net opening at will. The distance between the fishing vessels when fishing dictates the spread or horizontal opening of the mid-water trawl. An acoustic transducer is usually located at the centre of the head-rope of the net. This sends an acoustic echo of the bottom and the footrope of the net, back to a read out or 'net sounder' in the fishing vessel, by means of an acoustic cable. This enables the vessel to mark schools of fish entering the net and provides the skipper with information on the distance between the bottom and the footrope of the net.

Fig. 2.1.3. The Danish two-boat midwater trawl in operation (Larsen type) (taken from Von Brandt, 1984)



2.2 Sampling Protocol

Two boxes of fish were provided per sample by the Dunmore East Co-op to give a maximum of 300 fish for analyses. The Co-op employees collected samples of whiting both from the auction hall floor, and also directly from the vessels. A sample was collected every two weeks where possible. A discard sample (defined as part of the catch returned to the sea as a result of economic, legal or aesthetic considerations (Anon, 2001)) was provided by the fleet assessment technician (FAT) on the 30th April 2001.

The first sample was obtained on the 01/02/01, and thereafter on the 12/02/01, 26/02/01, 15/03/01, 02/04/01, 09/04/01, 25/04/01, 30/04/01, 15/05/01, 05/06/01, 12/06/01, 10/07/01, 09/08/01, 03/11/01, 03/12/01 and 15/01/02.

2.3 Laboratory Analyses

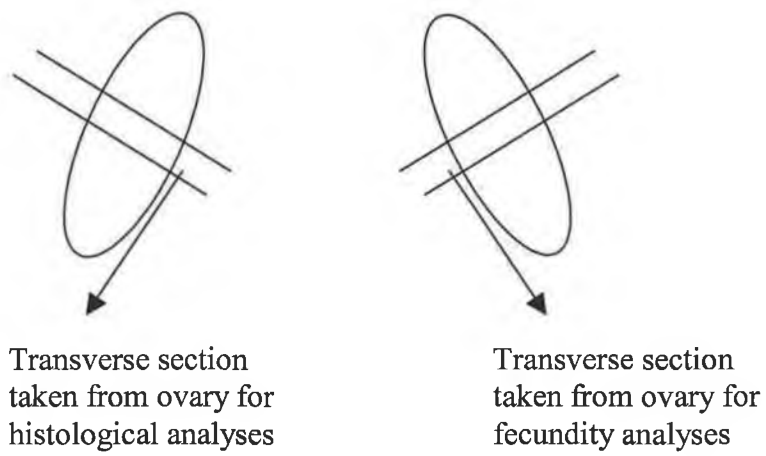
From the fish collected over the sampling period, the biggest and smallest fish were measured to the nearest cm below and a minimum of ten cm size classes were defined within the range. From the 26/02/01 the sampling strategy was altered, i.e. a minimum of fifteen cm size classes were obtained within the range, to achieve a greater number of size classes. The aim was to get a maximum of 20 fish in each cm size class, so that a maximum of five males and five females could be selected for further analyses from each centimeter size class. If in some instances 20 fish could not be collected within one cm size class, nearest size classes were amalgamated to give size classes of up to 3 centimetres. The fish were placed in labeled plastic bags and stored in a cold room in the auction hall. Whenever practical, whiting were analysed fresh, otherwise they were preserved by deep-freezing at -18°C. A total of 3415 whiting were measured for length over the sampling period.

A total of 1059 fish were examined in detail at the laboratory. Fish were opened until a maximum of five males and five females from each cm size class were obtained. Various measurements were taken on all whiting. Full body weight was measured to the nearest 0.5g. Total Length (TL) measurements were taken to the nearest cm below, from the tip of the snout to the extreme edge of the tail. Gonad size in relation to body cavity was recorded. The presence of parasites on the external surface of the whiting was noted. The liver was then removed and weighed and the number of parasites on it visually assessed. The gut was removed from the oesophagus to the anus and weighed to the nearest 0.1g. The fullness of stomach was also observed, using the following scale: empty, ¼, ½ and ¾ full or full. Up to the 02/04/01 the stomach and gut was weighed together to the nearest 0.5g. After this date the stomach and gut were weighed separately. Parasites, diet and liver weight were not analysed further for the purpose of the present investigation. However, an archive of all of the data from the project is lodged with the Fisheries Sciences Services (FSS) of the Marine Institute.

2.4 Reproductive Analyses

Male testes are solid and female ovaries are hollow. There is a visual difference between male testis and female ovaries in whiting as they are differently coloured and shaped. Two oval shaped organs join in the center of the female gonad and are usually orange in colour. The paired testes are long lobed and coiled structures, usually white or creamy in colour. The gonad was removed and weighed using a top pan electronic balance, without surface drying to the nearest 0.5g. The central section from each half of the gonad was then removed (Fig. 2.4.1.). The remainder of the gonad was also frozen separately for future sampling.

Fig. 2.4.1. Diagram showing a female gonad cut in half and the central section from each half removed.



Each fish was sexed and maturity stages were macroscopically assigned to each male and female gonad according to a visual scale provided by the Fish Stock Assessment Group, FSS in the Marine Institute.

Maturity stages were defined as follows:

Females

Stage I – Immature: gonads extremely small, approximately 1/5 in length of body cavity and translucent or white in colour.

Stage II – Developing/Resting: Maturing virgins or recovering spent (resting): gonads 1/3 of body cavity, flattish, reddish-orange or translucent in colour (Fig. 2.4.2).

Stage III – Ripening: gonads 1/2 of body cavity, pinkish white in colour and eggs opaque just visible (Fig. 2.4.3).

Stage IV – Ripening: gonads 2/3 of body cavity, orange pink in colour, opaque eggs clearly visible (Fig. 2.4.5).

Stage V – Pre-spawning: gonad very swollen in body cavity, some eggs transparent (Fig. 2.4.6).

Stage VI – Spawning: gonad very swollen in body cavity, transparent eggs easily extruded (Fig. 2.4.7).

Stage VII – Spent/ Post-spawning: gonad 1/3 – 1/2 of body cavity, reddish bloodshot, flaccid and shrunken.

Males

Stage I – Immature: very small gonad, thin narrow ribbon, translucent.

Stage II – Developing/Resting: Maturing virgins or recovering spent (resting): gonad about 2/5 in length of body cavity, becoming opaque white, slightly lobed and coiled.

Stage III – Ripening: gonad about 3/4 of body cavity, whitish-grey, more strongly coiled, blood vessels visible (Fig. 2.4.8).

Stage IV – Ripening: gonad ¾ of body cavity, becoming more swollen, opaque-white (Fig. 2.4.9).

Stage V – Pre-spawning: gonad nearly filling body cavity, opaque-creamy white, tightly convoluted lobes (Fig. 2.4.10).

Stage VI – Spawning: gonad nearly filling body cavity, opaque-creamy white, and milt easily extruded (Fig. 2.4.11).

Stage VII – Spent/ Post-spawning: yellow-white bloodshot, crinkled and shrunken.

Fig. 2.4.2. Stage II Female ovary (8 cm)

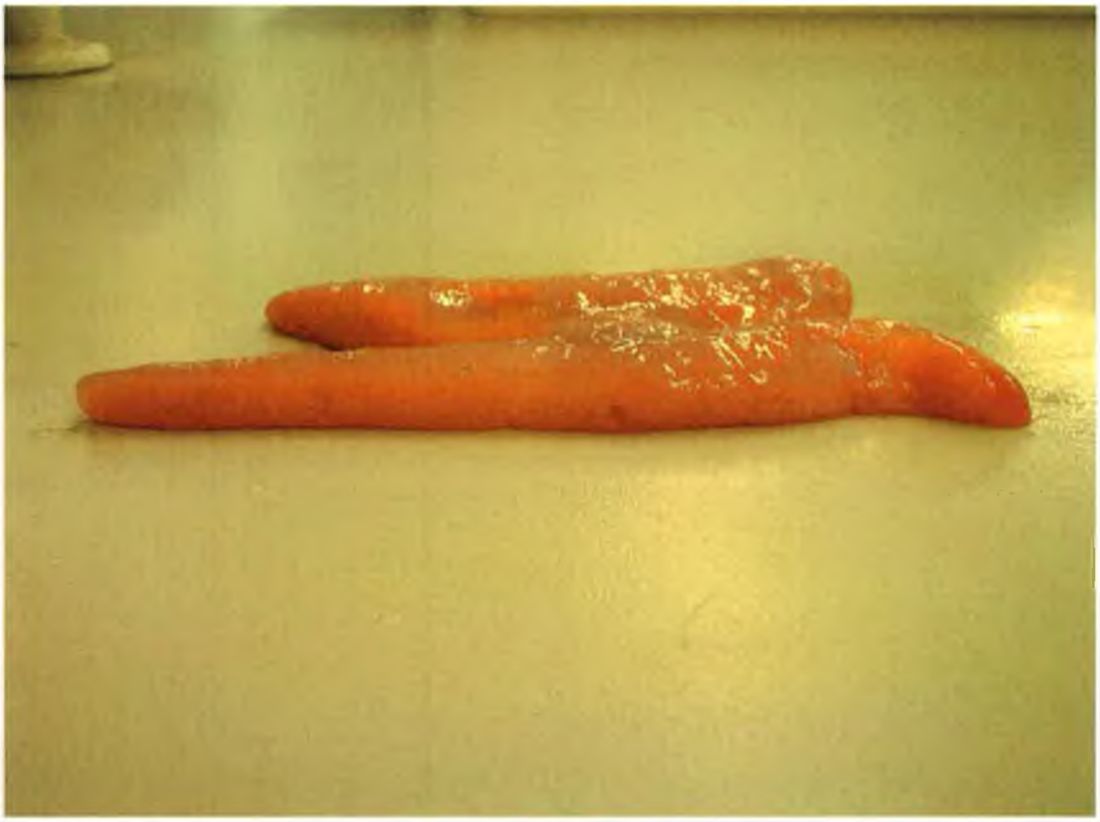


Fig. 2.4.3. Stage III Female ovary (10 cm)

Fig. 2.4.5. Stage IV Female ovary (12.5 cm)

Fig. 2.4.6. Stage V Female ovary (10 cm)

Fig. 2.4.7. Stage VI Female ovary (14 cm)

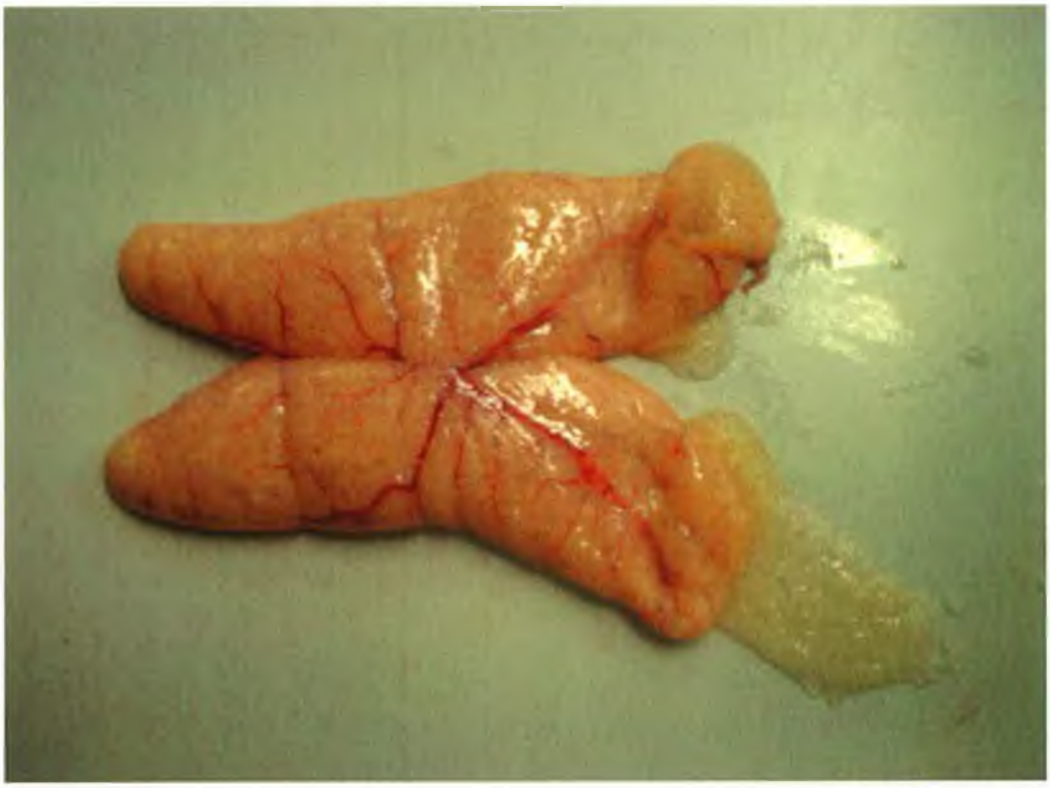


Fig. 2.4.8. Stage III Male testes (13 cm)

Fig. 2.4.9. Stage IV Male testes (14.5 cm)

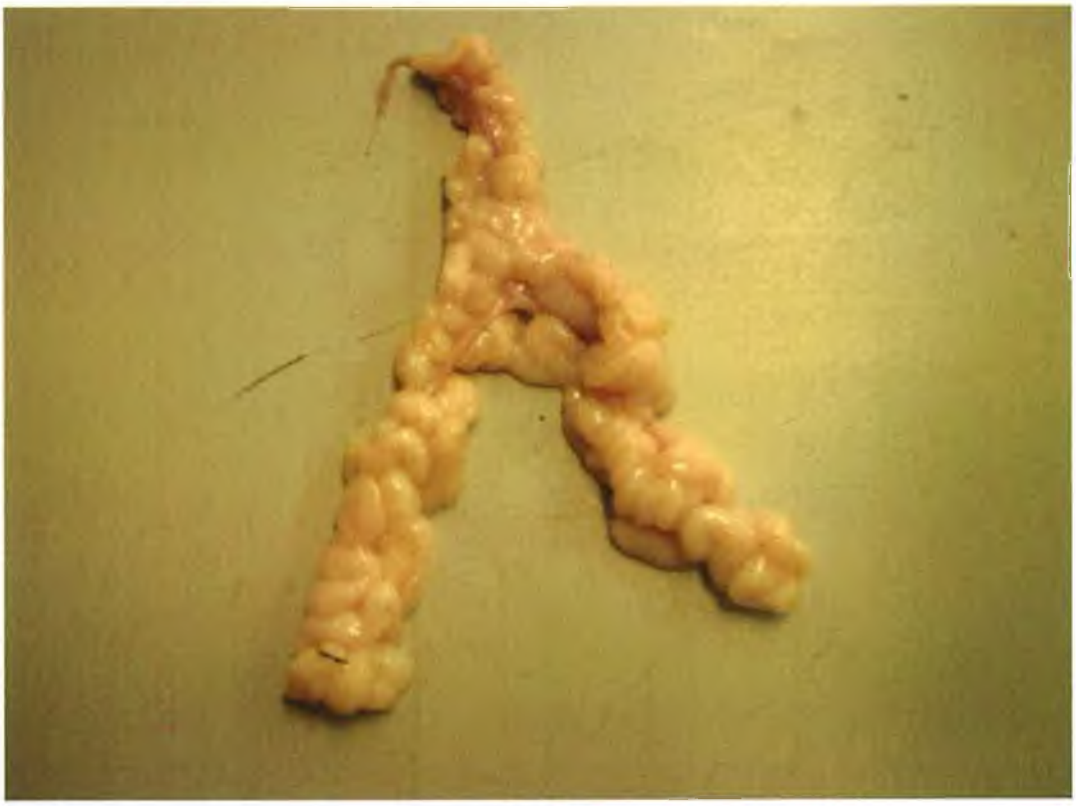


Fig. 2.4.10. Stage V Male testes (17 cm)

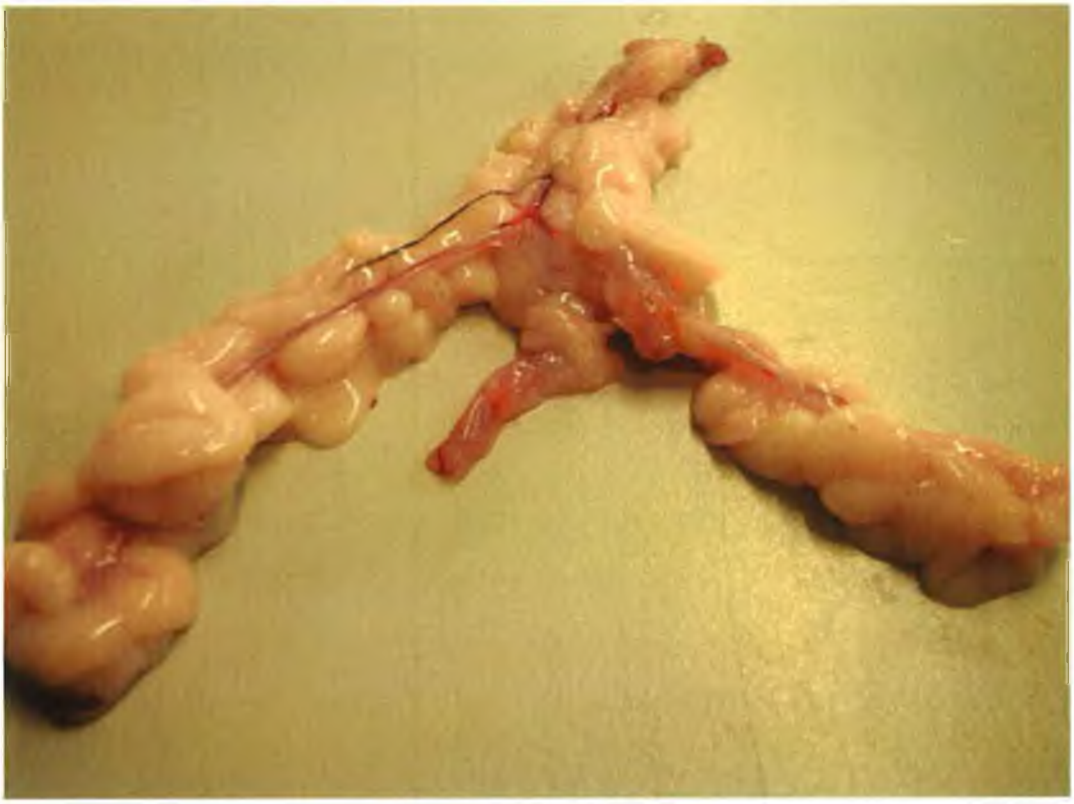
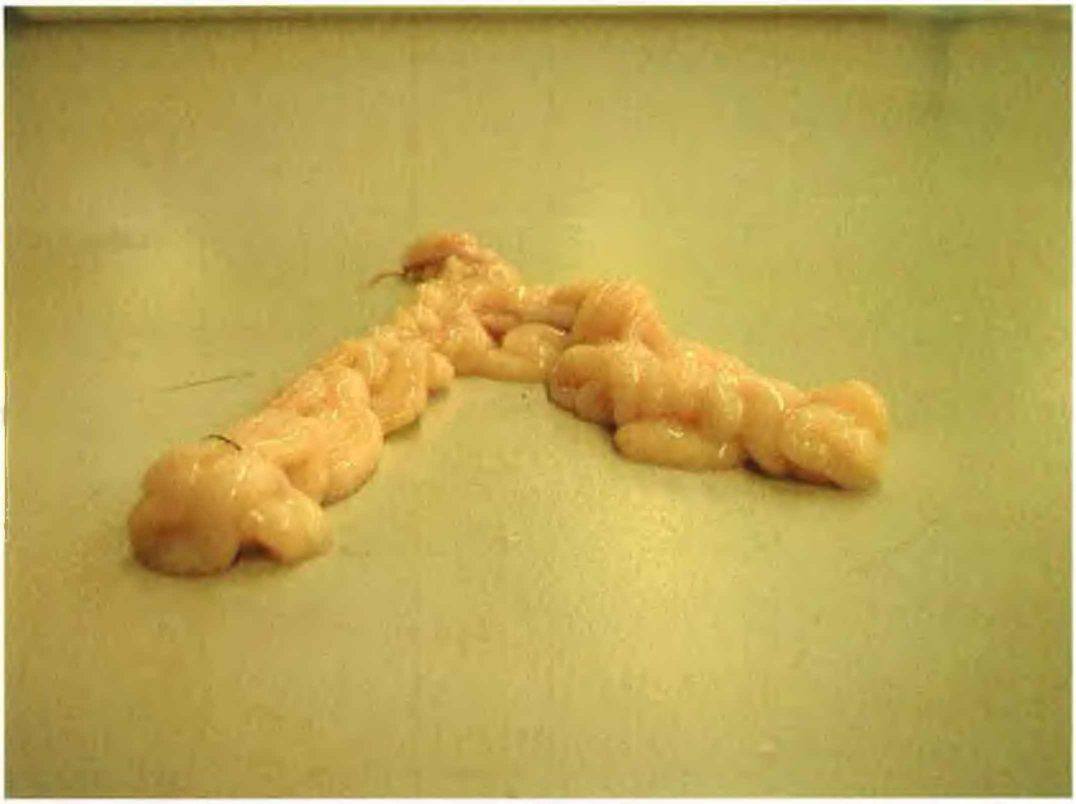


Fig. 2.4.11. Stage VI Male testes (18 cm)



2.4.1 Histology

Tissue Processing

A section from one gonad was placed in a labeled compartment of an ice cube tray and stored for histological analysis. 0.5g approximately was weighed from the other half and placed in a separate compartment of the ice cube tray for fecundity analysis. These gonad samples were preserved by deep-freezing at -18°C, pending further analyses. Samples for fecundity were analysed as part of a Diploma in Aquatic Science project on the 'Fecundity of whiting in the Celtic Sea' (Wall, 2003).

A maximum of 15 males and 15 females were chosen at random from selected sampling dates over the year for histological work. For a number of reasons male gonads were not always available. The selected gonadal samples for histology were removed from the freezer and defrosted. A series of procedures were carried out on the gonadal tissue so that a thin section of the tissue was obtained for staining and microscopic examination. Tissue processing was carried out in a histological lab in the Martin Ryan Institute, NUIG in Galway. The procedure was as follows;

Fixation

A thin section of gonad, approximately 5mm in width, was removed using a scalpel and placed in a pencil labeled cassette. The cassettes containing the gonad section were then placed in labeled 1-liter plastic jars (for 48 hours plus), containing 4 per cent buffered formalin, which was used as a fixative.

Dehydration

Once fixation was complete, the cassettes were placed in 70 per cent alcohol for a minimum of 24 hours. This was done to prevent the dilution of the alcohol in the Shandon Citadel 2000 rotary processor (see Fig. 2.4.1.1).

Fig. 2.4.1.1. Shandon Citadel 2000 rotary processor.

Clearing

Following dehydration, the alcohol was removed from the gonadal section. The cassette was placed in several changes of the solvent "Histoclear©". A maximum of 60 gonadal sections in their cassettes were placed in the processor for a period of 24 hours spending a different time interval in each of the solvents (Table. 2.4.1.1).

Table. 2.4.1.1. The different time intervals the cassettes were present in the different solutions in the processor.

Solution	Time interval (minutes)
70% alcohol	10
80% alcohol	120
90% alcohol	120
Absolute alcohol	120
Absolute alcohol	120
Absolute alcohol	30
Absolute alcohol & Histoclear II (1:1)	120
Histoclear	120
Histoclear	120
Histoclear	120
Wax	180
Wax	180

Embedding

The cassettes were removed from the processor and placed in a beaker containing molten paraffin wax and placed in a Gallenkamp vacuum oven (see Fig. 2.4.1.2) for 30 minutes, with a pressure gradient of 500 mm Hg. The gonadal sections were then embedded on a Shandon Histocentre (see Fig. 2.4.1.3). A hot stainless steel mould was placed on a hot surface and a small amount of molten wax was poured into it. The gonadal tissue was then removed from the cassette and placed in the mould. The cassette base with the identification number was placed on top of the mould and the mould was filled to the brim with wax. The mould was then transferred onto a cold plate so that wax could cool and set. The moulds were left on the cold plate for approximately two hours until the wax containing the gonadal tissue broke away easily from the mould, while remaining attached to the cassette base.

Fig. 2.4.1.2. Gallenkamp vacuum oven

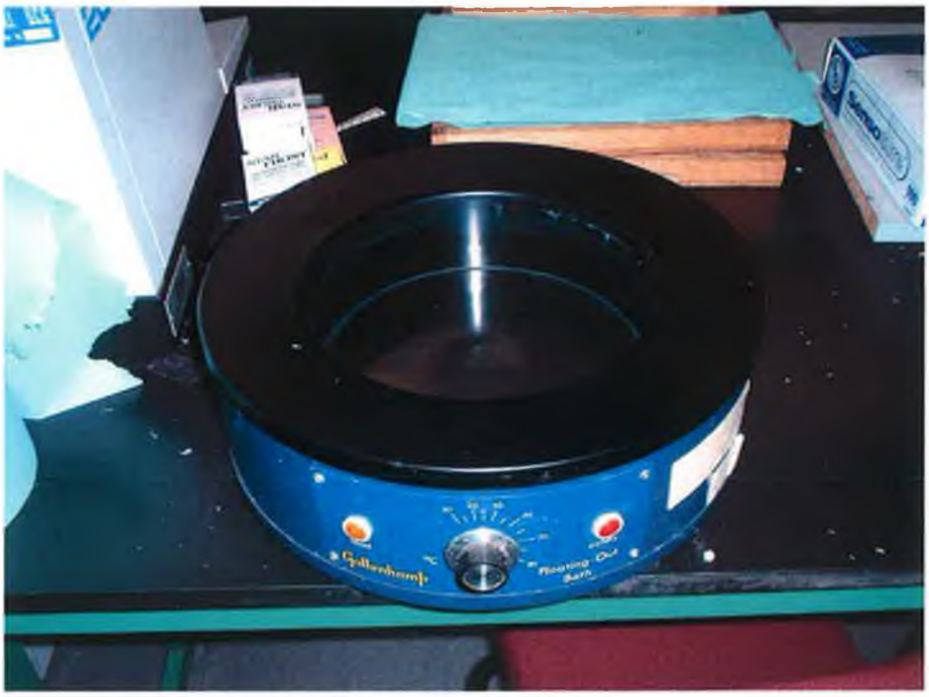
Fig. 2.4.1.3. Shandon Histocentre

Sectioning and floating out

The excess wax was cleaned away using a scalpel, so that the cassette base would fit correctly onto the microtome before sectioning. This was only carried out immediately before sectioning as the tissue may become damaged during storage prior to this point. Thin sections ~5-10μm in thickness of the gonadal tissue embedded in the wax were then cut using the Leica Jung RM2025 rotary microtome (see Fig. 2.4.1.4) and placed flat in a paraffin section mounting water bath (see Fig. 2.4.1.5) at 45°C. Glycerin albumen was smeared onto labelled glass slides and the slides were placed in the water bath to allow the sections (in ribbons of 2 – 5 links) to adhere onto them. Triplicate slides were prepared for each gonadal sample.

Fig. 2.4.1.4. Leica Jung RM2025 rotary microtome

Fig. 2.4.1.5. Mounting water bath



Staining

One of the triplicate slides from each sample was then stained with H & E (Haemotoxylin and Eosin) using a Shandon Linistain GLX (see Fig. 2.4.1.6). Haemotoxylin stains nuclei purple /blue while the counter-stain, Eosin, stains cytoplasm orange/ pink. There were 27 compartments in the stainer containing different solutions and stains in which the slides were stained (Table 2.4.1.2). Excess histoclear was wiped from the slides without damaging the gonadal tissue. The slides were then inverted onto large coverslips containing a couple of drops of DPX mountant. The slides were left flat to dry for a week or so and then stored safely in labeled slide boxes.

Fig. 2.4.1.6. Shandon Linistain GLX stainer

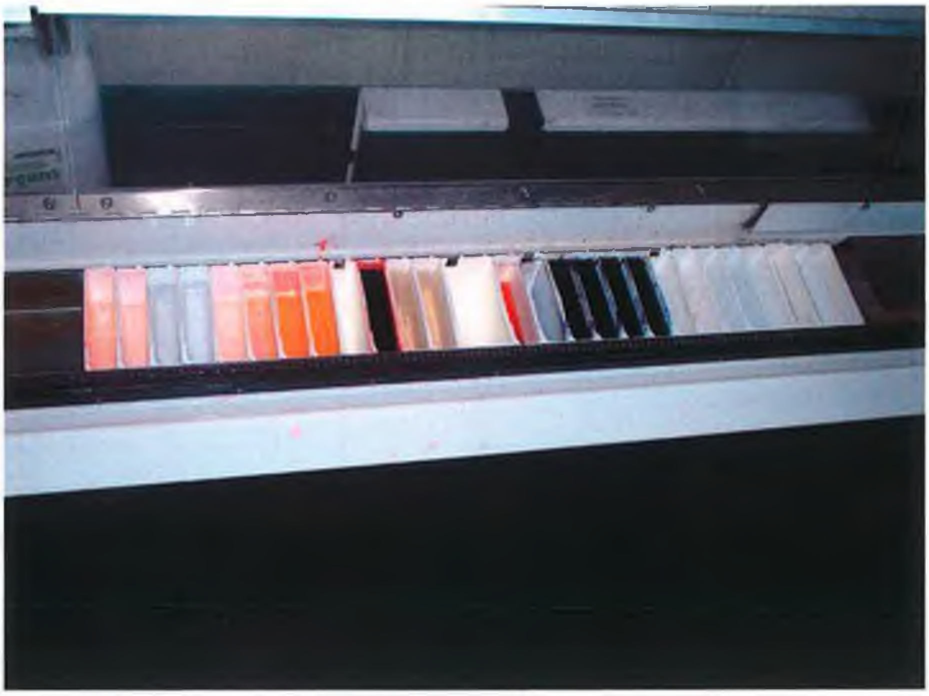


Table. 2.4.1.2. Table to show the different solutions and stains used in the Shandon Linistain GLX stainer.

Substances used in the stainer
Histoclear (X4)
Absolute Alcohol
90% Alcohol
70% Alcohol
Water
Haemotoxylin (X4)
Water (X5)
Eosin
Water
70% Alcohol
90% Alcohol
Absolute Alcohol (X2)
Histoclear (X4)

2.4.2 Classification of Histological Stages.

Image analysis was carried out using Olympus DP- Soft. Histological staging was carried out using an Olympus CX41 light microscope. There was no previous histological guide for staging the gonads of whiting. After initial scanning of the slides, containing the female and male gonadal tissue, the following stages were established. These were modified extensively, particularly in the earlier maturation stages, from that described for Cod by Morrison (1990) and are presented below:

Females

Stage I – Immature: oocytes are present ranging from 10 μm to 100 μm I diameter (Fig. 2.4.3.1). Oocytes showed a characteristic colour pattern, with two or three concentric colour bands (Fig. 2.4.3.2). Where three bands were present, the central band was purple in colour.

Stage II – Developing/ Resting: oocytes as in Stage I, but oocytes ranging 100 – 200 μm also present (Fig. 2.4.3.3).

Stage III – Ripening: Same as Stage II, with additional pink oocytes, containing a nucleus (250 – 300 μm) (Fig. 2.4.3.4).

Stage IV – Ripening: Vitellogenic oocytes present approximately 500 μm in diameter with nucleus present. Vitelogenesis obvious in some, yolk droplets present (Fig. 2.4.3.5). Ovary wall thinner. Oocytes present as in Stages I and II.

Stage V – Pre-spawning: tightly packed vitallogenic oocytes (500 μm) abundant, vitelogenesis present but not as extensive as in Stage IV (Fig. 2.4.3.6). Oocytes present as in Stages I and II.

Stage VI – Spawning: hydrated oocytes present (very irregular in shape and pink/ lilac in colour) (Fig. 2.4.3.7). Oocytes present as in Stages I and II.

Stage VII – Spent/ Post-spawning: pink flaccid oocytes (atresia). Oocytes present as in Stages I only.

Males

Stage I – Immature: no spermatocytes present. Spermatogonia at an early stage of development (Fig. 2.4.3.8).

Stage II – Developing/Resting: few spermatogonia and spermatocytes in clusters at a very early stage in development.

Stage III – Ripening: mainly spermatocytes, few spermatids, follicles appearing which persist until the gonad is spent (Fig. 2.4.3.9).

Stage IV – Ripening: spermatids forming into lamellae. (Fig. 2.4.3.10).

Stage V – Pre-spawning: spermatids and spermatozoa present. Lamellae obvious (Fig. 2.4.3.11).

Stage VI – Spawning: spermatozoa numerically dominant, few spermatids. Lamellar organization among spermatazoa. This stage was divided into early and late spawning histologically (Fig. 2.4.3.12 and Fig. 2.4.3.13).

Stage VII – Spent/ Post-spawning: Empty/ near empty follicles Empty spaces in gonad (Fig. 2.4.3.14).

Histological structure of whiting ovaries

Light microscopy photomicrographs of histological structure of whiting ovaries and testes in different stages of maturation are shown in Figs. 2.4.3.1 to 2.4.3.14. The histological preparations are stained with Haemotoxylin and Eosin.

Fig. 2.4.3.1. Ovary in stage I (Immature) female, 5/10/7/01, at 100x magnification. *Showing oocyte development stages (a) oogonia (10µm to 100µm) and (b) ovary outer membrane.*

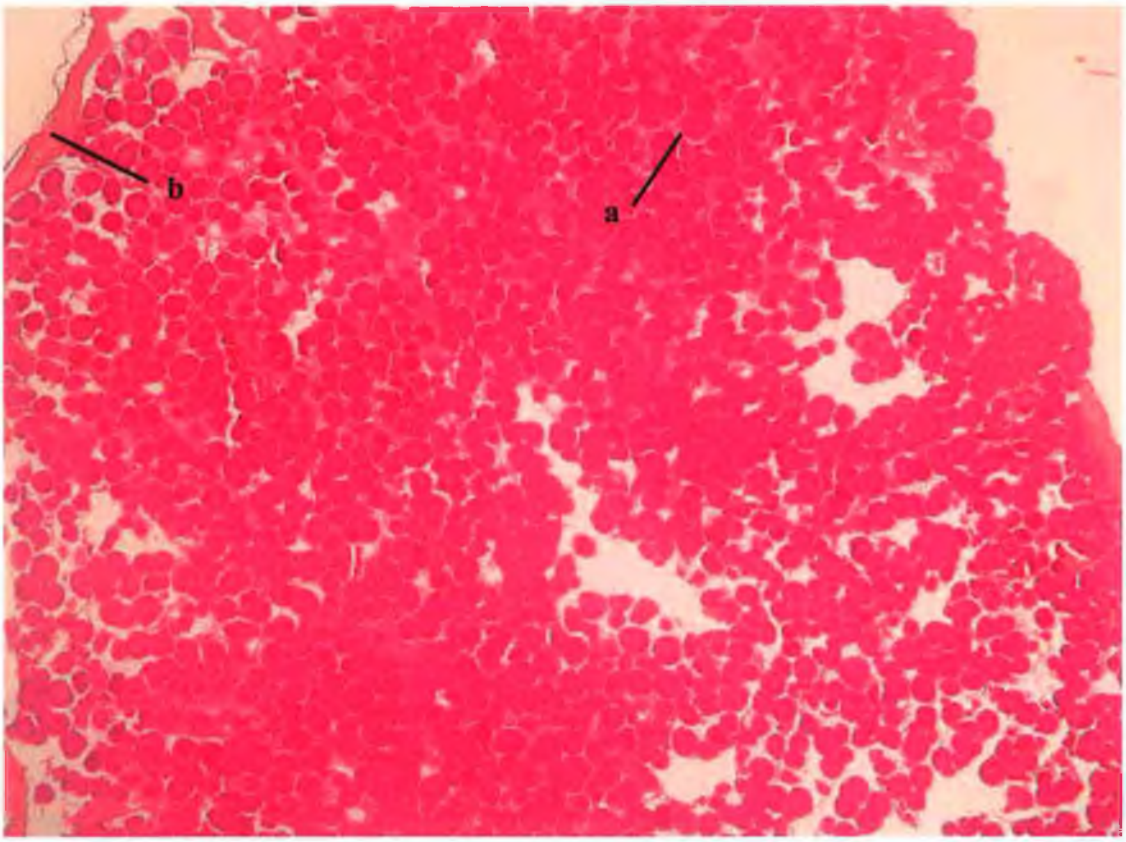


Fig. 2.4.3.2. Ovary in stage I (Immature) female, 5/10/7/01, at 400x magnification

Showing oocyte development stages (a) two concentric colour bands, (b) three concentric colour bands and (c) central purple band.

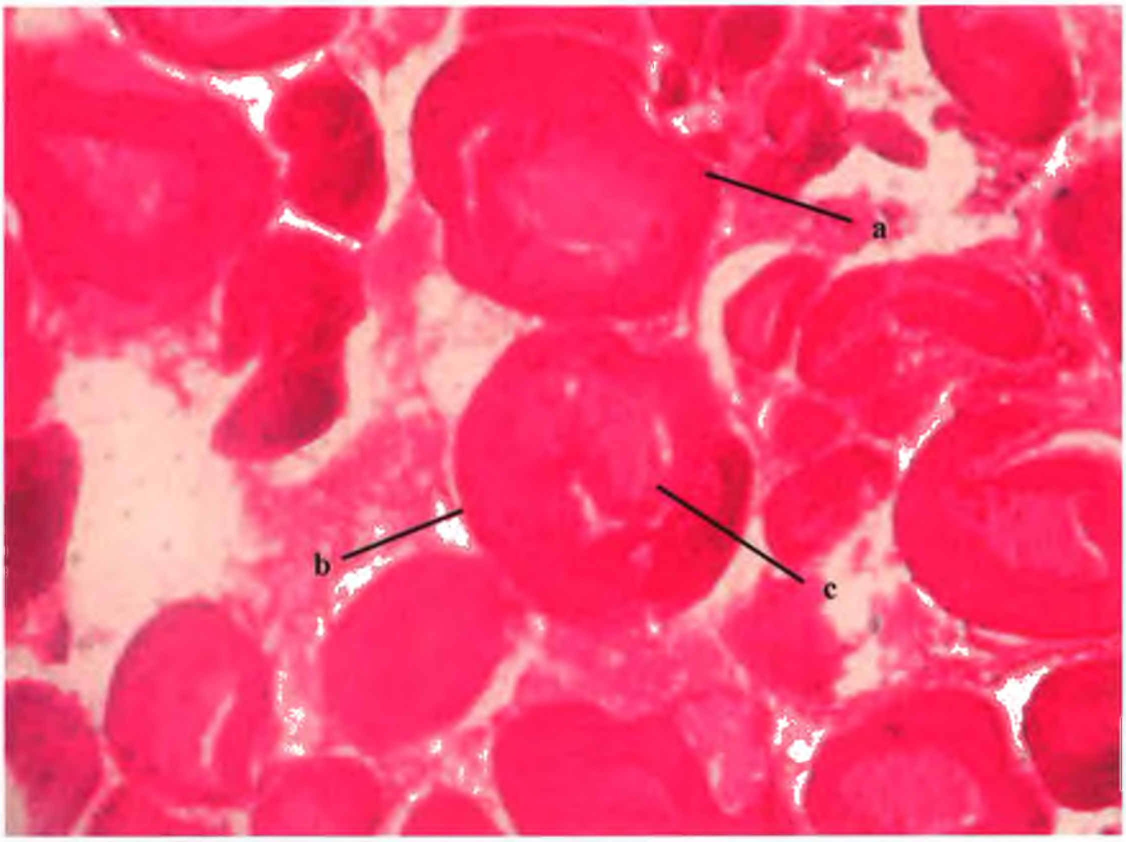


Fig. 2.4.3.3. Ovary in stage II female, 44/10/7/01, at 100x magnification.

Showing oocyte development stages, (a) oogonia (10μm to 100μm) and (b) oocytes (100 - 200μm)

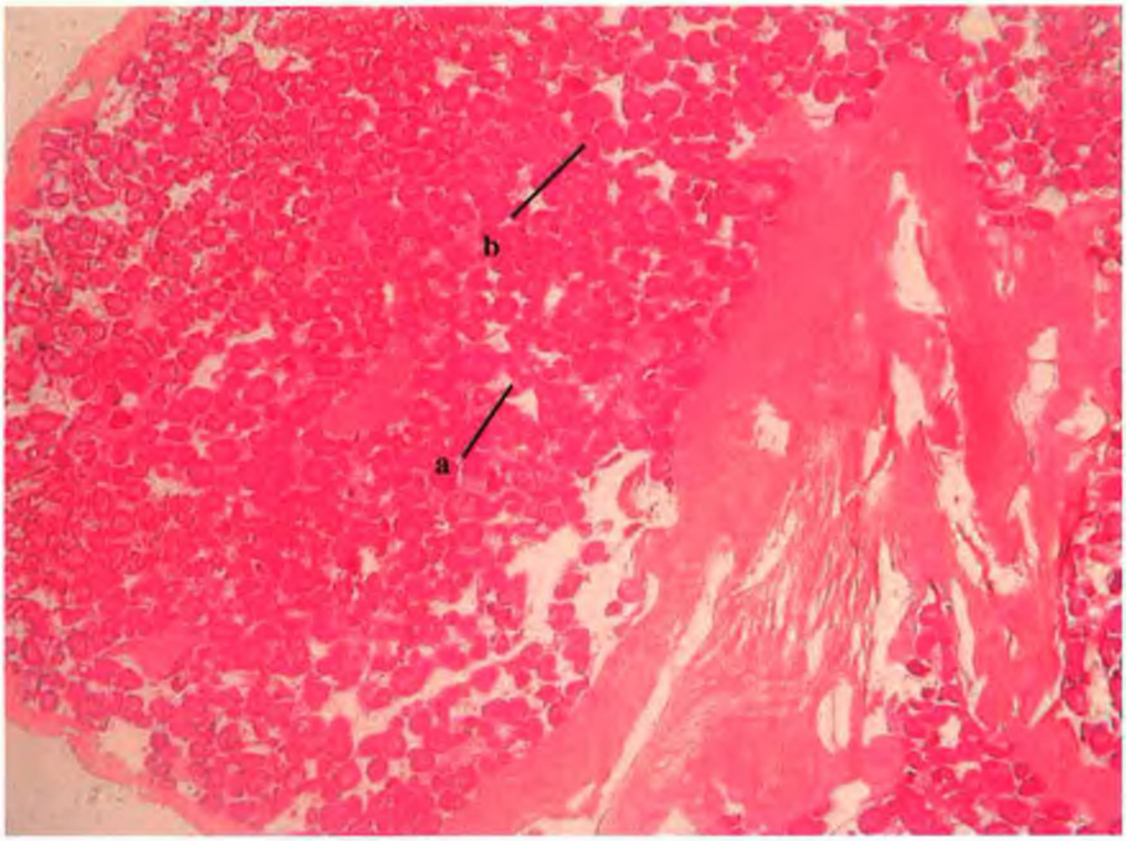


Fig. 2.4.3.4. Ovary in stage III (Ripening) female, 3/15/01/02, at 100x magnification.

Showing oocyte development stages (a) oogonia (10 - 100μm), (b) oocytes (100 - 200μm), (c) oocytes (250 – 300μm) and (d) nucleus.

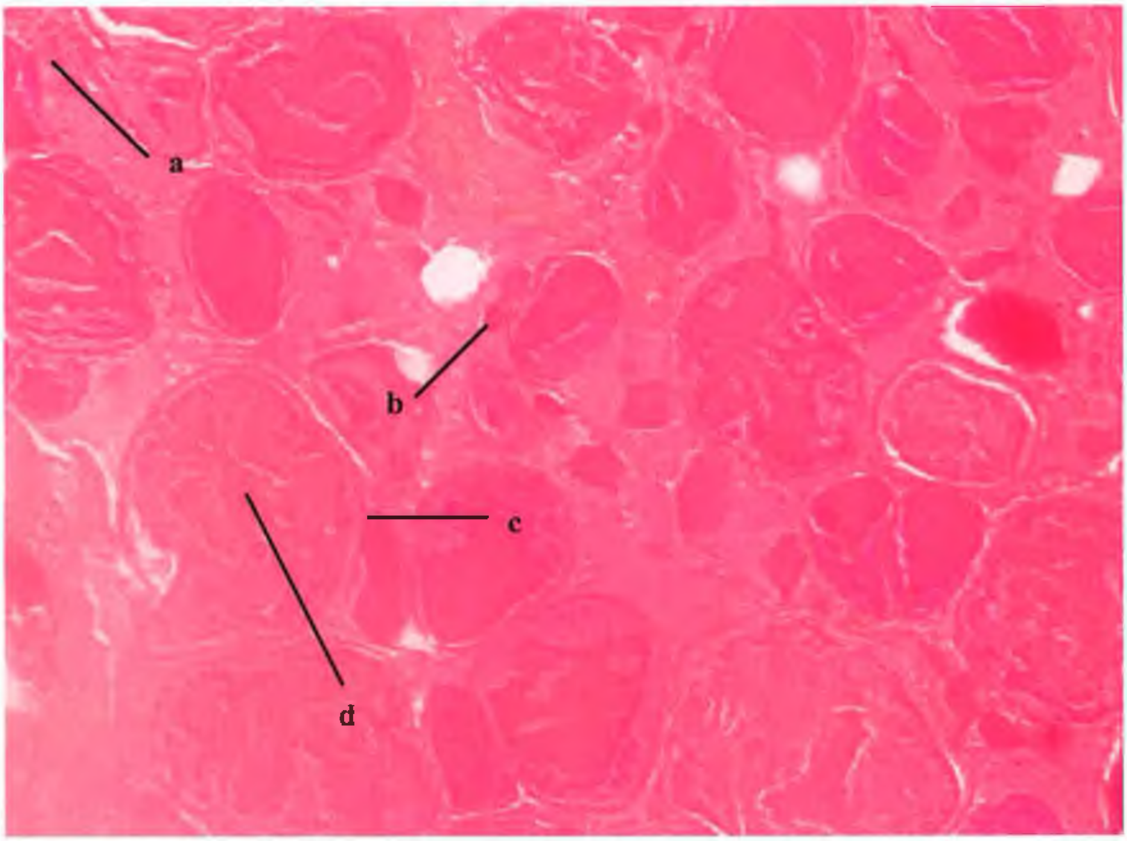


Fig 2.4.3.5. Ovary in stage IV (Ripening) female, 30/15/3/01, at 100x magnification.

Showing oocytes development stages (a) oocytes (250 – 300μm), (b) vitellogenic oocytes (500μm), (c) nucleus and (d) yolk droplets.

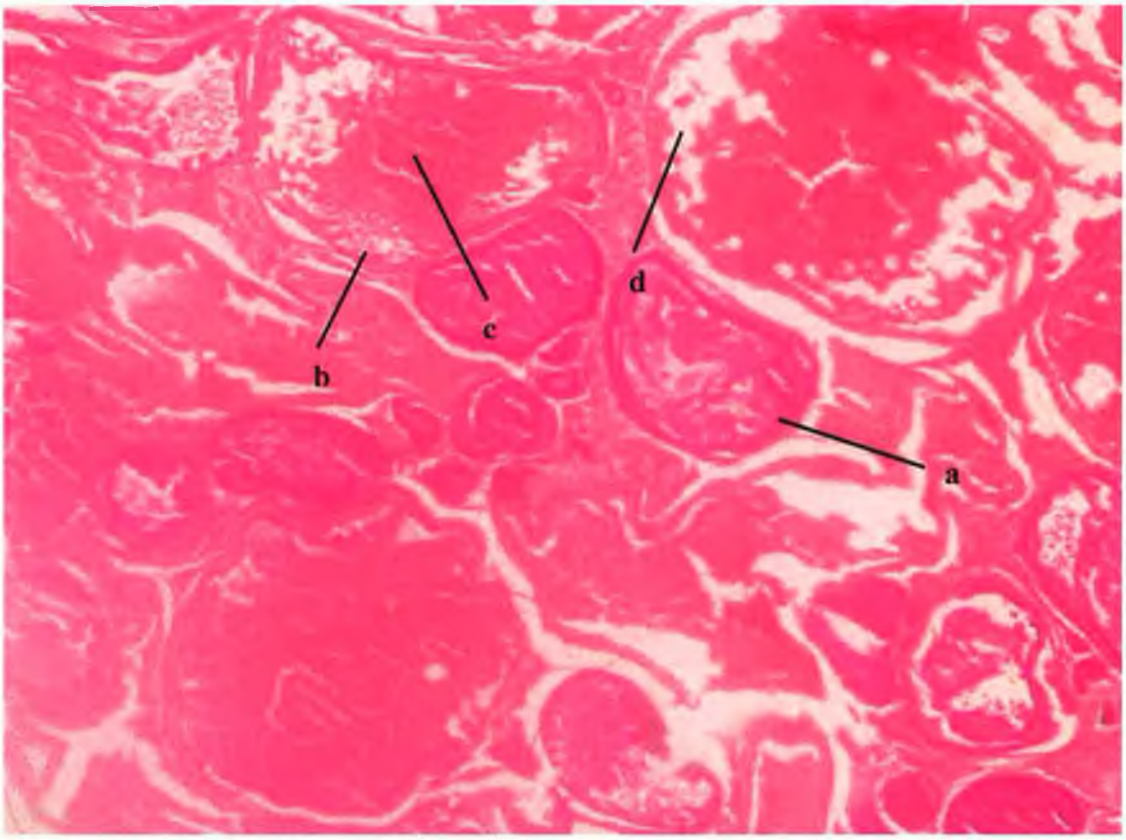


Fig. 2.4.3.6. Ovary in stage V (Pre-spawning) female, 11/15/1/02, at 100x magnification.

Showing oocyte development stages (a) vitellogenic oocyte (500μm).

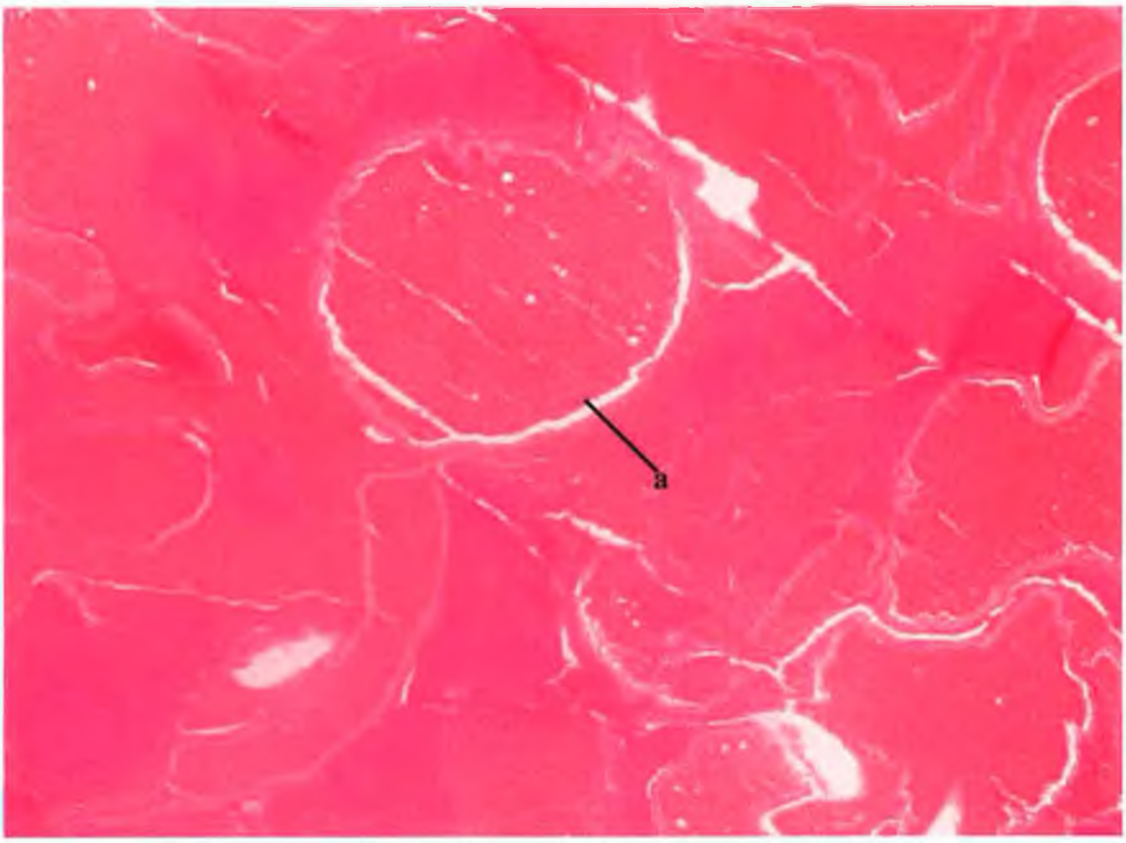


Fig. 2.4.3.7. Ovary in stage VI (Spawning), female 31/9/4/01, at 100x magnification.

Showing oocyte development stages (a) hydrate oocyte, (b) vitellogenic oocyte (500µm), (c) oogonia (10 - 100µm), (d) oocyte (100 - 200µm) and (e) lumen.

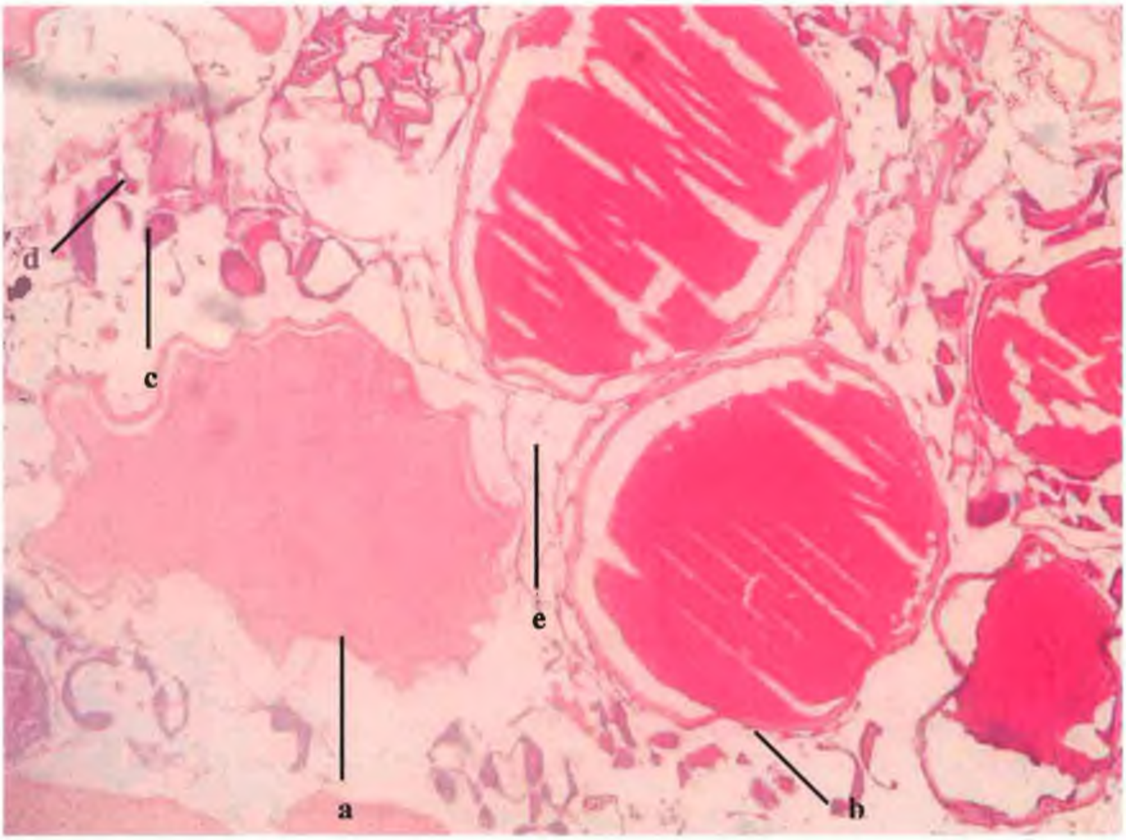


Fig. 2.4.3.8. Testes in stage I (Immature), male 34/3/11/01, at 100x magnification.

Showing development stages (a) spermatagonia and (b) gonadal tissue.

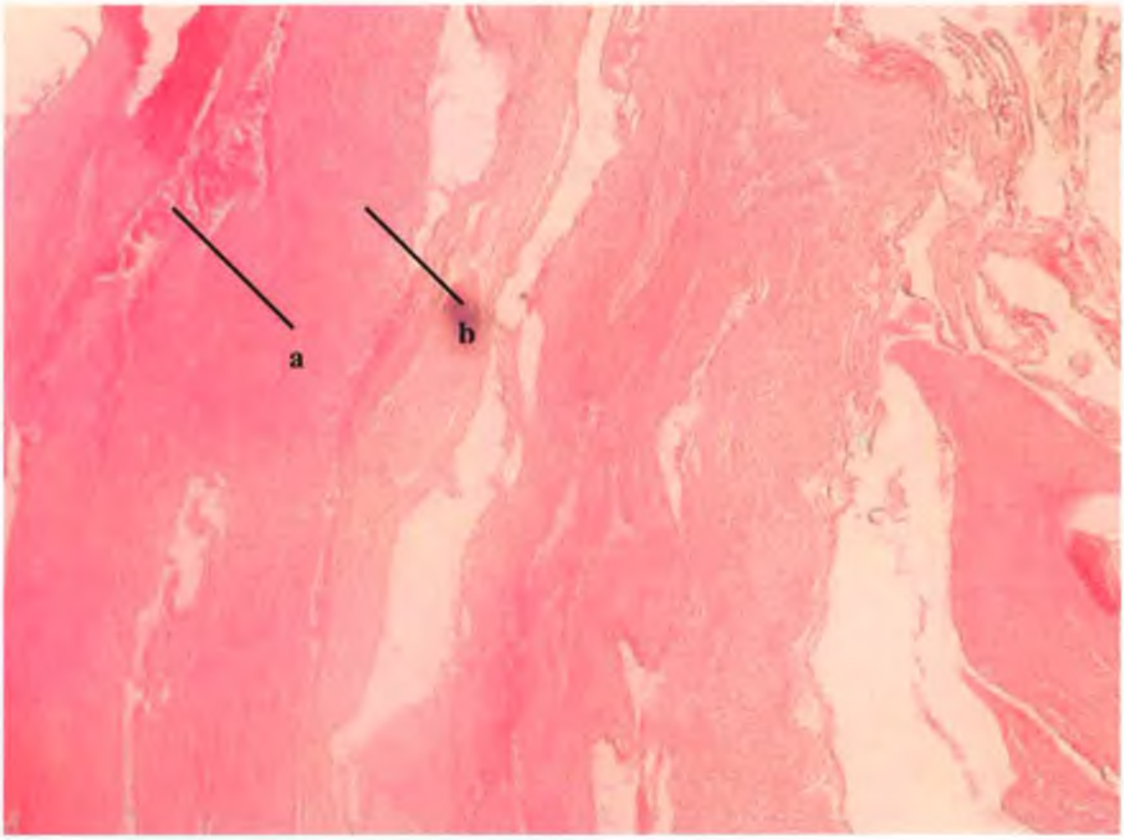


Fig. 2.4.3.9. Testes in Stage III (Ripening) male, 47/3/12/01, at 100x magnification.

Showing development stages (a) spermatids, (b) spermatocytes and (c) follicle.

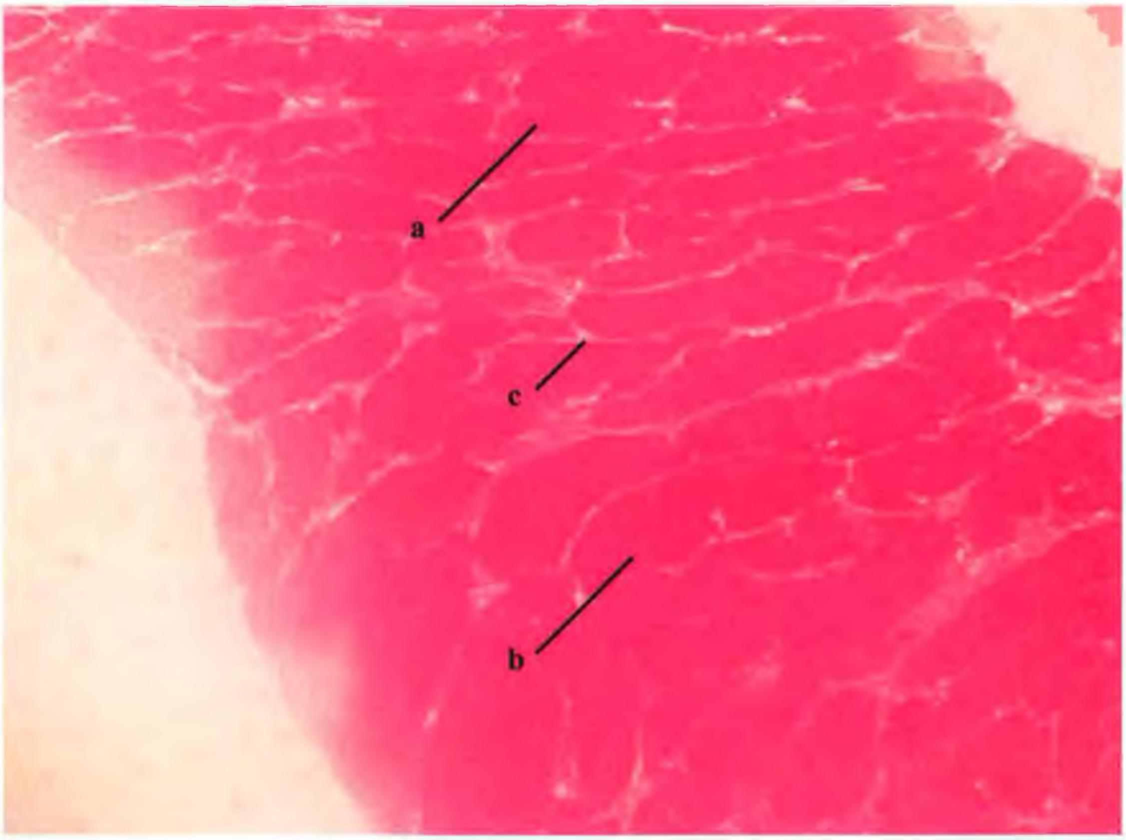


Fig. 2.4.3.10. Testes in stage IV (Ripening) male, 107/3/12/01, at 100x magnification.

Showing development stages (a) spermatids forming into lamellae.

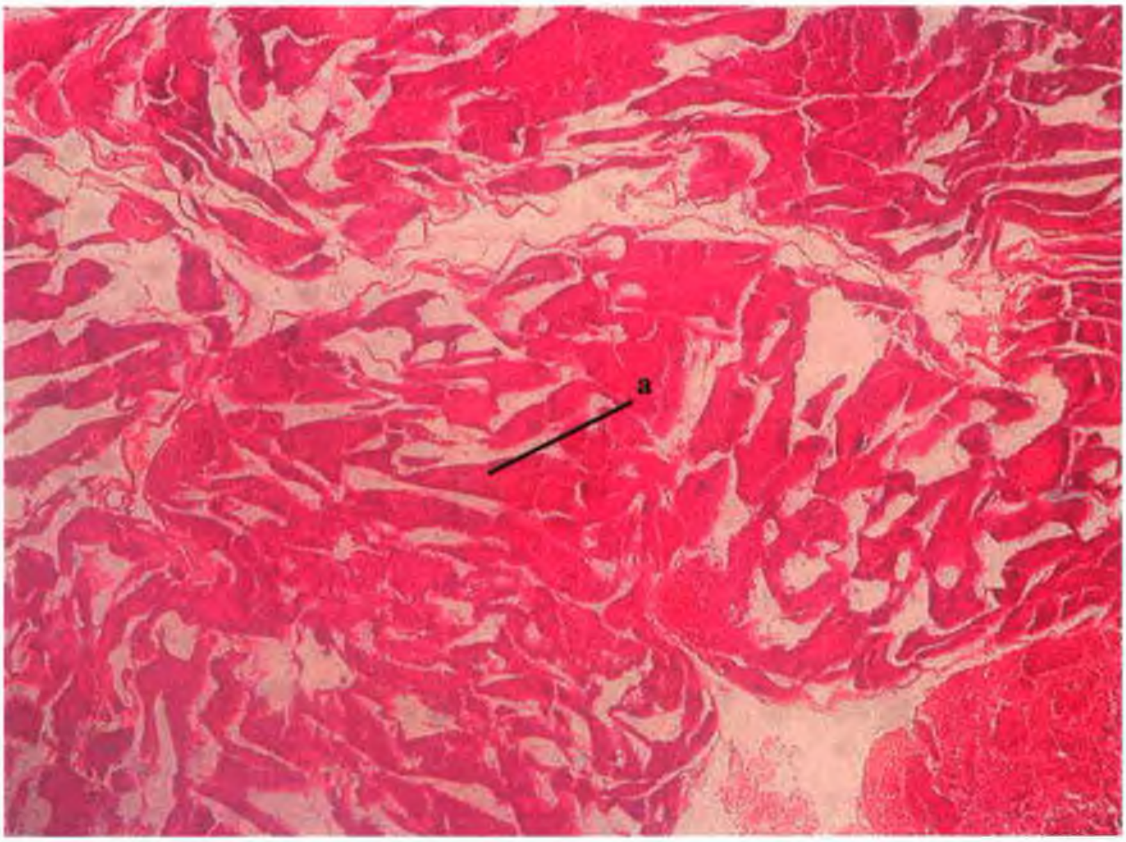


Fig. 2.4.3.11. Testes in stage V (Pre-spawning) male, 21/15/1/02, at 100x magnification.

Showing development stages (a) spermatids, (b) spermatozoa and (c) lamellae obvious.

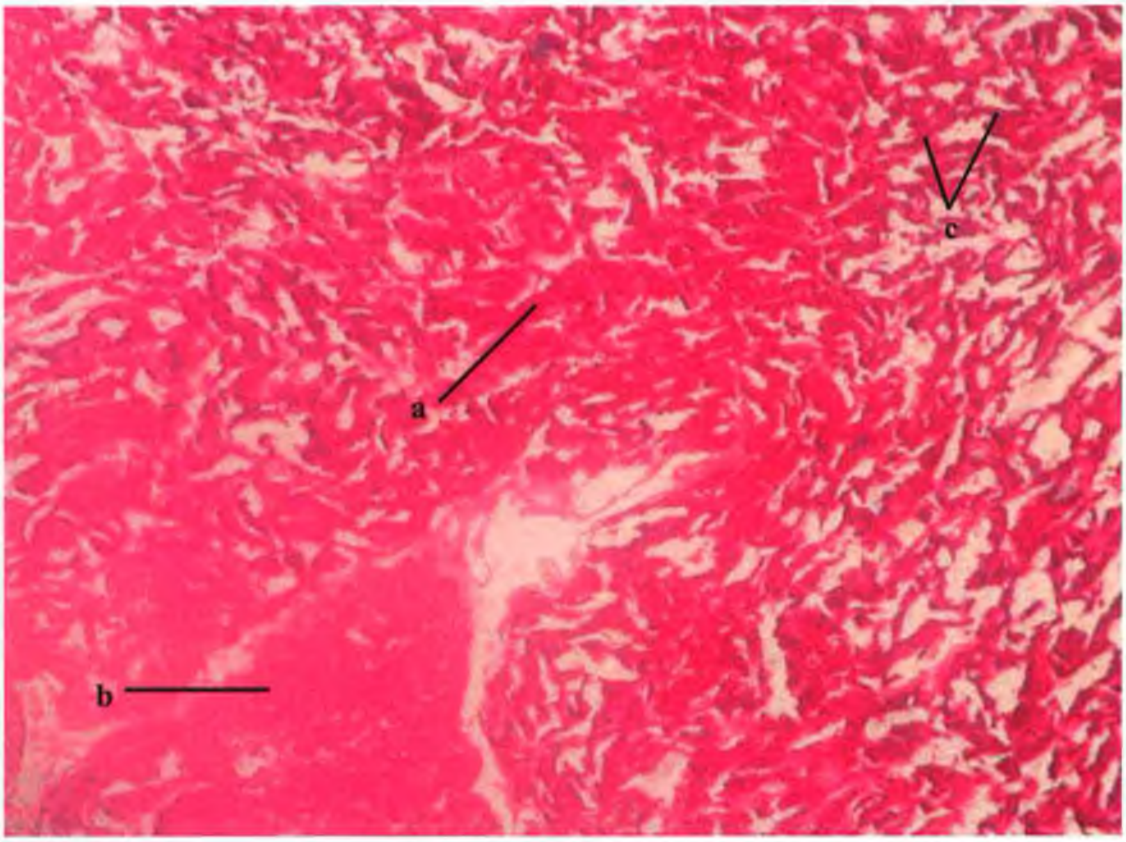


Fig. 2.4.3.12. Testes in stage VIa (Spawning) male, 33/15/1/02, at 100x magnification.

Showing the development stages (a) spermatozoa and (b) spermatids.

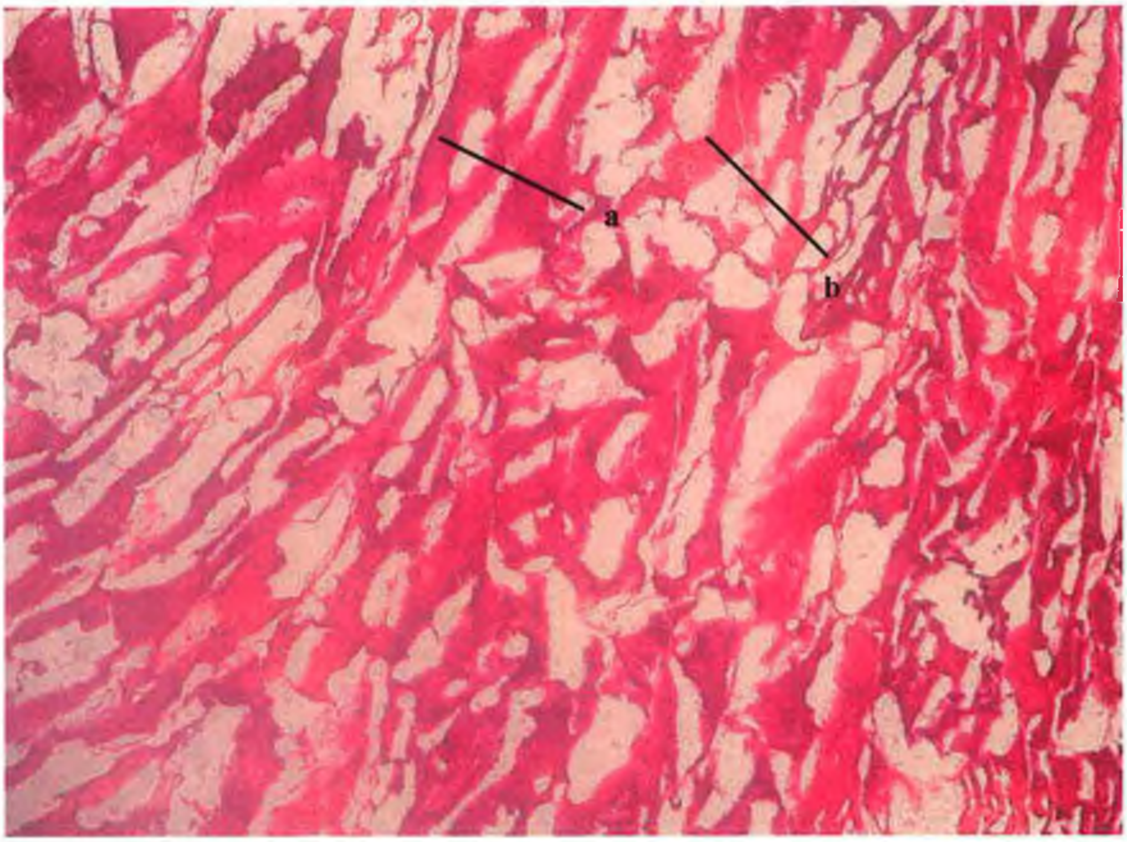


Fig. 2.4.3.13. Testes in stage VIb (Spawning) male, 19/25/4/01, at 100x magnification.

Showing development stages (a) spermatozoa and (b) follicle.

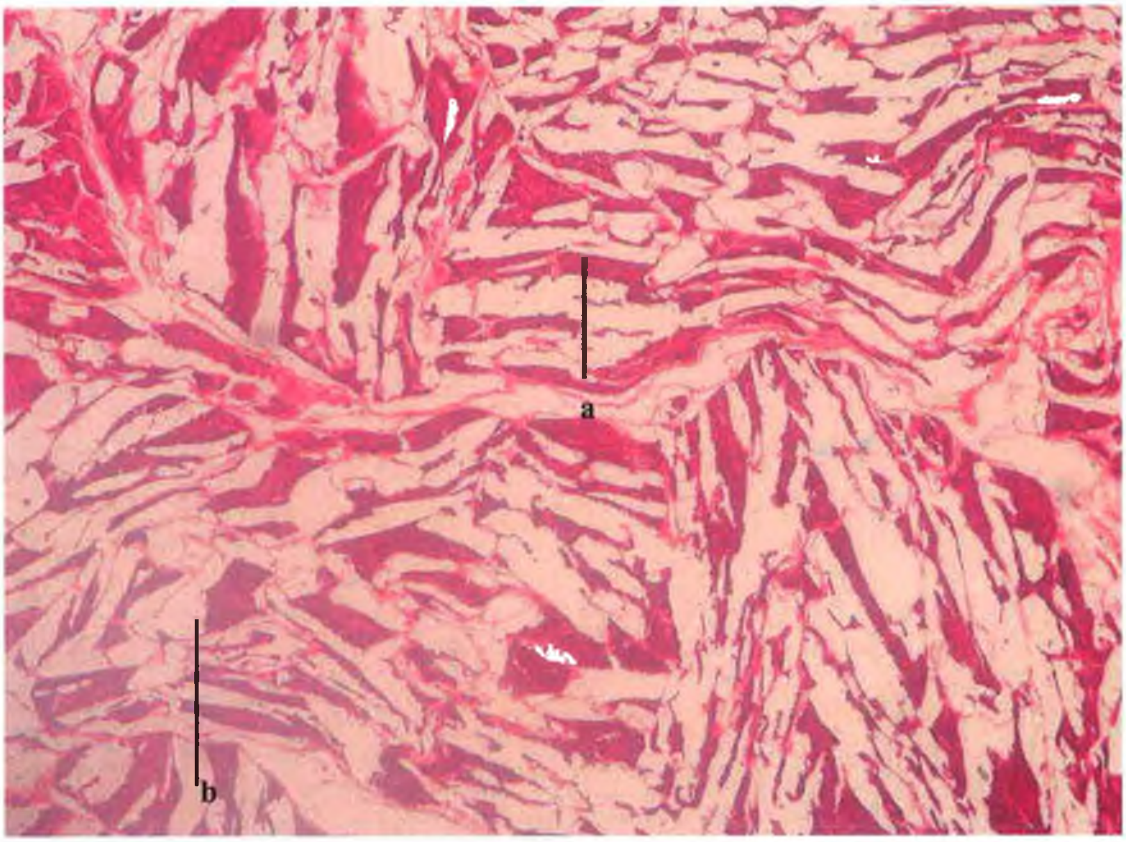
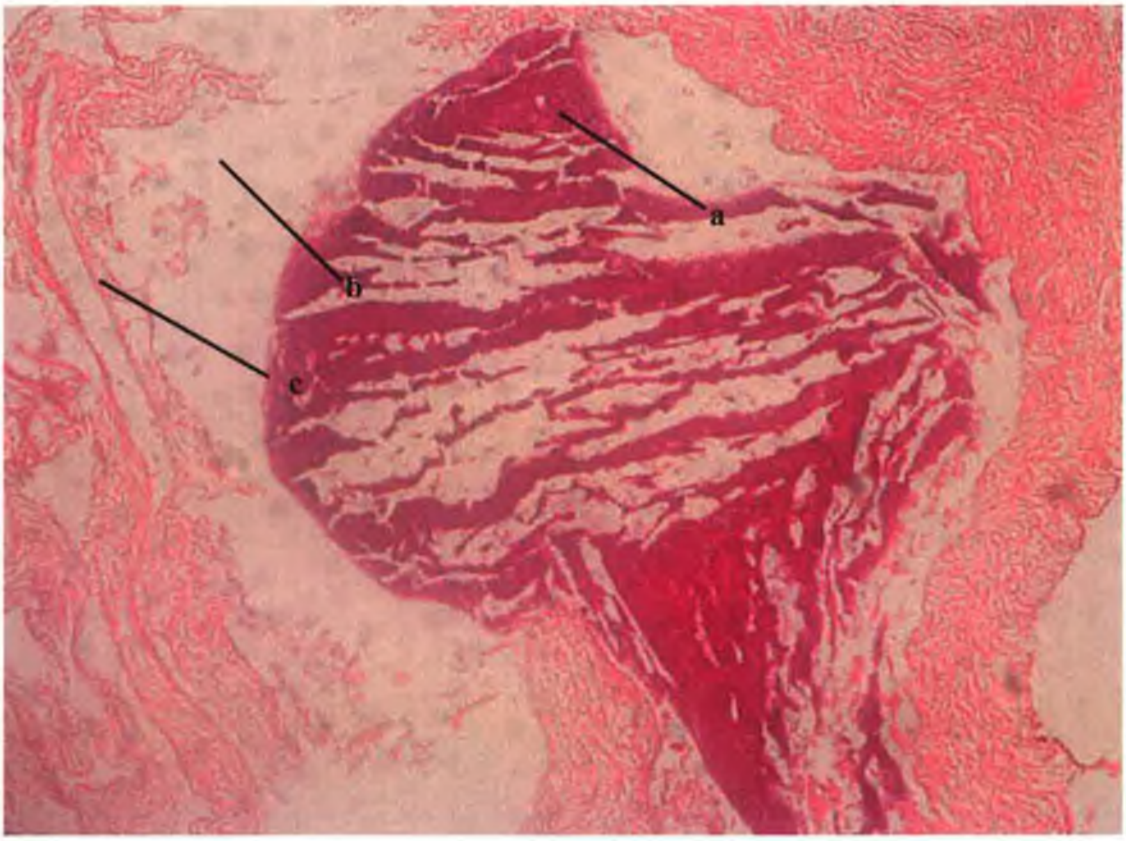


Fig. 2.4.3.14. Testes in stage VII (Spent) male, 3/5/6/01, at 100x magnification.

Showing development stages (a) spermatozoa, (b) Empty spaces in gonad and (c) gonadal tissue.



2.5 Ageing

The otoliths were removed from the cranium by means of a transverse incision through the head on the dorsal side, behind the eye, using a sharp knife (Fig. 2.5.1). The otoliths are located in the ventrolateral position in the sacculi of the ears (Bowers, 1954). Once the incision is made, the semi-circular canals are exposed and the sagittal otoliths are removed with a fine forceps. After cleaning, the otoliths were stored dry in specially designed labeled boxes, pending further examination (Fig. 2.5.2). The otolith of the whiting is an elongate structure, rounded or obliquely truncated anteriorly and tapering to a point posteriorly (Bowers, 1954) (Fig. 2.5.3). Whiting otoliths are thinner and flatter than those of most other gadoids (Scott, 1906). The two otoliths were stored separately, one for use by the FSS and the other for the purpose of determining the age and growth of whiting in the present study. Whiting otoliths are thick requiring sectioning in order to view the zones. The stored dry otoliths were embedded in resin in moulds before sectioning. Dry otoliths were essential to ensure that the resin adhered to the outside of the otolith.

Fig. 2.5.1. Photo showing the location of the otoliths in the cranium.

(a) Otolith and (b) Cranium

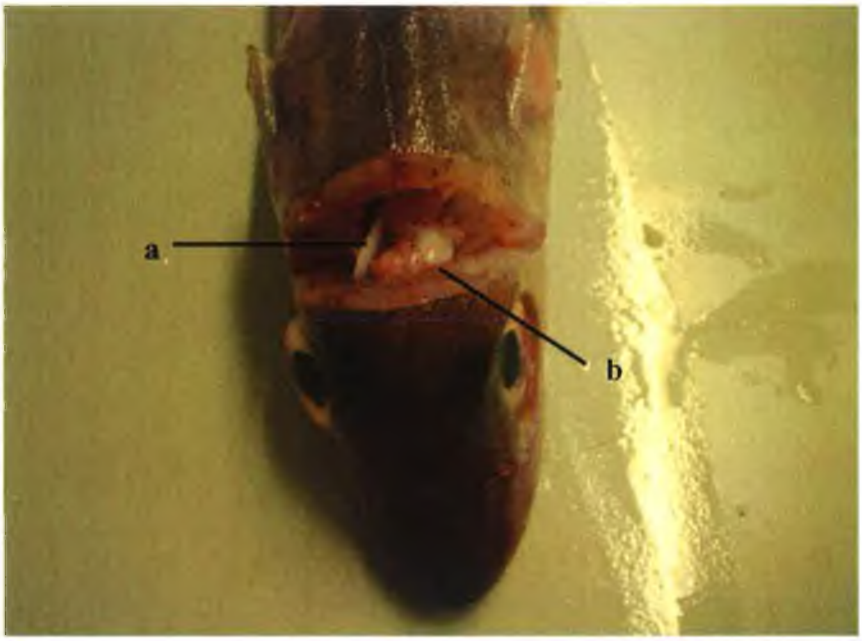


Fig. 2.5.2. Specially designed boxes for the storage of dry otoliths.

(a) Whiting otolith and (b) Individual compartment

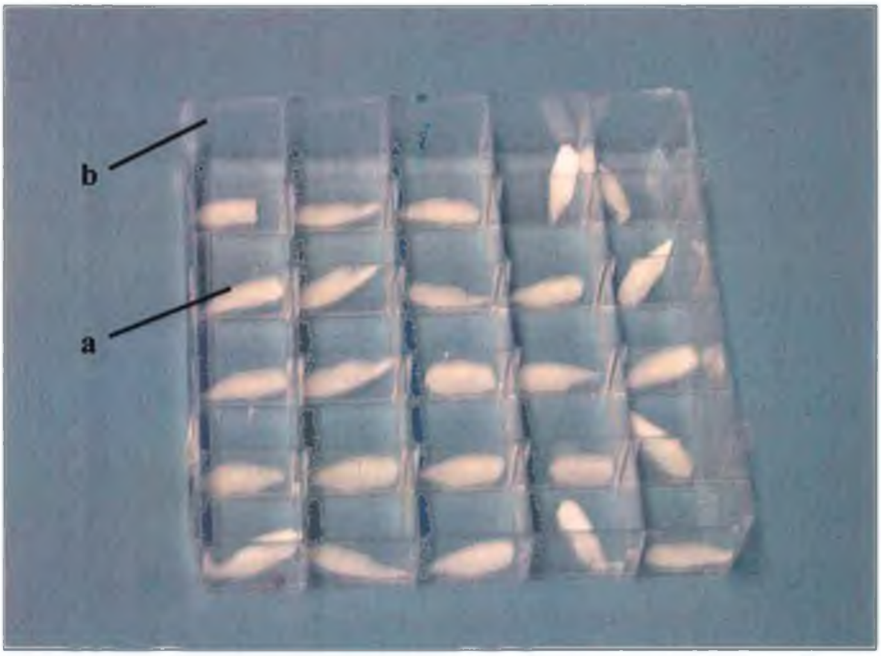
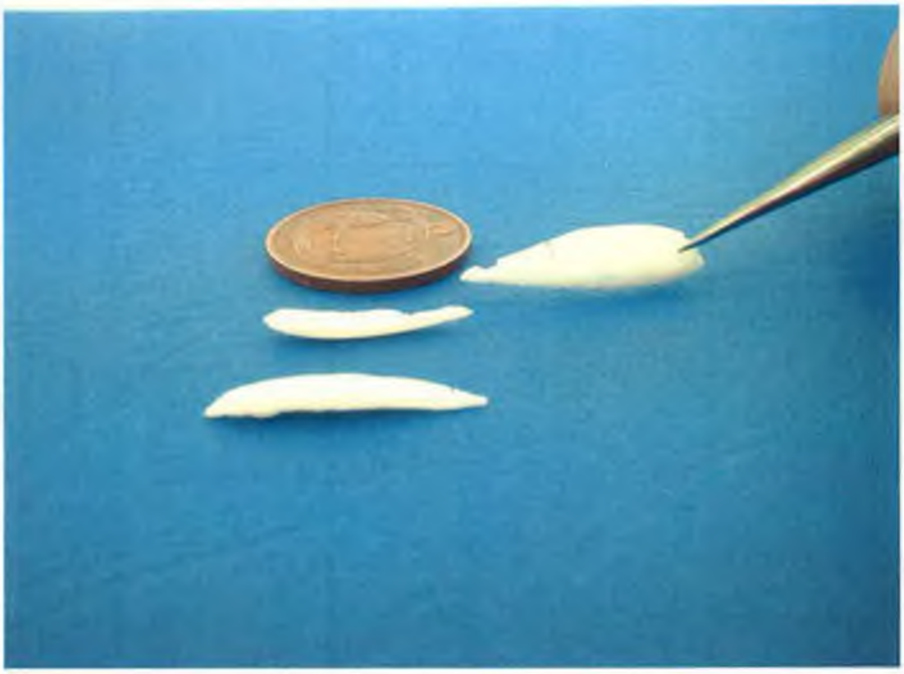


Fig. 2.5.3. Whiting otoliths: coin for scale is 2 cm in diameter.



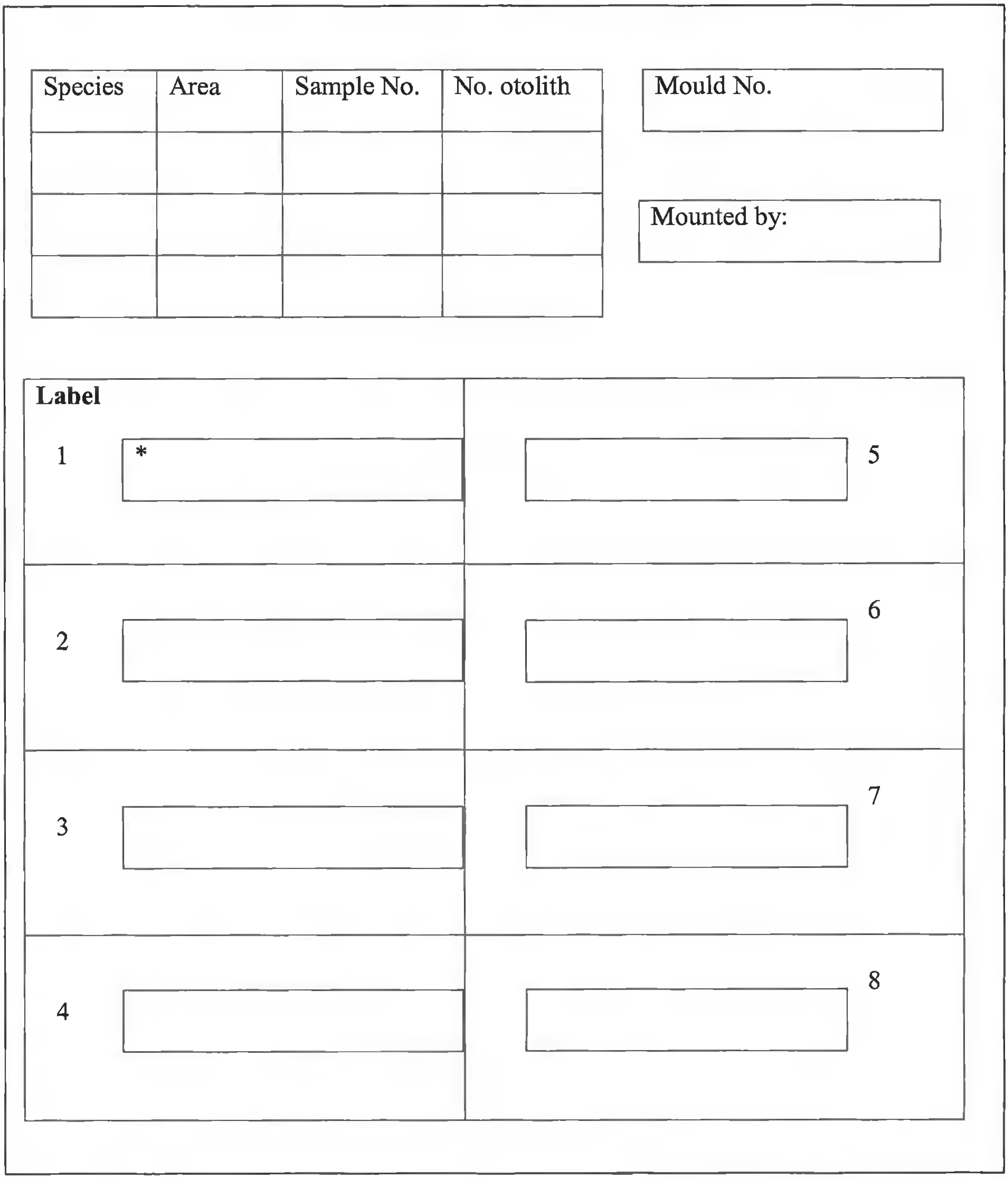
2.5.1 Sectioning process

The sectioning process was carried out as follows;

Mould Preparation

Stainless steel moulds with eight compartments were used to make resin blocks containing the otoliths for sectioning (Fig. 2.5.1.1a). The resin surrounding the otoliths worked as a support while sectioning. A layer of WD 40 was sprayed on the inside of clean moulds, therefore easing the removal of the resin blocks when set. A lump of Mirror Glaze wax was placed on the left hand side of each compartment, this was to facilitate the removal of the resin blocks when set. Each of the moulds were labelled on the top left hand corner with sequential numbers. Each of the moulds had a corresponding map showing the layout of the otoliths in the individual compartments. Each map contained the following information: sample number, species, number and layout of otoliths (Fig. 2.5.1.2). These maps were filed for reference.

Fig. 2.5.1.2. Otolith mould plan.



* is the spaghetti marker.

Resin Preparation

All resins and catalysts were handled according to the manufacturers instructions and were used in the fume cupboard. The resin was prepared using the following procedure: for each mould: 40mls of resin, 4mls of catalyst, plus half a spatula of black pigment were mixed together in a plastic cup. All ingredients were mixed thoroughly to ensure even binding of the pigment and catalyst. A layer of resin 1mm in thickness was poured into the prepared compartments of each mould. The resin was then left to dry for 3-4 hours until it became tacky.

Mounting

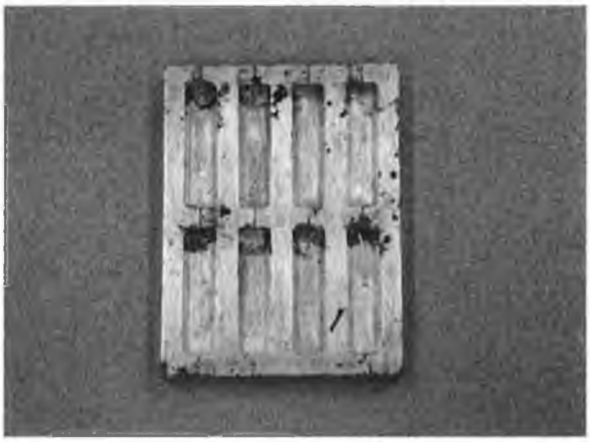
The otoliths were mounted in the compartments of the moulds according to the otolith maps. A small piece of spaghetti was placed at the beginning of the compartment, which indicated the start of the sequence in that compartment. A total of eight otoliths were placed in each compartment of the mould, therefore each mould contained sixty four otoliths. Extreme care was taken when laying down the otoliths to ensure that the nucleus was placed exactly down the center line of the compartment, so that when the resin block was sectioned, it cut through the nucleus. The otoliths were covered with another layer of freshly prepared resin. The moulds were left in the fume cupboard overnight. Once the resin was hard, the blocks containing the otoliths were removed, by lifting them carefully with a screwdriver. The blocks were then covered in talc and left to dry completely over a couple of weeks (Fig. 2.5.1.1b). Each block was labelled with the corresponding mould and block number.

Sectioning

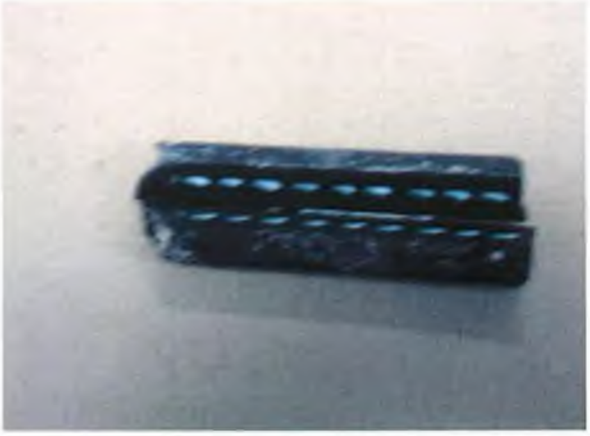
The blocks were sectioned using a special low speed diamond saw, which cuts a thin section through the nucleus of the otoliths embedded in the block (Fig. 2.5.1.1c). It was essential that the section went through the nucleus otherwise zones may be missed and age estimates would be underestimated. The resin block was placed bottom downwards on the chuck (a special compartment) in the sectioning machine. The block was then aligned on to but not touching the blades (Fig. 2.5.1.1d). The speed control knob was adjusted to the desired speed. When the cut was complete, the section was removed using a fine forceps. The sections were mounted onto labelled glass slides using DPX mountant (Fig. 2.5.1.1e).

Fig. 2.5.1.1. A chart showing the different materials and instruments used in the preparation of otoliths for ageing.

(a) Stainless Steel Mould



(b) Resin block containing otoliths



c) (Sectioning machine) Low speed diamond saw

(d) Chuck in the sectioning machine

(e) Glass slide containing sections

Reading

Otoliths were viewed using a stereoscopic microscope with 7x to 30x magnifications. Combinations of transmitted and reflected light were used when identifying the otolith zones. Ageing of the otoliths was carried out by looking at the alternate opaque and translucent zones, which were visible when examined against a matt black background by reflected light (Bowers, 1954). The opaque ring is formed in the summer and the translucent zone is formed in the winter (Gambell & Messtorff, 1964). One of each zone is laid down along the outer rim of the otolith each year. When ageing, the date of capture of the fish was taken into account. If the outer edge of the otolith was translucent, it was included in the age of the fish, but only if the fish was caught after the 1st January and before the end June. If, however the fish were caught between July and December this translucent zone would not be included in the age of the fish. A selection of photomicrographs of whiting otoliths examined during the present investigation are presented in Figs. 2.5.1.3, 2.5.1.4, 2.5.1.5 and 2.5.1.6.

Fig. 2.5.1.3. Otolith taken from a one year old whiting caught in the Celtic Sea in December 2001.

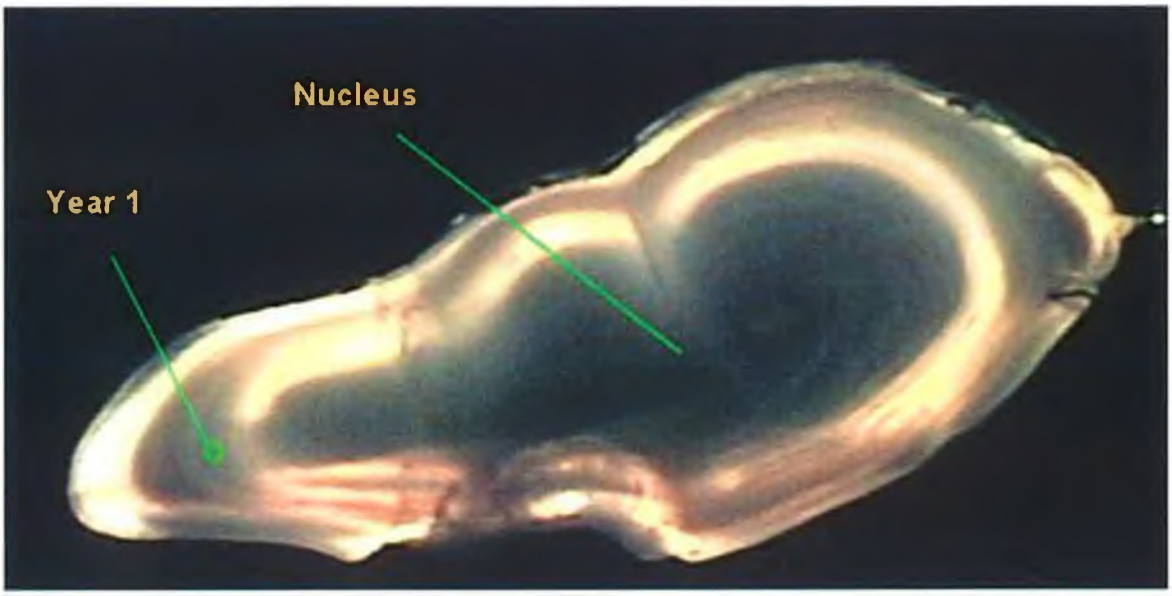


Fig. 2.5.1.4. Otolith taken from a three year old whiting caught in the Celtic Sea in December 2001.

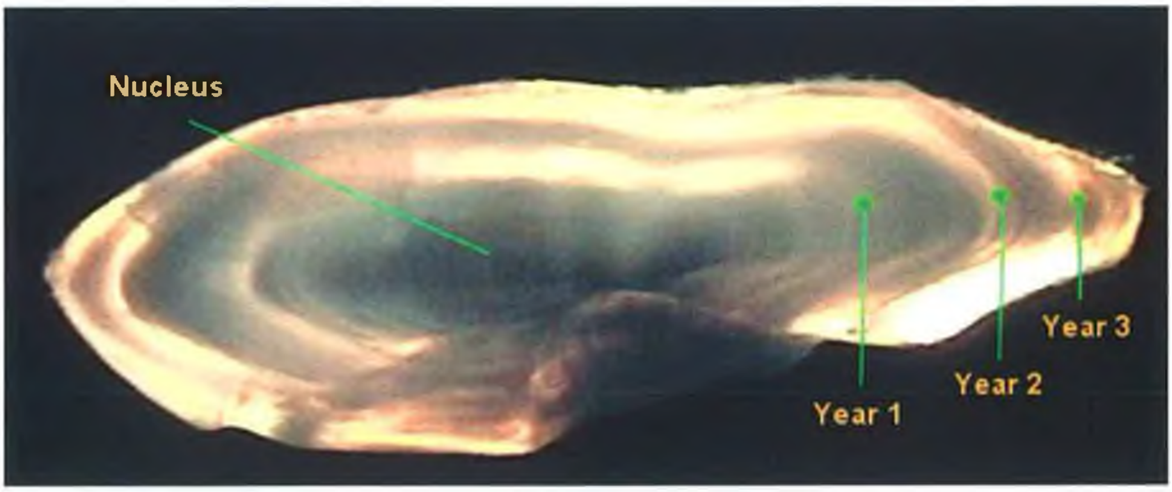


Fig. 2.5.1.5. Otolith taken from a three year old whiting caught in the Celtic Sea in January 2001.

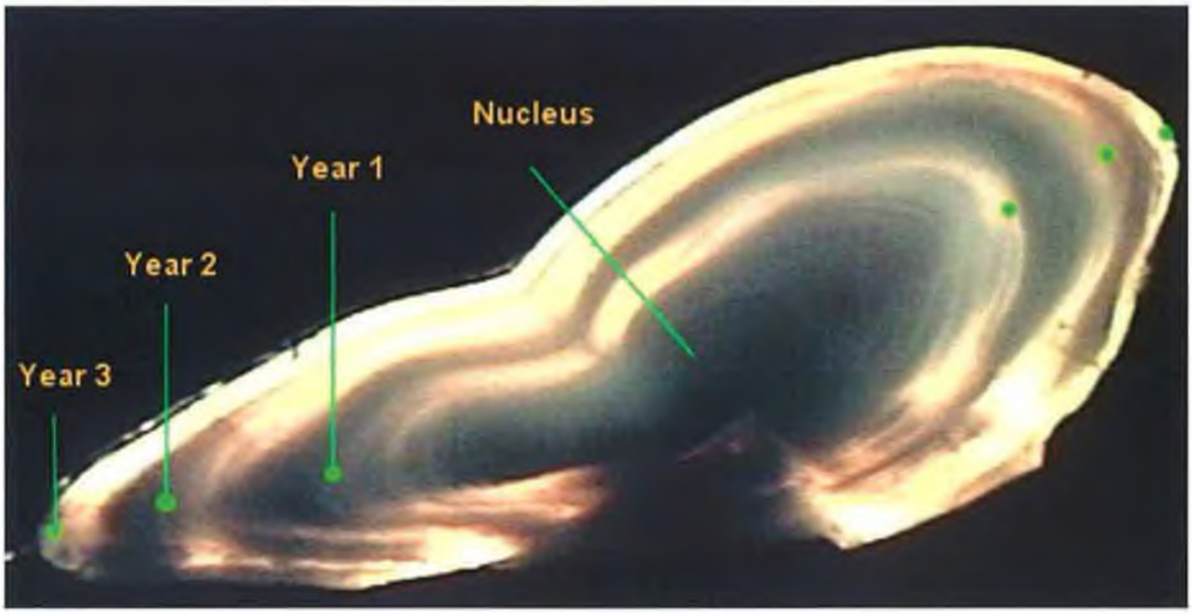
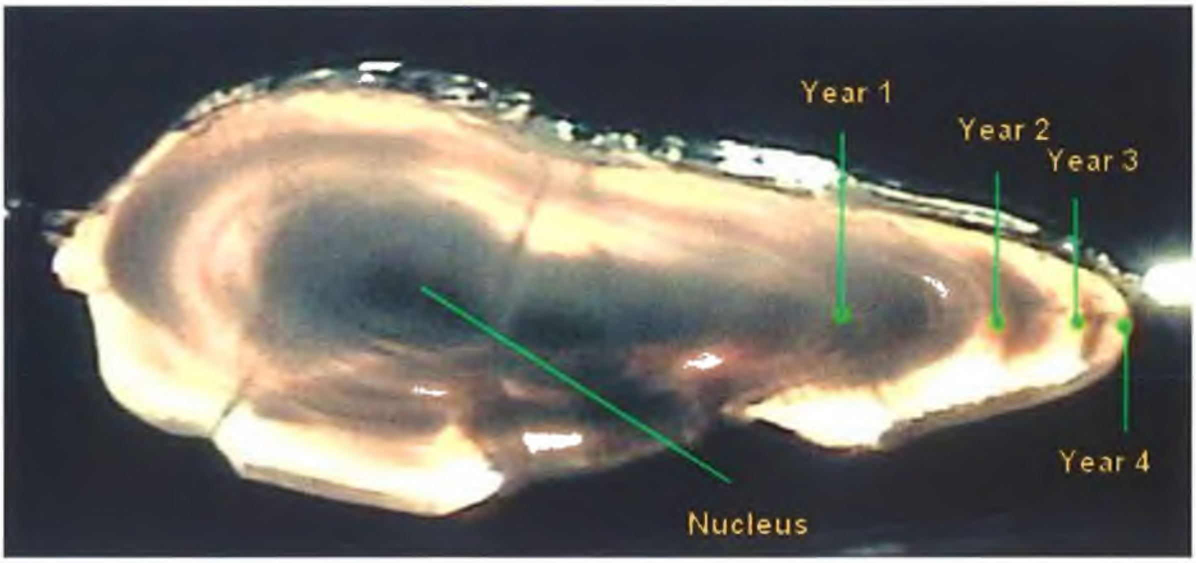


Fig. 2.5.1.6 Otolith taken from a four year old whiting caught in the Celtic Sea in January 2001.



2.5.2 Age Reading Comparisons

In order to check the accuracy of the age readings in the present project, an ageing intercalibration exercise was carried out between the author and an expert in ageing whiting, Helen McCormick, at the FSS of the Marine Institute. Age readings were compared using a signed rank statistical test and a linear regression plot.

2.6 Length-weight relationship

The length-weight relationship for the whiting, represented by the formula $W = qTL^b$ (Ricker, 1975) was log transformed into the following:

$$\ln W = \ln q + b\ (\ln TL).$$

W = weight of the fish in grams (g)

TL = total length of the fish in centimetres (cm)

q = a constant determined empirically

b = slope of the line (Ricker, 1975; King, 1995).

2.7 Growth

The Von Bertalanffy growth equation was the growth model used in this study, the formula for which is given below (von Bertalanffy, 1938):

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

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 the fish at time t

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

(Beverton and Holt, 1957; Ricker, 1975).

The method of the Ford-Walford plot (Beverton and Holt, 1957) from Ford (1933) and Walford (1946) combined, was used during the present study to estimate the Von Bertalanffy growth parameters (VBGP) for whiting. A Ford-Walford plot was calculated by plotting mean length at age (L_t) against mean length at age plus one years growth (L_{t+1}). The straight line fitting these data had a slope of b = exp [-k] and an intercept on the y-axis of $a = L_\infty$ (1 – exp [k]). These formulae 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).

Catch Curves

A catch curve was constructed by plotting the natural logarithms of the number of fish surviving by age (Edser, 1908; Baranov, 1918; Ricker, 1948). Since the age group at the peak of the dome may or may not be totally vunerable to the gear, the portion of the descending leg used to estimate Z (the total mortality coefficient) was taken as one age group to the right of the dome (Gulland, 1985). The latter age group was then taken to be the age group at which the fish are fully recruited to the fishery (t_r). The Fishing mortality coefficient (F) was estimated by substituting M (the natural mortality coefficient) into the following formula (Beverton and Holt, 1957):

$$Z = F + M$$

2.9 Maturity ogives and Gonosomatic Index (GSI)

The percentage of mature fish in each age group or length category collected during the spawning season, were plotted on maturity ogives. Maturity ogives were constructed for both age and length (Malcolm Haddon, Tasmanian Aquaculture and Fisheries Institute, pers. comm., 2002).

Seasonal changes in the gonad cycle were established by calculating the gonosomatic index for each whiting sampled, where GSI = gonad weight in grams/ whole body weight in grams x 100 (Htun Han, 1978). Monthly averages were used to plot the changes in this index.

3.0 Results

3.1 AGE, GROWTH AND POPULATION DYNAMICS

3.1.1 Length Frequency

The percentage length frequency distribution for all whiting (N = 3415), sampled from the commercial catch, from the Celtic Sea between February 2001 and January 2002 is presented in Fig. 3.1.1.1. Length varied from 24 cm to 48.99 cm, with a peak length frequency at 32-32.99 cm. Minitab was used to calculate a test for normality. A P-value of 0.648 was calculated using the Ryan-joiner normality test, therefore, the length data for the sampled population was determined to be normally distributed.

Fig. 3.1.1.2 shows the length frequency for each sample of whiting captured during the entire sampling period. The mode ranged from 27 cm (12/02/01) to 35 cm (26/02/01 and 12/6/01). There was no temporal pattern evident. The number of fish, the range, the mean and mode and the standard error of length data at each sampling date over the sampling period between February 2001 and January 2002 are given in Table 3.1.1.1. In order to choose a suitable statistical test, to investigate whether the mean size of the sampled whiting changed over the year, an investigation of the null hypothesis (H_o) i.e. that the lengths followed a normal distribution at each sampling date was firstly carried out. The H_o was accepted for samples on the 26/02/01, 5/6/01, 3/11/01 and the 3/12/01. However, because the majority of samples did not follow a normal distribution, a Kruskal Wallis test was carried out. The hypothesis (H_o) is that the median size of the sampled whiting did not change over the year. Results of the Kruskal Wallis test indicated there was a significant difference (H = 290.77, DF = 15, P = 0.000) between median lengths of whiting over the sampling period. A Mood Median test was then carried out to show which samples were significantly different from each other. Results

Fig. 3.1.1.1. Percentage length frequency distribution for all whiting in the commercial catch in the population sampled from the Celtic Sea between February 2001 and January 2002.
(N is the number of fish sampled, discards are not included)

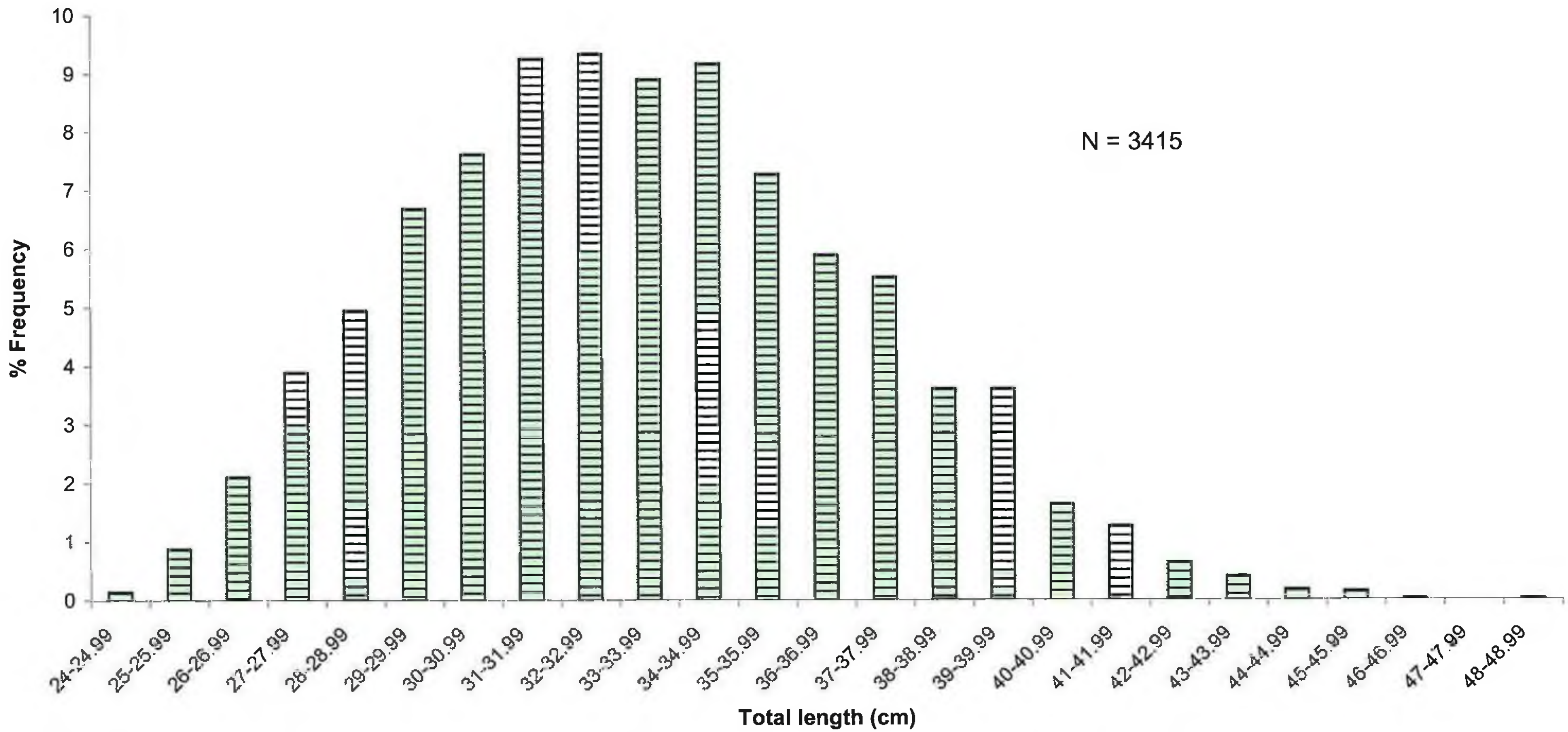


Fig. 3.1.1.2. Percentage Length Frequency distribution for each sample of whiting from the Celtic Sea between February 2001 and January 2002.

N is the number of fish per sample

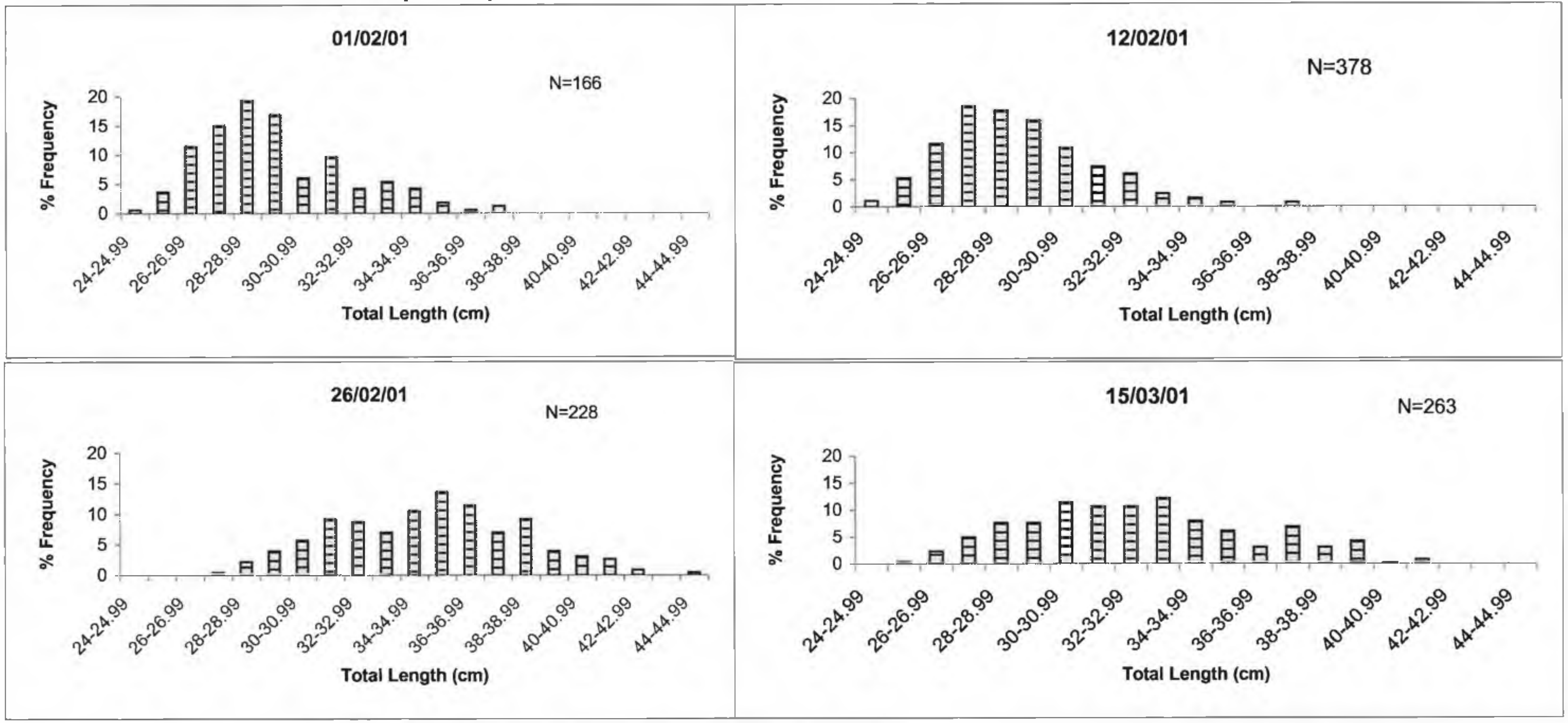


Fig. 3.1.1.2. (continued) Percentage Length Frequency distribution for each sample of whiting from the Celtic Sea between February 2001 and January 2002.

N is the number of fish per sample

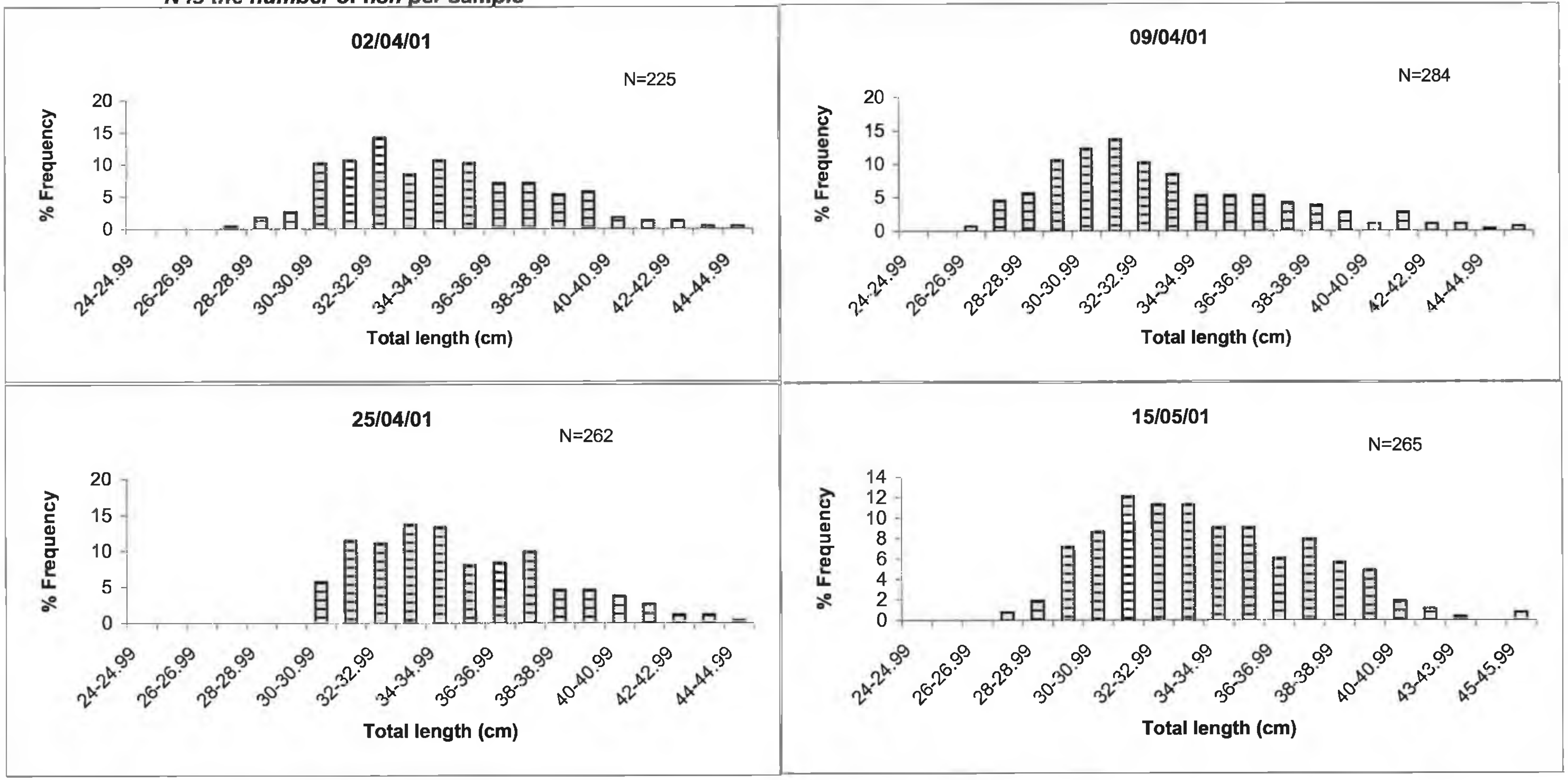
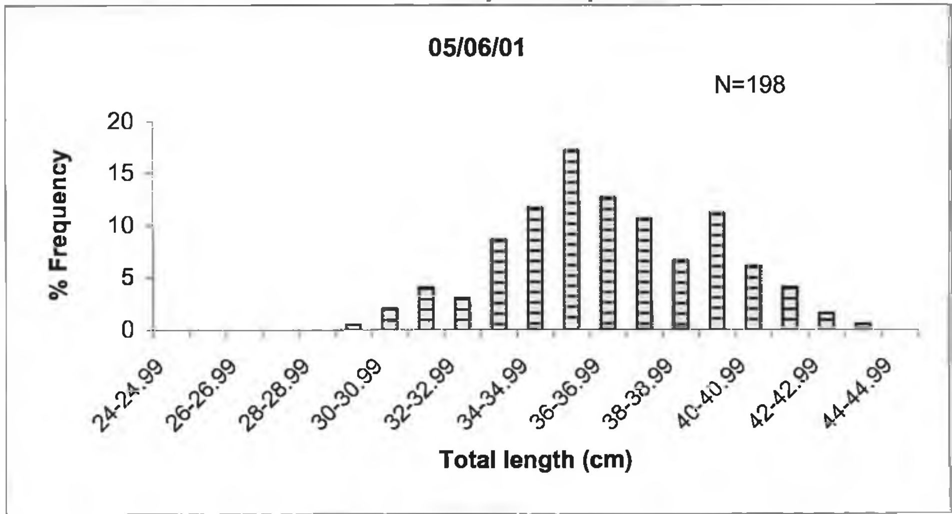
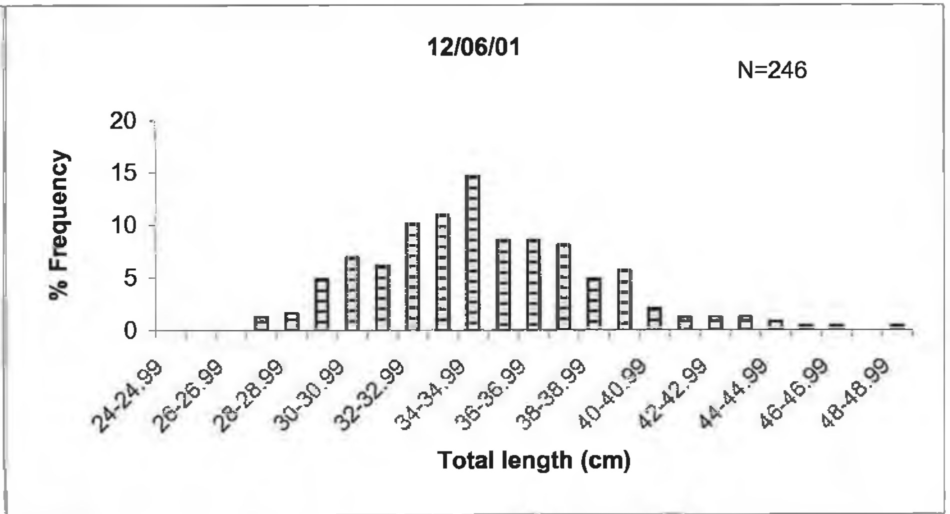
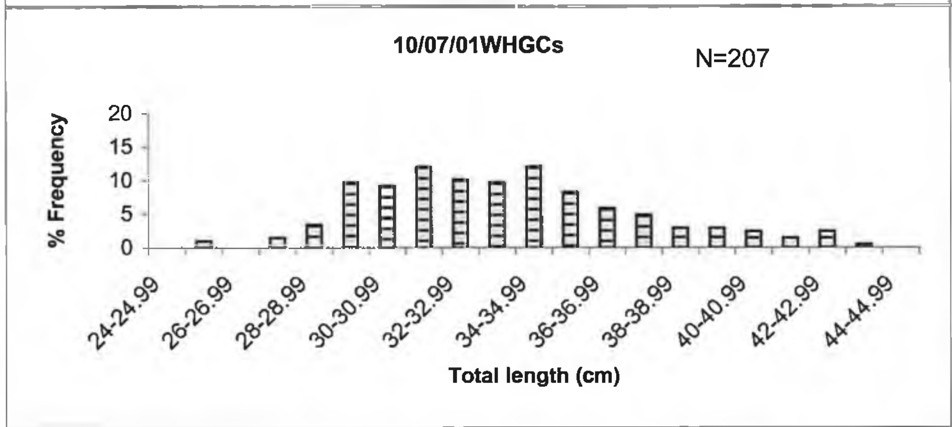


Fig. 3.1.1.2. (continued) Percentage Length Frequency distribution for each sample of whiting from the Celtic Sea between February 2001 and January 2002.

N is the number of fish per sample







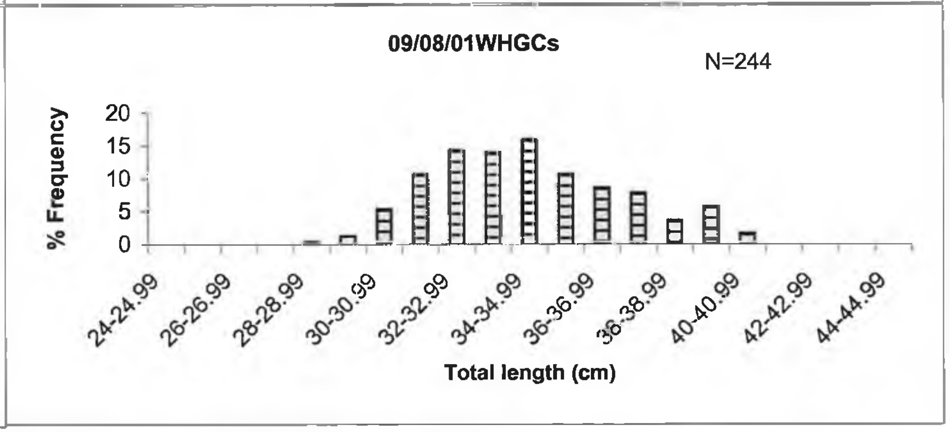
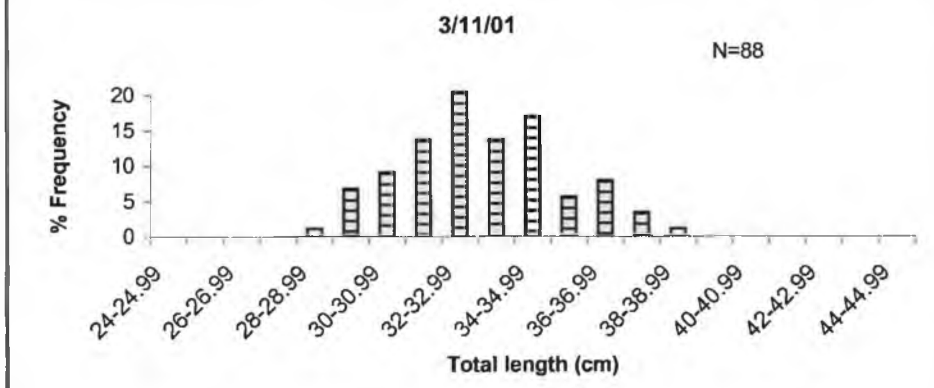
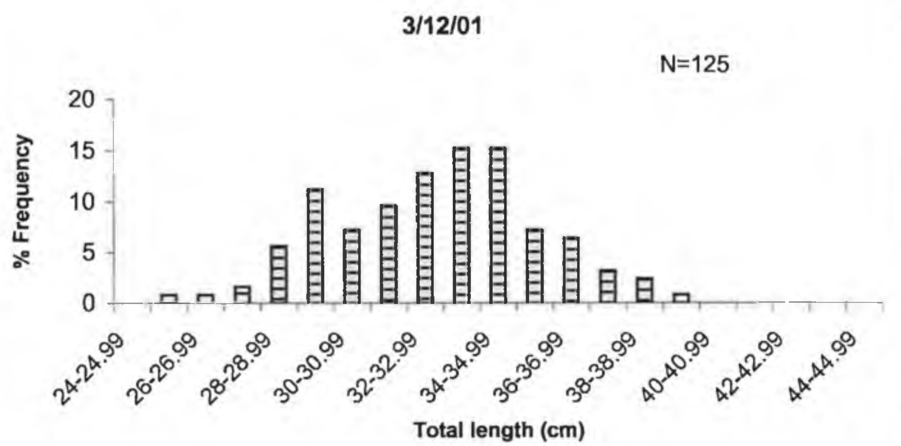


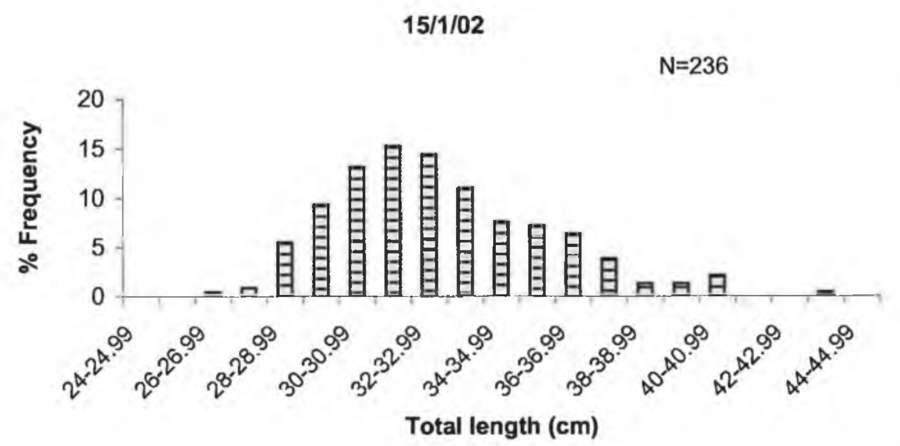
Fig. 3.1.1.2. (continued) Percentage Length Frequency distribution for each sample of whiting from the Celtic Sea between February 2001 and January 2002.
N is the number of fish per sample

September and October 2001

No sample







are presented in Table 3.1.1.2. Some samples are significantly different from others but no obvious pattern presented itself.

Table 3.1.1.1. The number of fish, the range, the mean and mode and the standard error at each sampling date over the sampling period between February 2001 and January 2002. (Accepting ($P > 0.05$) or rejecting ($P < 0.05$), the null hypothesis (H_0), that the data follows a normal distribution).

Date	Number of Fish	Range (cm)	Mode (cm)	Mean length (cm)	Standard error	Accept/Reject H_0
01/02/01	166	24-37.99	28	29	0.206	Reject
12/02/01	378	24-37.99	27	27	0.120	Reject
26/02/01	228	27-44.99	35	35	0.22	Accept
15/03/01	263	25-41.99	33	32	0.213	Reject
02/04/01	225	27-44.99	32	34	0.22	Reject
09/04/01	284	26-45.99	31	34	0.22	Reject
25/04/01	262	30-44.99	33	34	0.196	Reject
15/05/01	265	27-45.99	31	33	0.208	Reject
05/06/01	198	29-43.99	35	36	0.202	Accept
12/06/01	246	27-48.99	34	34	0.235	Reject
10/07/01	207	25-43.99	31, 34	33	0.251	Reject
09/08/01	244	28-40.99	34	34	0.167	Reject
03/11/01	88	28-38.99	32	32	0.234	Accept
03/12/01	125	25-39.99	33, 34	33	0.25	Accept
15/01/02	236	26-43.99	31	32	0.188	Reject

Table 3.1.1.2. Mood median test for data for each sample over the sampling period between February 2001 and January 2002.

Chi-Square = 161.28 DF = 15 P = 0.000

Individual 95.0% CIs

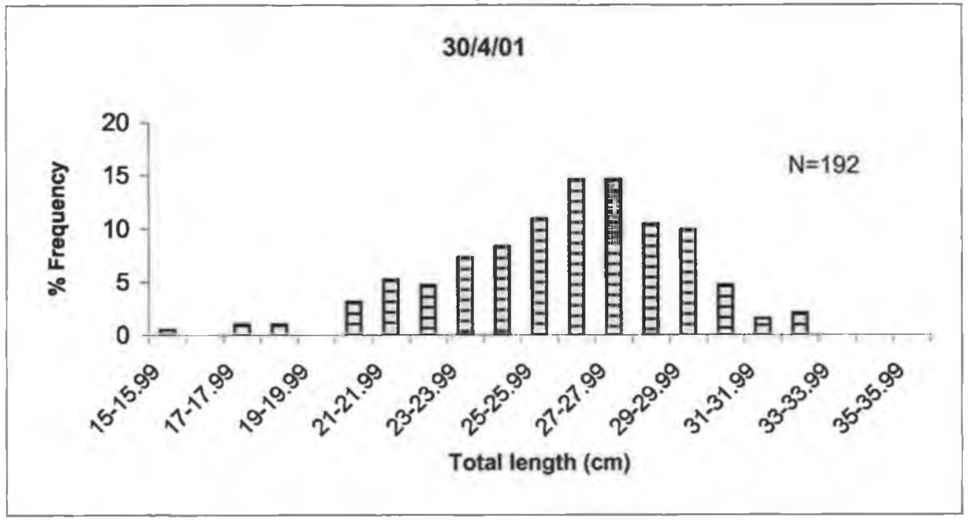
sub	N<=	N>	Median	Q3-Q1	-+---------+---------+---------+-----
01/02/20	17	10	28.0	8.0	(--+----------------)
12/02/01	64	11	30.0	5.0	(---+--)
26/02/01	17	51	35.0	4.8	(+-----)
15/03/01	45	27	31.5	5.8	(---+---)
02/04/01	25	38	35.0	6.0	(-----+-----)
09/04/01	40	42	34.0	5.0	(--+)
25/04/01	25	44	36.0	6.0	(-----+--)
15/05/01	42	35	33.0	5.5	(--+--)
05/06/01	7	31	36.0	4.0	(-----+--)
12/06/01	22	41	35.0	5.0	(--+-)
10/07/01	29	15	33.0	3.0	(----+
09/08/01	23	42	34.0	4.5	+-----)
03/11/01	57	31	32.0	3.0	+--)
03/12/01	81	44	33.0	4.0	(--+
15/01/02	48	21	32.0	4.0	(-+--)
					-+---------+---------+---------+-----
					24.5 28.0 31.5 35.0

Overall median = 33.0

Fig. 3.1.1.3 shows the length frequency for discards (30/4/01). Length ranged from 15 to 32.99 cm, with a modal size class of 27 cm.

Fig. 3.1.1.3. Percentage Length Frequency distribution for the discard sample of whiting from the Celtic Sea

N is the number of fish per sample



3.1.2 Length weight relationship

The linear relationship between Log_e body weight (W) and Log_e total length (TL) was determined for the overall sampled population using regression analysis in Fig 3.1.2.1. An R^2 value of 0.91 was obtained, indicating a high correlation between the two variables. The length weight relationship was calculated as:

$$\mathbf{W\ (g) = 0.01025\ TL\ (cm)^{2.9501}}$$

Where **W** = weight in grams (g)

TL = Total length in centimetres (cm).

The linear relationships between Log_e body weight (W) and Log_e total length (TL) for male and female whiting separately are presented in Fig. 3.1.2.2. The linear relationship between Log_e (W) and Log_e (TL) for the males in the sampled population was calculated as:

$$\mathbf{W\ (g) = 0.01529\ TL\ (cm)^{2.8338}}$$

An R^2 value of 0.92 was calculated, which indicated a positively high correlation for male fish. The linear relationship between Log_e (W) and Log_e (TL) also showed a positively high correlation for females i.e. R^2 = 0.9 and the relationship for female whiting was calculated as:

$$\mathbf{W\ (g) = 0.00822\ TL\ (cm)^{3.013}}$$

It was clear from the graph that the relationship between W and TL was almost the same for male and female fish. The values for the exponent b in the length-weight relationship for the overall sampled population and for males and females separately were close to 3 indicating isometric growth.

Fig. 3.1.2.1. Log$_e$ body weight versus Log$_e$ Total length for a population of whiting sampled from the Celtic Sea between January 2001 and January 2001.
(N is the number of fish)

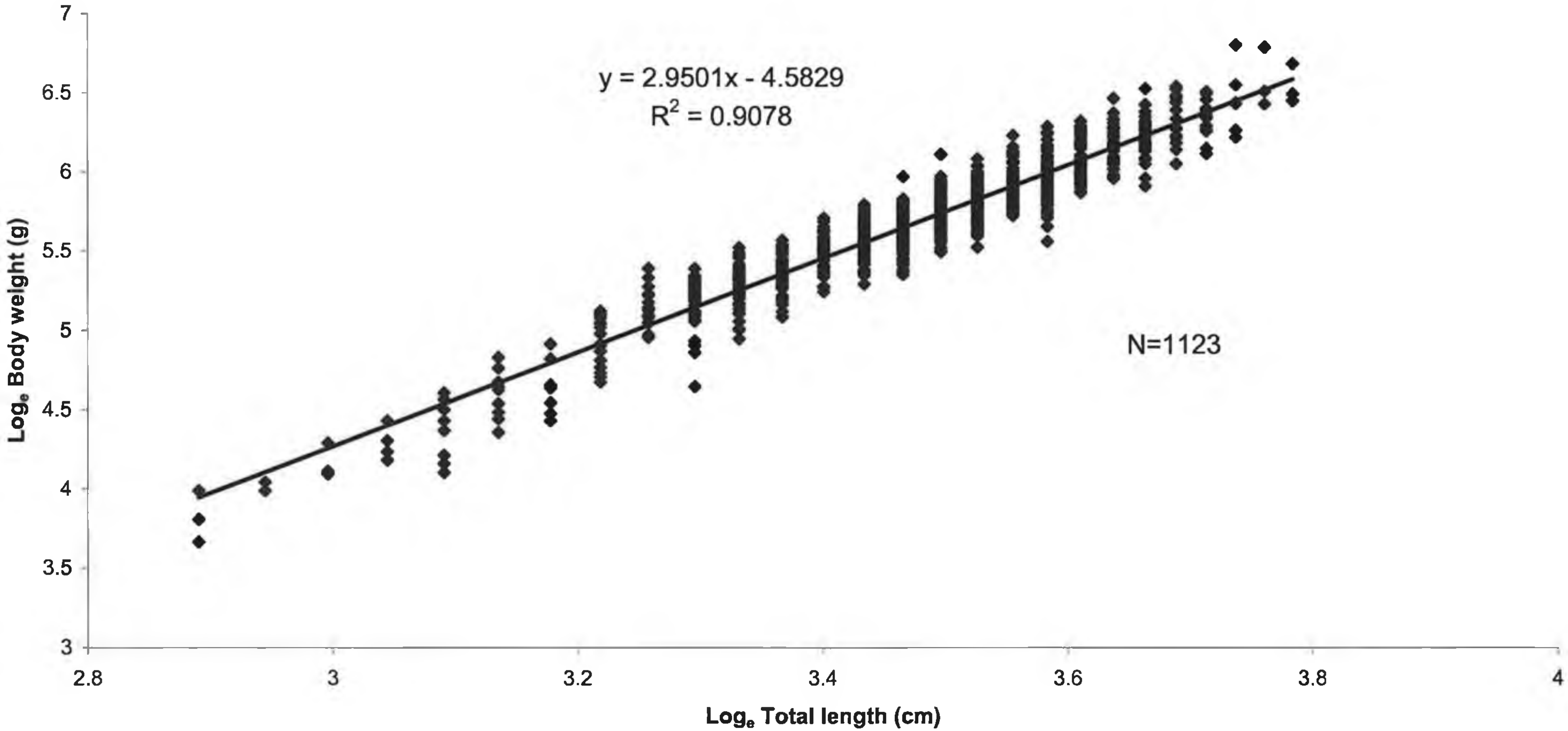
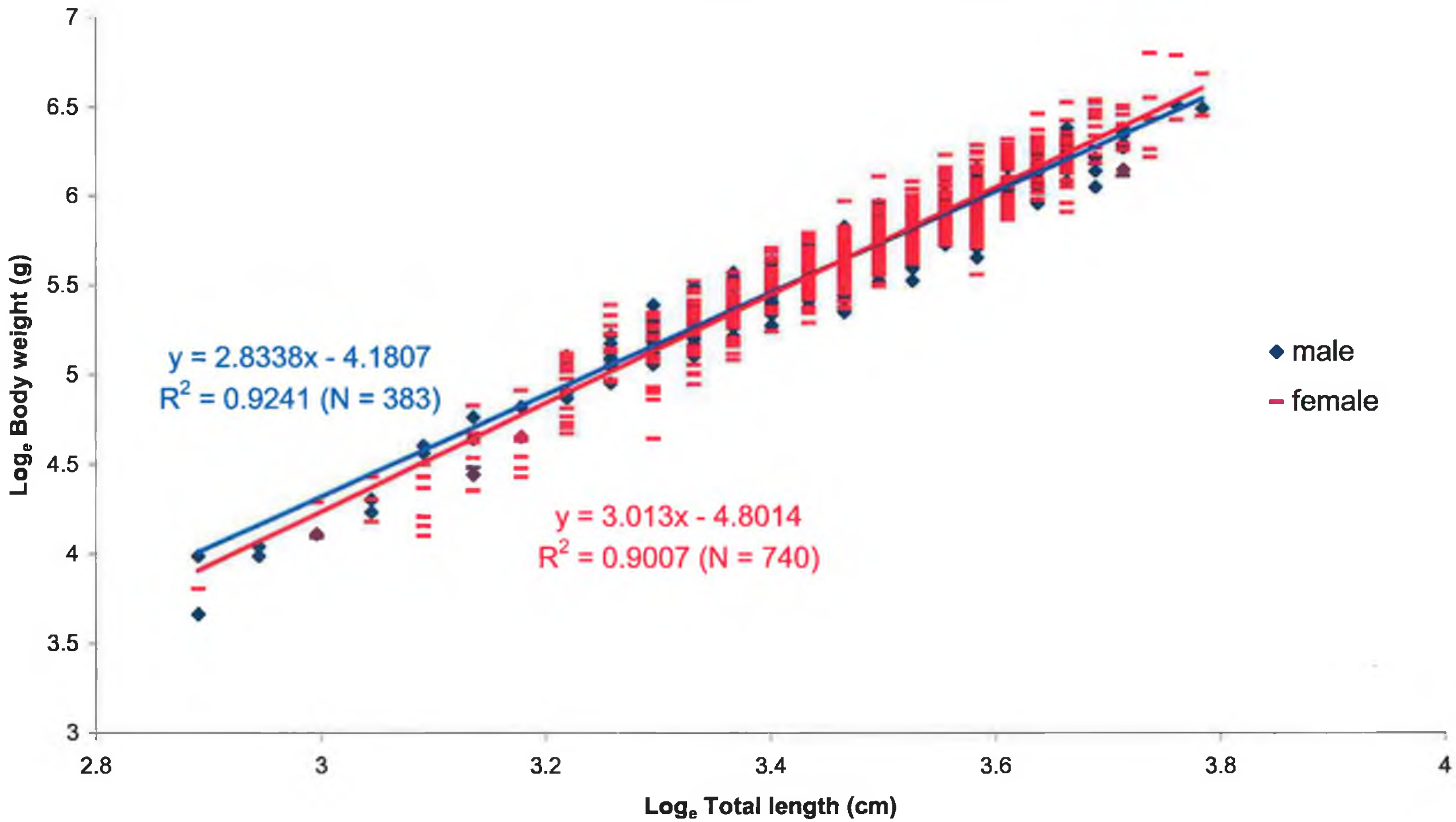


Fig. 3.1.2.2. Log$_e$ body weight versus Log$_e$ Total length for male and female whiting separately sampled from the Celtic Sea between January 2001 and January 2001.
(N is the number of fish)



3.1.3 Sex ratios

Overall, 1123 fish were sexed throughout the sampling program. However, because of the biased method used, as explained in the methods section above, the sex ratio was calculated using 854 fish. The latter count is derived from the first five fish examined for each length category in each sample over the sampling period. 263 (30.8%) of these were male and 591 (69.2%) were female, giving an overall male: female (M: F) sex ratio of 1:2.25 (Fig. 3.1.3.1), which is highly significantly different from the expected ratio of 1:1 ($\chi^2 = 6.63$, P<0.01).

Fig. 3.1.3.1. Sex ratio for male and female whiting, derived from the first five fish examined for each length category in each sample for the overall population sampled off the Celtic Sea between January 2001 and January 2001.

Seventeen samples were collected over the sampling period. The number of males and females recorded in each sample is presented in Table 3.1.3.1. The dates correspond to when the samples were received from the Dunmore East Co-operative. The fish would have been caught in the previous 1 to 10 days. Four samples (indicated on the Table by an asterisk) varied in sampling procedure from the rest as follows: a representative sample of the total stock i.e. discarded and commercial size fish, was collected by the Fisheries Assessment Technician (FAT) of Dunmore East on the 21/01/01; on the 30/4/01 a discard only sample was collected at sea by the Fisheries Assessment

Technician (FAT); samples on the 3/11/01 and the 3/12/01 were obtained by analysing the contents of one box only of fish from the Co-operative and no size selection was employed during the analysis.

In the majority of samples, females were numerically the dominant sex, with the exception of 21/1/01, where males were more abundant. No further analytical work was carried out on these data because of the bias involved.

Table 3.1.3.1. The number of male and female whiting recoded per sample, in the Celtic Sea between January 2001 and January 2002 (* are the samples that varied in sampling procedure).

Sample No.	Sample Date	No. of Males	No. of Females	Total
1	* 21/01/01	33	30	66
2	01/02/01	10	17	27
3	12/02/01	19	56	75
4	26/02/01	23	45	68
5	15/03/01	26	46	72
6	02/04/01	15	48	63
7	09/04/01	33	49	82
8	25/04/01	27	42	69
9	* 30/04/01	1	34	35
10	15/05/01	28	49	77
11	05/06/01	12	26	48
12	12/06/01	18	45	63
13	10/07/01	13	31	44
14	09/08/01	25	40	65
15	* 03/11/01	22	66	88
16	* 03/12/01	49	76	125
17	15/01/02	29	40	69
Total		**383**	**740**	**1123**

The number of male and female whiting, derived from the first five fish examined for each length category in each sample in the Celtic Sea between January 2001 and January 2002, are presented in Table 3.1.3.2. The results of chi square (χ^2) analyses, testing the null hypothesis (H_o) of no departure from a 1:1 ratio, and significance levels are shown in the same Table. However, on the 30/4/01, a chi square (χ^2) was not used, as the numbers of male fish were < 5. The M: F sex ratios calculated for the overall population, 12/02/01 to 02/04/01, 25/04/01, 10/07/01 and 03/11/01 were highly significantly different from the expected M: F sex ratio of 1:1. In contrast, the χ^2 values for 21/01/01, 01/02/01, 09/04/01 and 15/01/02 indicated no significant departure from a 1:1 ratio. In summary, females numerically dominated the catch in the overall population and in thirteen of the seventeen samples investigated.

Table 3.1.3.2. The number of male and female whiting, derived from the first five fish examined for each length category in each sample for the overall population in the Celtic Sea between January 2001 and January 2002 together with chi square (χ^2) values. (* = *Significant* (P < 0.05), ** = *Highly significant* (P < 0.01), NS = *Not significant* (P > 0.05) and NT = not testable) **(* are the samples that varied in sampling procedure).**

Sample No.	Sample Date	No. of Females	No. of Males	Grand Total	Expected	χ^2	Significance
1	* 21/01/01	30	33	63	31.5	0.14	NS
2	01/02/01	12	8	20	10.0	0.80	NS
3	12/02/01	40	15	55	27.5	11.36	**
4	26/02/01	34	11	45	22.5	11.76	**
5	15/03/01	35	10	45	22.5	13.89	**
6	02/04/01	41	7	48	24.0	24.08	**
7	09/04/01	29	21	50	25.0	1.28	NS
8	25/04/01	32	12	44	22.0	9.09	**
9	* 30/04/01	34	1	35	17.5	31.11	NT
10	15/05/01	34	16	50	25.0	6.48	*
11	05/06/01	21	9	30	15.0	4.80	*
12	12/06/01	31	14	45	22.5	6.42	*
13	10/07/01	24	6	30	15.0	10.80	**
14	09/08/01	27	14	41	20.5	4.12	*
15	* 03/11/01	66	22	88	44.0	22.00	**
16	* 03/12/01	76	49	125	62.5	5.83	*
17	15/01/02	25	15	40	20.0	2.50	NS
Total		**591**	**263**	**854**	**427.0**	**125.98**	**

The sex ratio data were tested again by combining samples within the same month. The number of male and female whiting, derived from the first five fish examined for each length category per month in the Celtic Sea between January 2001 and January 2002, together with chi square (χ^2) values, and significance levels are presented in Table 3.1.3.3. The same H_o: no departure from a 1:1 sex ratio was tested. The M: F sex ratios calculated for all months, except January of both years, were highly significantly different from the expected M: F sex ratio of 1:1. In summary, therefore, females numerically dominated the total population and in all months except January of both years.

Table 3.1.3.3. The number of male and female whiting, derived from the first five fish examined for each length category per month for the overall population in the Celtic Sea between January 2001 and January 2002 together with chi square (χ^2) values. **(* = *Significant* (P < 0.05), ** = *Highly significant* (P < 0.01) and NS = *Not significant* (P > 0.05)).**

Sample Month	No. of Females	No. of Males	Grand Total	Expected	χ^2	Significance
Jan-01	30	33	63	31.5	0.14	NS
Feb-01	86	34	120	60.0	22.53	**
Apr-01	136	41	177	88.5	50.99	**
May-01	34	16	50	25.0	6.48	*
Jun-01	52	23	75	37.5	11.21	**
Jul-01	24	6	30	15.0	10.80	**
Aug-01	27	14	41	20.5	4.12	*
Nov-01	66	22	88	44.0	22.00	**
Dec-01	76	49	125	62.5	5.83	*
Jan-02	25	15	40	20.0	2.50	NS
Total	591	263	854	427.0	125.98	**

3.1.4 Sex and length

The percentage length frequency for all whiting, excluding discards, whose sex was determined, is illustrated in Fig. 3.1.4.1. A range of 25 to 44.99 cm was recorded, with a peak length frequency of 32-32.99 and 34-34.99 cm for males and females respectively.

The numbers of male and female fish in each length category are shown in Table 3.1.4.1. A total of 1025 whiting were examined. Samples 21/1/01 and 30/4/01 were excluded, as these samples included discards. The hypothesis (H_o) that there was no statistically significant excess of female whiting in any centimetre length category i.e. there was no significant departure from a 1:1 sex ratio in any length class, was tested using chi square (χ^2). In certain length categories a chi square (χ^2) was not used, as numbers of fish were < 5. The abundance of females exceeded the number of males in all length classes. There was no significant departure from a 1:1 ratio in favour of females between 26 and 30 cm in total length. The excess of females was however significant from 31 – 36.99 cm and 38 –39.99 cm. The 37 cm length class was recorded as not significant, however, it was approaching significance as the χ^2 was close to the critical value (χ^2 = 3.84, P = 0.05). In summary, at larger lengths there were more females present in the catches.

Fig. 3.1.4.1. Percentage length frequency distribution for each sex of whiting (all fish) analysed from the Celtic sea between February 2001 and January 2002.

(N is the number of fish sampled, discards not included)

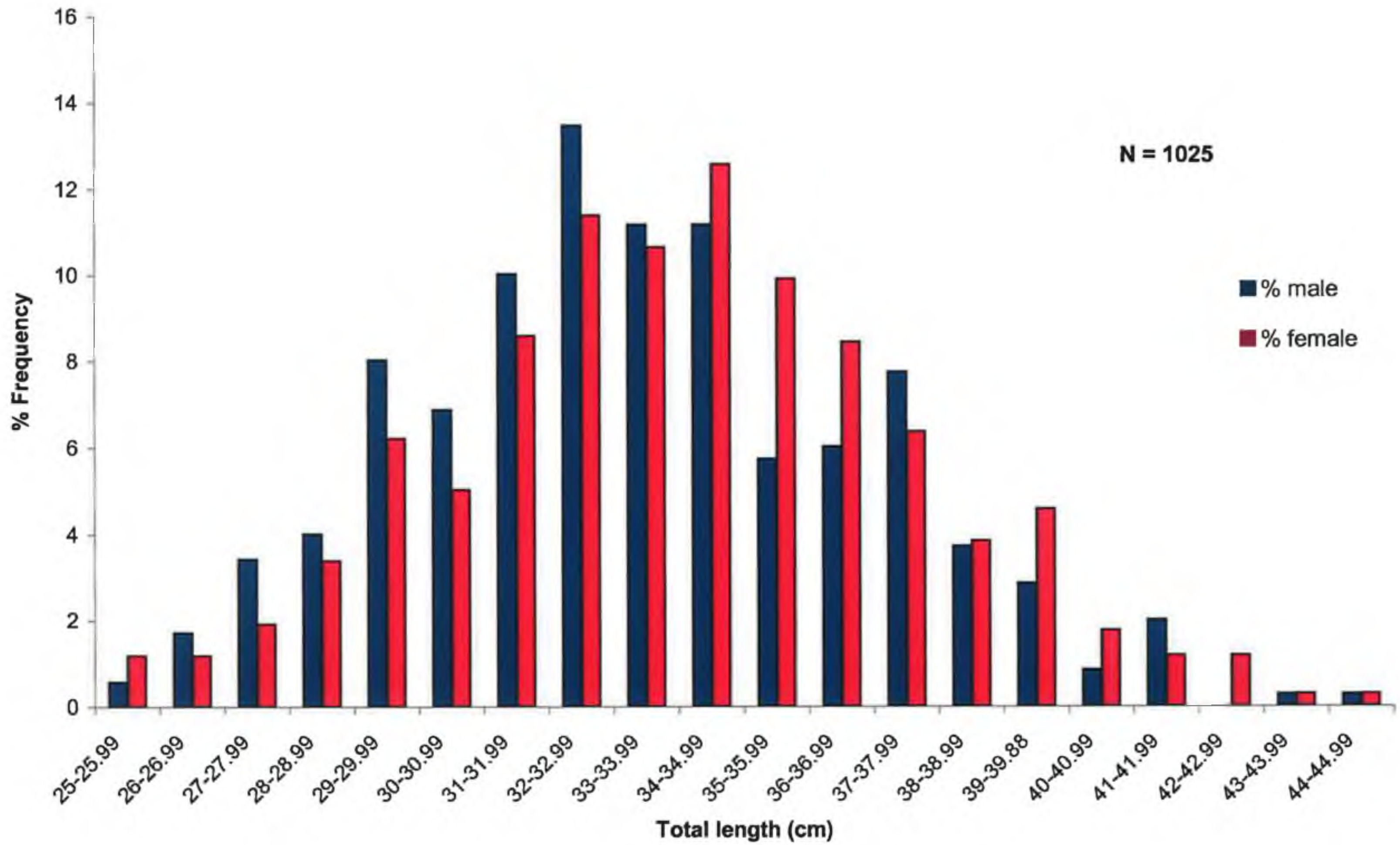
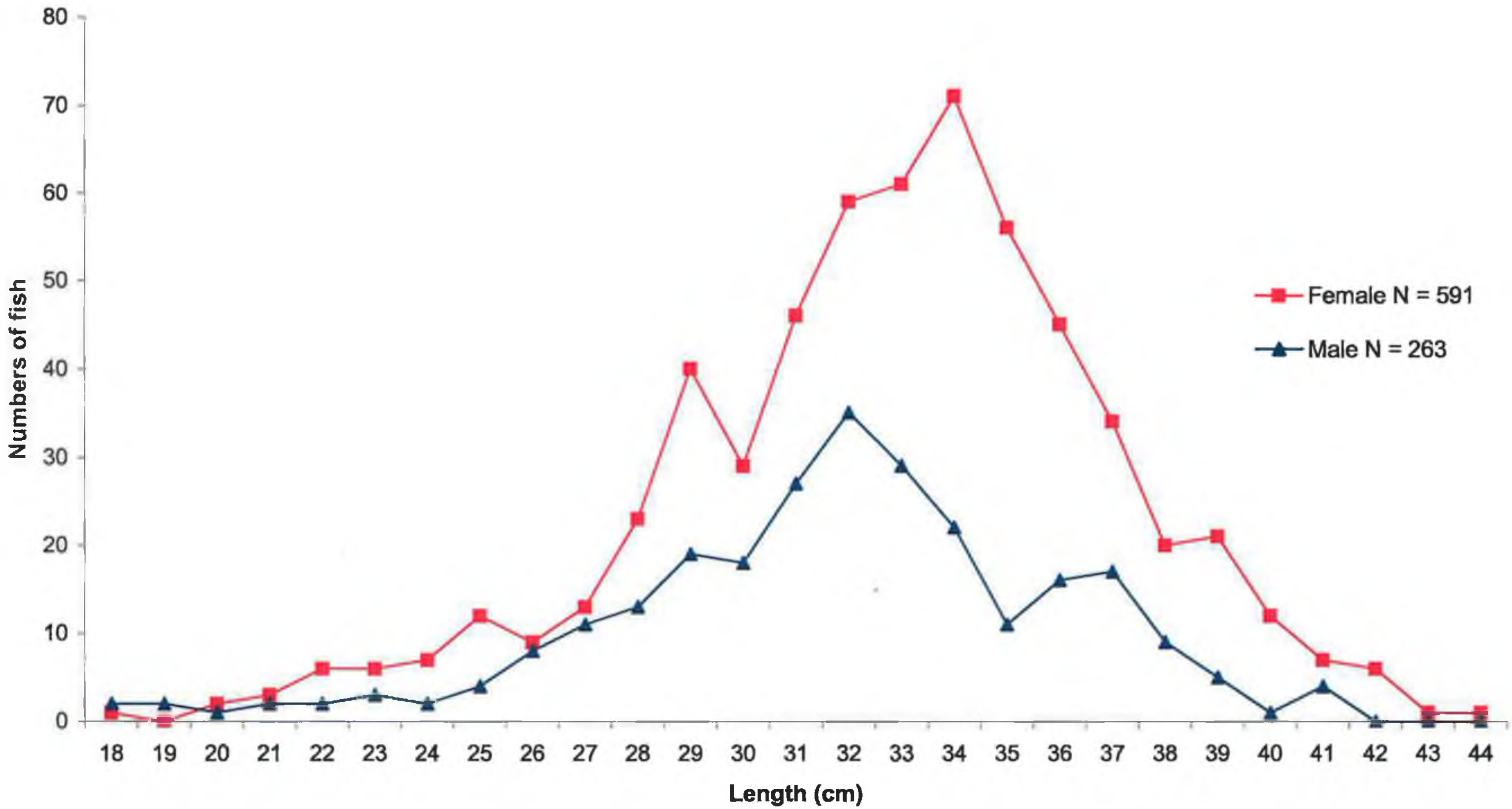


Table 3.1.4.1. Numbers of male and female whiting at each centimetre size class over the sampling period, in the Celtic Sea between January 2001 and January 2002 together with chi square (χ^2) values. (* = *Significant* (P < 0.05), ** = *Highly significant* (P < 0.01), NS = *Not significant* (P > 0.05) and NT = not testable)

Lt (cm) size class	Female	Male	Total	Expected	χ^2	Significance
25-25.99	8	2	10	5.0	3.60	NT
26-26.99	8	6	14	7.0	0.29	NS
27-27.99	13	12	25	12.5	0.04	NS
28-28.99	23	14	37	18.5	2.19	NS
29-29.99	42	28	70	35.0	2.80	NS
30-30.99	34	24	58	29.0	1.72	NS
31-31.99	58	35	93	46.5	5.69	*
32-32.99	77	47	124	62.0	7.26	**
33-33.99	72	39	111	55.5	9.81	**
34-34.99	85	39	124	62.0	17.06	**
35-35.99	67	20	87	43.5	25.39	**
36-36.99	57	21	78	39.0	16.62	**
37-37.99	43	27	70	35.0	3.66	NS
38-38.99	26	13	39	19.5	4.33	*
39-39.99	31	10	41	20.5	10.76	**
40-40.99	12	3	15	7.5	5.40	NT
41-41.99	8	7	15	7.5	0.07	NT
42-42.99	8	0	8	4.0	8.00	NT
43-43.99	2	1	3	1.5	0.33	NT
44-44.99	2	1	3	1.5	0.33	NT
Total	**676**	**349**	**1025**	**512.5**	**104.32**	**

The number of male and female fish in each centimetre length category, for the first five fish sexed, including discards, sampled over the investigation period is shown in Fig. 3.1.4.2. The size range for the overall sample was 18 to 44 cm. Both male and female whiting showed this size range. Females appeared to be larger in size than males. To test the hypothesis (H_o), that there was no difference in length between males and females, a test for normality was calculated on male and female length data separately. The test showed that H_o was accepted for the length distribution in both sexes (males: R = 0.9981, P < 0.05; females: 0.9996, P < 0.05), thus, both males and females length data were determined to be normally distributed. A t-test for samples with unequal variances was then calculated on the data. The null hypothesis (H_o) that there was no difference between mean lengths of male and female whiting was rejected. Therefore a significant difference (t = 3.321, P < 0.05) between mean length values of male and female whiting was recorded. While there was a similar range of length (cm) size classes for males and females there was an obvious difference in length between the sexes. In summary, females had a larger mean per length (cm) size compared to males in the sampled population.

Fig. 3.1.4.2. Numbers of male and female whiting in each length (cm) size class for the first five fish sexed captured from the Celtic Sea from January 2001 to January 2002.
(N is the number of fish sampled, discards included)



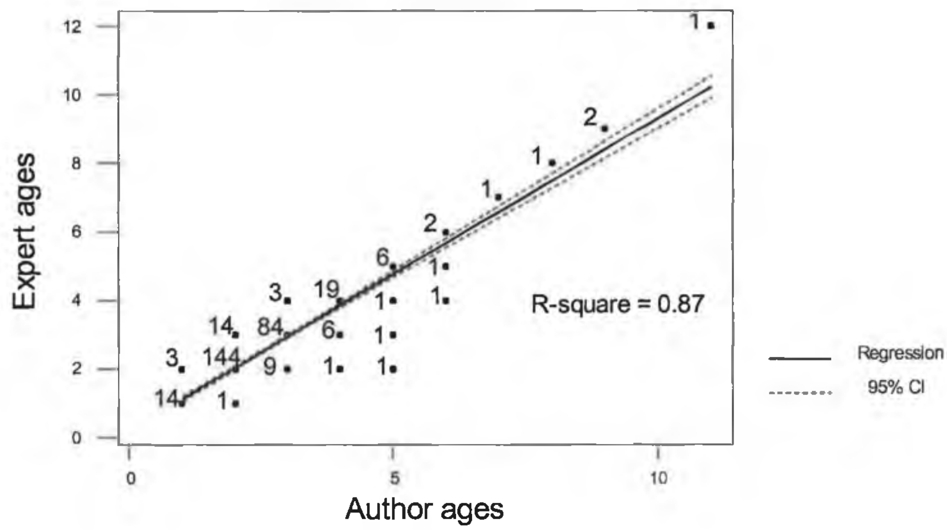
3.1.5 Ageing

A total of 986 paired otoliths were examined. Thirteen otoliths were not possible to age as they were crystallised or unclear i.e. they were not cut through the nucleus. Therefore a total of 973 otoliths were aged.

3.1.6 Age reading comparisons

Results from an intercalibration exercise between the author and an ageing expert at the Marine Institute are presented in Fig. 3.1.6.1. 316 otoliths were compared for age. In 273 (87%) cases, there was agreement in age readings between the author and an expert in ageing whiting. In 39 (12%) cases there was disagreement by one year. In 3 (1%) cases there was disagreement by 2 years. The greatest deviation was 3 years, which occurred once. Wilcoxon signed rank test was calculated on the data and the null hypothesis (H_o) was that the age readings recorded were not the same between the author and the expert. The numbers of values above and below the hypothesised median were counted. The test statistic ($P = 0.999$) was greater than the critical value ($P < 0.05$), therefore, H_o was rejected at the 95% confidence level i.e. that the age readings recorded were remarkably the same between the author and the expert.

Fig. 3.1.6.1. Comparison between the ages in years recorded by the author and an ageing expert at the Marine Institute.



3.1.7 Sex and age

The numbers of male and female whiting at each age in the sampled population are presented in Table 3.1.7.1. The number of females exceeded the number of males from ages 1 to 3. From ages 4 to 9 there were more males than females. One male fish aged 11 was recorded. Chi square (χ^2) tests were used to test the null hypothesis (H_o) that there was no departure from a 1:1 sex ratio at any age. However, in certain age categories a chi square (χ^2) could not be tested, as numbers of fish were < 5. Results from this showed that at ages 2 and 3, the abundance of females was highly significantly greater than that of males. The abundance of males was highly significantly greater than females at ages 5 and 6. The χ^2 values for age groups 1 and 4 showed no significant departure from a 1:1 sex ratio.

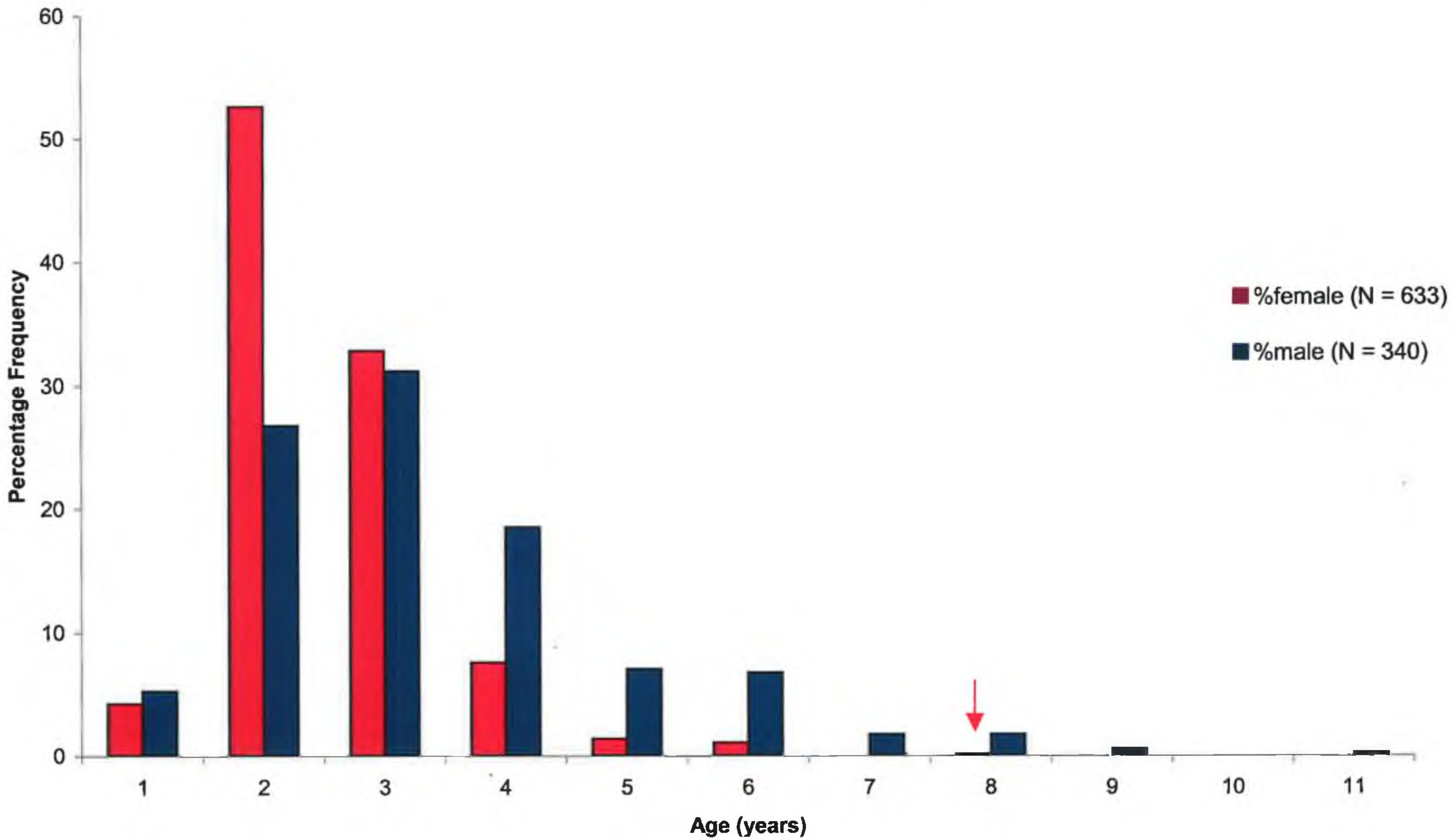
Table 3.1.7.1. Numbers of male and female whiting at each age over the sampling period, in the Celtic Sea between January 2001 and January 2002 together with chi square (χ^2) values. (* = *Significant* (P < 0.05), ** = *Highly significant* (P < 0.01), NS = *Not significant* (P > 0.05) and NT = not testable).

Age (Years)	Female	Male	Total	Expected	χ^2	Significance
1	27	18	45	22.5	1.80	NS
2	333	91	424	212.0	138.12	**
3	208	106	314	157.0	33.13	**
4	48	63	111	55.5	2.03	NS
5	9	24	33	16.5	6.82	**
6	7	23	30	15.0	8.53	**
7	0	6	6	3.0	6.00	NT
8	1	6	7	3.5	3.57	NT
9	0	2	2	1.0	2.00	NT
10	0	0	0	0.0	0.00	NT
11	0	1	1	0.5	1.00	NT
Total	633	340	973	486.5	88.23	**

3.1.8 Age Frequency

The age frequencies for male and female whiting captured in the Celtic Sea between January 2001 and January 2002 are illustrated in Fig. 3.1.8.1. The age range was 1-8 years for females and 1-11 years for males. The most frequently recorded age group for females was 2 years, while 3-year-old males were most abundant in the catches.

Fig. 3.1.8.1. Age Frequencies for both male and female whiting sampled from the Celtic Sea between January 2001 and January 2002.



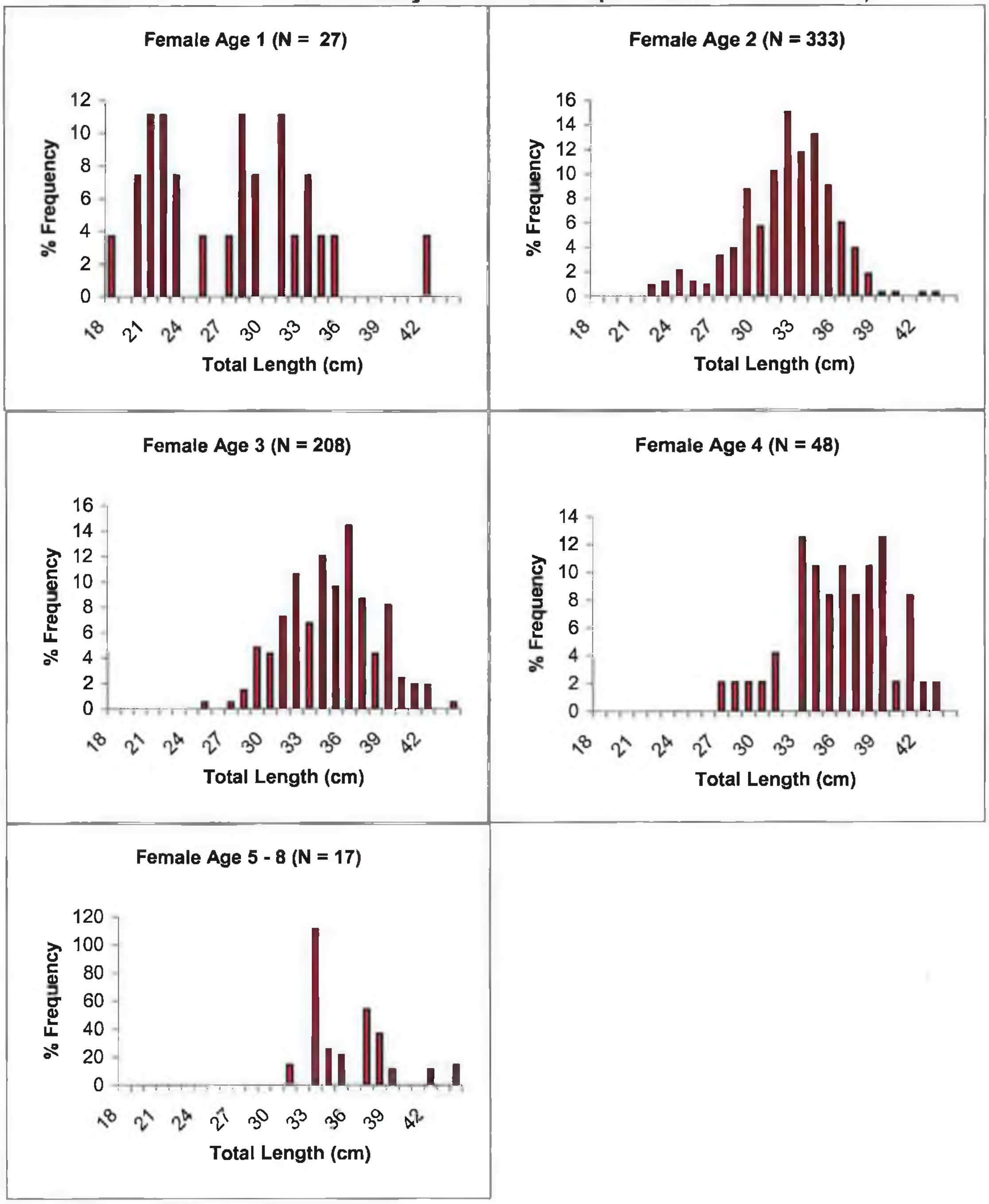
3.1.9 Length at age

The numbers of female fish at each age in each length class is shown in Table 3.1.9.1, and the percentage length frequency for females at each age is presented in Fig. 3.1.9.1. One-year-old females ranged from 18 – 35 cm with the exception of one fish measuring 42 cm in length. Two and 3 year olds ranged from 22 – 43 cm and 25 – 44 cm respectively. The smallest 5 year old female measured 33 cm, while the largest was 42 cm in total length. The largest 6 year old female measured 44 cm. One 8-year-old female was recorded measuring 33 cm in total length. There was a decrease in the range in length at age with advancing years.

Table 3.1.9.1. Age Length Key - Numbers of female whiting at each age in each length (cm) class sampled from the Celtic Sea between January 2001 and January 2002.

Females									
	Age (years)								
Length (cm)	1	2	3	4	5	6	7	8	Total
18	1								1
19									
20	2								2
21	3								3
22	3	3							6
23	2	4							6
24		7							7
25	1	4	1						15
26		3							10
27	1	11	1	1					20
28	3	13	3	1					30
29	2	29	10	1					49
30		19	9	1					35
31	3	34	15	2		1			60
32	1	50	22						79
33	2	39	14	6	1			1	72
34	1	44	25	5	1	1			86
35	1	30	20	4	2				68
36		20	30	5					58
37		13	18	4	1	3			44
38		6	9	5	2	1			26
39		1	17	6	1				31
40		1	5	1					12
41			4	4					8
42	1	1	4	1	1				8
43		1		1					2
44			1			1			2
Total	27	333	208	48	9	7	0	1	633
Mean length (cm)	27	32	34.63	35.94	36.78	36.86		33	236.207

Fig. 3.1.9.1. Percentage length frequency for female whiting at each age sampled from the Celtic Sea between January 2001 and 2002 *(N is the number of fish)*

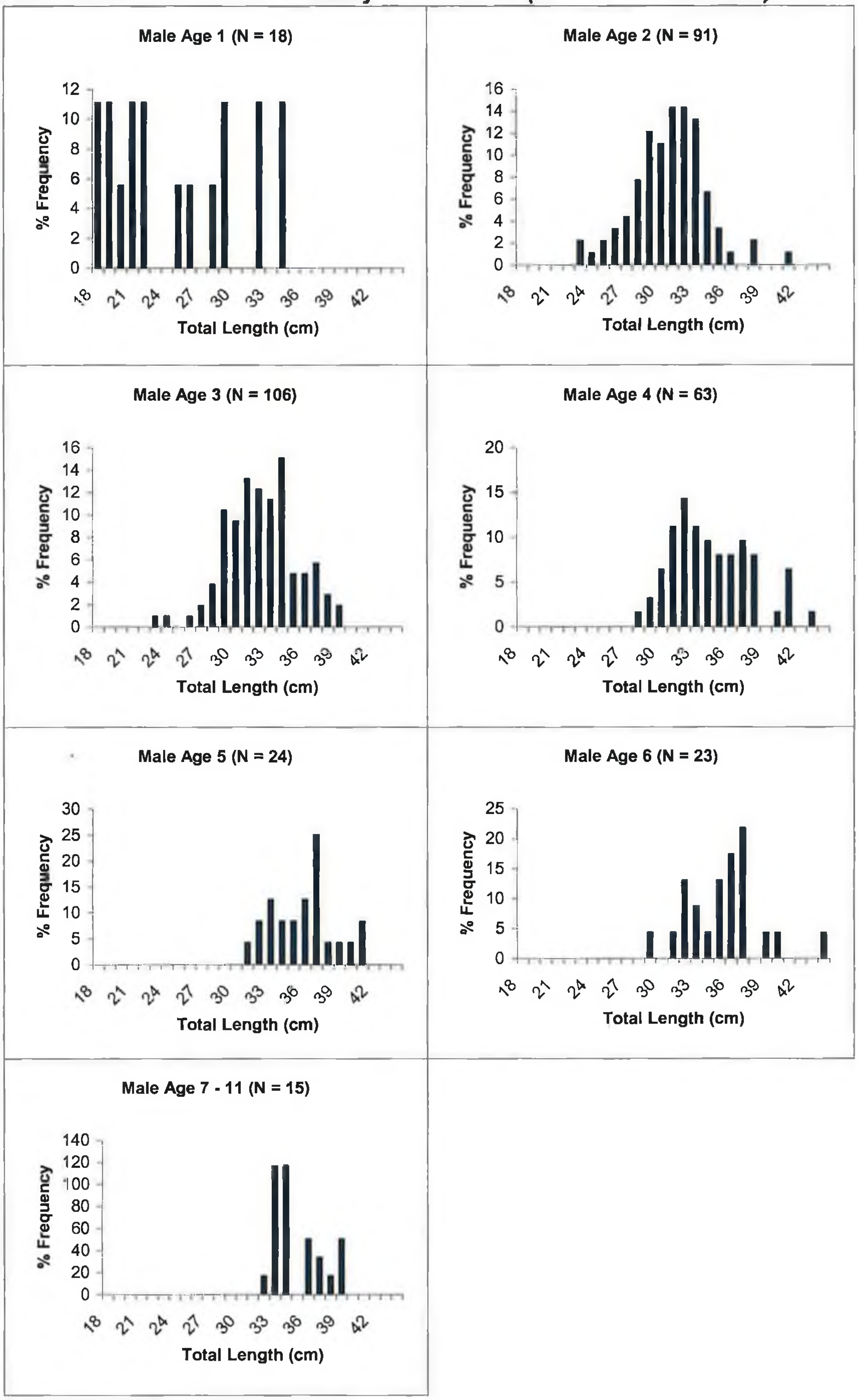


The numbers of male fish at each age in each length class is shown in Table 3.1.9.2, and the percentage length frequency for males at each age is presented in Fig. 3.1.9.2. The majority of male fish were seen at age 3 (N = 106), ranging from 23 – 39 cm. One and 2 year olds ranged from 18 – 34 cm and 23 – 41 cm respectively. Small numbers of males were found at ages 7 to 11. One 11 year old male was recorded measuring 34 cm in total length.

Table 3.1.9.2. Age Length Key - Numbers of male whiting at each age in each length (cm) class sampled from the Celtic Sea between January 2001 and January 2002.

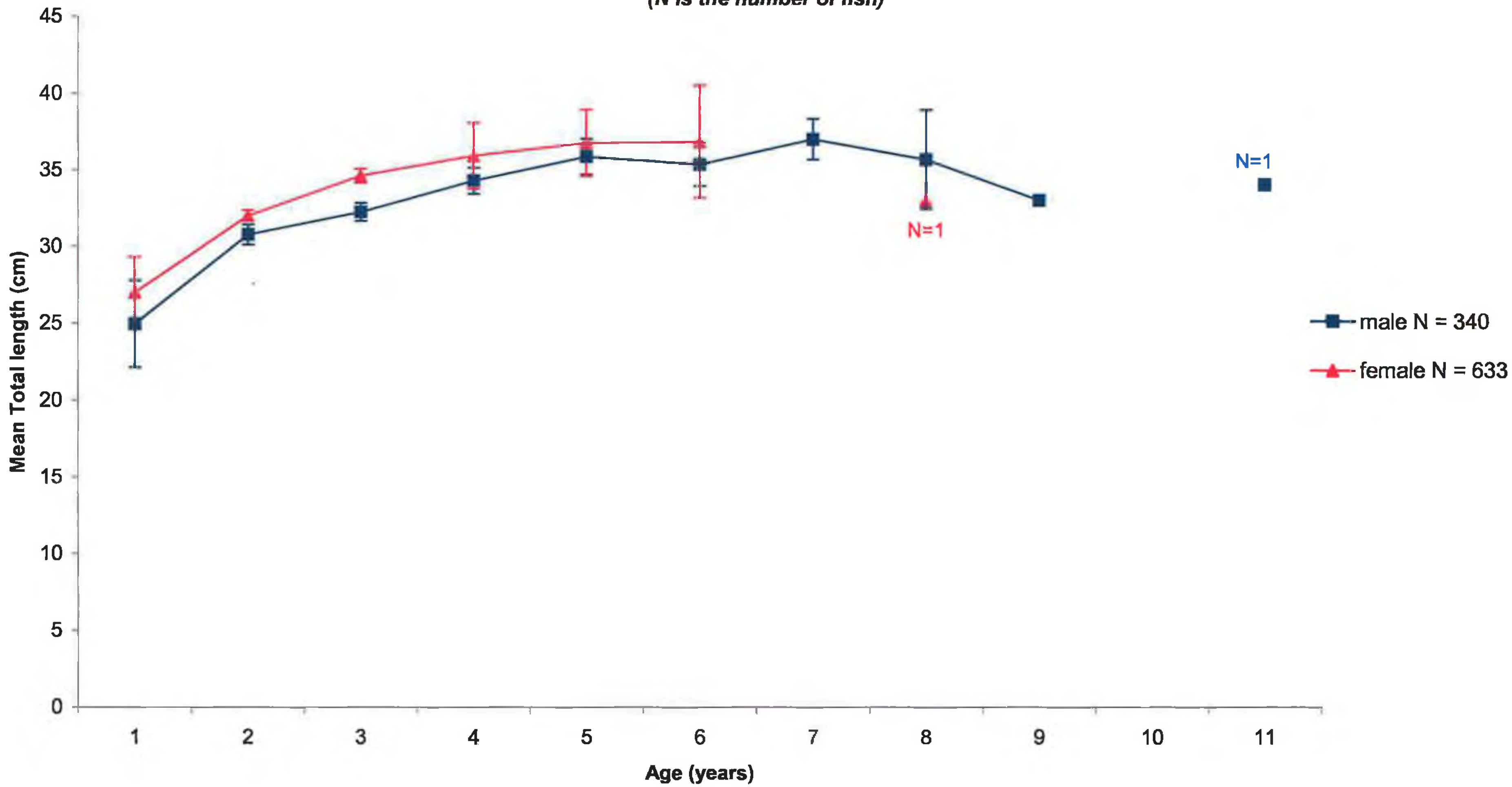
Males											
	Age (years)										
Length (cm)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
18	2											2
19	2											2
20	1											1
21	2											2
22	2											2
23		2	1									3
24		1	1									2
25	1	2										4
26	1	3	1									8
27		4	2									14
28	1	7	4	1								16
29	2	11	11	2		1						30
30		10	10	4								26
31		13	14	7	1	1						37
32	2	13	13	9	2	3		1				49
33		12	12	7	3	2		1	2			41
34	2	6	16	6	2	1		1			1	39
35		3	5	5	2	3						20
36		1	5	5	3	4	3					22
37			6	6	6	5	1	1				27
38		2	3	5	1		1					13
39			2		1	1	1	2				11
40				1	1	1						3
41		1		4	2							7
42												
43				1								1
44						1						1
Total	**18**	**91**	**106**	**63**	**24**	**23**	**6**	**6**	**2**	**0**	**1**	**340**
Mean length (cm)	24.94	30.75	32.24	34.29	35.88	35.35	37	35.67	33		34	333.1

Fig. 3.1.9.2. Percentage length frequency for male whiting at each age sampled from the Celtic Sea between January 2001 and 2002 *(N is the number of fish)*



Mean length values for male and female whiting at age are shown in Fig. 3.1.9.3 with 95% CI values indicated. Females show a very gradual increase in mean length at age ranging from 27 cm at age 1 to 36.9 cm at age 6. There is a significant difference between mean lengths at age for males and females at age groups 2 and 3, as the confidence intervals (CI) do not overlap. The difference between mean lengths at age is not significant at age 1 and from 4 to 6 years of age, i.e. the CI overlap. Males show an overall increase in mean length from ages 1 – 7 years (the mean length deceases slightly at age 6 (35.3 cm)). After 7 years of age the males showed a gradual decrease in mean size, however, the samples at this stage were numerically small. Females showed a larger mean size at all ages between 1 – 6 years.

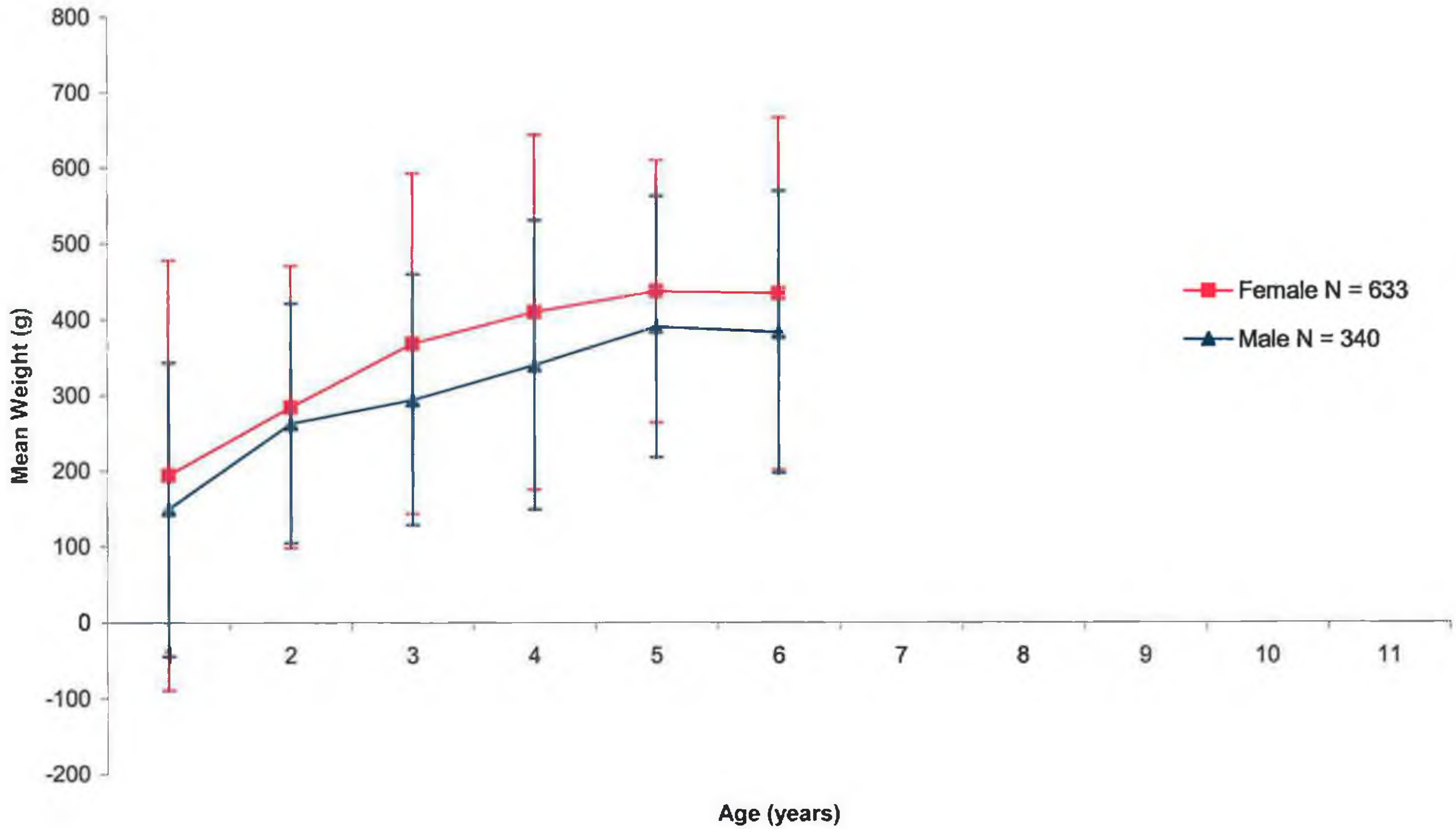
Fig. 3.1.9.3. Mean length at age for male and female whiting sampled from the Celtic Sea between January 2001 and January 2002 (95% confidence intervals indicated by error bars).
(N is the number of fish)



3.1.10 Weight at age

Mean weights at age for male and female whiting are shown in Fig. 3.1.10.1 with 95% CI values indicated. Only one 8-year-old female was recorded and the numbers of males at ages 7 to 11 years were ≤ 6 fish and were therefore excluded from the graph. Males and females considerably increased in weight up to 5 years of age and thereafter the rate of growth slowed down. Weight increased from means of 149.68g to 390.13g and 194.9g to 437.4g for males and females, respectively, for ages 1 to 5 years. Mean values indicated that females were heavier than males at all ages, however the difference does not appear to be significant ($P > 0.05$) as CI values overlap.

Fig. 3.1.10.1. Mean weight at age for male and female whiting sampled from the Celtic Sea between January 2001 and January 2002 (95% confidence intervals indicated by error bars).
(N is the number of fish)



3.1.11 Growth

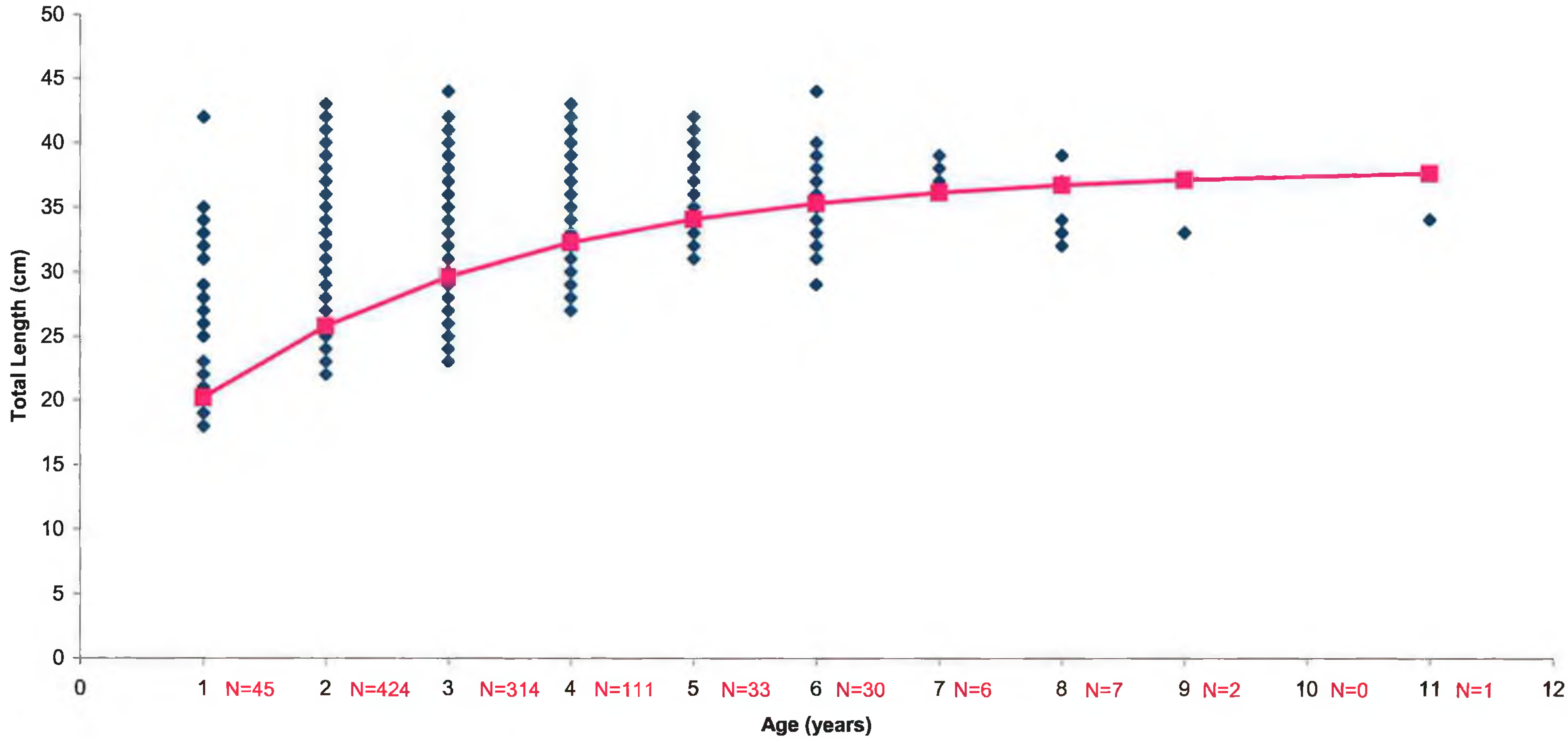
Ford Walford Plot

Parameters estimated from the Ford Walford plot were used to plot a Von Bertalanffy growth curve for the overall sample. While age groups 1 – 11 years were recorded in the overall sample only age groups with sufficient numbers of fish (2, 3 and 4 years) were used in the calculation for the Ford Walford plot. L_∞ was estimated as 38 cm, K = 0.376878 year $^{-1}$ and t_o = -1.01229.

Von Bertalanffy

The Von Bertalanffy growth model for all whiting sampled (sexes combined) from the Celtic Sea is illustrated in Fig. 3.1.11.1. The model illustrates a scatter plot of the length at age for all fish examined together with the fitted Von Bertalanffy growth curve. The Von Bertalanffy growth equation was calculated using the estimates from the Ford-Walford plot above. In the present study, both male and female reached a length of about 20 cm at the end of the first year. They grew about 6 cm in the second year. They maintained an increase in length of 3 cm in the third and fourth year and thereafter the growth rate slowed down. Therefore, there was a steady increase in fish length from ages 1 – 4 years. Thereafter growth increased gradually but more slowly up to 11 years.

Fig. 3.1.11.1. Von Berthalanfy growth curve for whiting sampled from the Celtic Sea between January 2001 and January 2002.
(Note: Symbol may represent multiple year class values. N is the number of fish)



3.1.12 Catch Curves

The age composition of the overall sampled population is presented using a catch curve in Fig. 3.1.12.1. Catch curves representing the males and females separately are shown in Fig. 3.1.12.2. The age at full recruitment (t_r) for the overall population was 3 years. Males were fully recruited at 4 years of age and females at 3 years.

Total Mortality (Z) was calculated using the descending leg of the catch curve. Z for the overall population was 0.83 yr^{-1} (Fig. 3.1.12.1.). Z was calculated as 0.5 yr^{-1} and 1.18 yr^{-1} for males and females respectively, where males and females were examined separately (Fig. 3.1.12.2).

The formula used to calculate fishing mortality (F) and natural mortality (M) coefficient (Z) was as follows:

$$\mathbf{Z = F + M}$$

Where F = Fishing mortality

M = Natural mortality.

Fishing Mortality (F) was calculated for the overall sample and also for males and females separately. ICES (International Council for Exploration of the Seas) assigned an arbitrary M value for whiting of 0.2 (Anon., 2002b). F was calculated for the overall sample as follows:

$$F = 0.83 - 0.2$$

$$\mathbf{F = 0.63}$$

F value for the males was 0.3, and for the females was 0.98, where males and females were examined separately (Fig. 3.1.12.2).

Fig. 3.1.12.1. Catch curve for all whiting sampled in the Celtic Sea between January 2001 and January 2002.

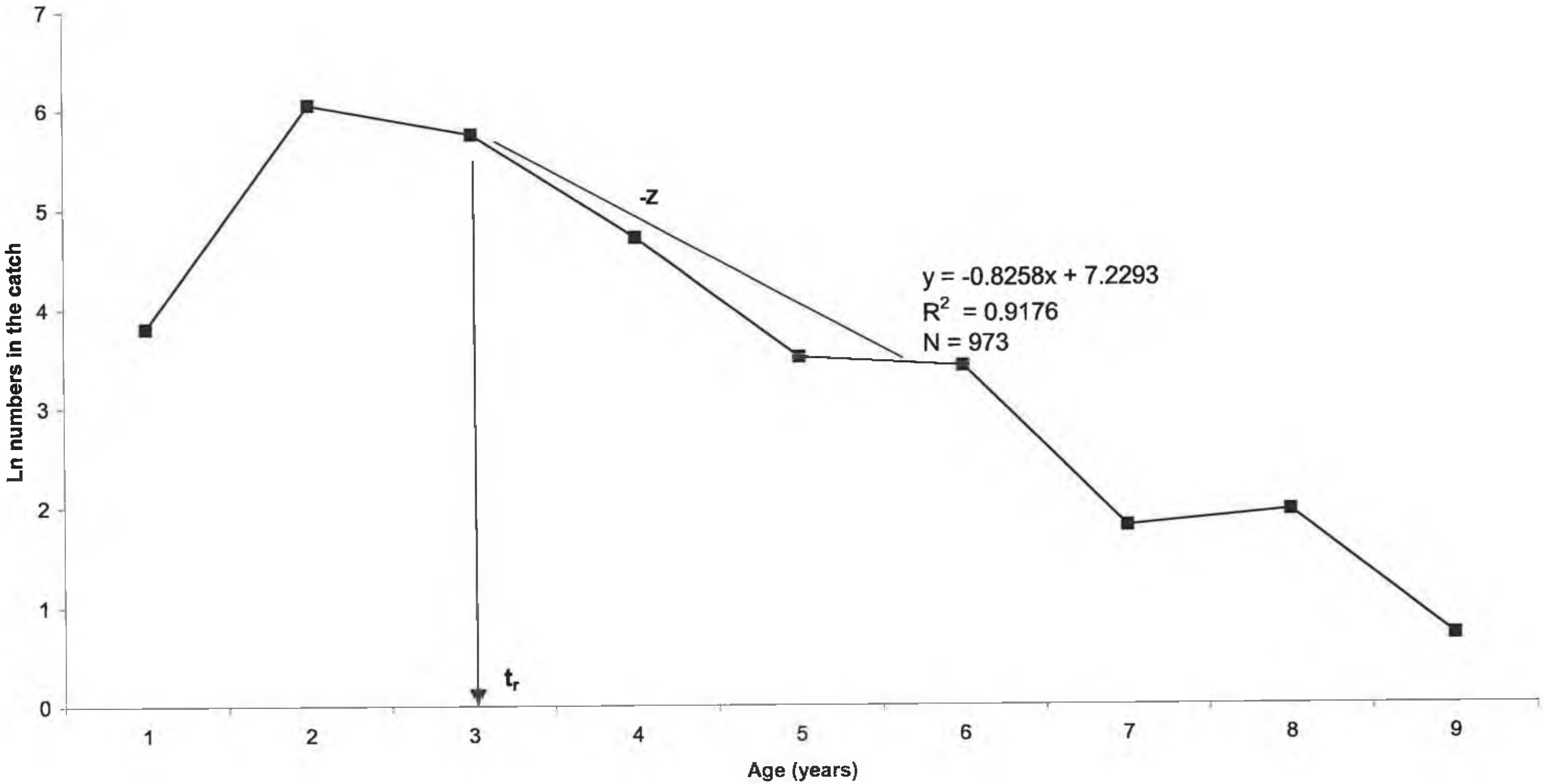
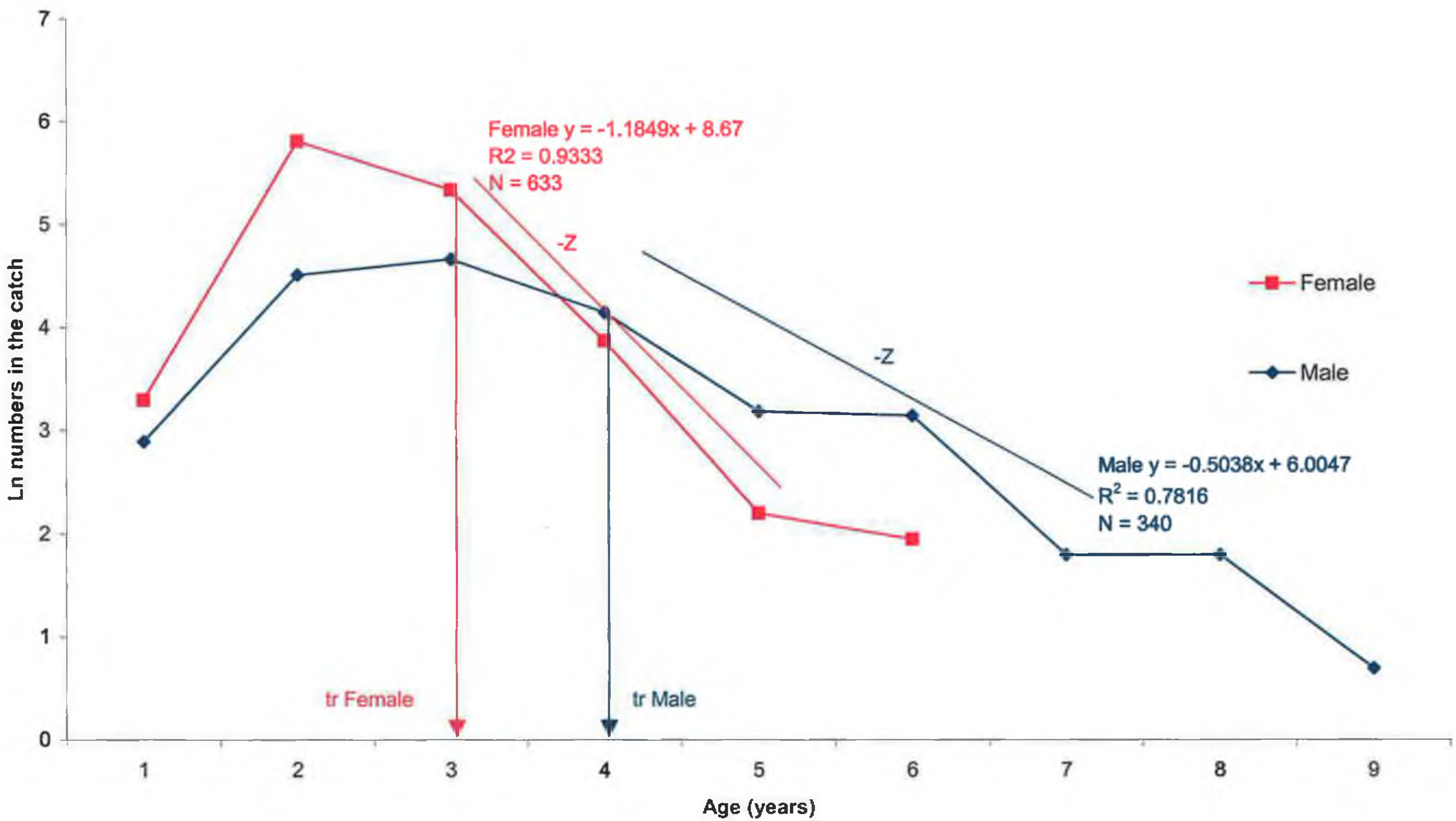


Fig. 3.1.12.2. Catch Curve for male and female whiting sampled between January 2001 and January 2002 from the Celtic Sea.

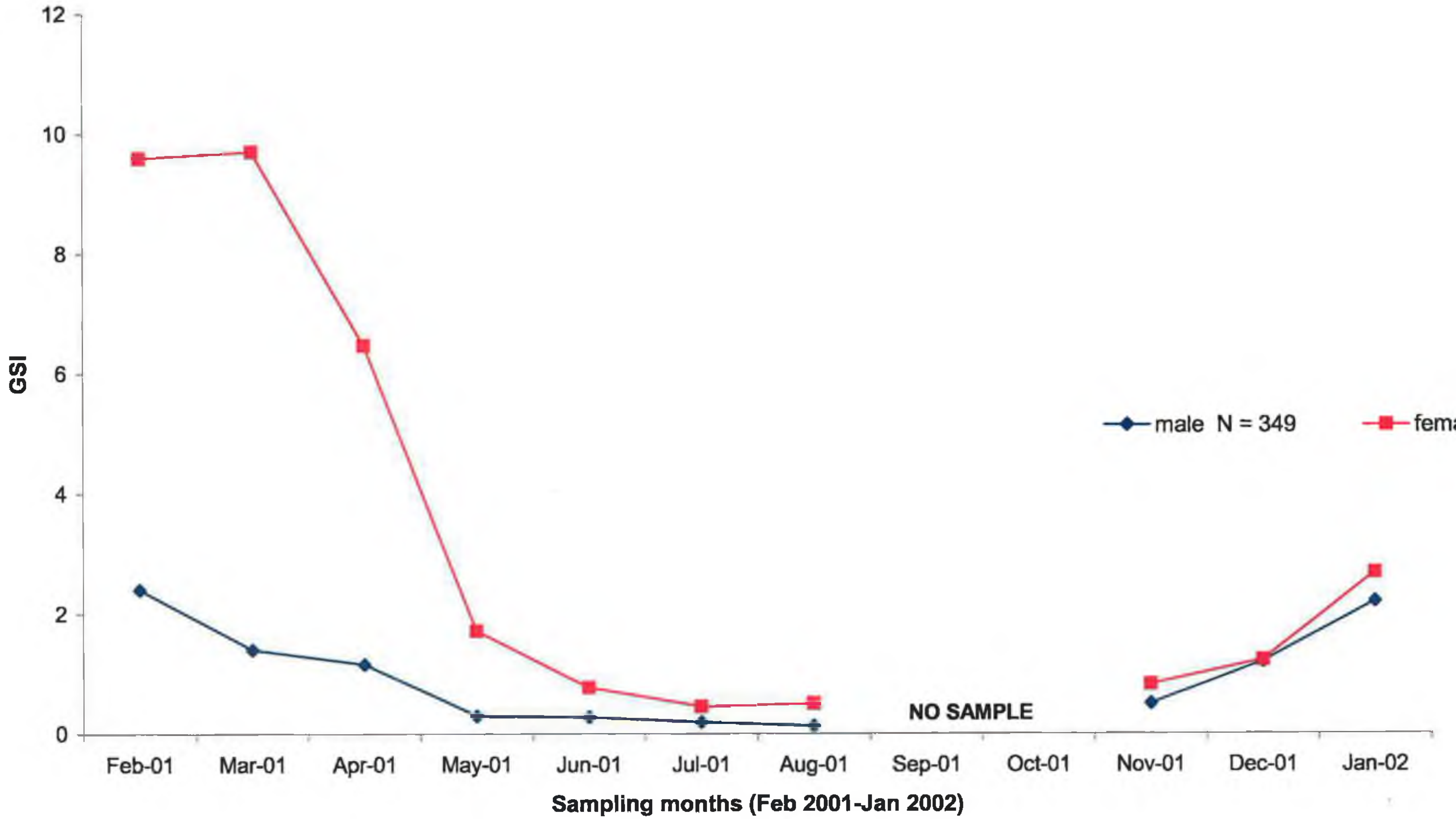


3.2 REPRODUCTIVE BIOLOGY AND MATURITY

3.2.1 Gonosomatic Indices

The seasonal changes in the whiting reproductive cycle are represented using a gonosomatic index (GSI) in Fig. 3.2.1.1. Fish were analysed between January 2001 and January 2002. An increase in GSI indicates an increase in gonad development, while a decrease in gonad size with a corresponding decrease in GSI indicates spawning. Peak GSI occurred between February and March 2001 indicating maximum numbers of ripe females. February 2001 shows the highest value for males. The female GSI progressively decreased from March to June 2001 and it remained relatively low until August 2001. No samples were taken in September and October 2001. Female GSI had increased by November 2001 and continued to increase until January 2002. The male GSI gradually decreased from February to May 2001 and remained low until August 2001. Male GSI had increased by November 2001 and continued to increase until January 2002.

Fig. 3.2.1.1. Gonosomatic Index (GSI) for male and female whiting in the Celtic Sea per month between February 2001 and January 2002. *(N is the number of fish)*



3.2.2 Gonad Development

Macroscopical examination:

The numbers of females and males in each sample at each macroscopic maturity stage over the entire sampling period is shown in Tables 3.2.2.1 and 3.2.2.2 respectively. These data are also presented as percentage frequency graphs in Figs. 3.2.2.1 and 3.2.2.2 respectively. In practice, it was extremely difficult with macroscopic examination to distinguish between, immature (I), developing/resting (II) and spent (VII) stages. In Figs. 3.2.2.1 and 3.2.2.2, immature (I) fish were omitted, as they were generally small fish, which did not contribute to the reproductive cycle. Developing/resting (II) and spent (VII) stages were combined for the present purposes. To simplify results, ripening (III/IV) stages were also combined. Data as actually assessed are presented in Figs. 5.1 and 5.2 in Appendix I.

Ripening (III/IV) female fish were most common from January 2001 to May 2001, occurred in low numbers thereafter until January 2002, when this stage was again abundant. This stage was most abundant in January of both years (Fig. 3.2.2.1). Pre-spawning (V) fish occurred mostly in mid February 2001, but were also prominent in the catches from early February 2001 to late April 2001. Spawning (VI) females ranged in the samples from late February 2001, where they were most abundant, to late April 2001. Developing/resting (II) and spent (VII) females were most abundant from late April 2001 to January 2002. Both stages occurred most frequently in early June and July 2001, while they were also present in small percentages in the early months of the year.

Ripening (III/IV) males were most common in the catches from early February to May 2001, occurred in small percentages thereafter in mid June, July 2001 and from

November 2001 to January 2002 (Fig. 3.2.2.2). This stage was most abundant in mid February 2001. Pre-spawning (V) males ranged in the samples principally from mid February to late April 2001, while they occurred also in January 2002. A few spawning (VI) males were recorded in early and late February and late April, while this stage was most abundant in the January 2002. Developing/resting (II) and spent (VII) males were most common from late February 2001 to January 2002. Both stages occurred most frequently in January, June and August 2001. Only 1 male fish was analysed on the 30/4/01 and therefore was excluded for present purposes. Macroscopic results of the percentage occurrence of female and male whiting in each maturity stage over the sampling period are presented in Fig. 5.3 in Appendix I.

Table 3.2.2.1. Maturity stages assessed after macroscopic examination of female whiting at each sampling date between January 2001 and January 2002 in the Celtic Sea.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Female								
Macroscopic Maturity Stage								
Date	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
21/01/01	6	3	18	3				30
01/02/01	1	2	2	8	4			17
12/02/01			1	10	45			56
26/02/01			2	10	17	16		45
15/03/01		1	2	18	24	1		46
02/04/01		1	4	25	15	3		48
09/04/01			10	11	27	1		49
25/04/01	4	5	8	8	13	2	2	42
30/04/01	14	15	3	2				34
15/05/01	12	15	12	8	2			49
05/06/01	9	8					9	26
12/06/01	3	6	2	1	2		31	45
10/07/01		3					28	31
09/08/01		18	1				21	40
03/11/01		65	1					66
03/12/01		73	3					76
15/01/02		8	17	13	2			40
Total	49	223	86	117	151	23	91	740

Table 3.2.2.2. Maturity stages assessed after macroscopic examination of the numbers of male whiting at each sampling date between Jan 2001 and Jan 2002 in the Celtic Sea.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Male								
Macroscopic Maturity Stage								
Date	I	II	III	IV	V	VI	VII	Total
21/01/01	3	28					2	33
01/02/01			6	3		1		10
12/02/01			6	12	1			19
26/02/01		4	8	4	4	2	1	23
15/03/01	1	11	4	7	3			26
02/04/01		4	6	2	3			15
09/04/01		9	8	10	6			33
25/04/01	1	10	8	5	2	1		27
30/04/01				1				1
15/05/01	4	20	2	2				28
05/06/01		12						12
12/06/01	3	4	6				5	18
10/07/01	2		1				10	13
09/08/01		8					17	25
03/11/01	3	17	1	1				22
03/12/01		19	19	10	1			49
15/01/02		4	1	2	16	5	1	29
Total	17	150	76	59	36	9	36	383

Fig. 3.2.2.1. Percentage of each development stage in the gonad cycle at each sampling date over the sampling period January 2001 to January 2002 for female whiting examined macroscopically
Number of fish analysed = 740

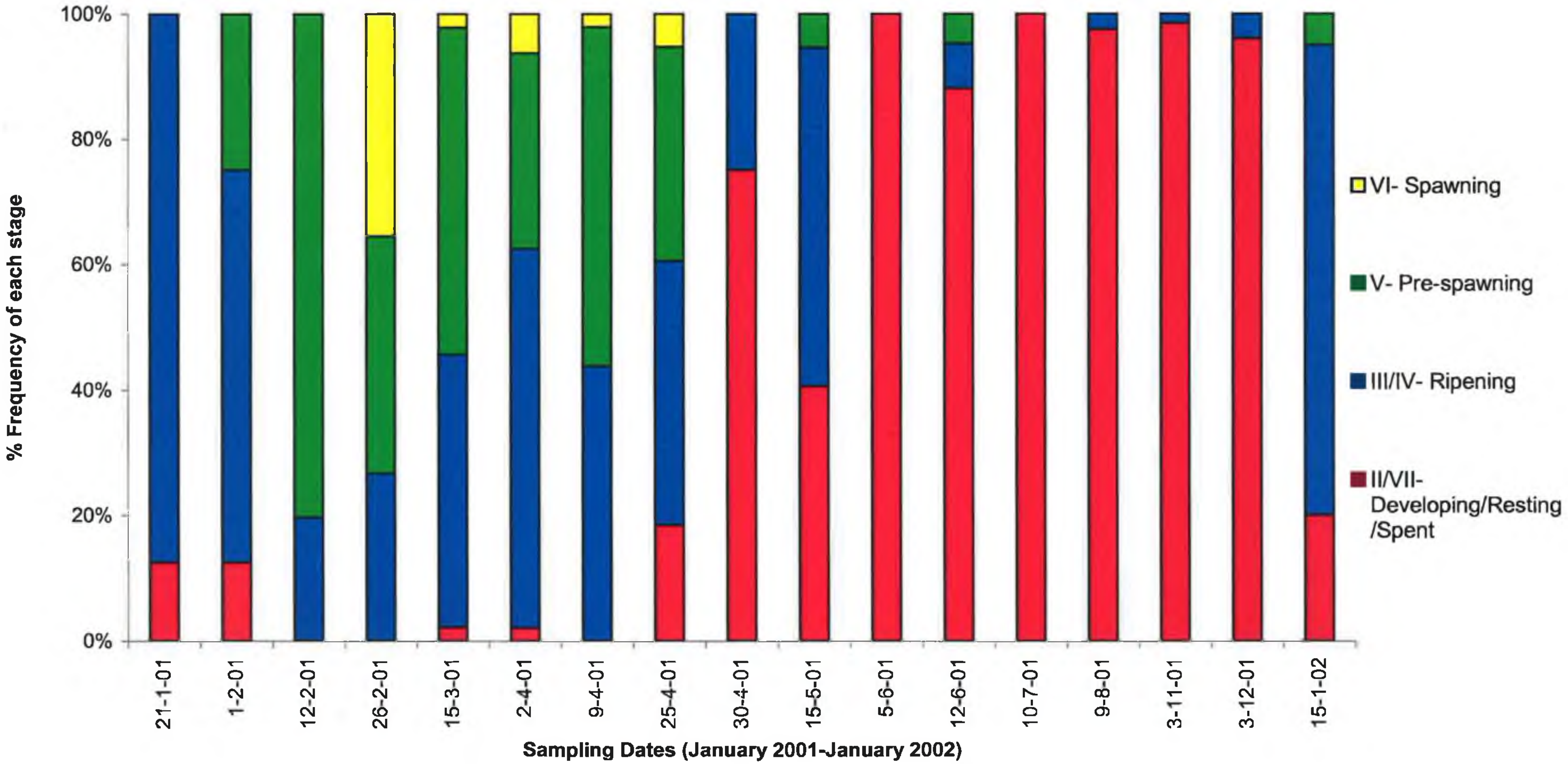
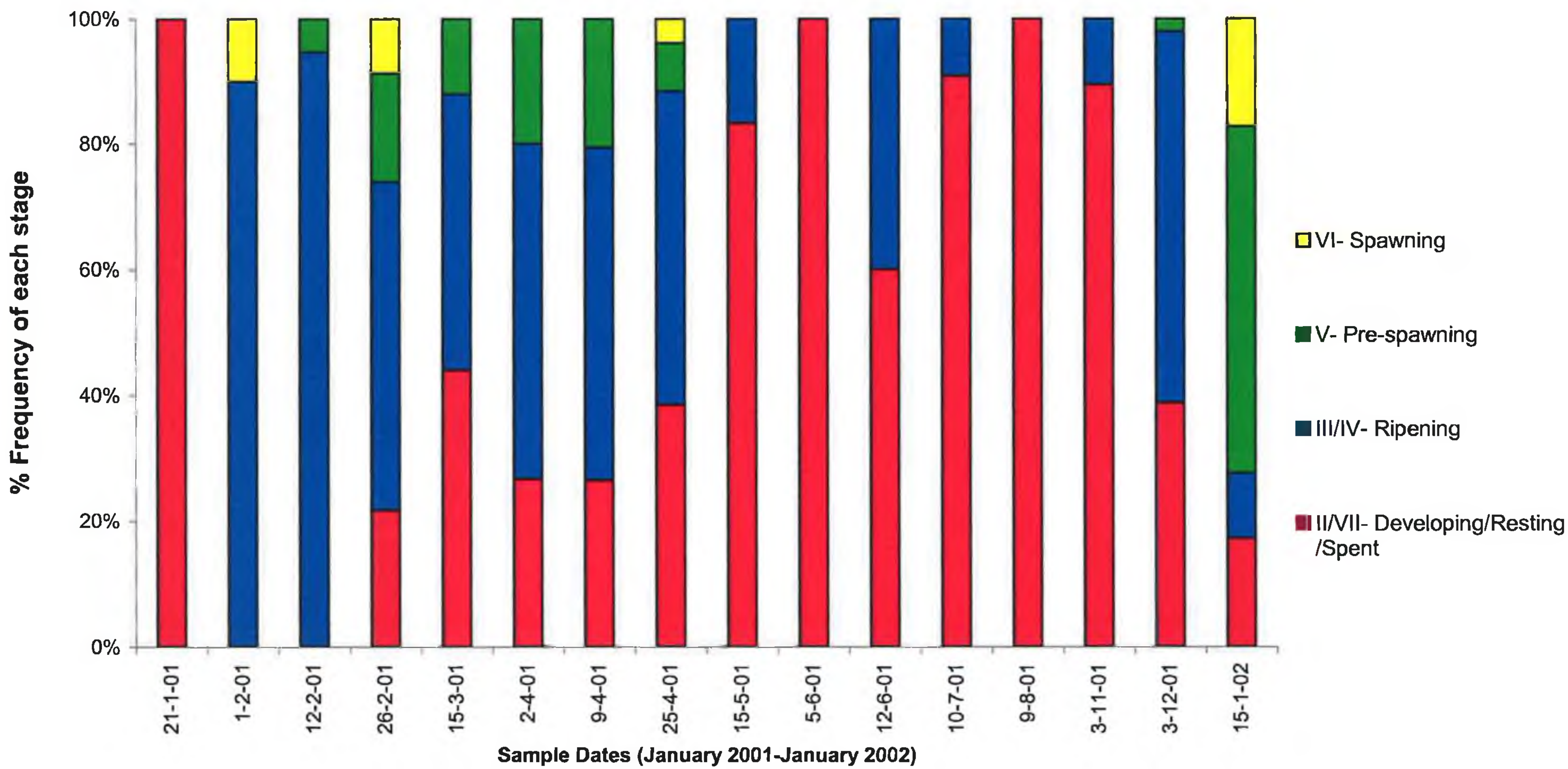


Fig. 3.2.2.2. Percentage of each development stage in the gonad cycle at each sampling date over the sampling period January 2001 to January 2002 for male whiting examined macroscopically

Number of fish analysed = 383

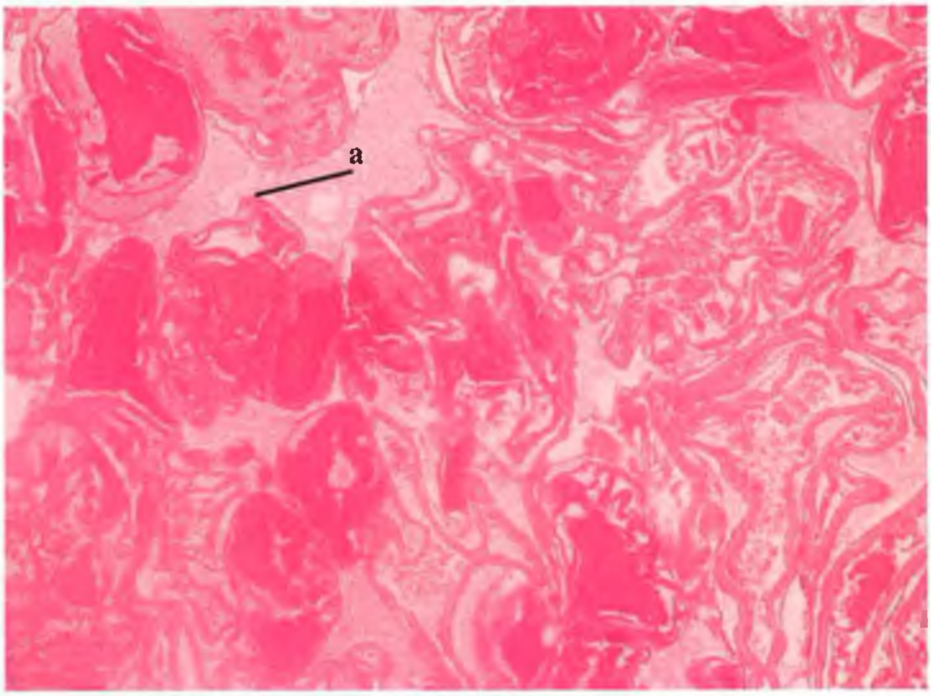


Histological examination:

The method of storing the gonad samples (i.e. freezing -18°C) prior to the histological analysis was problematic. Prior to fixation, freezing and defrosting of the gonads caused the oocytes to rupture. The oocytes had a jagged edge as a result of this method (see Fig.3.2.2.3). Therefore it was difficult to identify between the different oocytes. Results from histological analyses of maturity stages for male and female whiting are presented in Tables 3.2.2.3 and 3.2.2.4 respectively. These data are also presented as percentage frequency graphs in Figs. 3.2.2.4 and 3.2.2.5 respectively. For the purpose of the present investigation, immature (I) fish were excluded from the data set, as they represented small fish, which were not reproductively active. Histological examination distinguished between immature (I), developing/resting (II) and spent (VII) gonads, thus resolving the problems encountered macroscopically. Developing/resting (II) and spent (VII) stages are separated in Figs. 3.2.2.4 and 3.2.2.5. To simplify results, ripening (III/IV) stages were again combined. The full data set as interpreted from the slides is presented in Figs. 5.4 and 5.5 in Appendix I.

Fig. 3.2.2.3. Female maturity stage, 66/26/2/01, 100x magnification.

(a) oocyte showing jagged edge.



Developing/resting (II) female fish occurred predominantly in November and December 2001, they were also present in small percentages in January of both years and from May to June 2001. The majority of ripening (III/IV) females were recorded in the early months of the year (February to May 2001) and reoccurred once again in January 2002 (Fig. 3.2.2.4). In early February 2001, the highest percentages of pre-spawning fish were seen. Spawning (VI) occurred in late February and equal percentages of spawning females were recorded in early and late April 2001 catches. Spent fish were first observed in April and continued through to August 2001, while the majority of spent females occurred in July and August 2001.

Developing/resting (II) male fish occurred most frequently in August 2001 as seen in Fig. 3.2.2.5. Ripening (III/IV) fish were most abundant in the November and December

2001 catches. Pre-spawning (V) males occurred predominantly in the January 2002 sample. Spawning (VI) males occurred primarily in the early months of the year from February to June 2001 and also in January 2002. Spent (VII) fish were also most abundant in the early months of the year, from February to June 2001, with a peak in late April 2001. The percentage occurrence of female and male whiting at each maturity stage over the sampling period according to histological examination are presented in Fig. 5.6 in Appendix I.

Table 3.2.2.3. Histologically assessed maturity stages for numbers of female whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Female								
Histological Maturity Stage								
Date	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
01/02/01		1	2	7	4			14
12/02/01			1	6				7
26/02/01				5	1	2		8
15/03/01				15				15
09/04/01				15		8		23
25/04/01				5		4	3	12
30/04/01	27		1	1			1	30
15/05/01	1	2	2	4			5	14
05/06/01		1					13	14
12/06/01	1	2	1	1	1		9	15
10/07/01	10						4	14
09/08/01	2						3	5
03/11/01	1	19						20
03/12/01		16						16
15/01/02		2	7	5	2			16
Total	42	43	14	64	8	14	38	223

Table 3.2.2.4. Histological maturity stages for numbers of male whiting, sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Male								
	Histological Maturity Stage							
Date	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
01/02/01	2	2		1	1	3	1	10
12/02/01								
26/02/01								
15/03/01								
09/04/01						3	2	5
25/04/01						6	12	18
30/04/01						1		1
15/05/01								
05/06/01	2	7				1	2	12
12/06/01								
10/07/01								
09/08/01	3	2						5
03/11/01	4	1	10	1				16
03/12/01			4	7	1		1	13
15/01/02	1	1			3	7	1	13
Total	12	13	14	9	5	21	19	93

Fig. 3.2.2.3. Percentage development at each stage estimated after histological examination of the gonad, in each sample for female whiting over the sampling period (February 2001-January 2002).
Number of fish analysed = 223

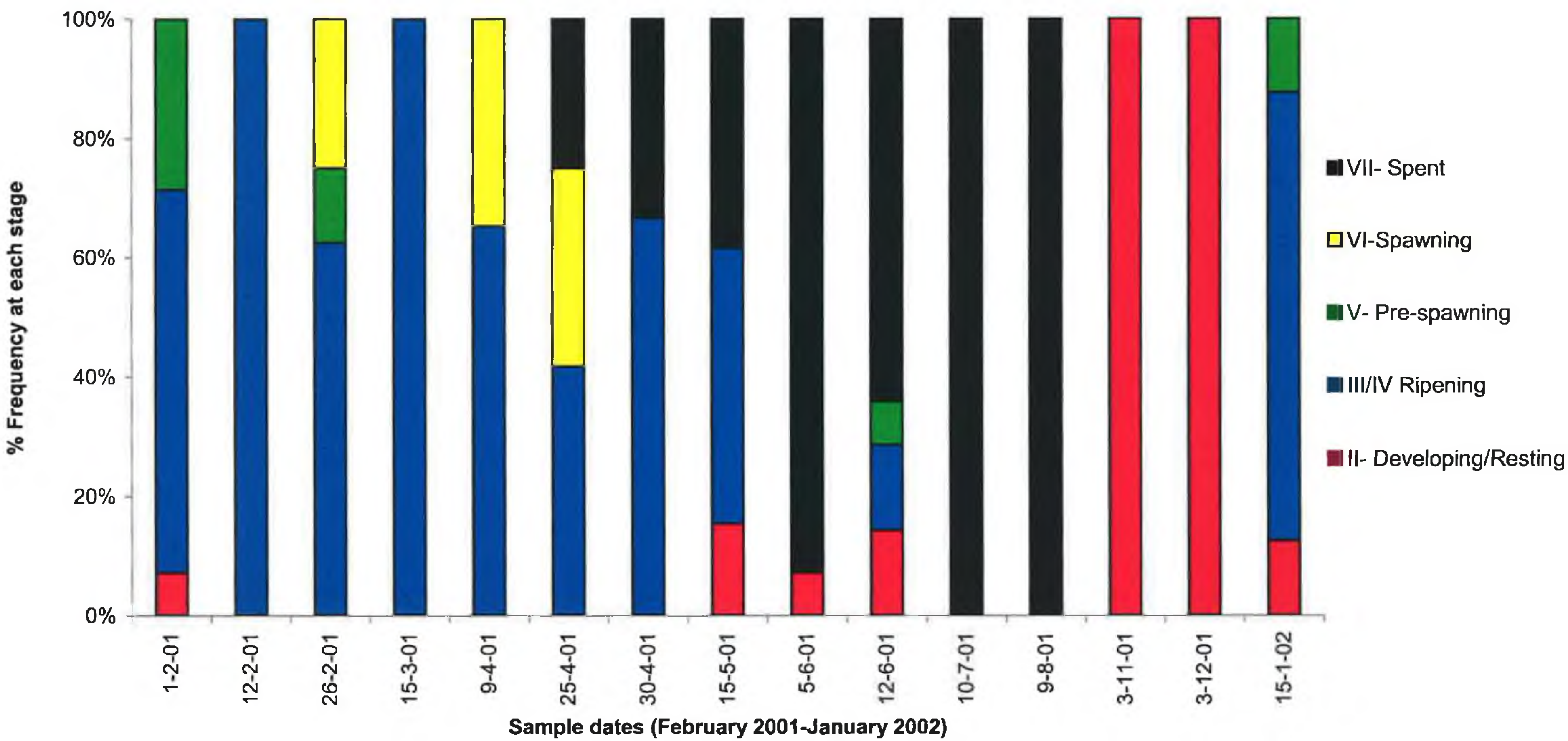
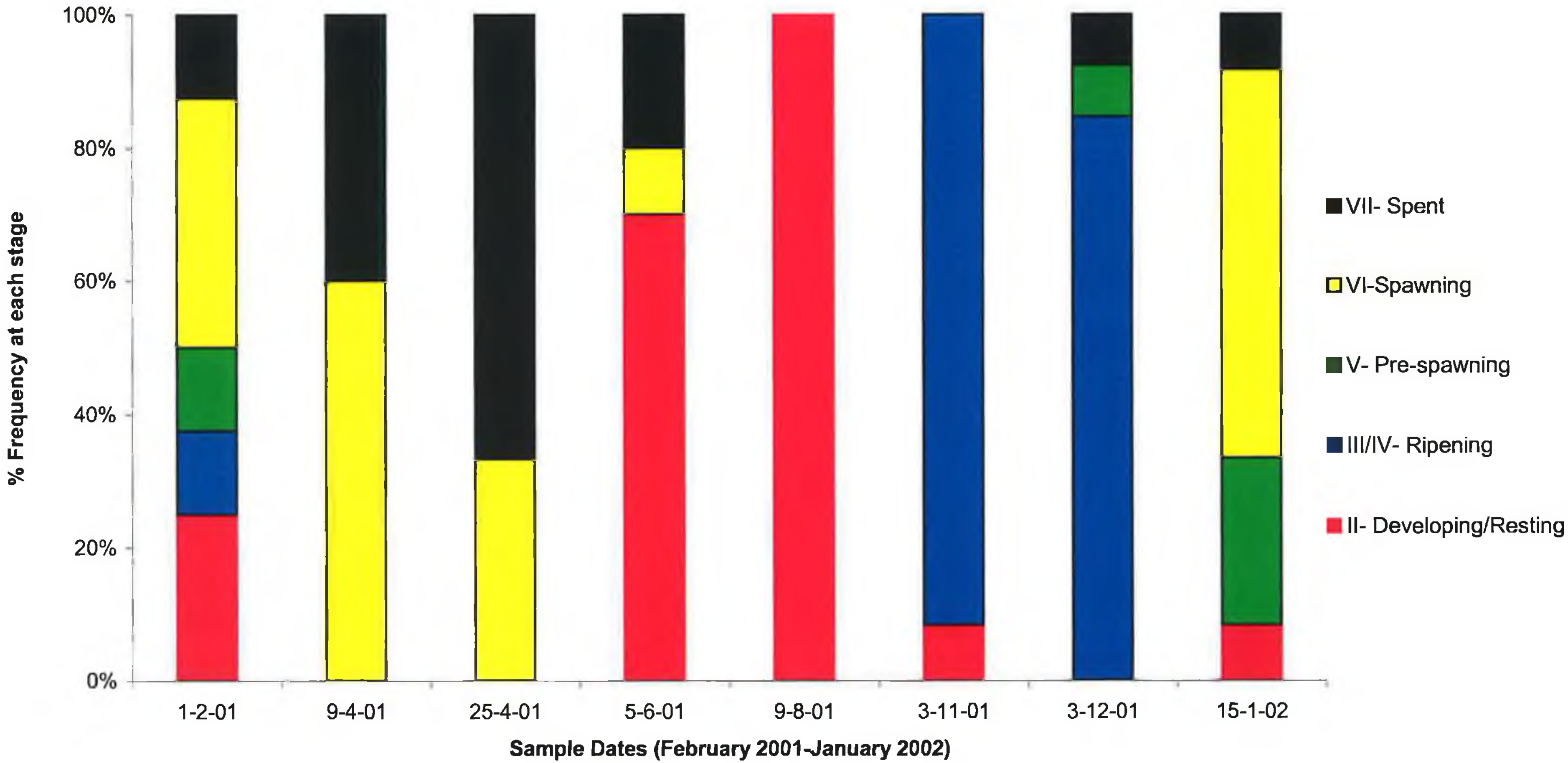


Fig. 3.2.2.4. Percentage development at each stage estimated after histological examination of the gonad, in each sample for male whiting over the sampling period (February 2001-January 2002).

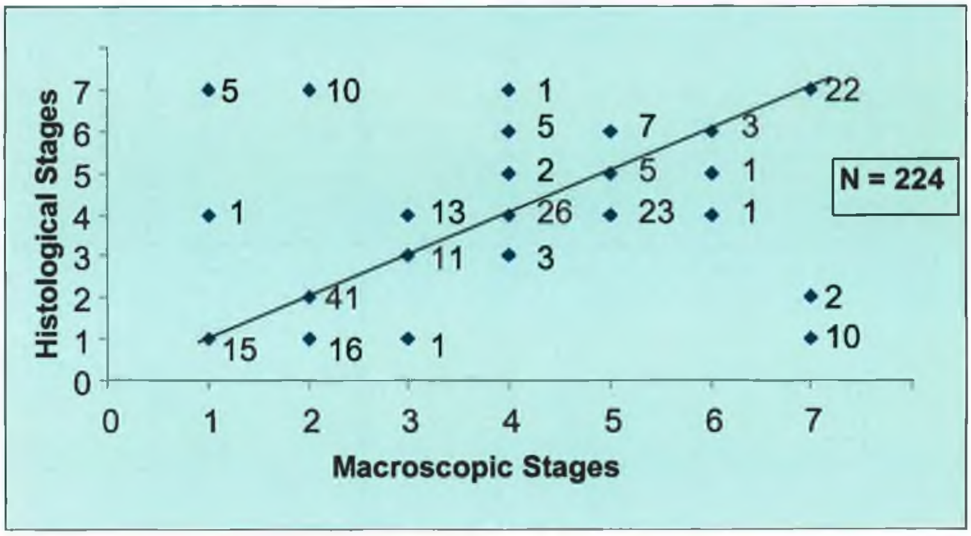
Number of fish analysed = 93



3.2.3 Comparison of Macroscopic and Histological methods

The number of macroscopically assessed maturity stages in comparison to histologically assessed maturity stages for females, sampled from the Celtic Sea between January 2001 and January 2002 are presented as a scatter plot in Fig. 3.2.3.1. A Pearson correlation test was calculated for the data using Minitab. The hypothesis (H_0) tested that there was no correlation between macroscopic and histological methods of assessment. The test statistic (0.488) was greater than the critical value therefore H_0 was rejected. Thus, there was a strong significant correlation between the two methods. As seen from Fig. 3.2.3.1 more than half of the females were assigned the same stage both macroscopically and histologically. The greatest disagreement between macroscopic and histological methods occurred at immature, developing/resting and spent stages. Sixteen female fish were macroscopically assessed as developing/resting, while they were recorded as immature histologically. Fifteen females were recorded as either immature or spent with one of the methods of assessment, but were recorded as the opposite (either immature or spent) with the other method. This also occurred for 12 females, which were either developing/resting or spent. Twenty three females were recorded as ripening histologically whereas they were recorded as pre-spawning macroscopically. The outliers portray the difficulties in distinguishing between these maturity stages.

Fig. 3.2.3.1. Scatter plot of the number of macroscopically assessed maturity stages versus histologically assessed maturity stages for female whiting, sampled from the Celtic Sea between January 2001 and January 2002.



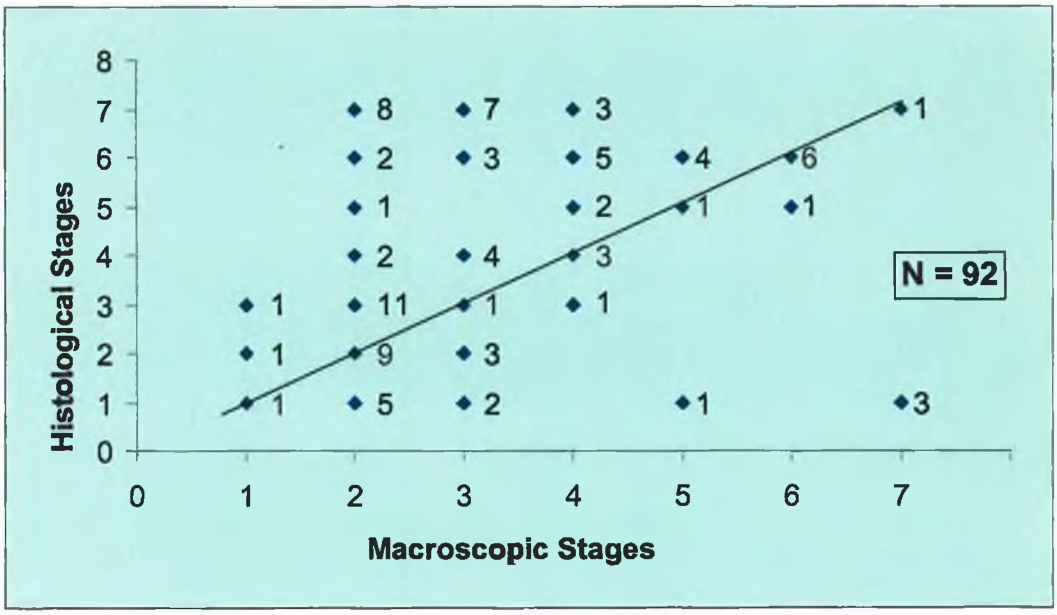
Legend representing histological and macroscopic maturity stages are as follows:

1 = Immature, 2 = Developing/resting, 3 = Ripening, 4 = Ripening, 5 = Pre-spawning, 6 = Spawning and 7 = Spent.

(Number on the graph refers to the number of fish at that stage).

The number of macroscopically assessed maturity stages in comparison to histollogically assessed maturity stages for male whiting, sampled from the Celtic Sea between January 2001 and January 2002 are presented as a scatter plot in Fig. 3.2.3.2. A Spearman rank correlation coefficient was used for male whiting (N < 100). The same H_o i.e. no correlation between macroscopical and histological methods of assessment was tested. The test statistic (0.267) was greater than the critical value, therefore H_o was rejected. Therefore, in this case also, a strong significant correlation between the two methods was observed. It was more difficult to stage male whiting in comparison to the females. There was only approximately one-fifth agreement between macroscopic and histological methods for male whiting. Assessment of spawning individuals showed the best agreement on the scatter plot between the two methods. Eleven males were recorded as ripening histologically, while they were recorded as developing/resting macroscopically. The greatest outlier was the histologically assessed spent stage, which was confused as developing/resting or ripening macroscopically.

Fig. 3.2.3.2. Scatter plot of the number of macroscopically assessed maturity stages versus histologically assessed maturity stages for male whiting, sampled from the Celtic Sea between January 2001 and January 2002.



Legend representing histological and macroscopic maturity stages are as follows:

1 = Immature, 2 = Developing/resting, 3 = Ripening, 4 = Ripening, 5 = Pre-spawning, 6 = Spawning and 7 = Spent.

(Number on the graph refers to the number of fish at that stage).

3.2.4 Maturity at length

Macroscopically assigned maturity stages at each length for female whiting are presented in Table 3.2.4.1. Immature (I) fish ranged in length from 18 cm to 40 cm, while females showed signs of development from 20 cm upwards. Female fish were ripe (III and IV) from 23 cm and 25 cm onwards. Pre-spawning (V) occurred from 25 cm upwards. The first signs of spawning (VI) were observed at 27 cm, but primarily from 33 cm upward. Spent (VII) females were first encountered at 29 cm. From 29 cm upwards, the full range of maturity stages were observed. The largest females caught (44 cm) showed reproductive activity, as indicated by ripening (IV) and pre-spawning (V) gonads.

Table 3.2.4.1 Maturity stages at each length class (cm) examined macroscopically, for female whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Females								
	Macroscopic Maturity Stage							
Total Lt (cm)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
18	1							1
19								
20	1	1						2
21	3							3
22	5	1						6
23	1	3	2					6
24	3	3	1					7
25	4		2	1	8			15
26			3	1	6			10
27		7	1	5	6	1		20
28	2	8	5	5	10			30
29		22	9	5	11		2	49
30		15	4	8	4		4	35
31	2	16	8	14	9		11	60
32	1	31	8	16	6		17	79
33	3	25	9	10	14	1	10	72
34	2	34	9	10	13	5	13	86
35	5	20	5	8	18	4	8	68
36	8	14	3	7	11	6	9	58
37	4	12	5	6	7	4	6	44
38	2	4	5	5	6		4	26
39	1	5	5	7	8	1	4	31
40	1			1	9		1	12
41				5	2		1	8
42		1	2	1	2	1	1	8
43		1		1				2
44				1	1			2
Total	49	223	86	117	151	23	91	740

The numbers in each macroscopically assigned maturity stage at each length for male whiting can be seen in Table 3.2.4.2. Immature (I) fish ranged in length from 18 cm to 34 cm, while males showed signs of development (II) from 19 cm upwards. Male fish were ripe (III and IV) from 25 cm and 23 cm respectively. Pre-spawning (V) occurred from 26 cm upwards. Male spawning (VI) ranged from 32 cm to 39 cm. Spent (VII) males were first encountered at 21 cm and not again until 28 cm. From 28 cm upwards, the full range of maturity stages were observed. The largest fish caught (44 cm) showed reproductive activity, as indicated by pre-spawning (V) gonads.

Table 3.2.4.2. Macroscopic Maturity stages at each length class (cm) for male whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Male								
Macroscopic Maturity Stage								
Total Lt (cm)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
18	2							2
19	1	1						2
20		1						1
21		1					1	2
22		2						2
23		2		1				3
24		2						2
25		3	1					4
26		3	3	1	1			8
27	1	3	4	6				14
28		5	6	3	1		1	16
29	5	11	5	6	2		1	30
30	1	13	6	2	4			26
31	2	19	6	2	2		6	37
32	2	17	8	11	5	1	5	49
33		15	11	5	5	2	3	41
34	3	14	3	6	3	3	7	39
35		6	6	3	4		1	20
36		7	3	4	1	2	5	22
37		15	4	3	3		2	27
38		3	6	2			2	13
39		4	1	2	1	1	2	11
40		1	2					3
41		2	1	2	2			7
42								
43					1			1
44					1			1
Total	17	150	76	59	36	9	36	383

Maturity stages assessed histologically for each length class for male and female whiting separately are shown in Table 3.2.4.3 and 3.2.4.4 respectively. Female immature (I) whiting ranged in size from 21 cm to 39 cm (Table 3.2.4.3). Female fish developing/resting (II) ranged from 28 cm to 42 cm in total length and were most frequently recorded at 32 cm (N = 13). Numbers of ripe (III/IV) females were first encountered at 26 cm and the largest ripe (IV) fish was 44 cm in total length. Only 8 females were in the pre-spawning (V) category. Spawning (VI) females ranged in length from 28 cm to 37 cm. One spent (VII) female was recorded at 25 cm and spent fish then ranged from 29 cm to 43 cm thereafter. As with macroscopic analysis the full range of maturity stages were also seen histologically from 29 cm upwards.

Table 3.2.4.3. Histologically assessed maturity stages at each length class (cm) for female whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Female								
	Histological Maturity Stage							
Total Lt (cm)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
21	1							1
22	4							4
23	4							4
24	5							5
25	4						1	5
26			1	4				5
27	5			1				6
28	1	4	1	2	1	1		10
29	5	2	1	5		1	2	16
30		4	1	1				6
31	3	3		7			2	15
32	2	13		3	1		1	20
33	2	2	4	6		2	2	18
34	2	10	3	3	2	4	4	28
35	2	3		10	1	3	5	24
36	1	1		8	2		7	19
37				3		3	4	10
38			1				3	4
39	1		2	2	1		3	9
40				3			1	4
41				2			1	3
42		1		3			1	5
43							1	1
44				1				1
Total	**42**	**43**	**14**	**64**	**8**	**14**	**38**	**223**

Immature (I) male whiting ranged in size from 26 cm to 36 cm, while developing/resting (II) gonads ranged from 27 cm to 39 cm (Table 3.2.4.4). Ripening (III and IV) males were observed first at 25 cm and 27 cm respectively. Only 5 males were recorded in the pre-spawning (V) category. Those found ranged from 26 cm to 34 cm. The commonest stage of male whiting was spawning (VI), they ranged in size from 23 cm to 41 cm in total length. Spent males ranged from 28 cm to 41 cm. The full range of maturity stages were observed histologically from 28 cm upwards.

Table 3.2.4.4. Histologically assessed maturity stages at each length class (cm) for male whiting from the Celtic Sea between January 2001 and January 2002.

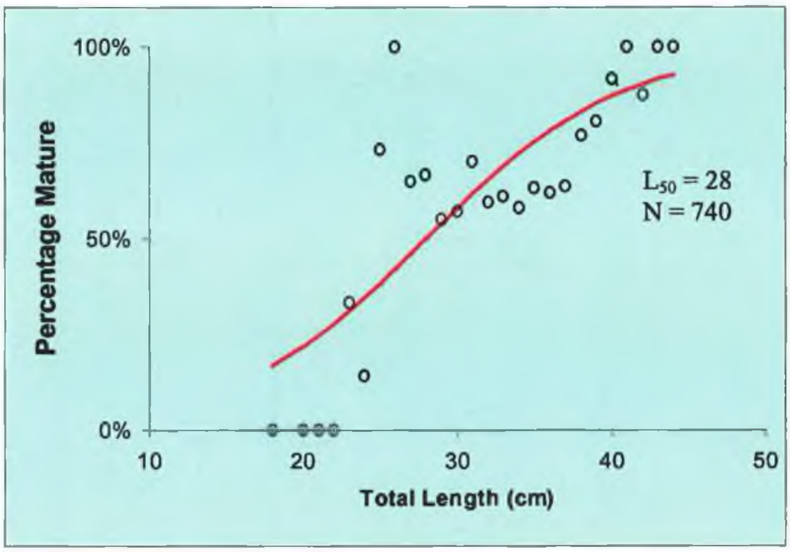
(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Male								
	Histological Maturity Stage							
Total Lt (cm)	I	II	III	IV	V	VI	VII	Total
21								
22								
23						1		1
24								
25			1					1
26	1				1	1		3
27	1	2		1		1		5
28				1			2	3
29	1	1	1				1	4
30			2	1				3
31			4				2	6
32	2		1		2	7		12
33	3	3	2	5	1	2	2	18
34	1	4	1	1	1	1	1	10
35						3	1	4
36	3		2			3		8
37		2				1	4	7
38							4	4
39		1						1
40								
41						1	2	3
42								
43								
44								
Total	12	13	14	9	5	21	19	93

<u>Ogives at length</u>

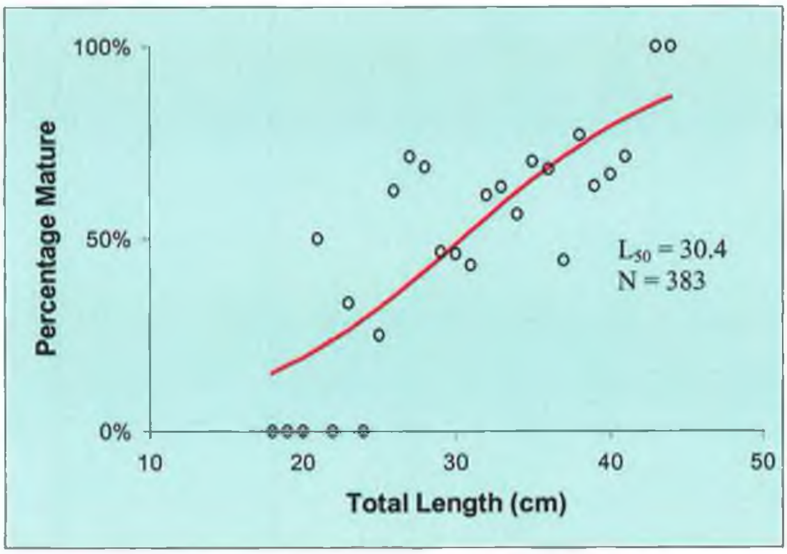
The maturity at length ogives for female and male whiting sampled from the Celtic Sea between January 2001 and January 2002 are presented in Fig. 3.2.4.1 and 3.2.4.2. Only two fish were recorded at 43 cm in the raw data. One of them was immature (I or II) which creates a 50% probability of maturity at that length. This is more a product of low sampling at this length than something biologically sensible. Alternatively, this fish could have been spent (VII), which appeared immature on macroscopic assessment of maturity stages. Fortunately it does not cause too big a problem in fitting the model, because virtually all fish around this length are fully mature. Changing all 43 cm fish to all being mature makes biological sense and makes the model fit more sensibly. The L_{50} (50% mature at length) for females was at a total length of 28 cm (Fig. 3.2.4.1). The L_{95} (95% mature at length) was at a total length of 46.5 cm. Upper and lower 95% confidence limits were also estimated for $L_{50\%}$ and $L_{95\%}$. 95% confidence was calculated at $L_{50\%}$, showing that 50% of the fish were mature between 27.9 cm and 33 cm. 95% confidence was also calculated at $L_{95\%}$, showing that 95% of the fish were mature between 42.5 cm and 60.9 cm.

Fig. 3.2.4.1. Percentage mature at length ogive for female whiting, captured in the Celtic Sea between January 2001 and January 2002.



The L_{50} (50% mature at length) for males was at a total length of 30.4 cm (Fig. 3.2.4.2). The L_{95} (95% mature at length) was at a total length of 51.7 cm. Upper and lower 95% confidence limits were also estimated for $L_{50\%}$ and $L_{95\%}$. 95% confidence was calculated at $L_{50\%}$, showing that 50% of the fish were mature between 27.9 cm and 33 cm. 95% confidence was also calculated at $L_{95\%}$, showing that 95% of the fish were mature between 42.5 cm and 60.9 cm.

Fig. 3.2.4.2. Percentage mature at length ogive for male whiting, captured in the Celtic Sea between January 2001 and January 2002.



3.2.5 Maturity at age

Macroscopically assessed maturity stages at each age for female and male whiting are shown separately in Table 3.2.5.1 and 3.2.5.2. Immature (I) females were recorded from ages 1-4. Mature females were recorded as young as age 1. Two and 3 year olds showed the maximum numbers of mature female fish. Spawning (VI) females were recorded for fish of 2, 3 and 5 years old. The oldest fish aged 8 years, also showed reproductive activity and was determined to be at the pre-spawning stage.

Table 3.2.5.1. Maturity Stages assessed macroscopically at each age for female whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Females								
	Macroscopic Maturity Stage							
Age (years)	I	II	III	IV	V	VI	VII	Total
1	10	14			1		2	27
2	22	138	38	44	45	3	43	333
3	10	47	31	33	40	14	33	208
4	5	9	8	15	5		6	48
5		3	2		2	2		9
6		3		1	2		1	7
7								
8					1			1
Total	47	214	79	93	96	19	85	633

Immature (I) males were recorded from ages 1-3 (Table 3.2.5.2). The full range of maturity stages were recorded at age 1 and upward. Spawning (VI) gonads were observed in 2 to 5 year olds. The oldest fish i.e. an 11-year-old male was recorded as spent (VII).

Table 3.2.5.2. Maturity Stages assessed macroscopically at each age for male whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Males								
	Macroscopic Maturity Stage							
Age (years)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Total**
1	3	10	1	3			1	18
2	8	40	18	10	6	1	8	91
3	6	38	18	15	16	2	11	106
4		26	13	6	6	3	9	63
5		13	4	2	1	1	3	24
6		12	5	3	3			23
7		2		1	1		2	6
8		2	2	1			1	6
9		2						2
10								0
11							1	1
Total	17	145	61	41	33	7	36	340

Histologically assessed maturity stages at each age for female and male whiting are shown separately in Table 3.2.5.3 and 3.2.5.4. Immature (I) females were recorded from ages 1-4, the same was recorded macroscopically. The full range of maturity stages were recorded at age 2 and upward. Spawning (VI) was observed in 2 to 5 year olds. Two 6 year old females were observed as ripening (IV), while the other 6-year-old female was recorded as spent (VII).

Table 3.2.5.3. Histological Maturity Stages at each age for female whiting sampled from the Celtic Sea between January 2001 and January 2002.

(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Females								
	Histological Maturity Stage							
Age (years)	I	II	III	IV	V	VI	VII	Total
1	6	3		1				10
2	26	25	2	19	1	6	17	96
3	7	9	4	19	3	4	10	56
4	1	1	3	7		2	9	23
5		1	1	1		1		4
6				2			1	3
Total	40	39	10	49	4	13	37	192

Immature (I) males were recorded from ages 1-9. The full range of maturity stages was recorded histologically at age 2 and upward. Spawning (VI) gonads were observed in the 2 to 6 year olds. The oldest male fish aged 11 years, was recorded as spent (VII).

Table 3.2.5.4. Histological Maturity Stages at each age for male whiting sampled from the Celtic Sea between January 2001 and January 2002.

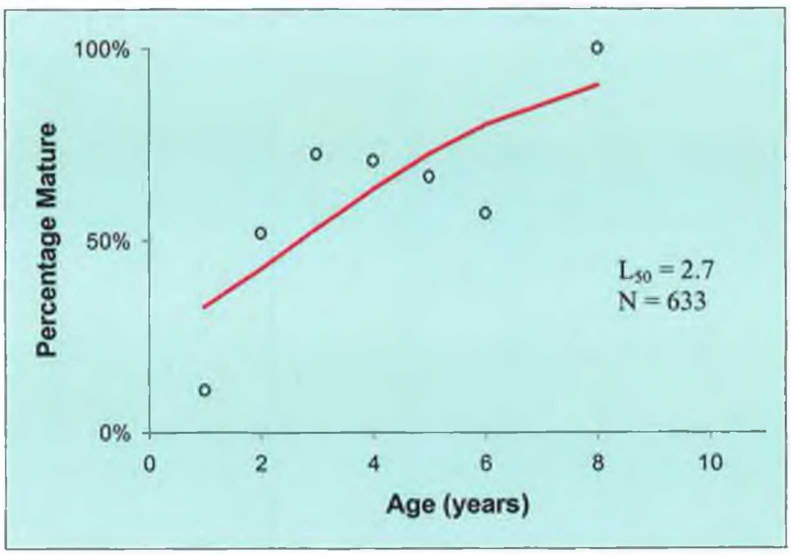
(I = Immature, II = Developing/resting, III = Ripening, IV = Ripening, V = Pre-spawning, VI = Spawning and VII = Spent)

Males								
	Histological Maturity Stage							
Age (years)	I	II	III	IV	V	VI	VII	**Total**
1	1		1					2
2	4	1	9	4	2	3	2	25
3		2	2	3	1	6	3	17
4	1	3		1	1	5	6	17
5	2					2	3	7
6		2	1			1	3	7
7	1	1						2
8		1						1
9	1	1						2
10								
11							1	1
Total	10	11	13	8	4	17	18	81

Ogives at age

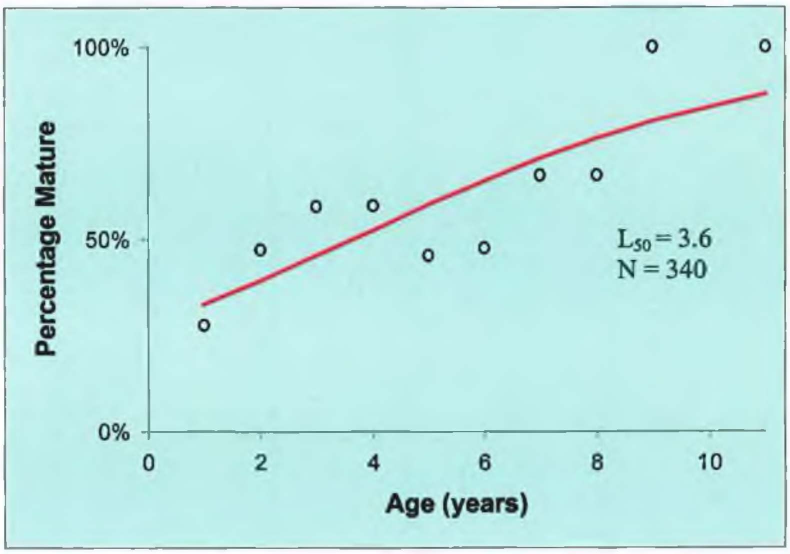
The maturity at age ogives for female and male whiting sampled from the Celtic Sea between January 2001 and January 2002 are presented in Fig. 3.2.5.1 and 3.2.5.2. 50% of females were mature (L_{50}) at 2.7 years of age (Fig. 3.28). 95% were mature (L_{95}) at 9.7 years of age. Upper and lower 95% confidence limits were also estimated for $L_{50\%}$ and $L_{95\%}$. 95% confidence was calculated at $L_{50\%}$, showing that 50% of the fish were mature between 1.3 and 5.3 years of age. 95% confidence was also calculated at $L_{95\%}$, showing that 95% of the fish were mature between 6.6 and 20.9 years of age.

Fig. 3.2.5.1. Percentage mature at age ogive for female whiting, captured in the Celtic Sea between January 2001 and January 2002.



Two male fish recorded as age 9, were immature (I or II) in the original data. This caused a big problem in fitting the model. Changing these fish to all being mature at this age makes biological sense and makes the model fit sensibly. 50% of males were mature (L_{50}) at 3.6 years of age (Fig. 3.2.5.2). 95% were mature (L_{95}) at 14.7 years of age. Upper and lower 95% confidence limits were also estimated for $L_{50\%}$ and $L_{95\%}$. 95% confidence was calculated at $L_{50\%}$, showing that 50% of the fish were mature between 1.6 and 5.7 years of age. 95% confidence was also calculated at $L_{95\%}$, showing that 95% of the fish were mature between 7.1 and 22.2 years of age.

Fig. 3.2.5.2. Percentage mature at age ogive for male whiting, captured in the Celtic Sea between January 2001 and January 2002.



4.0 Discussion

The samples of whiting used for this study were purchased from the Dunmore East Co-operative. With any fishery operation, selection of fish size may occur at a number of points before fish arrive to the scientist for analysis. We need to know about selectivity to understand biases in sampling programmes and to correct for their effects (Jennings *et al.,* 2001). Fish may be size selected in the catch by any one or other of the following:

- The ground fished
- The gear used
- Mesh size in the net
- Fishers - on board selection and discarding
- Selection by the analyst

Selectivity occurs on the grounds fished for whiting. The Celtic Sea exhibits higher growth rates for whiting than in the Irish Sea (Anon., 2002b). This higher growth rate may be related to temperature and feeding. Temperatures in the Celtic Sea are warmer and therefore whiting grow faster. The Celtic Sea has large nursery grounds for juvenile whiting, while larger fish are observed in the feeding areas (G. Power, GMIT, pers. comm. June 2003).

The main types of gear used for catching whiting are otter trawls and seining. All gears used to sample fished species are selective to some degree. Seining targets larger adult whiting (>35 cm), while trawling targets the smaller 'round' whiting (< 35 cm). There is some anecdotal evidence that trawling allows escape of larger fish in the stock, resulting in relatively smaller fish in the catches.

Mesh size selectivity can be used to control size of catches and to change mortality rates for different size classes. To match the size of the mesh to the levels of escapement, the selectivity of the net must be known (Jennings *et al.,* 2001). The mesh size for whiting was 90 mm in the Celtic Sea until the Hake recovery plan was put in place in 2001. Since then the mesh size was revised and is now 100 mm (Anon., 2003a). Recovery plans aim to protect spawning aggregations and/or juveniles through TCM's (Anon., 2002a). Mesh sizes are one of the Technical Conservation Measures (TCM's) used to conserve stocks and are designed to allow escape of smaller sized fish. There may have been a change in selectivity because of a change in mesh size regulations in the Celtic Sea.

Once on deck, selection by the fishers may occur. A percentage of the catch below the legal minimum landing size is discarded. Discarding is considered in detail later in this discussion. The legal minimum landing size for whiting was 27 cm in 2001 in the Celtic Sea (Anon., 2002a). Smaller fish, but larger than this minimum legal landing size, may also be discarded, i.e. where catches are in excess of what can be held on board (G. Power, pers. comm., May 2003). The minimum landing size was 22.5 cm in 1999 in areas VIIe-k (Anon., 2000a), and in 1954 was 24.1 cm off the east and west coasts of Ireland (Elkin, 1955). This must be remembered when historical studies are compared with the present investigation.

Further selection occurs on marketable whiting (fish above minimum landing size) on board the vessels. 'Round fish' are usually those between 27 and 35 cm. Larger whiting (> 35 cm) are gutted on board fishing vessels. Gutted large fish command a higher price at sale than whole round fish (G. Power, GMIT, pers. comm., May 2003). Sorting is purely visual, so there is some variation between fishers as to which fish are gutted (G. Johnston, MI, pers. comm., May 2003). The whiting retained are sorted into boxes. This on board selection could have an impact on the results of the present investigation and is an area of study that requires further attention. Thus, the absence of large fish in the catch reported upon here, could be a consequence of this practice.

During this study, further selection may have taken place when the analyst purchased two boxes of fish. It was requested that boxes of fish be picked haphazardly to avoid such selection. While all fish purchased were measured for length, selected sub samples with centimetre size classes, were used for the remaining parameters investigated.

In summary, the samples used in the present study were biased. These selection processes will generally tend to overestimate the mean size of smaller age classes, and underestimate that of larger ones.

In the present investigation, the overall length range for whiting measured from the Celtic Sea (Division VIIg), excluding discards was 24 – 48.99 cm with the mode at 32 cm. The population was determined to be normally distributed. For comparison, the length range, and the mode where available, of whiting for Division VIIg and adjacent sea areas are presented for different years and authors in Table 4.1.

Table. 4.1. The length range (cm) of whiting in Division VIIg and adjacent sea areas for different years and by different authors.

Source	**Location**	**Length Distribution (cm)**	**Mode (cm)**
Present Study (2001-2002)	Celtic Sea (VIIg)	24 - 48	32
Anon. (2002a)	Celtic Sea (VIIg)	24 - 60	30
Anon. (2000a)	Celtic Sea (VIIe-k)	25 - 54.5	33
Wheatley *et al.* (1999)	West Coast of Ireland VIIb and c	25 - 57	-
Wheatley *et al.* (1999)	Southwest coast of Ireland VIIj and k	23 - 58	-
Anon. (2002a)	Irish Sea (VIIa)	26 - 44	-
Anon. (2002a)	West of Scotland (VIa)	24 - 45	-

Little variation can be seen in the smallest size of whiting, which ranged from 23 – 26 cm in these studies. However, some variation in the maximum size of whiting was found between studies, with the largest size being 60 cm. The latter is considerably larger than that of 48 cm found in the present investigation. All these studies were based on samples from commercial stocks. Possible reasons are reviewed to explain the difference in maximum length of whiting. Firstly, this could be a reflection of sample size. If a sample size were very large there would be more possibility of catching and recording the bigger and smaller fish. 3415 whiting were sampled in the present investigation. However, the sample sizes from the Stock Book would be at least double this and Wheatley *et al.* (1999) measured approximately 28,000 whiting from the Southwest coast of Ireland. Alternatively, the absence of the larger fish may be due to the on board sorting practice by the fishers. As discussed earlier, the larger gutted fish may have been unavailable to this study, as they were of higher value to the fishers, when gutted. Finally, the absence of larger fish may be a reflection of the gear used.

There was a significant difference in the modal size of sampled whiting over the year in the present investigation. The smallest and largest mean size varied up to 9 cm. This may be due to fishers fishing different grounds, using different gear or other random selection events such as those reviewed above. No temporal pattern was observed in the modal size among samples.

The length range for discard whiting sampled on the 30/4/01 was 15 cm - 32 cm. This sample showed the same modal size as the minimum legal landing size i.e. 27 cm. Whiting as small as 15 cm are being caught by the fishing vessels. G. Johnston, MI, (pers. comm., May 2003) found that the size for discarded whiting ranged from a minimum of 14 cm, although numbers at this length were rarely encountered, to the largest at 35 cm, which were equally rare. The more common range of discards would be 23 cm - 33 cm. The length distribution, in 1999, of discards in Divisions VIIe-k was 17 cm to 36 cm (Anon., 2000a). Therefore, it can be concluded that commercially sized whiting are frequently discarded. Discarding of whiting is a problem in the Irish fleet because of the probable low survival of discarded fish (see below). The Marine Institute's, FSS, working in the Celtic Sea in 1999, suggested that about 16.7% of the total weight of fish caught (38% by number) was discarded. Almost all (95%) of the discarded catch was of a landable size (Anon., 2000a).

In the present study, only 3.7 % of whiting sampled were below the legal minimum landing size. A rough estimate from the length frequency distribution presented in Stock Books for the Celtic Sea over the period 2000 – 2002 show a range of 1.8% to 3.9% of landed stock are below the legal minimum landing size. Given that selectivity by fishers is visual on board fishing vessels, these are small percentages. Therefore, fishers err on the side of caution.

A male to female sex ratio of 1:2.25 was derived for the sampled population captured in the Celtic Sea. This departure from a 1:1 sex ratio in favour of females in the overall sample was highly significantly different from the expected 1:1 ratio (χ^2 = 6.63, $P<0.01$). The numerical dominance of female whiting was observed in thirteen of the seventeen samples over the sampling period. When samples were combined into months, females numerically dominated the population except in January of both years when 1: 1 ratios were observed. The metabolic strain of spawning is generally considered to be greater in older males than in older females (Hickling, 1930; Menon, 1950; Beverton & Holt, 1957; Ursin, 1963). This could result in an excess of females at spawning time (February to June). Cooper (1983) concluded that variations in sex ratio are probably related to differences in the age composition of the local stock associated with greater mortalities in older males and the preference of larger fish for deeper water. Since females grow faster than males (Cooper, 1983), populations at shallow sampling sites would include a higher proportion of males (Cooper, 1983). Thus, sampling depths may explain, at least in part, the variability in sex ratios in the catches of whiting.

Gerritsen *et al.* (2003) working in the Irish Sea found that whiting do not appear to have sex specific behavioural patterns that result in skewed sex ratios throughout the spawning grounds, although individual catches may be dominated by one sex. Sex ratio in the Irish Sea, however varied between locations but no consistent spatial patterns were evident (Gerritsen *et al.*, 2003). Cooper (1983), sampling whiting off the west coast of Scotland, found that overall there was no significant departure from a 1:1 sex ratio.

Male to female sex ratios for whiting (*Merlangius merlangus*) sampled in the Celtic Sea during the present study and in different areas, together with chi square (χ^2) values and significance levels calculated from the raw data by the author are presented in Table 4.2. Two of the studies i.e. Nagabhushanam (1964) and Elkin (1955), both in the Irish Sea, showed a highly significant difference from 1:1 sex ratio in favour of females. In contrast, Bowers (1954) and Gerritsen *et al.* (2003) found a significant difference from a 1:1 ratio in favour of males in their total sample for the same area. When all data are combined from all studies it shows a departure from a 1: 1 sex ratio in favour of females.

Table 4.2. Male to Female Sex Ratio for Whiting (*Merlangius merlangus*) together with chi square (χ^2) values and significance levels. **(* = *Significant* (P < 0.05), ** = *Highly significant* (P < 0.01) and NS = *Not significant* (P > 0.05)).**

Source	**Location**	**M:F sex ratio**	**N = Total**	χ^2	**Significance**
Present Study	Celtic Sea	1:2.25	854	125.98	**
Bowers, 1954	Isle of man waters	1:0.89	3118	9.71	**
Nagabhushanam, 1964	Manx waters	1:1.70	820	54.81	**
Elkin, 1955	East Irish waters	1:1.13	7046	25.27	**
Gerritsen *et al.*, 2003	Irish Sea	1:0.96	10 285	4.09	*
Total		**1:1.05**	**22 123**	**15.15**	**

Hannan (2002) has listed five hypotheses in regard to the consistent departure in favour of females from a 1:1 male to female ratio. These are as follows:

I. There are not as many males as there are females in the stock.

II. Differential distribution among the sexes.

III. The fishing method is biased in favour of females.

IV. There is a sex change at some stage in their life cycle, and males become females.

V. The discarded fish are predominantly males.

The present investigation has shown that females are larger than males. Therefore, it is possible that females are being caught more by the nets. Alternatively, because of their smaller size, males are more likely to be discarded. The latter suggests that males should predominate discards. There is no evidence to determine whether males actually dominate discards. However, Desbrosses (1948) found that males predominate in the < 23 cm size classes, off the French coast. It would be advisable in the future to undertake further studies on discards by obtaining numerous samples throughout a sampling period. The abundance of females exceeded the number of males in all length classes in this study. This excess of females was significant in the larger length classes (>31 cm), in 8 out of 9 cases. In the length class where the excess of females was not significant, the value was approaching significance. There was also a significant difference between mean length values for male and female whiting, and as already mentioned, females were determined to be larger in size. It is widely in agreement in many studies that female whiting predominate at larger length classes. Elkin (1955) working in Irish waters found that all fish over 44 cm were females, while Saemundsson (1925) found that all fish over 58 cm were females. Desbrosses (1948) found in whiting off the French coast that females predominated in samples from 40 - 53 cm, and Bowers (1954) also found that nearly all fish examined of more than 40 cm in total length were females.

2 and 3 year olds dominated the sampled population from the Celtic Sea. Females dominated at younger ages, while males dominated in the older age classes. However, the numbers of males are smaller in the older age groups, and therefore they do not alter the overall population sex ratio. In contrast, Messtorff (1959) found that practically all whiting more than five years of age were females. Owen *et al.* (1995) found that females out numbered males in all age groups in the Black Sea. Older females are scarce relative to males in the Celtic Sea, according to this study. Given their larger size, they have most likely been removed from the stock by fishing effort.

Length-weight relationships, and the calculated length for whiting measuring 20 cm and 40 cm, in different areas, are presented in Table 4.3. In the present study, the length-weight relationship gave estimates of 'b' of 2.95 for the overall population, 2.83 for males and 3.01 for females. These values are close to 3, indicating that whiting in VIIg in 2001 - 2002 grow isometrically i.e. increase in all dimensions at the same rate (King, 1995). Gordon (1977), working on juvenile whiting in inshore waters of the west coast of Scotland, determined length-weight relationships for five different locations. In three of these studies, Firth of Lorne, Loch Linnhe and Loch Etive, the 'b' values were also close to 3. Nagabhushanam's (1964) results around the Isle of Man were similar which also showed that whiting grow isometrically. In contrast, for the remaining studies, Gordon (1977) in Loch Sunart and Upper Sound of Mull and Nagabhushanam's (1964) in the Irish Sea, values for 'b' increased steadily from 3. The larger of these values suggest the possibility of allometric growth.

In comparison to other studies, the length weight equation in the present investigation yielded a weight, which is the maximum value in the range, at the lower length class (20 cm) of whiting. The calculated weights for the 40 cm fish in the Celtic Sea showed that the mean value recorded in this study was the mid value in the range of all the studies. This latter weight was very close in value to that found in Loch Sunart. Only the largest whiting among the youngest age classes were present in the catch of the current study (as discards are absent). In contrast, the smaller mean size observed by Gordon (1977) and Nagabhushanam (1964) included discard whiting.

Table 4.3. Length-weight relationships for whiting, with weights calculated for 20 cm and 40 cm fish.

Source	Area	Length-weight relationship	Weight (g) for 20 cm length group	Weight (g) for 40 cm length group
Present Study	Celtic Sea	$W = 0.01025\ L^{2.9501}$	70.61	545.71
Gordon, 1977	Firth of Lorne	$W = 0.0072\ L^{2.969}$	52.49	411.00
Gordon, 1977	Loch Linnhe	$W = 0.0076\ L^{2.969}$	55.41	433.84
Gordon, 1977	Loch Sunart	$W = 0.0035\ L^{3.242}$	57.81	546.95
Gordon, 1977	Upper Sound of Mull	$W = 0.0035\ L^{3.272}$	63.25	610.95
Gordon, 1977	Loch Etive	$W = 0.0045\ L^{3.170}$	59.91	539.19
Nagabhushanam, 1964	Isle of Man	$W = 0.0074\ L^{3.002}$	59.55	477.10
Nagabhushanam, 1964	Irish Sea	$W = 0.0024\ L^{3.346}$	54.13	550.43

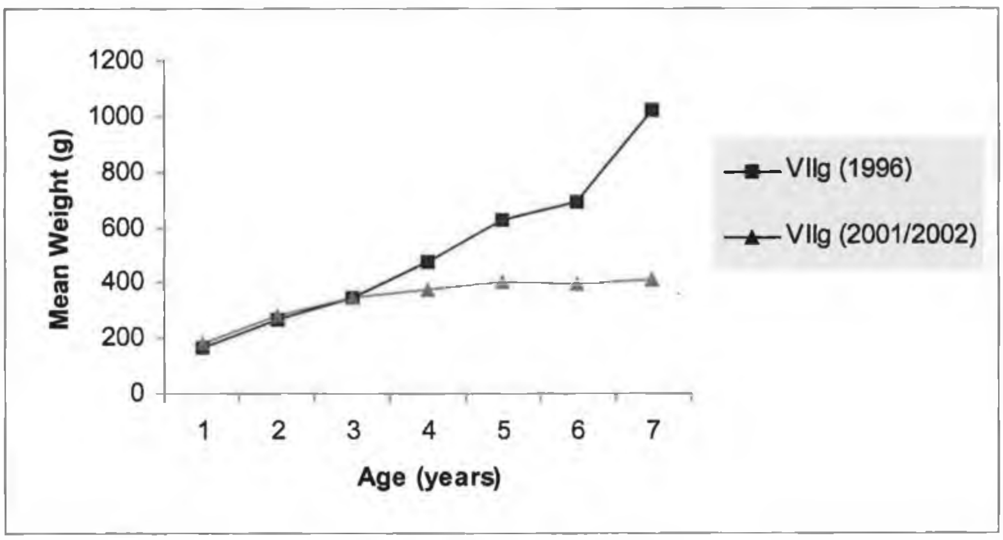
Nagabhushanam (1964) found a significant difference between the length-weight relationship of immature fish from an Isle of Man nursery area and fish from the Irish Sea. Elkin (1955) recorded that west coast whiting weighed slightly less than those from the east coast of Ireland for the equivalent length groups. A seasonal difference in weight was also observed. In the present study, the relationship between weight and total length was the same for male and female whiting, therefore, it can be concluded female whiting were not heavier than the males at any given length. However, females were larger in size than the males. As a result females were more abundant and this is reflected in the sex ratio.

In the present study, weight increase was at its greatest from ages 1-5 years for female whiting, while males showed an overall increase in weight up to 8 years. Mean values indicated that females weighed slightly more than males at each age but the difference was not significant. In Table 4.4 and Fig. 4.1, the mean weights at age for whiting captured in the present investigation, are compared with results from a 1996 study in the Celtic Sea (Anon., 1998a and Anon., 1998b). There is an obvious difference in the weight of older fish between the two studies. The mean weights were similar up to age 3 but thereafter there was a larger mean weight with age recorded in the 1996 study. From 4 years of age there were significantly less large fish in the current study's samples. There are a number of possible reasons for this. The first is that the fishers selectively kept the large fish, providing the smaller less valuable fish only for the current investigation. Secondly, whiting may not be growing as fast as they did 6 years earlier (1996). Finally, intense fishing pressure may have removed all the large fish. If the latter is true and if this trend continues it could cause a collapse of the Celtic Sea fishery. (1995) interpreted a decline in whiting length and weight values from 1987 through to 1990 in the Black Sea, as a slowing down in the growth rate.

Table 4.4. Comparison of mean weights at age (years) for whiting in the Celtic Sea (VIIg), where N≥30 for the present studies results.

Age (Years)	Present Study VIIg mean (g) N=973	1996 VIIg mean (g)
1	177	165
2	280	264
3	343	347
4	370	475
5	403	622
6	395	687
7	407	1017
8	-	NA
9	-	NA

Fig. 4.1. Mean weight at age for the present investigations results and a 1996 study in the Celtic Sea (Anon., 1998a and Anon., 1998b) in Wheatley *et al.*, (1999).



Ages for whiting captured in the Celtic Sea during the present investigation and other studies are presented in Table. 4.5. In the present study ages ranged from 1-11 years (although only a few fish were found at the older age groups). The majority of studies showed an age distribution up to 8 years and a mode at either 2 or 3 years. Therefore all studies are in general agreement in regards to the age composition of whiting stocks.

Table 4.5. Ages for whiting captured in the Celtic Sea during the present investigation and other studies.

Source	Location	Age range (years)	Mode (years)
Present study (2001-2002)	Celtic Sea (VIIg)	1 - 11	2
Bowers (1954)	Isle of Man waters	1 - 8	-
Anon. (2002a)	Celtic Sea (VIIg)	2 - 8	2
Anon. (2000a)	Celtic Sea (VIIg)	1 - 8	3
Anon. (2002a)	Irish Sea (VIIa)	2 - 7	3
Anon. (2002a)	West of Scotland (VIa)	2 - 7	3

In the present investigation, 2 and 3 year olds were well represented in the Celtic Sea i.e. 85.5% of the overall catch. Similarly, FSS sampling indicated that very young fish dominated the Irish landings in 2001 with 68% of the landings being between 2 and 3 year olds at lengths of 28-32cm (Anon., 2002a). Elkin (1955) reported that 96% of whiting from all areas in Irish waters were 1 and 2 year olds. Bowers (1954) recorded that age groups 1 to 3 were well represented, but the older fish were scarce. In contrast, Knudsen (1950) stated that age groups 0 and 1 dominated in Danish waters and constituted 90.4% and 88.2%, respectively, of all the fish examined. Older whiting in the North Sea migrate to deep water (Ellis, 1950).

The youngest and smallest females and males sampled in the Celtic Sea in the present investigation were 1 year olds measuring 18 cm in total length. Similarly, Elkin (1955) working off the east and west coasts of Ireland, found that the smallest female whiting was 19.8 cm (1 year old) and the smallest male was 18.6 cm (1 year old). The oldest male aged 11 years measured 34 cm, while the oldest female aged 8 years measured 33 cm in the present study. In contrast, Bowers (1954), researching in the Isle of Man waters, found that the oldest female fish was an 8 year old measuring 52.5 cm, while the largest male was 47.6 cm and could not be aged. The largest whiting caught in Danish waters was 40 cm long belonging to age group 5, while the oldest fish was 9 years old and measured 35 cm (Knudsen, 1950). In the current study, the biggest female and male whiting, measuring 44 cm, were 6 year olds. As already mentioned, the Celtic Sea stock is a fished stock and so larger and older fish are selectively removed. There was also selection for increased mean length at younger ages, as small fish escape through the net or were discarded. However, the size of whiting at younger ages is in agreement with Elkin (1955). In the present investigation, older fish were of smaller size in comparison to Bowers (1954) and Knudson (1950).

In the present study, 2 and 3 year olds ranged from 22 – 43 cm and 25 – 44 cm respectively. In contrast, 2-year-old whiting in the Irish Sea ranged from 22.9 cm to 27.9 cm, (Kennedy, 1954). Therefore the range at this age for the present study in the Celtic Sea is much greater than the study mentioned above for the Irish Sea.

Male and female whiting show greatest growth in the early years of life. The greatest growth (increase in mean length at age) in the current study was observed from 1 – 3 years for males and females. Mean length at age recorded for whiting in the present study and other studies are presented in Table 4.6. Whiting reached a mean length of 26 cm during their first year of life. Therefore, the younger fish (1^+) are much bigger in size compared to the other studies and may be an indication of selectivity in the sampling of the Celtic Sea stock. There was also a significant difference between mean lengths at age for males and females at age groups 2 and 3, with females being larger. Gerritsen *et al.* (2003) reported that females grow to a larger size, the discrepancy increasing with age after the second year of life.

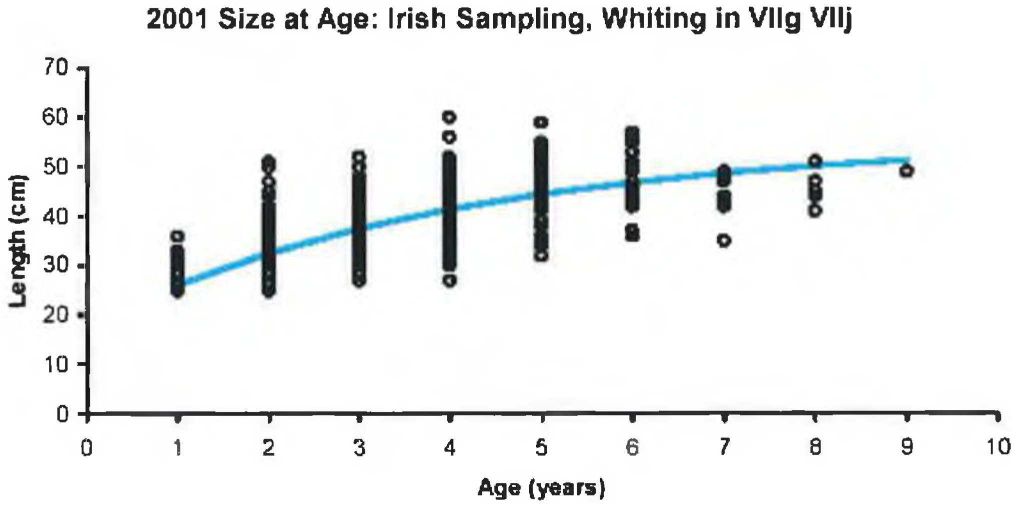
Table. 4.6. Mean length at age recorded for whiting in the present study and other studies.

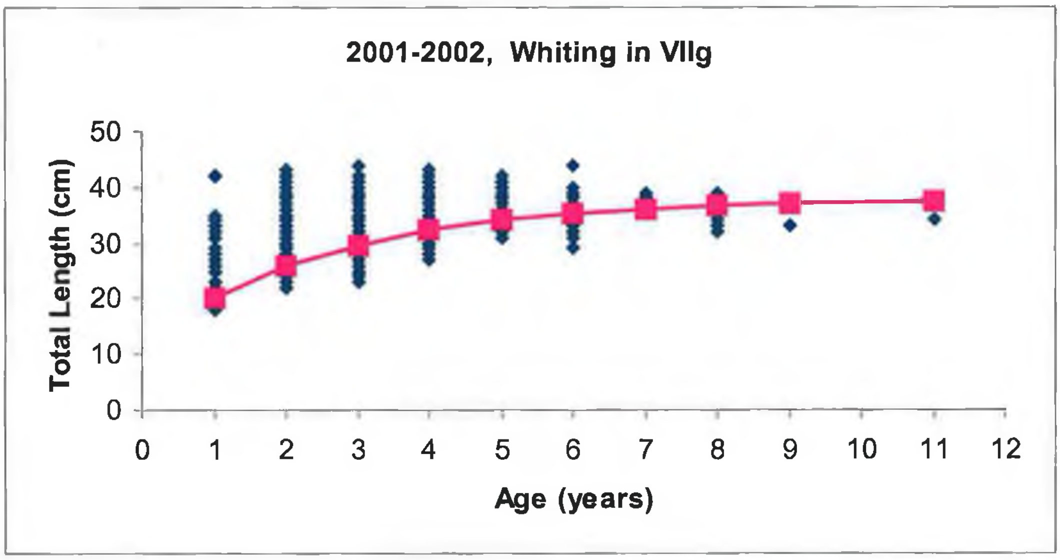
Source	Area	1^+	2^+	3^+
Present Study	Celtic Sea	26	31	32
FSS	Irish waters	-	28	32
Knudson (1950)	Danish waters	18.5	25.2	34
Gerritsen *et al.* (2003)	Irish Sea	17		

The Von Bertalanffy growth curves are presented in Fig. 4.2, for whiting sampled in VIIg and VIIj in 2001 (Anon., 2002a), as calculated by FSS and for the present study

(VIIg). In the present study, both male and female fish reached a length of about 20 cm at the end of the first year in the Celtic Sea, while whiting reached a larger length (26 cm) at the end of the first year, in VIIg and VIIj (Anon., 2002a). Similarly, whiting grew about 6 cm in the second year according to both studies. The rate of growth was slower in the present study thereafter when compared to area VIIg and VIIj (see Fig. 4.2). By contrast, Bowers (1954) described that both male and female whiting reached a smaller length of about 19 cm at the end of the first year. Similarly, they grew about 6 cm in the second year and male whiting grew less than females after the second year. Females maintained this growth pattern i.e. 5 or 6 cm per year up to five years. Therefore, these studies show similar growth patterns to the present study and we can conclude that the growth rate is greater in the younger year classes. Hannerz (1964) working in the North Sea, also, found that the rate of growth is greatest in the younger year classes. Hannerz (1964) used the scales rather than otoliths for age determination in the North Sea. Hannerz (1964) found that the rate of growth of female whiting during their second year was about 7 % more rapid, in the third year about 21 % and during the fourth year up to the time they were caught about 35 % better than that of males. Thus, Hannerz (1964) concluded that the difference in growth rate between males and females increased rapidly with increasing size of fish. Therefore, the slower growth in older age classes observed in the present investigation may be a refection of the males rather than the females in the stock. Hannerz (1964) found that variations in temperature from year to year followed the variations in the size of year classes and the rates of growth, therefore concluding that temperature is very influential.

Fig. 4.2. The Von Bertalanffy Growth curves for whiting sampled in VIIg and VIIj in 2001 (Anon., 2002a), as calculated by FSS (sexes combined).





The Von Bertalanffy growth model was used to describe the growth of the population of whiting in the Celtic Sea (VIIg), between January 2001 and January 2002. The Von Bertalanffy growth parameters (VBGP) were calculated using the Ford Walford Plot. The Von Bertalanffy growth model was constructed for the overall sampled population in order to allow comparisons with other studies. L_∞ calculated from the Ford Walford plot for males and females combined was 38 cm. This is less than the largest fish observed, 44cm, in the sampled population. However, very few fish were recorded in length groups > 38 cm. Observed maximum lengths for both males and females exceeded the L_∞ value. The growth rate (K) of 0.3769 $year^{-1}$ illustrates the very fast rate at which whiting grow. The higher the value the faster the fish grows. The value estimated for t_0 was recorded as –1.01. The negative t_0 in this study, may be a result of the high mean length at age 1 on the curve. The sampled population is affected by the absence of smaller whiting, therefore increasing the observed mean length at age for younger fish. This value at age 1 is high as the overall sample is a biased one. Catching the bigger fish at age 1 causes the curve to rise at the left hand side, while the absence of bigger fish causes the right hand side of the curve to descend. If more discards were available to this study, a decrease of the curve on the left hand side would have occurred. L_∞, K and t_0 calculated for the present study and other investigations are presented in Table. 4.7. L_∞ values are similar for all areas. However, K values for divisions VIIb, c and VIIj, k were greater than that of the present study indicating faster growth in these areas. A positive value for t_0 was calculated in areas VIIb and c. t_0 values for the present study and VIIj,k are remarkably similar. Smaller values for K and t_0 may be a result of larger sized fish at younger ages present in any catch. Musick (1999) reported that species with K coefficients below 0.1 are at particular risk of over-fishing. The latter was not true for whiting sampled during the present study in the Celtic Sea or in areas VIIb, c, j and k.

Table 4.7. Estimates of L_∞, K and t_0 recorded for the present study and other investigations.

Year	**Stock**	L_∞	**K**	t_0
Present study	Celtic Sea (VIIg)	38	0.3769	-1.01
Wheatley *et al.* (1999)	VIIb,c	39.7	0.83	0.13
Wheatley *et al.* (1999)	VIIj,k	38.03	0.52	-1.09

The age at full recruitment (t_r) for the overall population was 3 years. This was equivalent to the female t_r, while males were fully recruited at 4 years of age. The earliest signs of mature whiting were recorded at 1 year of age. Therefore, females are given 2 years to grow and thus contribute to the new recruits, while males are given 3 years before they reach t_r, and so are fully recruited to the fishery. In this examination, the total mortality co–efficient (Z) was higher for male whiting than for female whiting. Natural mortality (M) was recorded as an arbitrary value of 0.2 as set by ICES for whiting (Anon., 2002b). The stock was also assessed considering both males and females combined. Z was calculated as 0.83 year^{-1}, and fishing mortality (F) was calculated as 0.63. F was higher than M for all three estimates (overall, male and female) indicating that this stock is heavily fished. Also, fishing results in more deaths than natural mortality for the overall population, i.e. whiting were 3 times more likely to die from fishing effort than from natural causes.

The catch curve illustrating the age at full recruitment (t_r) for males and females indicates that females are younger than males when fully recruited to the fishery. It has already been stated that females are bigger than males and therefore they appear first, in higher numbers, in the catch curve. As a result, females are being fished faster than the males in the stock. Males appear to be healthier in the catch and therefore could afford to be fished more than females, i.e. as males are not moving out of the fishery as fast. If females were given one more year before recruitment, it would make a substantial difference to the current state of the fishery. There would be a substantial increase in Spawning Stock Biomass (SSB) leading to increased sustainability within the Celtic Sea stock. The absence of discard data may have an impact on the catch curves. If discards were included in the catch curve the t_r values would probably shift to the left, indicating a smaller age at full recruitment to the fishery for both male and female whiting. The t_r value for the Celtic Sea present study is therefore probably overestimated. Studies have shown that subsequent to periods of high catch levels major changes occurred in certain biological characteristics, particularly, population structure, growth parameters and sexual maturity rates (Brodie *et al.*, 1991). If fishing were allowed on immature fish, a level of fishing mortality would exist that the stock could not sustain.

F_{pa} is a precautionary reference point designed to ensure that there is a high probability that F_{lim} will be avoided and that spawning stock biomass (SSB) will remain above the threshold (B_{pa}) below which the probability of good to average recruitment is decreased. F_{lim} is the limit fishing mortality. F_{lim} should be avoided with high probability because it is associated with unknown stock dynamics and stock collapse. F_{max} is the rate of fishing mortality for a given exploitation pattern rate of growth and natural mortality, that results in the maximum value of yield-per-recruit. Spawning stock biomass (SSB) is the total weight of all sexually mature fish in the population. The size of SSB for a stock depends on the abundance of year classes, the exploitation pattern, the rate of growth, fishing and natural mortality rates, the onset of sexual maturity and environmental conditions (Anon., 2002a).

Estimates of Z, F, M, F_{pa} and F_{max} for the present study, adjacent areas and from areas VIIb,c and VIIh-k in 1995 and VIIb,c and VIIh-k in 1996 (Wheatley *et al.*, 1999) in Irish waters are given in Table 4.8. The recorded arbitrary value as set by ICES for M was used in all studies. Estimates of Z and F increased from 1995 to 1996 in areas VIIb and c. Z and F estimated for the overall population in the present study was lower than all values except for areas VIIj, k in 1996. ICES reported that fishing mortality was very high during the 1980s, decreased in the early 1990s, and gradually increased once again in the late 1990s (Anon., 2002b). Similarly, FSS reported that fishing mortality was estimated to have declined generally until 1977 but has increased slightly in recent years. Fishing mortality was very high for West of Scotland and Irish Sea whiting in 2001, being well above the F_{pa}. There is no proposed or defined F_{pa} for the Celtic Sea. Fishing mortality rates have been increasing since the 1940s in Scottish waters (Zheng *et al.*, 2001).

Table 4.8. Estimates of Z, F, M, F_{pa} and F_{max} obtained from the present study and adjacent areas (unshaded area) **and from catch and Thompson Bell yield per recruit curve for whiting in ICES Divisions VIIb,c and VIIh-k in 1995 and VIIb,c and VIIj-k in 1996 (from Wheatley *et al.*, 1999)** (shaded area).

Source	Year	Location	Z	F	M	F_{pa}	F_{max}
Present study	2001-2002	Celtic Sea (VIIg)	0.83	0.63	0.2		
Anon. (2002b)	1999	Celtic Sea		0.78	0.2		
Anon. (2002b)	2001	Celtic Sea		0.6	0.2		
Anon. (2002a)	2001	VIIe-k		0.53	0.2		
Anon. (2002a)	2001	West of Scotland		0.85	0.2	0.6	
Anon. (2002a)	2001	Irish Sea			0.2	0.65	
	1995	Whiting VIIb,c	1.09	0.89	0.2		0.6
	1995	Whiting VIIh-k	0.92	0.72	0.2		0.5
	1996	Whiting VIIb,c	1.40	1.20	0.2		0.7
	1996	Whiting VIIj,k	0.72	0.52	0.2		0.8

Mature fish are identified by examination of the gonads. Gonadal development is staged to allow seasonal patterns in the reproductive cycle to be identified by showing when fish begin to mature, spawn and recover (Jennings *et al.*, 2001). Whiting cannot be sexed by external examination. However, during spawning, the female can often be identified by the swollen ripe ovaries, pushing out the skin along the length of the body.

In the present investigation both macroscopic and histological methods of assessing maturity stages were employed. It was difficult to distinguish macroscopically between immature, developing/resting and spent maturity stages in females. To obtain more reliable estimates of the frequency of occurrence of maturity stages, histology was used. Histology provides a more accurate assessment of identifying maturity stages and was carried out to clarify any discrepancies between these stages using macroscopic assessment. Histological examination reveals certain characteristics that cannot be identified macroscopically. A comparison was carried out between macroscopic and histological methods of assessment. The greatest disagreement between macroscopic and histological methods occurred at immature, developing/resting and spent stages in females. Therefore, it was appropriate to amalgamate these stages for the percentage development indices (although immatures were excluded). A recommendation for future work would be to amalgamate immature, developing/resting and spent as one stage in the macroscopic assessment of female maturity stages. However, these stages can be identified separately with histology. A revised visual scale for macroscopic assessment of female maturity stages is presented in Appendix II.

For male whiting, the greatest agreement between macroscopic and histological assessment occurred at the spawning stage (although small numbers were encountered at this stage). This latter stage is the most important maturity stage from a fisheries biology prospective. There is little information available on the macroscopic assessment of male maturity stages. Many difficulties were encountered in staging the males macroscopically. There were no major apparent differences between the stages over the year (especially developing/resting (II), ripening (III/IV) and pre-spawning (V)), i.e. colour, shape, texture and size. Therefore, this assessment was determined to be inconclusive and will not be included in the results of the reproductive cycle. Histology was deemed to be a more accurate assessment of identifying male maturity stages. Therefore, histological results only will be used for the purposes of the reproductive cycle in the present study.

Macroscopic analysis has the advantage of speed in method, while wax histology is time consuming. The method of storing the gonad samples (i.e. freezing -18°C) prior to the histological analysis was problematic. Freezing caused considerable damage to the gonadal tissue, mentioned in the results section. If the gonadal samples were directly placed in the fixative after removal from the fresh fish, this problem may have been eliminated. However, circumstances are not always favourable for this practice i.e. sampling on commercial vessels at sea, no fume cupboard in the laboratory. As histology is time consuming, an alternative to this method might be cryosectioning using a cryostat/freezing microtome.

A further issue deals with the definition of maturity. Whilst all females in which vitellogenesis had been triggered were considered mature, not all of these fish may have spawned. In many species of fish, some vitellogenic eggs degenerate through the process of atresia (Gerritsen *et al.*, 2003). Atresia is resorption rather than spawning of fully developed oocytes (Jennings *et al.* 2001).

Allowing for the problems encountered with the methods, the seasonal patterns in the whiting reproductive cycle are reviewed. Ripe females were observed between January and May 2001 in the present study. Bowers (1954) found in the Isle of Man waters that ripe fish were dominant in April, one month later compared to the present study. Pre-spawning occurred between early February and late April in the Celtic Sea (VIIg). Females spawned from late February to June 2001. Developing/resting and spent females occurred between late April 2001 and January 2002.

In the present investigation, the peak value for ripe males occurred in February 2001. Pre-spawning occurred in small percentages in December 2001 and also in January of both years. Males spawned from February to June 2001. Developing/resting males occurred in June and August, while spent males were observed from February to June 2001.

A comparison of spawning times for the present study and other studies in different areas are presented in Table 4.9. Bowers (1954) and Elkin (1955) found similar results in the Isle of Man and Irish waters. Whitehead *et al.* (1986) found that whiting spawned from January in the south to July in the north, throughout its range. Nagabhushanam (1964) found that spawning occurred from January to June with peak occurrence during March and April in Manx waters. Owen *et al.* (1995) working in the Black Sea found that whiting spawned all year round, but most intensively during the winter months. Timing of spawning in the present study supports the majority of the research reviewed.

Gordon (1977) did not observe any spawning in juvenile whiting in inshore waters off the West coast of Scotland and assumed active migration of whiting from the open sea.

Table. 4.9. Spawning time of the year for the present study and other studies in different areas.

Source	Area	Maturity Stage	Time (Months)
Present Study	Celtic Sea (VIIg)	Spawning	February to May
Bowers (1954)	Isle of Man waters	Spawning	February to June
Elkin (1955)	Irish waters	Spawning	January to June
Whitehead *et al.* (1986)	European coasts, Western Mediterranean, Black Sea.	Spawning	From January (South) to July (North)
Nagabhushanam (1964)	Manx waters	Spawning	January to June
Cooper (1983)	West of Scotland	Spawning	March to June
Owen *et al.* (1995)	Black Sea	Spawning	All year round

Only small numbers of whiting were recorded as spawning during the present investigation. The latter suggests that this stage lasts for only a short time period, therefore making it difficult to assess fish at this stage. Similarly, only a very small proportion, 0.3% of the adult stock were recorded as spawning off the west coast of

Scotland (Cooper, 1983). In the Irish Sea, gonad development is greatest when sea temperatures are low, in February and March, and spawning is at a maximum in April when sea temperature starts to rise (Bowers, 1954). Desbrosses (1945) also recorded that variation in spawning time is closely connected with sea temperature. Nagabhushanam (1964) agreed with Graham (1924) working on North Sea cod i.e. males remain spawning after most of the females have spawned. This might be to ensure fertilization of the many batches of eggs of cod. Nagabhushanam (1964) suggested that the same is true for whiting. Gokhale (1957) found that female whiting mature only one batch of eggs in the Manx waters, while Messtorff (1959), working in the east and south-east North Sea, gave histological evidence that whiting eggs ripen in batches, not all together. Similar observations were made during the present histological examination, which showed the presence of both inactive and developing oocytes in mature stages (III, IV, V, VI and VII). The long spawning season has been widely noted and is indicative of whiting being a serial spawner.

Gordon (1977) concluded that gonad development depends on a nutritional store built up during the feeding and growth periods rather than on material assimilated during maturation when many fish feed less intensely, although this has not been observed in whiting. Whiting are known to spawn at temperatures above 3° C, at salinities of about 25‰ (Arntz & Weber, 1972), and at depths between 36 and 80 m, over bottom deposits of sandy mud, shell and soft mud (Bowers, 1954). In some other gadoids, first time spawners exhibit lower fecundity and produce smaller eggs with lower survival rates (Trippel, 1998).

The majority of females and males were immature at age 1 in the present study. Females were first recorded as mature at a total length of 23cm and at 1 year of age. Mature males were encountered firstly at 21cm (spent VII) and also at 1 year of age. The full range of female maturity stages were observed at 29 cm and in the second year, while the full range of male stages were observed at 28 cm and also in the second year. Bowers (1954) similarly recorded that the smallest Manx whiting examined at an advanced stage of maturity, i.e. V, VI or VII, were females of 21 cm and a male of 19 cm in total length. In contrast, Gerritsen *et al.* (2003) working in the Irish Sea found mature males from 15 cm and females from 18 cm. However, Gerritsen *et al.* (2003) study included higher numbers of smaller fish i.e discards, therefore, smaller whiting are likely to have been found mature at smaller sizes. Gerritsen *et al.* (2003) also found that most 2 year-old females were either mature or immature fish, and were found in the smallest length classes (20-25cm). Bowers (1954) found that age group 1 females were either immature or developing only. In the present study, >50% were mature (III-VII) at age 2 for both male and female whiting. Gerritsen *et al.* (2003) recorded that most whiting reached maturity by two years of age. Likewise, Elkin (1955) found that most whiting in Irish waters were mature at 2 years of age, although some may have spawned at the end of their first year. He also observed that males mature earlier than females. Similarly, whiting were found to be mature at 2 years of age in the Irish Sea, (Kennedy, 1954). Owen *et al.* (1995) investigated the size-age composition of whiting in different areas of the Black Sea. Owen *et al.* (1995) found that whiting attain sexual maturation in the second year of life, males at a length of 9.5 cm, and females at 11 cm. Gerritsen *et al.* (2003) found that maturity in 1-year-old male whiting was strongly dependent on length. Mature 1-year-old females were found in length classes of 18 cm. Gerritsen *et al.* (2003) also found that maturity was more strongly dependent on age in females rather than in males. Early maturation might put whiting in an advantageous position

(Hessen and Daan, 1996) as the majority of the catch would have reproduced at least once before capture, thus providing a high spawning stock biomass (SSB).

In the present study spawning individuals ranged from 2 – 5 years. The smallest spawning male was 32 cm, while the smallest spawning female was 27 cm. In contrast, Nagabhushanam (1964) recorded the smallest spawning male whiting at 17 cm, while the smallest female was 18.5 cm in total length. Most fish spawned for the first time at 2 years of age, although a small number of males and females spawned at age 1 (Cooper, 1983). Bowers (1954) found that around the Isle of Man female whiting generally spawn for the first time at the end of their second year of life, and by the end of the third year all females are mature. Also male whiting may well spawn at the end of their first year, while practically all males of age group 2 spawn.

In this investigation female whiting reached L_{50} (50% mature) at a total length of 28 cm and 2.7 years of age, while the L_{50} for males was calculated as 30.4 cm and 3.6 years of age. As already stated, the legal minimum landing size for whiting is 27 cm, therefore it is guaranteed that half of the whiting will be caught before they are mature. It was mentioned earlier that the majority of whiting were found to be mature at 2 years of age. Therefore, more than half the 2 year olds would not have spawned before they are caught. In contrast, Gerritsen *et al.* (2003) working in the Irish Sea reported that L_{50} averaged around 19cm in males and 22cm in females. These are much smaller lengths than those found in the present study. This may be related to over-fishing in the Irish Sea. There are very serious concerns about the state of the Irish Sea whiting stock. There has been a serious decline in abundance in the western Irish Sea where the bulk of the catch has been fished (Anon., 2002a). Trippel (1995) reported that continual high fishing mortality might also result in the formation of selective early maturing genotypes. Cooper (1983) constructed maturity ogives for whiting which showed mean lengths at first maturity of 25.5 cm for males and 27.5 cm for females.

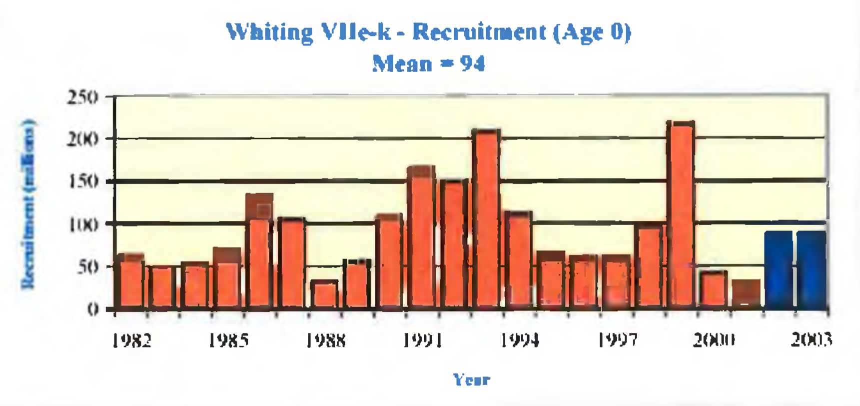
In summary, female whiting spawned from late February to June 2001. They matured at a total length of 23 cm and in their first year. Female whiting reached L_{50} at a total length of 28 cm and 2.7 years of age. Male whiting spawned from February to June 2001. They matured at a total length of 21 cm and in their first year. Male whiting reached L_{50} at a total length of 30.4 cm and 3.6 years of age.

A variety of management measures are available to regulate fisheries. These include international and national total allowable catches (TAC), controls of effort expended by the fleets, closed areas and regulation of mesh and minimum landing sizes (TCM's). The more widespread use of 110mm mesh nets in 2002, and the requirement to fit square mesh panels to certain towed gears since late 2000, may improve the selection pattern for whiting in West Scotland (Anon., 2002a). Whitefish trawlers in the Irish Sea are using 100mm mesh sizes, which should also improve the selectivity for whiting. Most fisheries are managed with a combination of measures mentioned above. These measures will somehow affect the overall level of fishing mortality directed onto the stock and the selectivity of that effort with the age or size of fish (Horwood, 1993).

The whiting stock in the Celtic Sea appears to exhibit periods of good recruitment followed by periods of very poor recruitment (Anon., 2002b). The 2002 assessment indicated that during the period 1995 – 1997, year classes were all below average. The 1999 recruitment was the highest in the time series, but the 2000 and 2001 year classes were near the lowest in the time series (Anon., 2002b). These results are presented in

Fig. 4.3 (Anon., 2002a). It is known that recruitment is reduced as the stock declines. Taking into account the location of spawners improves the prediction of recruitment (Rochet, 2000).

Fig. 4.3. Recruitment of whiting in the Celtic Sea between 1982 and 2001 with predicted recruitment for 2002 and 2003 (Anon., 2002a)



Fishing selectively removes larger fishes from the population (Jennings *et al.*, 2001). It also changes the size and age structure of a population, with mean body size and mean age decreasing as fishing mortality increases (Jennings *et al.*, 2001). Declines in abundance of gadoids such as cod, caused by high rates of fishing mortality, have been associated with reductions in age at maturity (Gerritsen *et al.*, 2003). It is likely that intensive fishing effort may have removed all the large fish from the Celtic Sea stock. If this trend continues a collapse in the fishery is likely to occur. Therefore, fishing effort should be reduced in the Celtic Sea with a corresponding reduction in TACs and quotas.

Little information is available on the reproductive history of whiting in the Celtic Sea. In the present study, female whiting reached L_{50} at a smaller size and age than males. This is interesting from a recruitment point of view. Brodie *et al.* (1991) found that in areas where fish were been commercially exploited L_{50} was reduced over the years. In the present investigation, discard data was limited and therefore increased the uncertainty of the estimates of L_{50}. The assumption of constant maturity ogives in many stock assessments probably leads to an underestimation of the variability in spawning stock biomass (SSB). Alternatively, virtual population analysis (VPA) can overestimate stock sizes when certain assumptions of the model are not met (Walters and Maguire, 1996). Virtual population analysis is an analysis of the catches from a given year class over its life in the fishery (Anon., 2002a).

For management purposes, it is important to take into consideration that the majority of the fish aged from the Celtic Sea stock, in the present study, were 2 and 3 year olds. Male and female whiting are, therefore, a very short time in the fishery before they are captured. Protective measures such as larger mesh size would need to be implemented. Increasing the mesh size would allow more escapements of smaller fish. The latter, together with increasing the legal minimum landing size would allow a greater proportion of the fish to mature before the possibility of capture. The Hake Recovery Plan (Anon., 2002a) may already have contributed to this.

Zheng *et al.* (2001) notes that fishery data are imperfect. Landings data may be inaccurate due to the misreporting of fishing areas or illegal landings. Also landings may not accurately reflect catches due to discarding. Discarding occurs for various reasons, including quota restrictions, catches of fish under the minimum landing size and "high-grading". The influence of economic forces is taken to extremes when fishers discard target species that are above the minimum landing size in order to make room for more valuable larger fish in the fish-hold and this process is known as high-grading. It has been reported that up to around 30,000 t of whiting may be discarded in Scottish waters annually (Zheng *et al.*, 2001). Discard ratio of 50% by weight and 60 – 70% by number have been reported by Anon, (2002a) for the West of Scotland, while estimates for 2000 and 2001 in the Irish Sea indicate that 60 – 70% of the catch was discarded (Anon., 2002a). The levels of discarding by trawl fleets in the Celtic Sea have not been described in detail to date. Sampling undertaken aboard Irish otter trawl vessels indicates that discarding levels may be substantial, although estimates of discarding from the fleet were obtained aboard few vessels in some years and therefore may not be representative of the fleet (Anon., 2002b). In the years where sampling levels were highest, discard rates of up to 49 % by number were estimated from the Irish otter trawl fleet (Anon., 2002b). Survival rates of discards have never really been measured, and it is difficult to see how it could be assessed. It is assumed that there is a very low survivability, probably very close to zero. Some might survive if they were on top of the pile on deck and were immediately discarded. It is possible to see some swimming away once they are discarded, but scale damage could mean that they soon die due to infection, or are picked up by predators in their weakened state (G. Johnston, MI, pers. comm., May 2003).

As discard mortality, once the fish are on board, is close to 100%, it is suggested that increasing legal minimum landing size would be of little value as a conservation tool in the management of the fishery.

Further assessment of the state of the stock whiting in the Celtic Sea is necessary in order to determine long-term management plans. The fate of discards in particular needs urgent attention.

In summary, it is suggested that the following critical points should be taken into account for better management of the Celtic Sea whiting stock:

1. An F_{pa} should be established for this stock in order to assess the current level of fishing mortality.
2. The maturity ogives need further study. L_{50} for females is 28 cm. Given that the legal minimum landing size is 27 cm almost 50% of female fish may be caught before they contribute to the spawning stock biomass (SSB). The male L_{50} is larger at 30.4 cm so males are more heavily impacted in this regard.
3. It is important to investigate the extent of gutting of large fish before landing by fishers in the fleet. This would throw light on the possible effect of this practice on the estimated size at age for older fish.
4. The apparent decline in size of 4 – 7 year old fish in the Celtic Sea between 1996 and 2001 needs further investigation.
5. Data for discards is lacking and therefore the results of the present study show a strong bias in the smaller size classes. This affects estimation of growth and maturity. Data on the level of discarding in the fishery is essential to provide more precise information on the stock.
6. Protective measures such as mesh size and legal minimum landing size should be revised regularly.
7. In order to implement the suggested criteria for the Celtic Sea stock, intensive sampling should be continued by the Marine Institute in the future.

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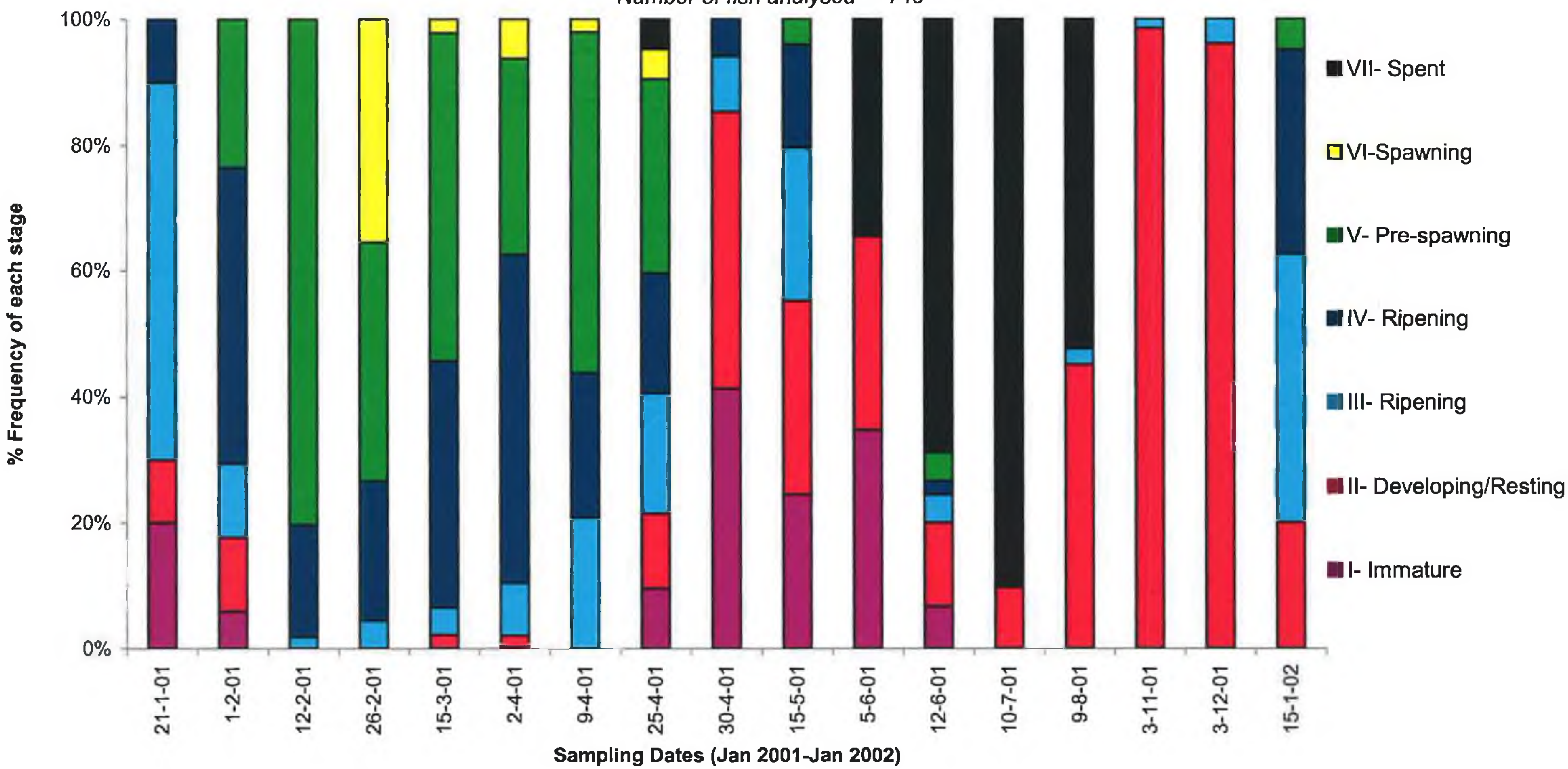
5.0 Appendices

Appendix I

Fig. 5.1. Percentage of each development stage in the gonad cycle at each sampling date over the sampling period January 2001 to January 2002 for female whiting examined macroscopically

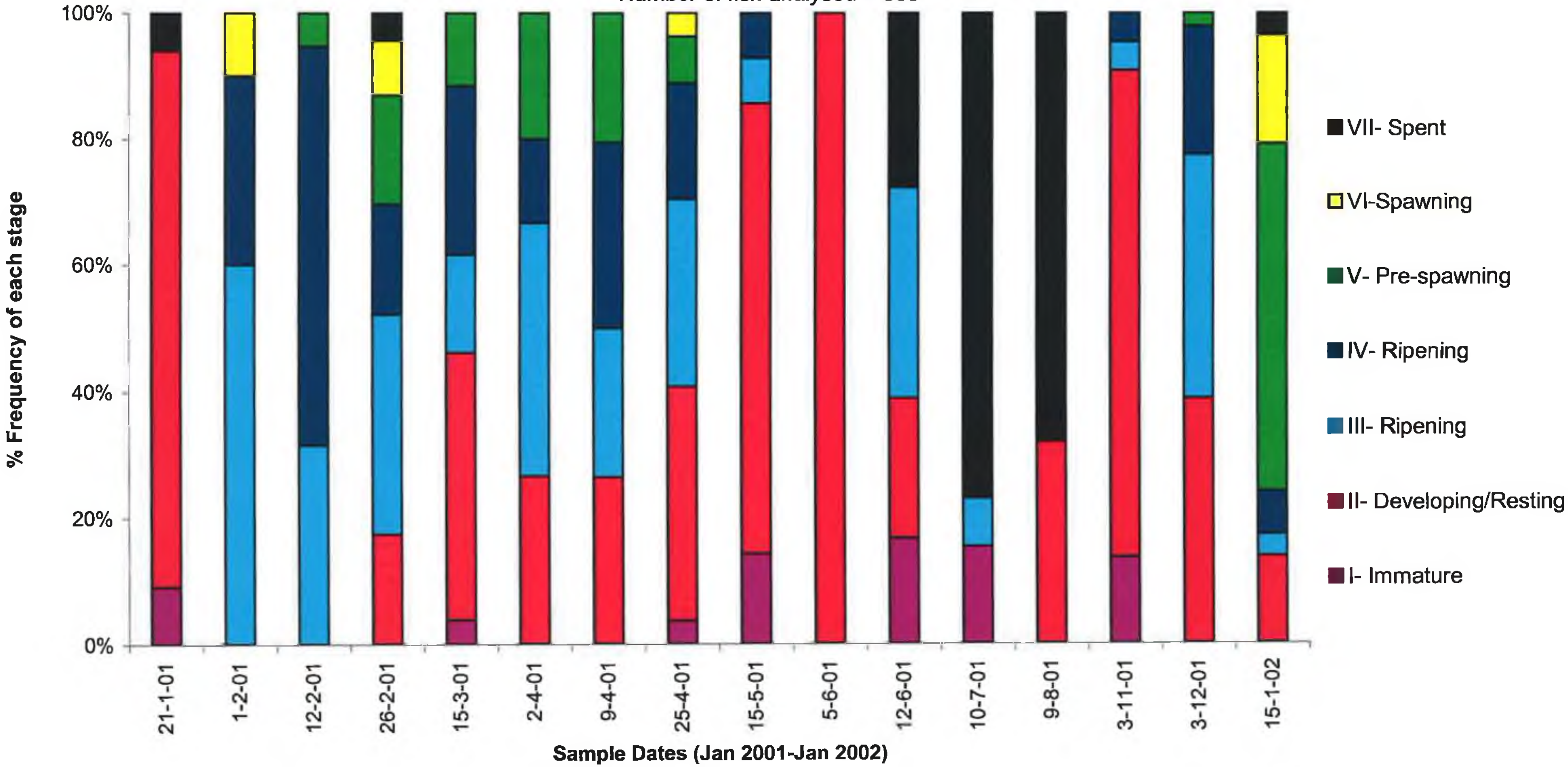
Number of fish analysed = 740



Appendix I

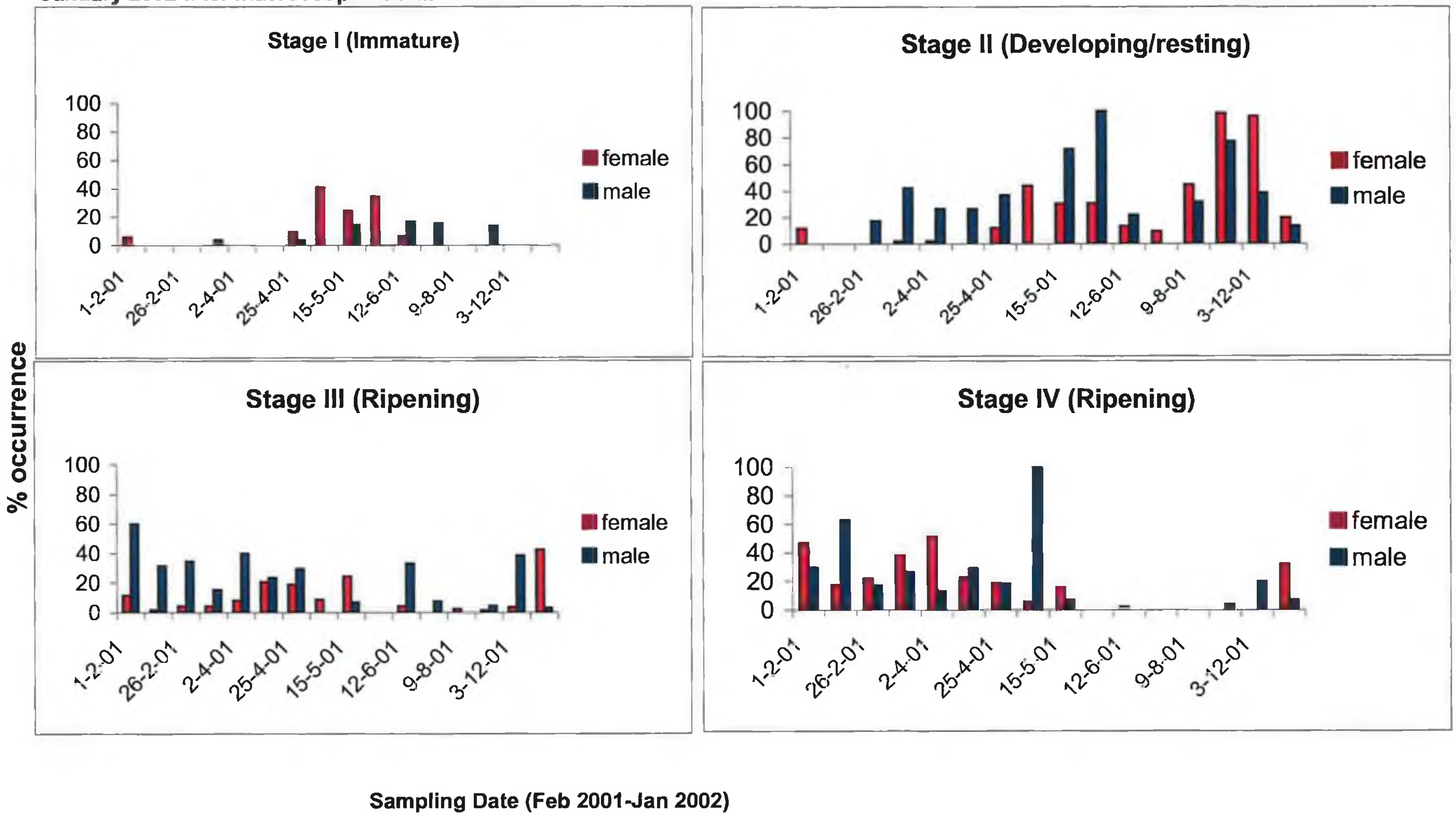
Fig. 5.2. Percentage of each development stage in the gonad cycle at each sampling date over the sampling period January 2001 to January 2002 for male whiting examined macroscopically

Number of fish analysed = 383



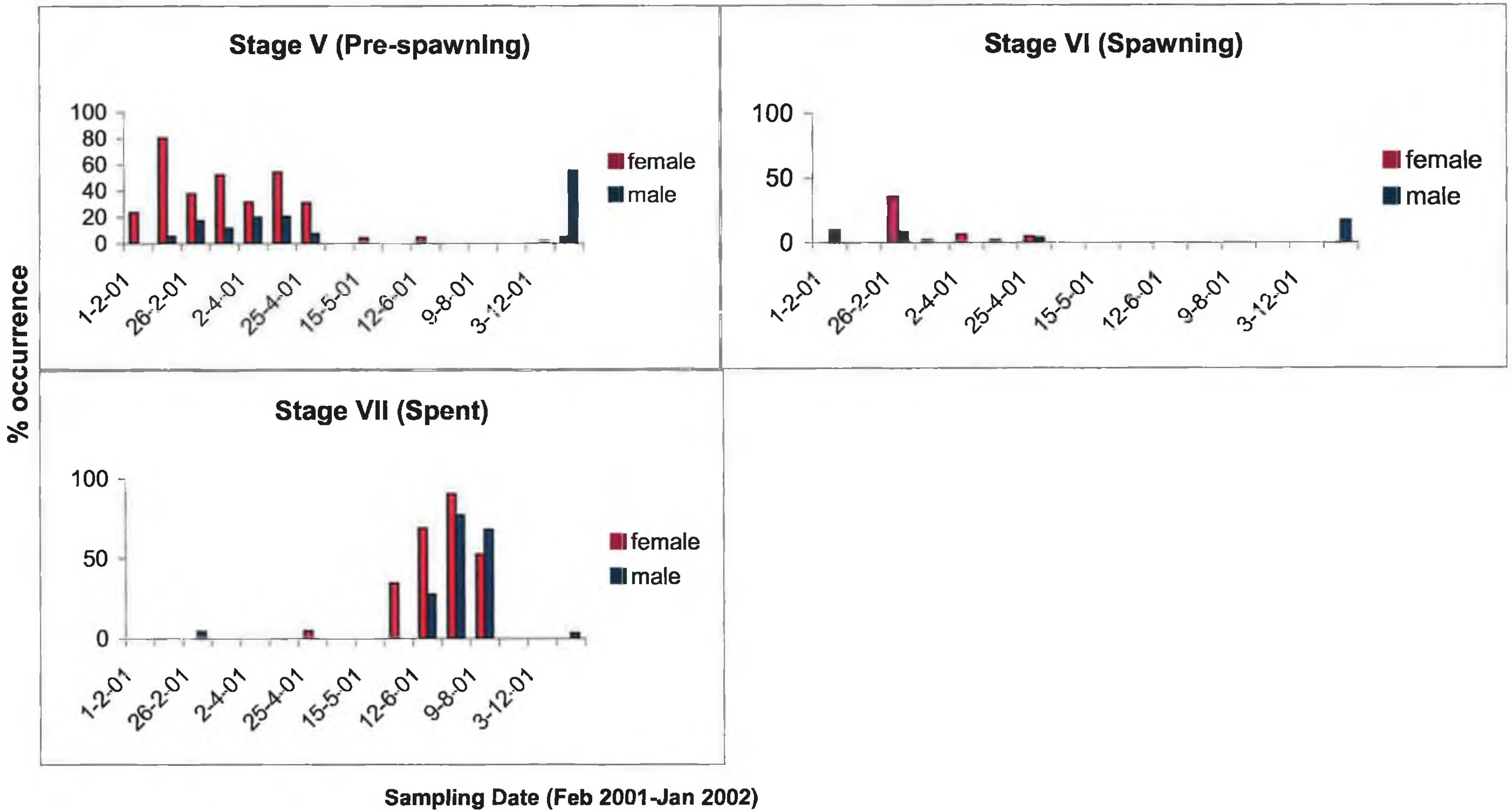
Appendix I

Fig. 5.3. Percentage occurrence of male and female whiting in each maturity stage over the sampling period February 2001 - January 2002 after macroscopic examination.



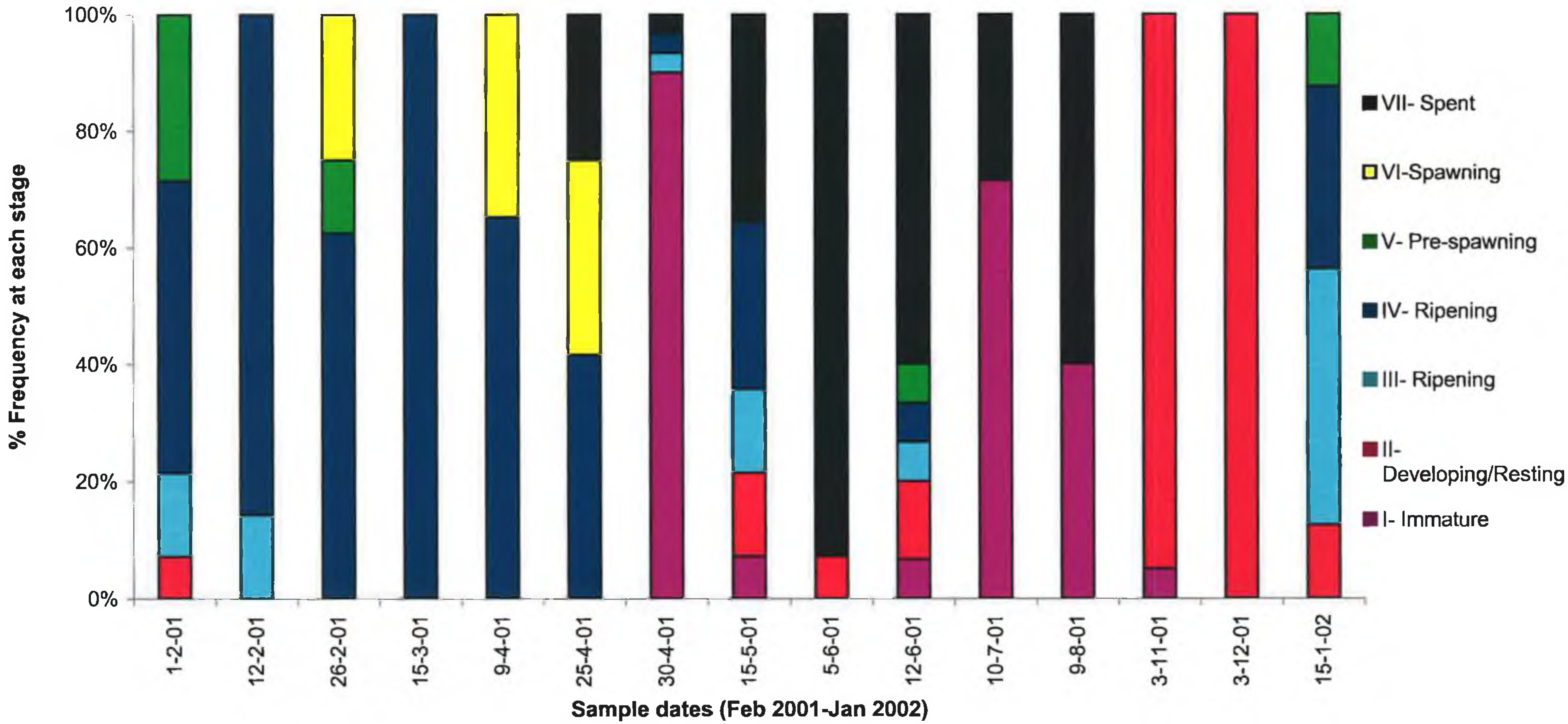
Appendix I

Fig. 5.3. (continued) Percentage occurrence of male and female whiting in each maturity stage over the sampling period February 2001 - January 2002 after macroscopic examination.



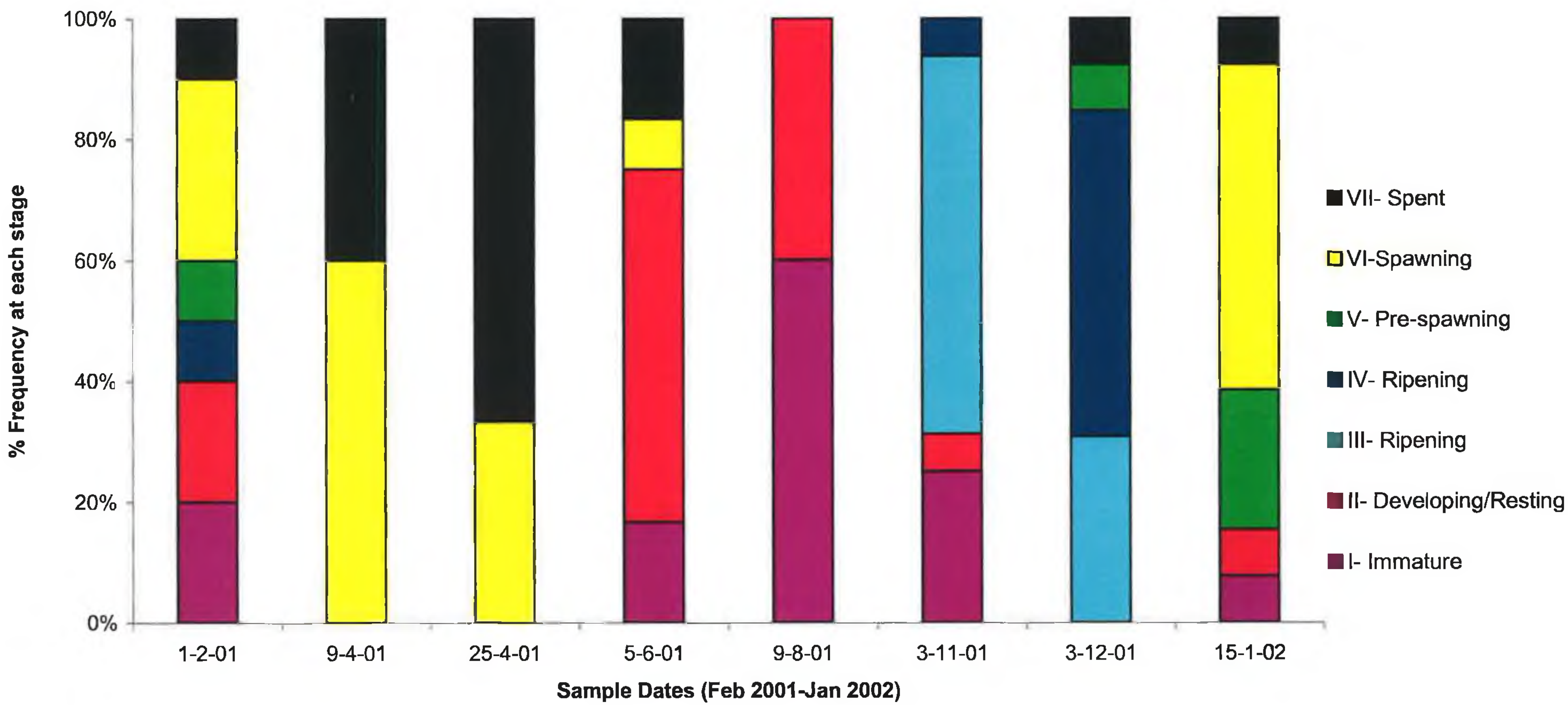
Appendix I

Fig. 5.4. Percentage development at each stage estimated after histological examination of the gonad, in each sample for female whiting over the sampling period (February 2001-January 2002) *Number of fish analysed = 223*



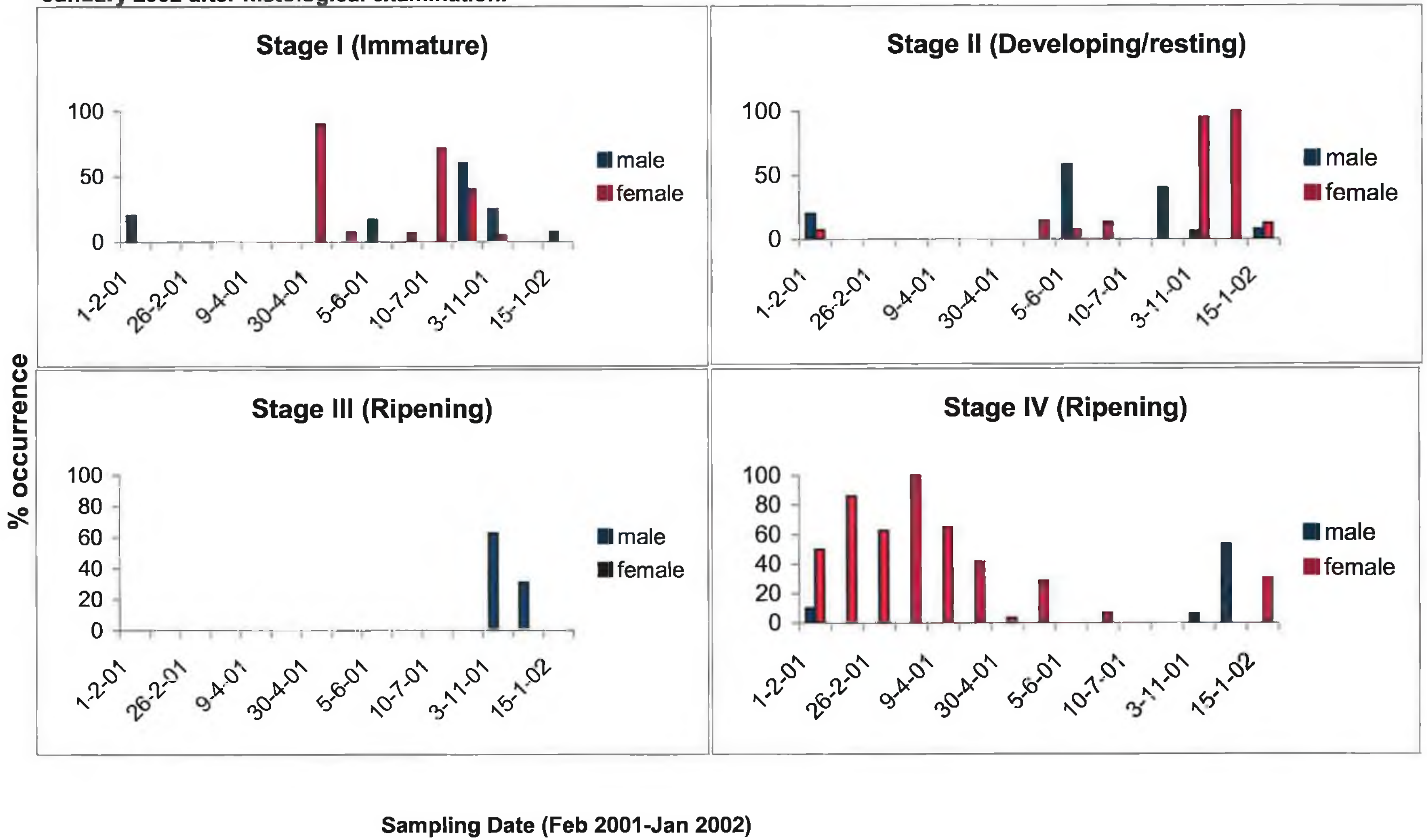
Appendix I

Fig. 5.5. Percentage development at each stage estimated after histological examination of the gonad, in each sample for male whiting over the sampling period (February 2001-January 2002) *Number of fish analysed = 93*



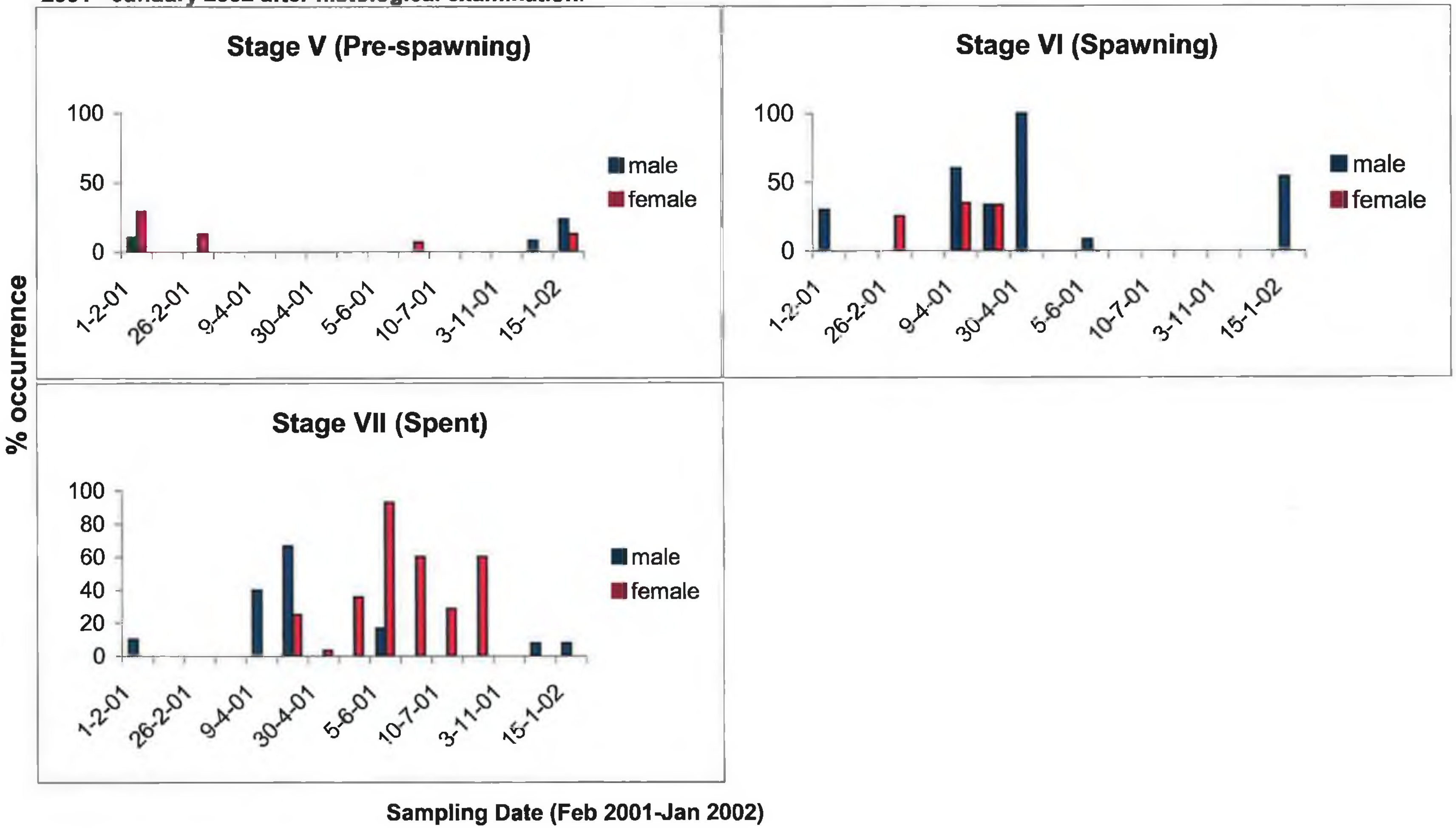
Appendix I

Fig. 5.6. Percentage occurrence of male and female whiting in each maturity stage over the sampling period February 2001 - January 2002 after histological examination.



Appendix I

Fig. 5.6. (continued) Percentage occurrence of male and female whiting in each maturity stage over the sampling period February 2001 - January 2002 after histological examination.



Appendix II – Revised Visual Scale for female whiting maturity stages.

Females

Stage I –	Immature, Developing/Resting and Spent: gonads 1/5 – 1/3 in length of body cavity, flattish, reddish – orange or translucent in colour.
Stage II –	Ripening: gonads 1/2 of body cavity, pinkish white in colour and eggs opaque just visible.
Stage III –	Ripening: gonads 2/3 of body cavity, orange pink in colour, opaque eggs clearly visible.
Stage IV –	Pre-spawning: gonad very swollen in body cavity, some eggs transparent.
Stage V –	Spawning: gonad very swollen in body cavity, transparent eggs easily extruded.