Irish Fisheries Investigation No. 13

Larval distribution of commercial fish species in waters around Ireland

by

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Abstract

In April 2000 a base line survey was conducted on the larval distribution of commercial fish species off the west, north and south coasts of Ireland. Ichthyoplankton samples and in situ CTD data were collected, whilst simultaneously capturing remote sensing images of chlorophyll and sea surface temperatures. The survey sampling area covered the Celtic Sea from the Irish south coast to 49°N, the western shelf including the Porcupine Bank and the northern shelf up to the Stanton Bank. The sample grid design was based on the international mackerel & horse mackerel egg survey with station spacings of 0.5° latitude and 0.5° longitude. Ichthyoplankton samples were collected with a Gulf III plankton sampler, which was deployed on oblique tows from the surface to within 5 metres of the bottom (200m max). A self-logging CTD sensor (Promonitor) was attached to the Gulf and recorded depth, temperature and salinity profiles for each deployment. Results from the Promonitor CTD showed that strong temperature and salinity gradients were encountered during the survey. Lowest temperatures coincided with lowest salinity in the North Channel of the Irish Sea while highest salinities and temperatures were found to the south west of Ireland. Thermal fronts were found in the eastern Celtic Sea and on the north west coast of Ireland. The AVHRR images showed a progressive increase in surface temperatures in the Celtic Sea and west of Ireland. Highest surface chlorophyll concentrations were associated with cooler less saline water in the Irish Sea and the coastal areas around Ireland. In the western Celtic Sea surface chlorophyll concentrations increased as the survey progressed to form a phytoplankton bloom towards the end of the survey. Larvae of interest showed distinct distribution patterns, with some species being confined to particular areas or spawning grounds while others were spread over the whole survey area. The survey identified two important larval hotspots: Cod larvae were concentrated in the eastern Celtic Sea, where other gadoid species such as haddock, whiting, pollack and saithe were also found in high numbers. This area is associated with the Celtic Sea front and shows increased primary productivity, which could present a favourable environment for successful larval survival. Stations in the southwest of Ireland sustained high concentrations of hake, megrim and mackerel larvae. The waters with high numbers of these three species stretched from shallow inshore stations to deeper ones along the continental shelf and were characterised by high temperatures and salinities. SeaWIFS satellite images suggest the formation of a phytoplankton bloom within this larval hotspot, which would provide the necessary resources for successful larval growth.

1 Introduction

Ichthyoplankton surveys are an important tool in providing information on the locations of fish spawning sites, timings of peak spawning, biological interactions with physical oceanography and larval survival generating variability in recruitment to fish populations (Brander, 1994; Cushing, 1990).

The knowledge of fish larval distribution in waters around Ireland is limited due to the fact that the only regular ichthyoplankton surveys, the international mackerel and horsemackerel egg surveys, only cover the shelf edge and offshore regions south, west and north of Ireland and only occur on a triennial basis. While providing a good coverage of the spawning grounds of mackerel, horse mackerel and hake it leaves the inshore areas virtually unexplored. Yet these areas are reputed to contain spawning grounds for commercially important demersal species such as cod, whiting, plaice and sole.

The primary purpose of this paper is to present results from a base line larval survey of the north, west and south coasts of Ireland, which was carried out in April 2000. Results were used to produce distribution maps and highlight the likely spawning areas of commercial fish species. Measurements of environmental parameters and the use of satellite oceanography were included in the analysis to identify any correlations between physical oceanography and larval distribution.

The survey was part of a collaborative project between the Marine Institute (MI) and National Oceanographic and Atmospheric Association (NOAA) aiming to combine ocean data management, remote sensing and modelling of ocean conditions to improve our understanding of the factors that may influence fisheries recruitment.

2 Materials and Methods

2.1 Sampling area and grid design

The survey was designed to cover the spawning grounds and larval distribution areas of commercially important fish species on the shelf area around Ireland during the spawning season. Sampling was conducted between the 9th of April and the 5th of May 2000. The basic grid design was based on the international mackerel and horse mackerel egg survey, which takes place every three years (ICES, 1999; ICES, 2002). This grid has a station spacing of 0.5° longitude by 0.5° latitude as shown in fig. 1. The standard survey grid was compiled taking into account the fixed resources of survey duration, vessel speed and deployment time. It was modified using information on spawning areas and previous larval distribution "hot spots" from fishermen and the historic mackerel and horse mackerel egg survey data sets. In cases where ancillary information indicated increased likelihood of encountering eggs and larvae the station spacing by latitude was halved. During the survey the station spacing was further modified where information on special oceanic features such as temperature fronts was available, or where large numbers of eggs or larvae were encountered.

2.2 Sampler deployments

The survey was carried out on the 35m pelagic fishing trawler, the *MFV Girl Stephanie*. The sampler consisted of a GULF III plankton sampler (Gehringer, 1952) with a net mesh size of 250 µm and a mouth opening of 24.5cm. A logging CTD sensor (Promonitor) was attached to the sampling frame and recorded depth, temperature and salinity profiles for each deployment. A calibrated flowmeter inside the nosecone monitored the volume of water filtered while a depth transducer with a real time cable was fixed to the base of the GULF III to allow accurate deployment to the chosen depths. The sampler was deployed at 4.5 knots on an oblique tow from the surface to within 5 metres of the bottom (200m max) and returned to the surface. At shallow stations, multiple/double-oblique dives were carried out to ensure that a sufficient volume of water was filtered. Sampler deployment time ranged between 6 and 30 minutes. A total of 162 stations were sampled.

2.3 Collection, sorting and identification of eggs and larvae at sea

At each station details of the haul position, timing and depth were entered into the station log book. Before and after each haul the manual flowmeter readings were recorded from inside the nose cone. Following deployment of the GULFIII, the CTD data was downloaded from the Promonitor. The end bag used during sample collection was removed, filtered through a 250µm sieve and washed into a sorting dish. A clean end bag was attached and the net was washed down from the nose cone to the end bag, using several end bags if necessary. The content of each end bag was added to the sorting dish. The sample tray was placed over a light box and manually scanned for fish eggs and larvae of the target species.

The remaining sample was poured into a labelled jar and preserved. The standard fixative for use on this survey was a 4% solution of buffered (pH 7 – 8) formaldehyde in distilled water (250g of sodium acetate trihydrate was dissolved in 10 litres of 30% formaldehyde to make a buffered stock solution. The stock solution was then diluted to 4% using distilled water).

Samples were split into two subsamples with a folsom splitter when the sample was either too dense (e.g. during a phytoplankton bloom) to guarantee that all eggs and larvae of interest were removed or when the weather was too rough for sorting. Upon return to shore, plankton samples were drained of formalin and transferred to 95% borax buffered ethanol, pH 8.5. A few chips of calcium carbonate were placed in the sample to buffer the ethanol. In the lab samples were filtered through a 250µm mesh and rediluted with fresh water. Samples were observed under a binocular microscope and all fish larvae were removed. The main identification keys used were Russell (1976), Fahay (1983) and O'Brien (1986).

2.4 Data analysis

Data were standardised according to Smith and Richardson (1977):

(1) $\text{Volume filtered } (m^3) = \dfrac{\text{Flowmeter revs} * \text{Nose cone aperture} * \text{Efficiency Factor}}{\text{Flowmeter calibration}}$

The number of larvae m^{-2} was calculated from the formula:

(2) $\text{Larvae } m^{-2} = \dfrac{\text{Larvae counted} * \text{Depth} * \text{Factor}}{\text{Volume filtered}}$

Where

Flowmeter revs	=Number of revolutions made by the flowmeter propeller during the tow.
Nose Cone Aperture	= The area of the nose-cone aperture of the sampler in m^2 (πr^2)
Flowmeter-calibration	= The number of flowmeter revolutions per meter towed, obtained from the flume or sea calibration in free flow.
Larvae counted	= Number of larvae in the sample
Efficiency factor	= Proportion accepted by the sampler in free flow.
Factor	= Raising factor from sub-sample to whole sample.
Depth	= The maximum depth, in metres, of the sampler during the tow.

To simplify comparison between the different species all maps are presented with the same numerical categories, with the exception of sprat and mackerel. Images were used from the larval base at www.larvalbase.org, which used (Halbeisen, 1988).

2.5 Satellite images

Weekly composites of Advanced Very High Resolution Radiometer (AVHRR) and Sea viewing Wide Field-of-view Sensor (SeaWiFS) satellite images were obtained from the remote sensing data analysis service of the Plymouth Marine Laboratory, UK. AVHRR images allow the visualisation of sea surface temperature while SeaWiFS images display the ocean color, which gives an indication of surface primary productivity.

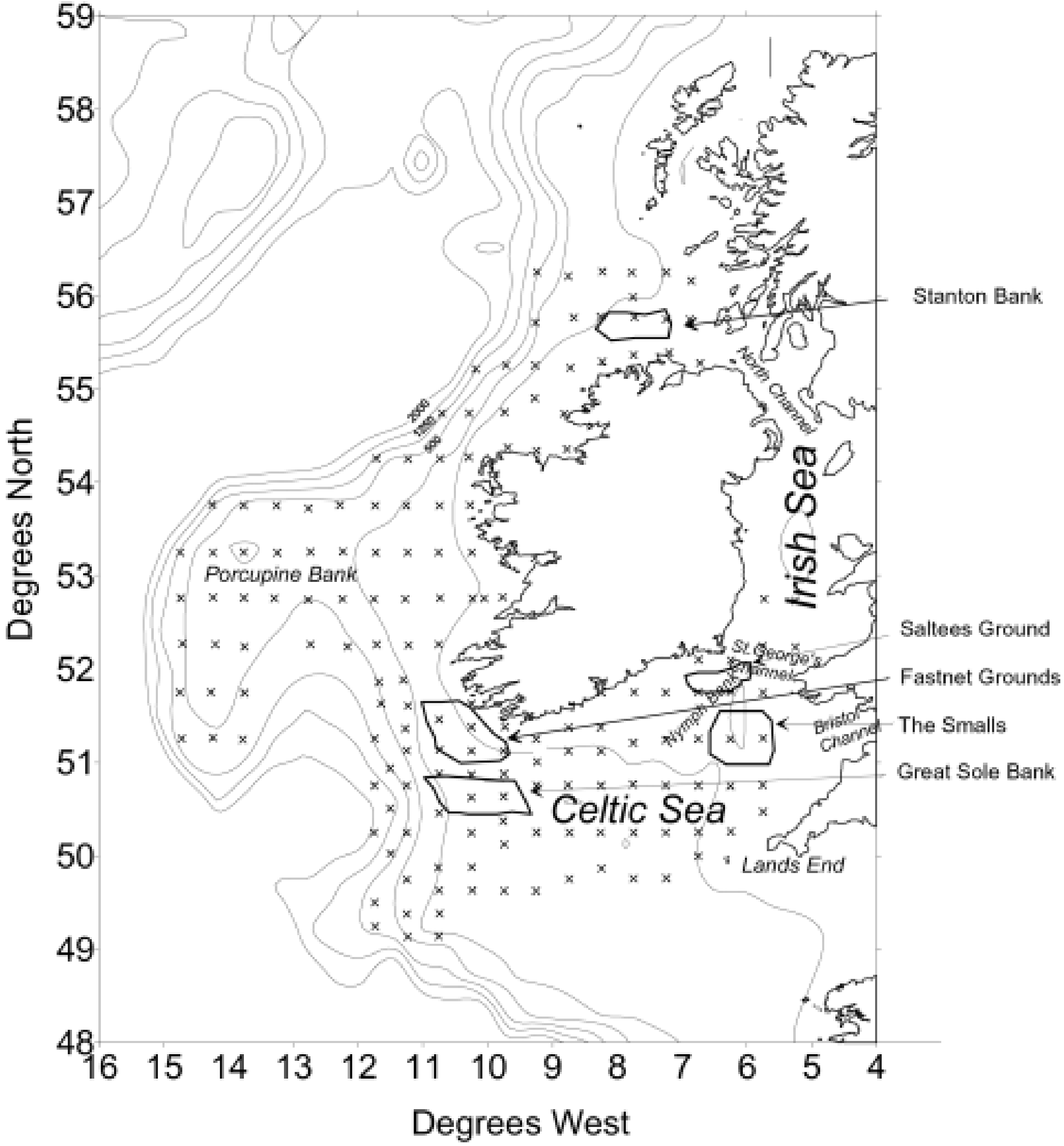


Fig. 1 Station positions of the Irish egg and larval survey, April 2000 and some of the fishing grounds covered during the survey.

3 Results and Discussion

3.1 Physical environment

A total of 162 stations were sampled in the southern Irish Sea, the Celtic Sea up to 49˚15'N, west of Ireland including the Porcupine Bank up to 15˚W and the north of Ireland up to 56˚15'N (Fig.1) between the 9th of April and the 5th of May 2000. The majority of stations (67%) were situated on the Irish shelf with station depths ranging from 32m to 200m, 26% of the stations were on the shelf edge in waters deeper than 200m and 7% of the stations were in waters deeper than 1000 metres.

Temperature and salinity depth profiles were taken at each station and contour plots of surface near temperature and salinity distribution are shown in Figs. 2.a and b. AVHRR and SeaWIFS satellite images captured during the survey period provided a dynamic picture of the changing surface temperature and chlorophyll distribution in the sampling area. Weekly composites of AVHRR and SeaWIFS satellite images are shown in Fig. 3 and 4 respectively.

Temperatures ranged from 8.3˚C to 11.6˚C, while salinity varied between 34.13 and 35.79. Lowest temperatures coincided with lowest salinity in the North Channel of the Irish Sea and highest salinities and temperatures were found southwest of Ireland. At the majority of stations (84%) waters exhibited temperatures above 9˚C and salinities above 35. Cooler, less saline water was encountered in the Irish Sea and coastal stations close to fresh water input. The River Shannon influenced inshore waters west off Ireland, while the Lee estuary caused fresh water dilution in the Celtic Sea. The transition from Irish Sea waters to Atlantic Ocean water resulted in strong temperature and salinity gradients. The Islay front was observed west of the North Channel. This thermohaline front exists throughout the year with some seasonal changes occurring in its extent and position (Hill and Simpson, 1989). In St. George's channel, temperature contours indicated an increase in temperature from coastal water of the Irish Sea to oceanic water in the Celtic Sea. Vertical profiles of temperature and salinity in St. George's Channel obtained at the beginning of the survey suggested that stratification in the Celtic Sea had not set in yet. However AVHRR images throughout the survey period showed a progressive warming in the Celtic Sea and a strengthening in the sea surface temperature gradient between the Irish Sea and the Celtic Sea. This front, the Celtic Sea front, is caused by tidal mixing in the Irish Sea and stratification in the Celtic Sea in the early summer months (Horsburgh *et al.,* 1998) and seems to be formed towards the end of the survey (Fig. 3e). Strong temperature and salinity gradients were also detected on the shelf edge along the west coast of Ireland. This is likely to be the Irish shelf front: a thermohaline front that separates the North Atlantic waters from the Irish shelf water (McMahon *et al.,* 1995). The front exists throughout the year but its location can vary seasonally and inter-annually (Huang *et al.,* 1991). The AVHRR images showed a progressive increase in surface temperatures in the Celtic Sea and the West of Ireland, particularly during the last week of the survey. As the Celtic Sea has been sampled in the first half of the survey, it is not possible to deduct that this temperature increase is associated with the onset of stratification. However the establishment and movement of the Celtic Sea frontal systems makes this highly likely.

Other oceanographic features apparent during the survey included cooler and less saline surface waters above the Porcupine Bank. This feature can be associated with a dome of cold less saline water, a Taylor column that is caused by the isopycnals doming to the surface above the bank. The Taylor column has been persistently encountered on the Porcupine Bank during spring and summer surveys (Kloppmann *et al.*, 2001) and supplies the surface waters with nutrients.

Satellite SeaWIFS images taken during the survey showed that primary productivity was associated with cooler less saline water and was highest in the Irish Sea and the coastal areas around Ireland (Fig. 4). Towards the end of the survey production increased in the Celtic Sea with a surface bloom formation becoming apparent in the south western Celtic Sea in the last week.

a.)

b.)

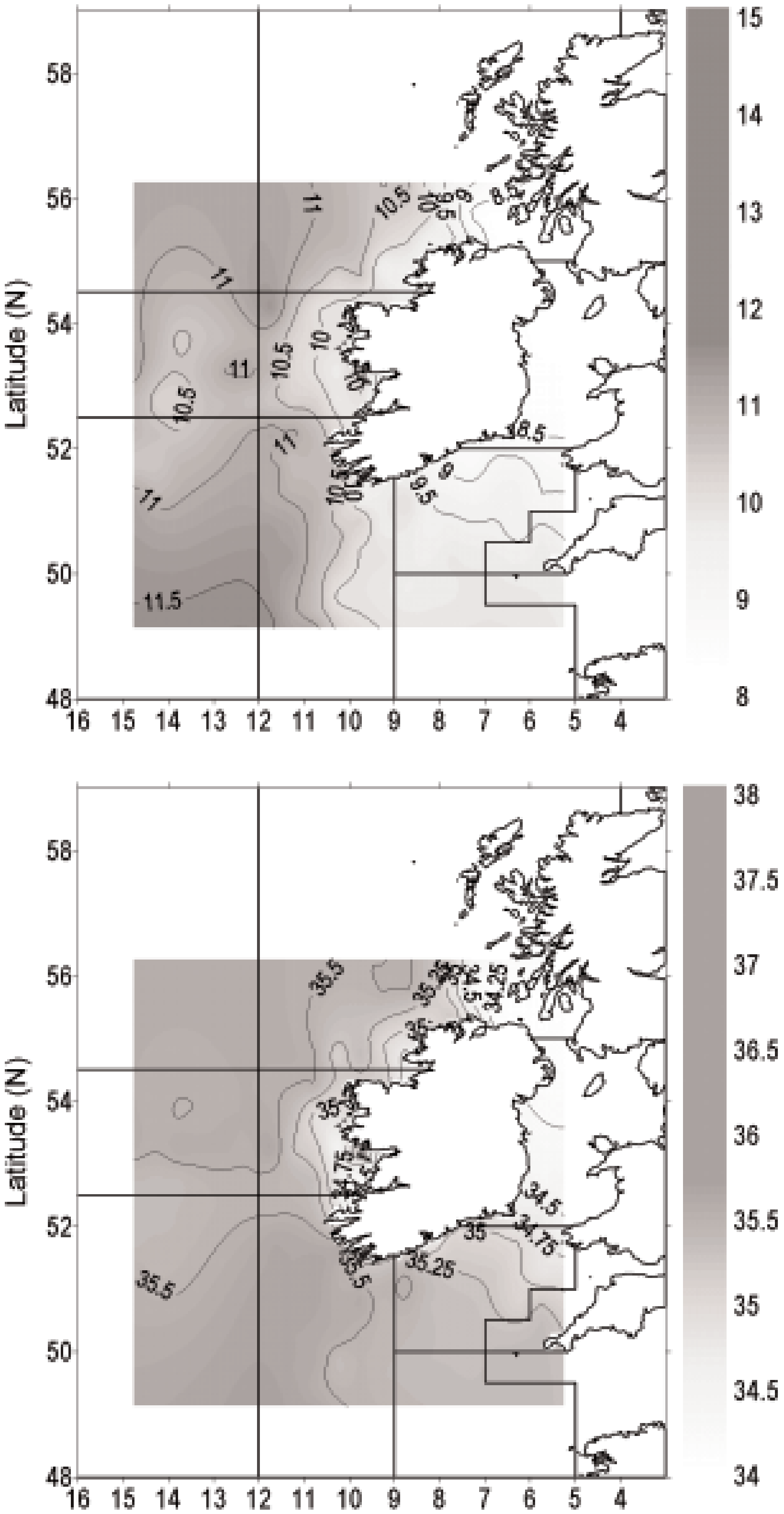


Fig. 2 Near surface temperature in ˚C and salinity distribution of the survey area in April, 2000. a.) Temperature with a contour interval of 0.5˚C, b.) near surface salinity (below) with 0.25 contour intervals. Data has been collected with a Promonitor CTD unit.

3.2 Distribution of fish larvae

In total, over 21 000 larvae were extracted and identified into 84 species and 17 family or genus levels. A full species list is shown in Table 1 with the nomenclauture adapted from Whitehead *et al.* (1986). Sprat and mackerel were the most abundant species, comprising 25% and 21 % of total larvae numbers respectively. The most widespread species were sprat, lemon sole and mackerel, all occurring in over 50% of all stations. Two other genus groupings, *Callionymus* sp. and *Trisopterus* sp. were also widespread, being found in over 50% of stations sampled. The locations of various areas of the survey, which are referred to in the text can be found in fig. 1.

3.2.1 Cod

Cod larvae were found at 18 stations of the sampling grid, most of them situated in the eastern Celtic Sea (Fig. 5a). Concentrations of larvae were low and the maximum number of larvae found per m^2 was 12. In the Celtic Sea cod larvae were aggregated close to the Saltees and the Smalls fishing grounds with small numbers also being found in the southern entrance to the Bristol Channel. Cod eggs and larvae were previously recorded in these areas in plankton surveys in 1938, 1939, 1953 and 1990 (Brander, 1994) suggesting that cod spawning areas are relatively persistent. In the eastern Celtic Sea and Bristol Channel, peak spawning has been reported to occur usually mid to late March (Brander, 1994). In the Irish Sea a daily cod egg production curve was constructed for 2000 and showed that spawning was at its peak in the beginning of March (Anon., 2001). Given that cod eggs have an approximate incubation period of 11 to 13 days in ambient temperature (Thompson and Riley, 1981) the larvae encountered in the eastern Celtic Sea would come from fish that had spawned after the peak.

3.2.2 Haddock

Haddock was more widely distributed than cod with low numbers of larvae found at 32 stations in the Celtic Sea, north west of Ireland and on the Porcupine Bank (Fig. 5b). In the Celtic Sea haddock larvae were found together with cod on the Saltees and the Smalls fishing ground, but also in the western Celtic Sea on the Fastnet Ground and the Great Sole Bank. In the northwest haddock larvae were primarily found across Stanton Bank. Larvae were dominated by small yolksac individuals, suggesting that peak spawning occurred just prior or during the early part of the survey (McCarney, 2001). Little is known about the egg and larval distribution of haddock around Ireland: in the Celtic Sea haddock larvae have mainly been found in transitional waters, ie between neritic stations and the shelf edge (Horstman and Fives, 1994; Acevedo *et al.*, 2002), but this data is derived from the ICES mackerel and horse mackerel egg surveys which do not extend into the eastern Celtic Sea. North of Ireland, haddock spawning grounds were reported south and northwest of the Hebrides (Heath and Gallego, 1998). This suggests that only the southern edge of this more northerly spawning area was covered by this survey.

3.2.3 Whiting

Whiting was the most abundant larva of commercial whitefish species both in total numbers and frequency of occurrence. Its distribution was more homogenous than the other gadoid species, and whiting larvae were consistently found in high numbers around the coastline, south, west and north of Ireland (Fig. 6a). Highest concentrations of whiting larvae were found on the shelf south and north of Ireland, in particular on the Saltees, the Smalls and the Fastnet fishing grounds in the Celtic Sea and Stanton Bank north of Ireland. Numbers declined rapidly towards the continental slope. No individuals were found on the Porcupine Bank. This corresponds well with the adult distribution of whiting as indicated by the 2000 Irish groundfish survey and commercial catch data that show that most of the catches were in waters shallower than 200 metres.

3.2.4 Hake

Hake larvae occurred in moderate to high numbers in the western Celtic Sea from the southwest corner of Ireland down to the shelf edge (Fig. 6b). Concentrations reached up to 34 larvae m^{-2} with highest concentrations being found within the 200m contour line. Small numbers were also found on the shelf edge west of Ireland. This agrees with Fives *et al.* (2001), who recorded most hake larvae in 1986, 1989 and 1992 south of 51.5°N latitude on or east of the shelf break and Coombs and Mitchell (1982) who found highest numbers of hake eggs and larvae close to the shelf edge near the Great Sole Bank. Alvarez *et al.* (2001) also identified the western Celtic Sea as an area where hake spawning occurs along the shelf break from the Bay of Biscay to the southern tip of Ireland. Maximum spawning in the Celtic Sea has been recorded from April to May with highest larval abundance occurring from April to June (Alvarez *et al.,* 2001; Coombs and Mitchell, 1982). In the ambient water temperature of 9.5° to 10.5° C the incubation period for hake is ca. 6-7 days (Coombs and Mitchell, 1982) suggesting that the timing of this survey was adequate to cover the peak spawning time. This is supported by the fact that the majority of hake larvae were in the smallest size category of recently hatched individuals (McCarney, 2001).

3.2.5 Megrim and Four-spotted Megrim

Megrim showed a very distinct distribution pattern with one large and two small aggregated patches. A high concentration of *Lepidorhombus whiffiagonis* was found in stations southwest of the Irish coast, stretching from shallow inshore to deeper stations along the continental slope (Fig. 7a). Megrim larvae were found in 26 stations of this region with numbers ranging between 1 and 112 larvae m^{-2}. Highest concentrations were encountered in the far south of the sampling grid, suggesting that spawning extended further south and that the entire spawning area was not covered by the survey. Two smaller patches of megrim larvae were found along the Porcupine Bank and on the west coast of Ireland. The four-spotted megrim, *Lepidorhombus boscii* was less abundant than *L. whiffiagonis*, but showed a similar distribution pattern with larvae found in the western Celtic Sea and on the Porcupine Bank (Fig. 7b).

3.2.6 Plaice and Common Sole

Plaice was found in five stations in the eastern Celtic Sea and the northwest of Ireland (Fig. 8a). Numbers at each station were small with highest concentration encountered being 9 larvae m^{-2}. Common sole was more widely distributed with patches of larvae being found on the Fastnet grounds, the Saltees and at the entrance to the Bristol Channel (Fig. 8b). Highest concentrations of sole were 20 larvae m^{-2}. Given that the biomass of plaice and sole stocks in the areas covered by the survey (Celtic Sea, South West and West of Ireland stocks) are small in comparison to the biomass of these species in the Irish Sea stocks (Marine Institute, 2001) it is likely that the main spawning grounds in waters around Ireland for both species were not covered by this survey. Plankton surveys in the Irish Sea have revealed higher concentrations of plaice and sole larvae over wider areas (Fox *et al.*, 1997; Nichols *et al.*, 1993). In 2000 a spawning curve has been constructed for plaice in the Irish Sea, which indicates that peak spawning occurred in the first week of March (Anon., 2001). If the timing of spawning events is similar for the Irish Sea and the eastern Celtic Sea it can be assumed that the larvae encountered on this survey do not come from the peak spawning time. In the case of sole, spawning curves are only available for 1995 in the Irish Sea and suggest peak spawning occurs between late April and May (Armstrong *et al.,* 2001).

3.2.7 Pollack and Saithe

Pollack larvae were found in 42 stations with a maximum concentration of 13 larvae m^{-2}. Abundance was highest in the eastern Celtic Sea where cod and haddock larvae were also found and in the coastal waters southwest of Ireland (Fig. 9a). Saithe was less abundant than pollack. Single larvae were found in Celtic Sea stations, with slightly higher numbers towards the east, close to the Smalls and the Fastnet fishing grounds (Fig. 9b).

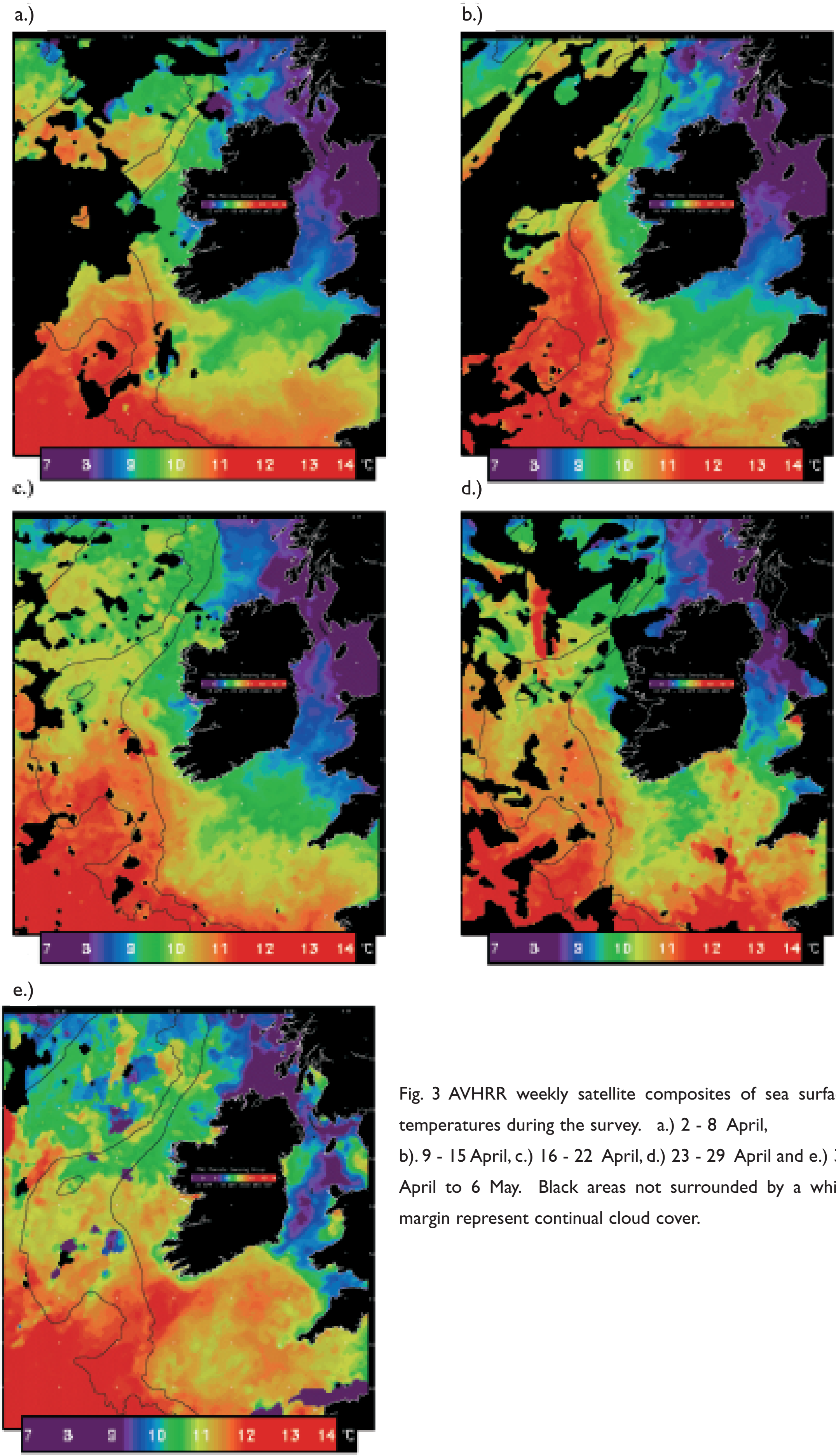
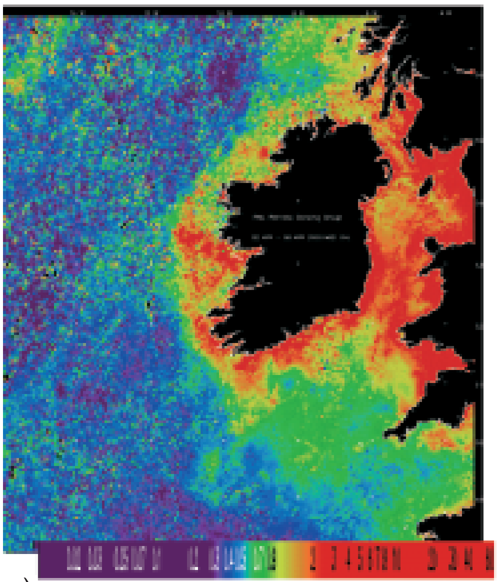
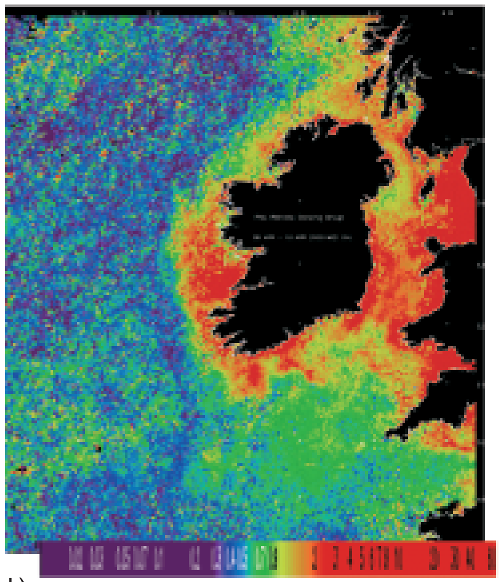


Fig. 3 AVHRR weekly satellite composites of sea surface temperatures during the survey. a.) 2 - 8 April, b). 9 - 15 April, c.) 16 - 22 April, d.) 23 - 29 April and e.) 30 April to 6 May. Black areas not surrounded by a white margin represent continual cloud cover.

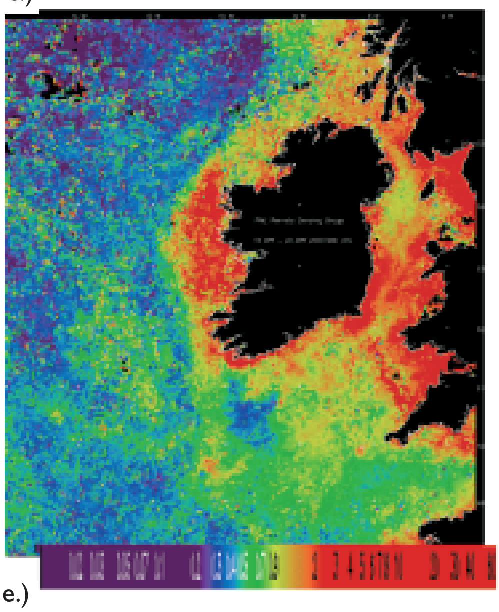
a.)



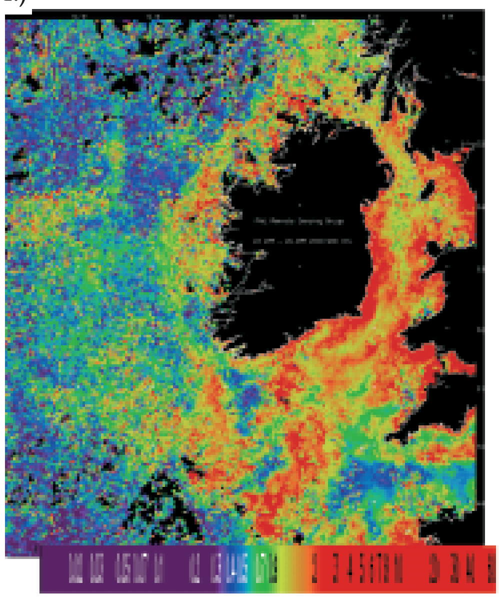
b.)



c.)



d.)



e.)

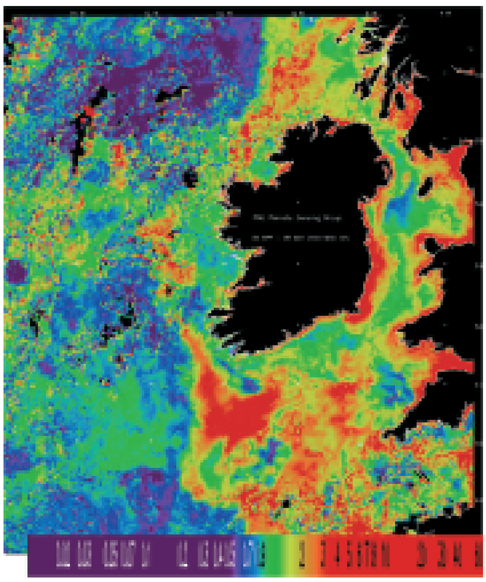


Fig. 4 SeaWIFS weekly satellite composites of sea surface chlorophyll a during the survey. a.) 2-8 of April, b). 9-15 April, c.) 16-22 April, d.) 23-29 April and e.) 30 April to the 6 May. Black areas not surrounded by a white margin represent continual cloud cover.

3.2.8 Mackerel

Mackerel was an abundant and widely distributed species, with larvae recorded in 56% of all stations. Maximum concentrations of mackerel larvae occurred in the western Celtic Sea and off the southwestern tip of Ireland in waters between 100 and 200 metres depth (Fig. 10a). High numbers were also found at most of the stations over the Porcupine Bank and along the shelf edge northwest of Ireland. Distribution was similar to that previously recorded for mackerel larvae during the triennial mackerel egg surveys, where it has been shown that mackerel spawn progressively from the Bay of Biscay to the west of Scotland (ICES, 1999, 2002). Concentrations during this survey were higher than April samples taken in previous years and were more comparable to results obtained in May and early June (Fives *et al.,* 2001). Numbers north of the Porcupine Bank were also higher than previously recorded for that time of year (Fives *et al.,* 2001). The North-eastern Atlantic mackerel stock has an extended spawning period from February to July with maximum spawning usually occurring in mid to late May (ICES, 1999, 2002). Spawning is concentrated along the shelf break, but larvae progressively drift eastwards onto the shelf (Kloppmann *et al.,* 2001). Stations in the eastern Celtic Sea are not sampled during triennial ICES mackerel egg survey and the absence of mackerel larvae at the eastern Celtic Sea stations during this survey indicate that the distribution of the larvae is restricted to the proximity of the shelf edge.

3.2.9 Horse Mackerel

Horse mackerel larvae were only found in 5 stations with a maximum number of 2 larvae m^{-2}. The stations were situated on the southwestern shelf edge and the Porcupine Bank (Fig. 10b). The occurrence and concentration of horse mackerel larvae was lower than previously recorded for the same time and area (Fives *et al.*, 2001). Horse mackerel spawning curves obtained during the triennial egg surveys show that in the majority of years peak spawning occurs towards the end of May (ICES, 1999, 2002). The concentration of horse mackerel larvae also increases in May and June (Fives *et al.*, 2001) it is therefore very likely that the main spawning event of horse mackerel was not covered by this survey.

3.2.10 Sprat and Herring

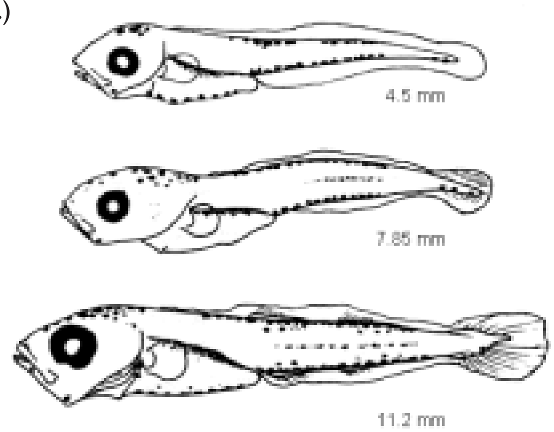
With an average of 45 larvae m^{-2} and a 59% occurrence, sprat was the most abundant and one of the most widespread species of fish larvae in the samples. The highest concentrations of sprat were noted in the inshore areas of the Celtic Sea (Fig. 11b). Herring larvae were found at 5 stations in the eastern Celtic Sea and one station west of Scotland (Fig. 11b). In the eastern Celtic Sea herring larvae were found close to established herring spawning grounds, however as

Celtic Sea herrings are autumn and winter spawners, it is not surprising that numbers of larvae found during the survey were small (Molloy, 1989).

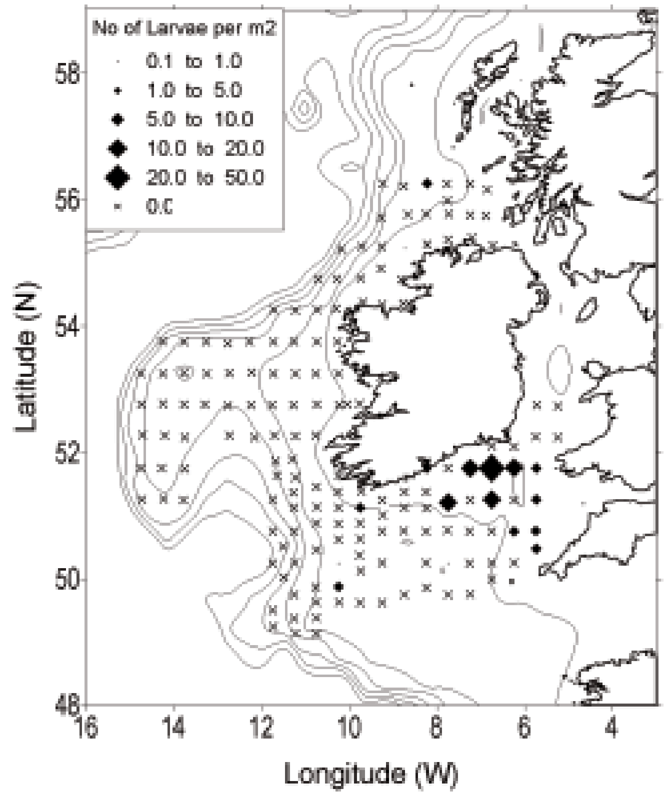
3.2.11 Blue Whiting

Blue whiting was moderately abundant, comprising 0.5% of the total larval count and occurring at 29% of all stations. Highest numbers of larvae were found on the Porcupine bank and along the shelf edge north and south of Ireland (Fig. 12). This agrees with the majority of studies who describe the Porcupine Bank as an important spawning ground for blue whiting (Bartsch and Coombs, 1997; Belikov, 1997; Kloppmann *et al.*, 2001). Smaller numbers were also found on the shelf edge west of Scotland as has previously been reported by Bailey and Heath (2001). The timing of blue whiting spawning occurs between late February and early May with a progressive spawning pattern (Bartsch and Coombs, 1997). Spawning commences north of Biscay in late February/early March, on the Porcupine Bank in mid March, and then occurs west of the Hebrides in April/May. Length frequency data from larvae found in the southern half of this survey indicate that peak spawning of blue whiting had occurred much earlier than the survey as most larvae were in the largest size category (McCarney, 2001). These data, however, do not include the concentrated patch found north of the Porcupine Bank. Blue whiting larvae were also found in shallower coastal stations in the eastern Celtic Sea and west of Ireland. This is surprising, as blue whiting larvae are normally associated with the shelf edge and deeper waters (Fives *et al.*, 2001; Horstman and Fives, 1994).

a.)



COD *Gadus morhua*	
No of Stations found	18
% Occurrence	11
Maximum No of Larvae found	12
Average No of Larvae m^{-2}	0.4



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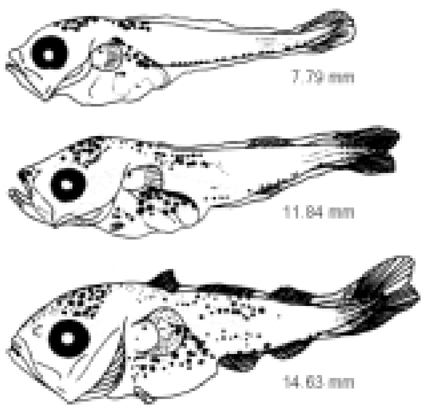


HADDOCK *Melanogrammus aeglefinus*	
No of Stations found	32
% Occurrence	19
Maximum No of Larvae found	8
Average No of Larvae m^{-2}	0.5

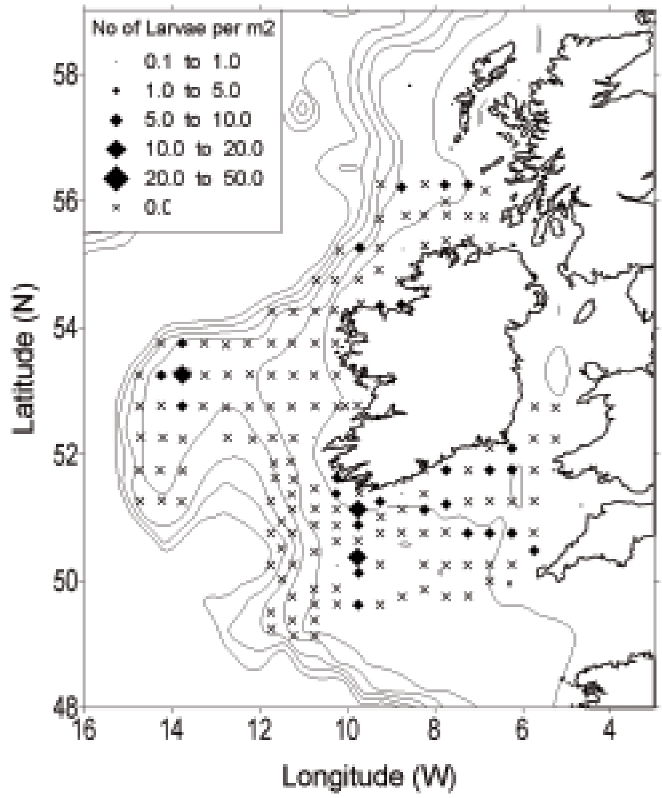
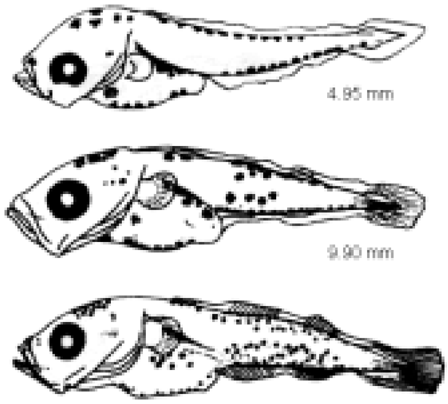
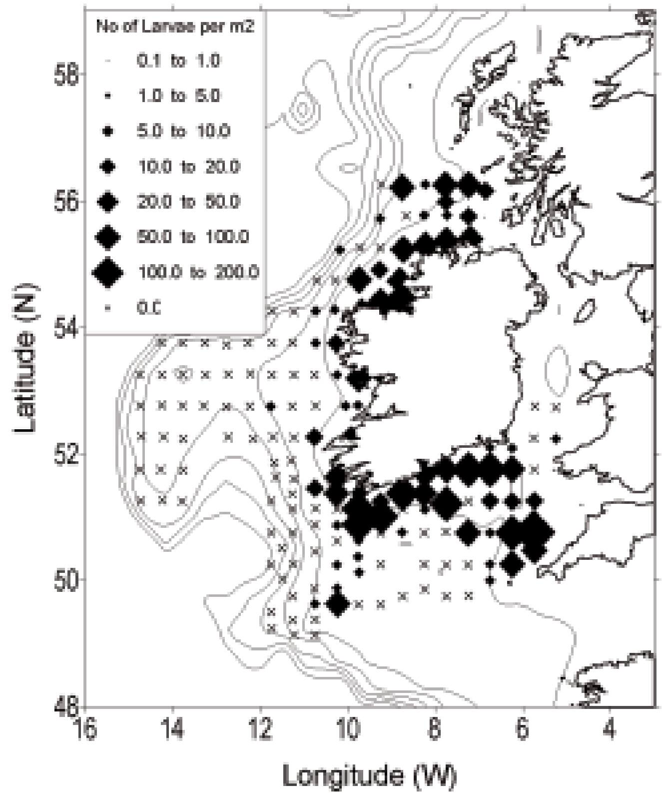


Fig.5 Larval images, occurrences and distribution maps of a.) cod (*Gadus morhua*) and b.) haddock (*Melanogrammus aeglefinus*) around Ireland during the Irish larval survey, 2000.

a.)



WHITING *Merlangius merlangus*	
No of Stations found	77
% Occurrence	46
Maximum No of Larvae found	55
Average No of Larvae m^{-2}	5.2



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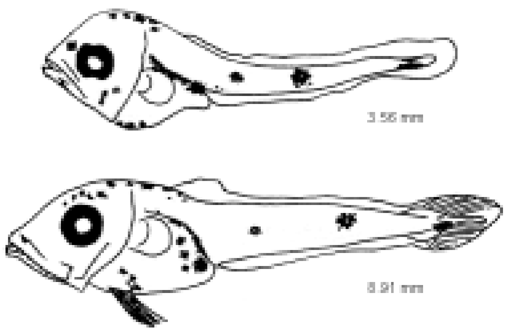


HAKE *Merluccius merluccius*	
No of Stations found	55
% Occurrence	33
Maximum No of Larvae found	34
Average No of Larvae m^{-2}	1.6

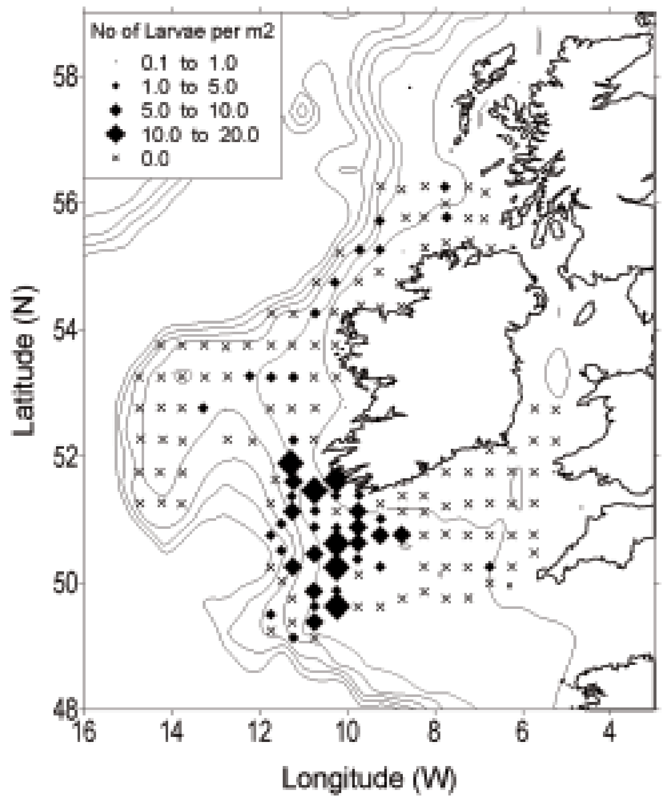
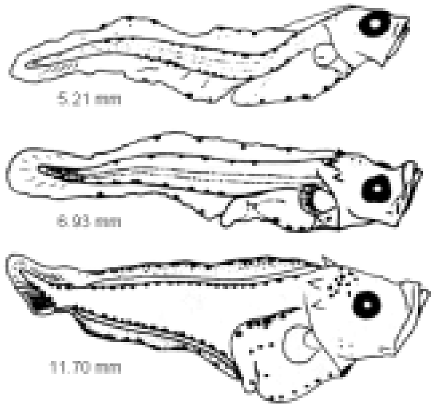
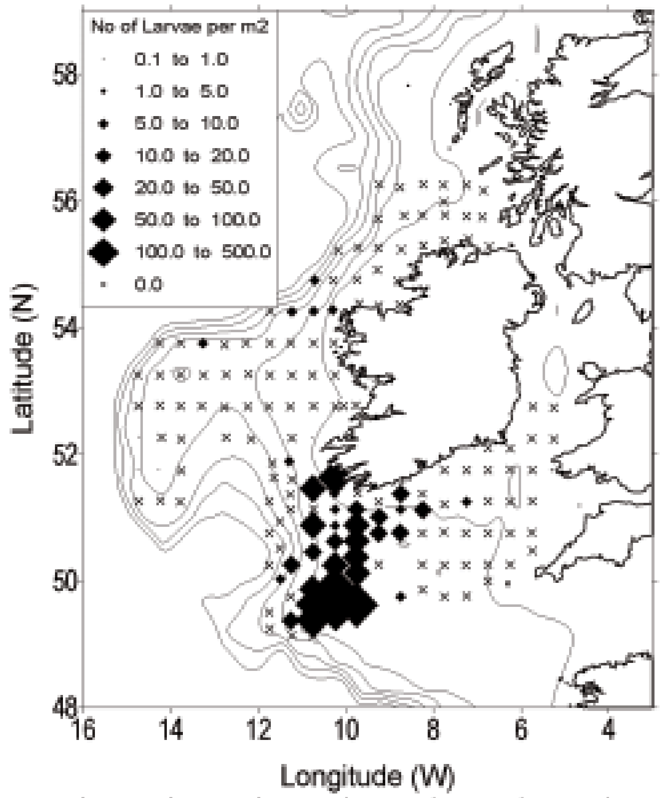


Fig.6 Larval images, occurrences and distribution maps of a.) whiting (*Merlangius merlangus*) and b.) hake (*Merluccius merluccius*) around Ireland during the Irish larval survey, 2000.

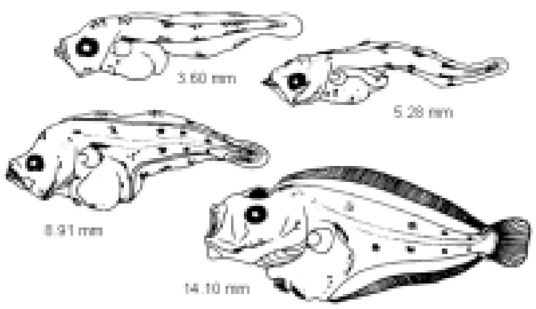
a.)



MEGRIM *Lepidorhombus whiffiagonus*	
No of Stations found	45
% Occurrence	27
Maximum No of Larvae found	112
Average No of Larvae m^{-2}	3.2



b.)



FOUR-SPOTTED MEGRIM *Lepidorhombus boscii*	
No of Stations found	32
% Occurrence	19
Maximum No of Larvae found	34
Average No of Larvae m^{-2}	1

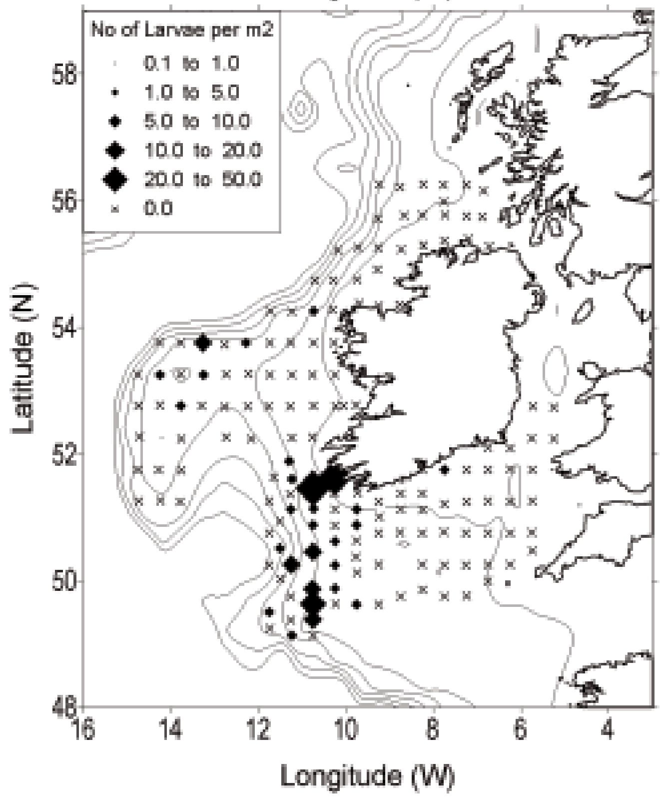
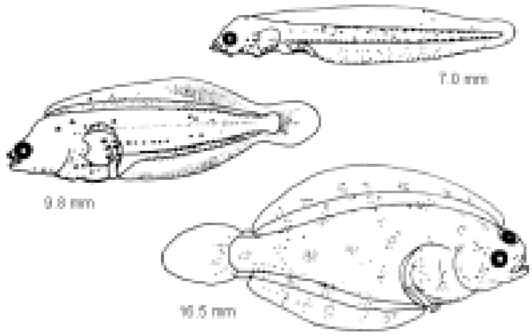
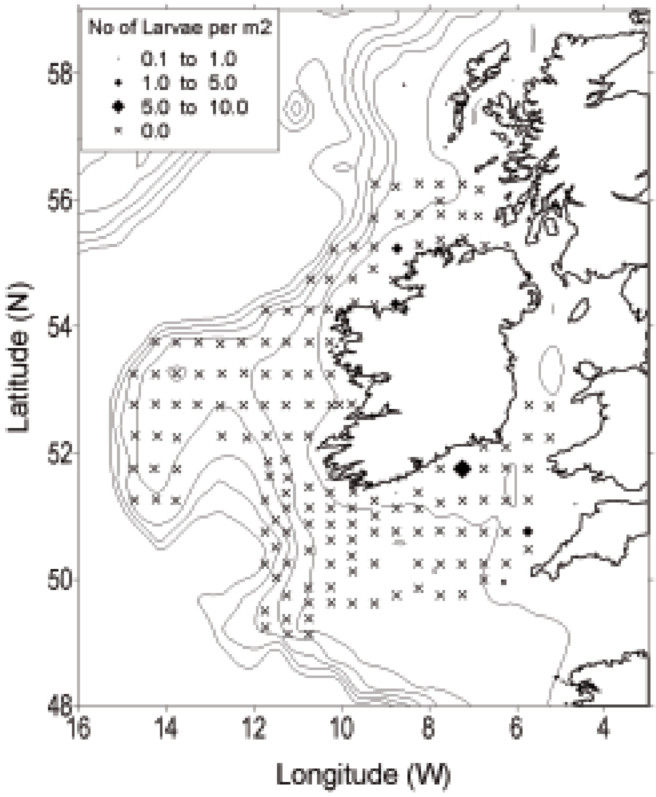


Fig.7 Larval images, occurrences and distribution maps of a.) megrim (*Lepidorhombus whiffigonus*) and b.) four-spotted megrim (*Lepidorhombus boscii*) around Ireland during the Irish larval survey, 2000.

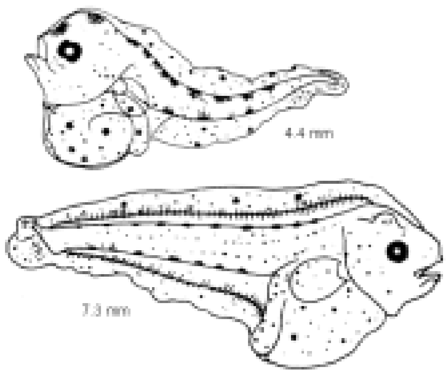
a.)



PLAICE *Pleuronectes platessa*	
No of Stations found	5
% Occurrence	3
Maximum No of Larvae found	9
Average No of Larvae m^{-2}	0.1



b.)



COMMON SOLE *Solea solea*	
No of Stations found	15
% Occurrence	9
Maximum No of Larvae found	20
Average No of Larvae m^{-2}	0.8

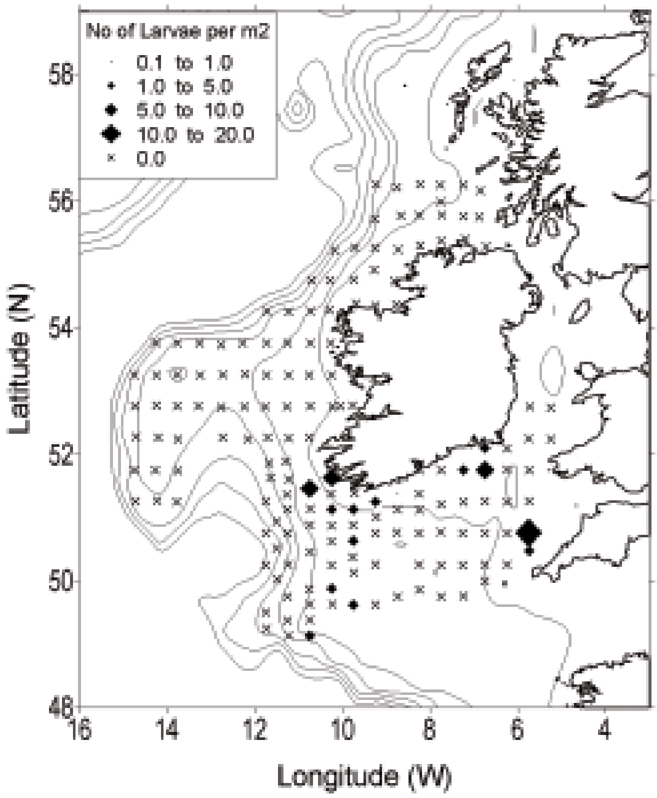
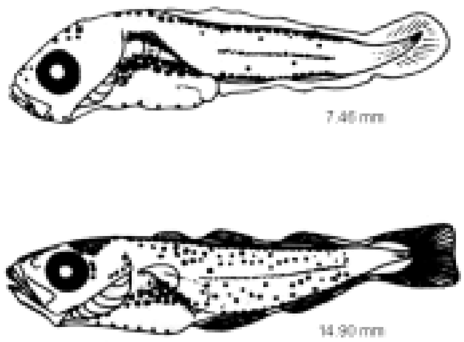
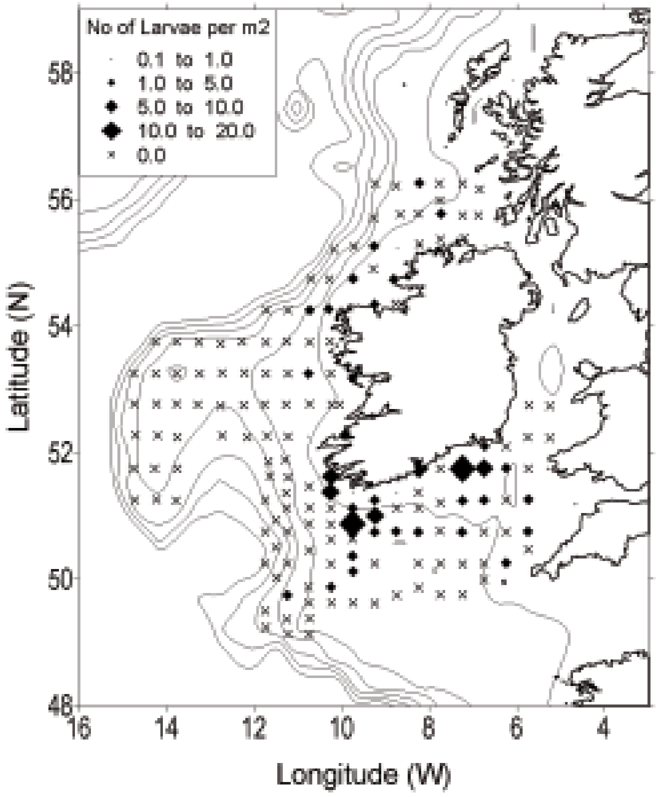


Fig.8 Larval images, occurrences and distribution maps of a.) plaice (*Pleuronectes platessa*) and b.) common sole (*Solea solea*) around Ireland during the Irish larval survey, 2000.

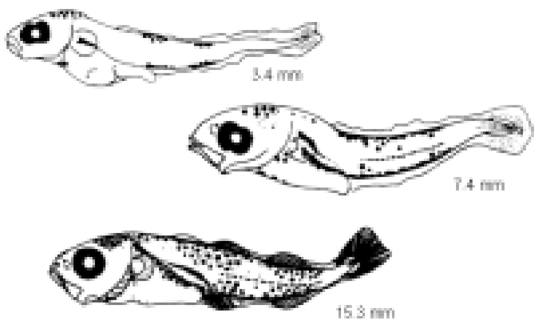
a.)



POLLACK *Pollachius pollachius*	
No of Stations found	42
% Occurrence	25
Maximum No of Larvae found	13
Average No of Larvae m^{-2}	0.7



b.)



SAITHE *Pollachius virens*	
No of Stations found	22
% Occurrence	13
Maximum No of Larvae found	8
Average No of Larvae m^{-2}	0.3

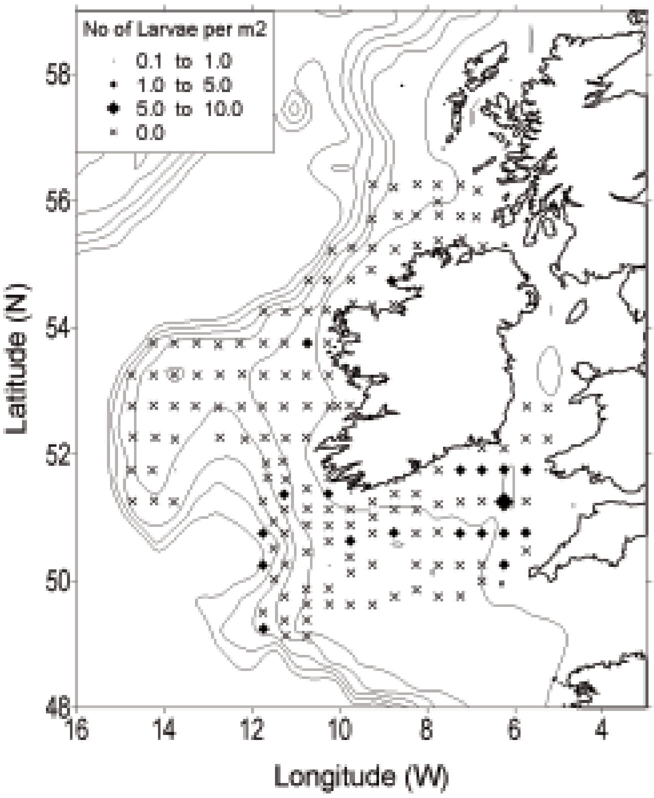
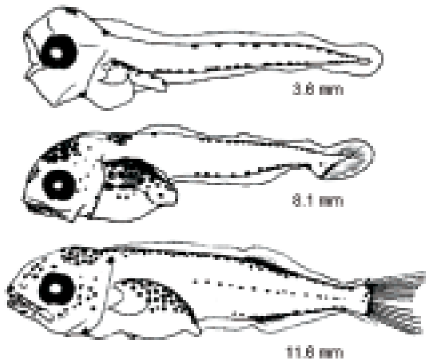
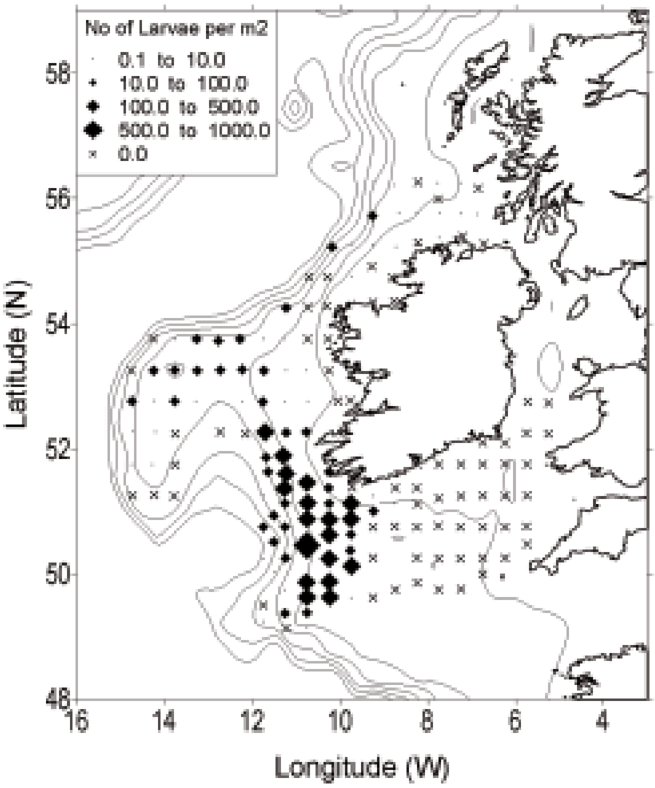


Fig.9 Larval images, occurrences and distribution maps of a.) pollack (*Pollachius pollachius*) and b.) saithe (*Pollachius virens*) around Ireland during the Irish larval survey, 2000.

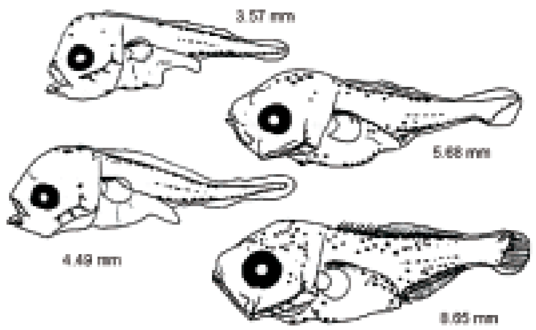
a.)



MACKEREL *Scomber scombrus*	
No of Stations found	92
% Occurrence	54
Maximum No of Larvae found	509
Average No of Larvae m^{-2}	37.4



b.)



HORSE MACKEREL	*Trachurus trachurus*	
No of Stations found		5
% Occurrence		3
Maximum No of Larvae found		2
Average No of Larvae m^{-2}		0.04

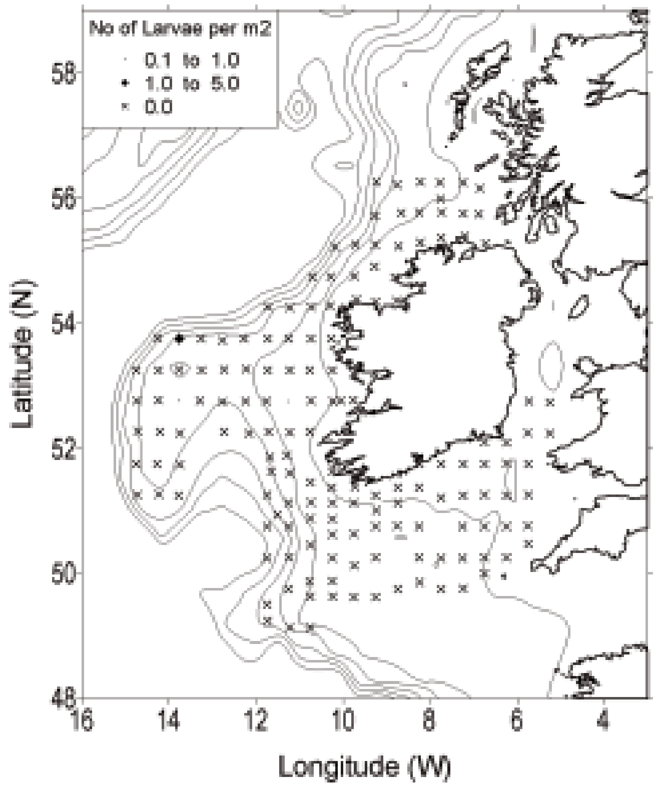
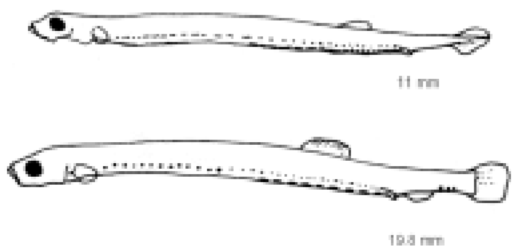
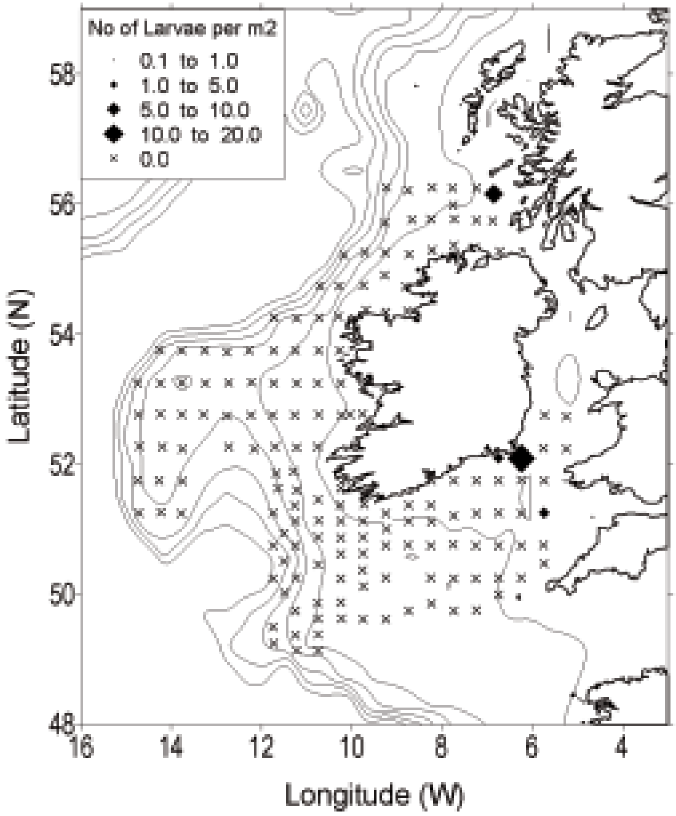


Fig.10 Larval images, occurrences and distribution maps of a.) mackerel (*Scomber scombrus*) and b.) horse mackerel (*Trachurus trachurus*) around Ireland during the Irish larval survey, 2000.

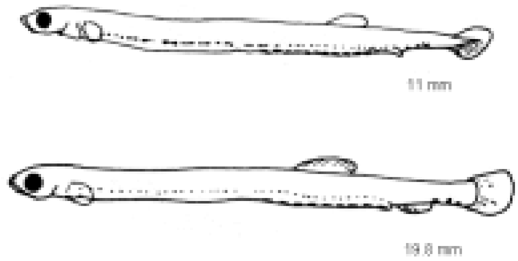
a.)



HERRING *Clupea harengus*	
No of Stations found	5
% Occurrence	3
Maximum No of Larvae found	13
Average No of Larvae m^{-2}	0.1



b.)



SPRAT *Sprattus sprattus*	
No of Stations found	100
% Occurrence	59
Maximum No of Larvae found	1339
Average No of Larvae m^{-2}	45.3

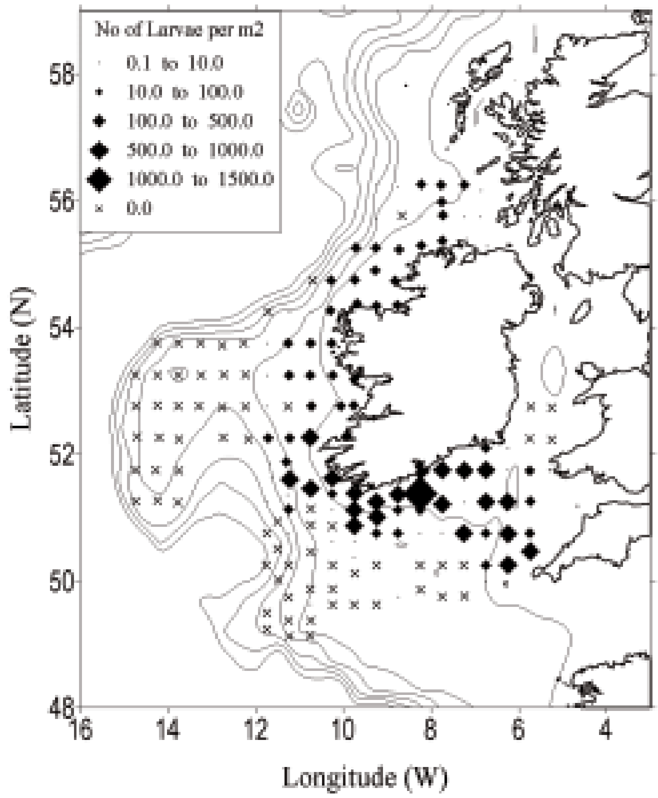
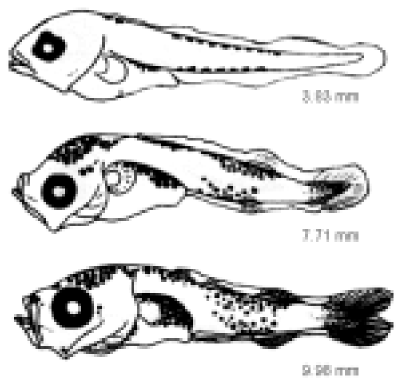


Fig.11 Larval images, occurrences and distribution maps of a.) herring (*Clupea harengus*) and b.) sprat (*Sprattus sprattus*) around Ireland during the Irish larval survey, 2000.

a.)



BLUE WHITING *Micromesistius poutassou*	
No of Stations found	48
% Occurrence	28
Maximum No of Larvae found	23
Average No of Larvae m^{-2}	1

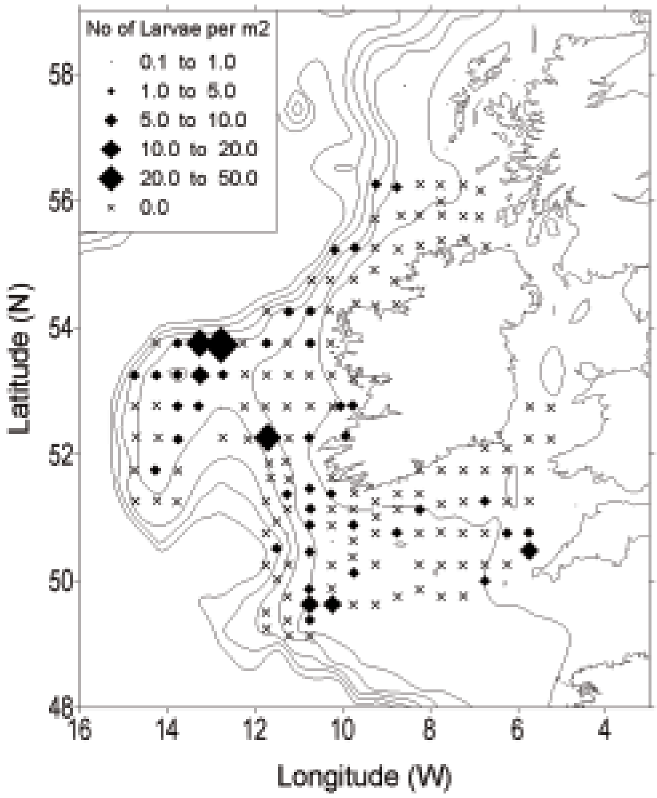


Fig.12 Larval image, occurrence and distribution map of blue whiting (*Micromesistius poutassou*) around Ireland during the Irish larval survey, 2000.

Family	Species	Common Name	% Abundance	% Occurrence
Agonidae	*Agonus sp.* (Schneider, 1801)		0.01	1.7
Ammodytidae	*Ammodytid sp.* (Reay)		1.15	28.5
	Ammodytes marinus (Raitt, 1934)	Sand Eel	2.03	16.3
	Ammodytes tobianus (Linnaeus, 1758)	Sand Eel	0.07	3.5
	Gymnammodytes semisquamatus (Jourdain, 1879)	Smooth Sand Eeel	0.03	1.7
	Hyperoplus immaculatus (Corbin, 1950)	Sand Eeel	0.10	3.5
	Hyperoplus lanceolatus (Lesauvage, 1824)	Greater Sand Eel	0.93	6.4
Angilidae	*Anguilliformes sp.* (Schrank, 1798)	Eel	0.003	0.6
Argentinidae	*Argentina sphyraena* (Linnaeus, 1758)	Argentine	0.69	38.4
	Nansenia groenlandica (Reinhardt, 1840)	Greenland argentine	0.03	2.9
Bathylagidae	*Bathylagus spp.* (Günther, 1878)		0.07	6.4
Blennidae	*Blennius gattorugine* (Bruennich, 1768)	Tompot Blenny	0.01	1.7
Bothidae	*Arnoglossus sp.* (Bleeker, 1862)	Scaldfish	0.01	1.7
	Arnoglossus thori (Kyle, 1913)	Thor's Scaldfish	0.02	2.3
Scopthalmidae	*Lepidorhombus boscii* (Risso, 1810)	Four-spotted Megrim	0.53	18.6
	Lepidorhombus whiffiagonis (Walbaum, 1792)	Megrim	1.75	26.2
	Phrynorhombus norvegicus (Günther, 1862)	Norwegian Topknot	0.45	19.8
	Scophthalmus rhombus (Linnaeus, 1758)	Brill	0.04	2.9
	Scopthalamus maximus (Linnaeus, 1758)	Turbot	0.01	1.2
	Zeugopterus punctatus (Bloch, 1787)	Topknot	0.32	17.4
Callionymidae	*Callionymus spp.* (Linnaeus, 1758)	Dragonet	10.50	80.8
Carangidae	*Trachurus trachurus* (Linnaeus, 1758)	Horse Mackerel	0.18	4.1
Carapidae	*Echiodon drummondi* (Thompson, 1837)	Pearl Fish	0.26	16.3
Clupeidae	*Clupidae sp.* (Whitehead)		1.94	25.0
	Clupea harengus (Linnaeus, 1758)	Herring	0.07	2.9
	Sardinia pilchardus (Walbaum, 1792)	Sardine	0.11	2.9
	Sprattus sprattus (Linnaeus, 1758)	Sprat	24.84	58.7
Cottidae	*Myxocephalus scorpius* (Linnaeus, 1758)	Bull Rout	0.01	0.6
	Taurulus bubalis (Euphrasen, 1786)	Sea Scorpion	0.03	3.5
	Taurulus lilljeborgi (Collet, 1875)	Norway Bullhead	0.01	1.2
Triglidae	*Trigla sp.* (Linnaeus, 1758)	Gurnard	0.01	0.6
	Aspitrigla cuculus (Linnaeus, 1758)	Red Gurnard	0.005	0.6
	Eutrigla gurnardus (Linnaeus, 1758)	Grey Gurnard	0.43	32.0

Table 1 Relative percentage abundance and occurrence of all species found.

Family	Species	Common Name	% Abundance	% Occurrence
Trigla lucerna	(Linnaeus, 1758)	Tub Gurnard	0.004	0.6
Gadidae	*Gadidae sp.* [Artedi, 1738] (Linnaeus, 1758)		0.17	8.7
	Gadiculus argenteus thori (Guichenot, 1850)	Silvery Pout	0.91	27.9
	Gadus morhua (Linnaeus, 1758)	Cod	0.21	10.5
	Melanogrammus aeglefinus (Linnaeus, 1759)	Haddock	0.27	19.8
	Merlangius merlangus (Linnaeus, 1758)	Whiting	2.84	44.8
	Micromesistius poutassou (Risso, 1826)	Blue Whiting	0.54	28.5
	Molva dypterygia (Pennant, 1784)	Blue ling	0.004	0.6
	Molva molva (Linnaeus, 1758)	Ling	0.56	33.1
	Phycis blennoides (Brunnich, 1768)	Fork beard	0.05	2.9
	Pollachius pollachius (Linnaeus, 1758)	pollack	0.41	24.4
	Pollachius virens (Linnaeus, 1758)	Saithe	0.19	12.8
	Trisopterus spp. (Rafinesque, 1814)		9.38	59.3
	Trisopterus luscus (Linnaeus, 1758)	Bib	0.19	7.6
	Raniceps ranius (Linnaeus, 1758)	Tadpole fish	0.03	1.2
	Gaidropsarus sp. (Rafinesque, 1810)	Rockling	1.68	43.6
Merluccidadae	*Merluccius merluccius* (Linnaeus, 1758)	Hake	0.87	33.1
Gobidae	*Ciliata mustela* (Linnaeus, 1758)	Five bearded rockling	0.07	2.3
	Antonogadus macrophthalmus (Günther, 1867)	Bigeye rockling	0.07	7.0
	Rhinonemus cimbrius (Linnaeus, 1766)	Four bearded rockling	0.003	0.6
	Aphia minuta (Risso, 1810)	Transparent goby	0.05	3.5
	Buenia jeffreysii (Günther, 1867)	Jeffrey's goby	0.68	33.1
	Crystallogobius linearis (von Duben, 1845)	Crystal's goby	0.19	11.0
	Gobisculus flavescens (Fabricius, 1779)	Two spot goby	0.02	3.5
	Gobius microps (Kroyer, 1840)		0.01	1.2
	Gobius paganellus (Linnaeus, 1758)	Rock Goby	0.01	1.2
	Lebetus scorpioides (Collett, 1874)	Diminutive goby	0.30	21.5
	Lebetus guilleti (Le Danois, 1913)	Guillet's goby	0.004	0.6
	Pomatoschistus norvegicus (Collett, 1902)	Norway goby	0.04	2.9
	Diplecogaster bimaculata (Bonnaterre, 1788)	Two spotted clingfish	0.03	2.3
Sternoptychidae	*Maurolicus muelleri* (Gmelin, 1788)	Pearl side	1.67	24.4
Labridae	*Labrus sp.* (Linnaeus, 1758)		0.01	0.6
	Crenilabrus melops (Linnaeus, 1758)	Corkwing wrasse	0.01	0.6

Table 1cont. Relative percentage abundance and occurrence of all species found.

Family	Species	Common Name	% Abundance	% Occurrence
	Labrus bergylta (Ascanius, 1767)	Ballan wrasse	0.08	7.0
	Labrus mixtus (Linnaeus, 1758)	Cuckoo wrasse	0.05	5.2
Lophiidae	*Lophius piscatorius* (Linnaeus, 1758)	Monkfish	0.04	1.7
Liparidae	*Liparis montagui* (Donavan, 1805)	Montagu's sea snail	0.01	1.2
Myctophidae	*Myctophid sp.* (Hulley)	Lantern fish	0.06	2.9
	Benthosema sp. (Goode & Bean, 1896)		0.13	4.1
	Benthosema glaciale (Reinhardt, 1837)	Glacier lanternfish	1.81	25.0
	Electrona rissoi (Cocco, 1829)	Chubby flashlightfish	0.003	0.6
	Lampanyctus crocodilus (Risso, 1810)	Jewel lanternfish	0.01	1.2
	Myctophum punctatum (Rafinesque, 1810)	Spotted lanternfish	0.12	6.4
	Notoscopelus sp. (Günther, 1864)		0.02	1.2
	Notoscopelus kroeyerii (Malm, 1861)	Lancet fish	0.02	1.7
	Protomyctophum (hierops) arcticum (Lutken, 1892)	Arctic telescope	0.01	0.6
Paralepidae	*Paralepis sp.* (Cuvier, 1817)		0.03	1.2
	Notolepis rissoi (Bonaparte, 1840)	Ribbon barracudina	0.18	8.7
	Paralepis coregonoides (Risso, 1820)	Sharpchin barracudina	0.03	4.7
	Paralepis elongata (Brauer, 1906)*		0.003	0.6
Pholidae	*Pholis gunnellus* (Linnaeus, 1758)	Rock gunnel	0.005	0.6
Pleuronectidae	*Pleuronectes sp.* (Linnaeus, 1758)		0.04	4.7
	Glyptocephalus cynoglossus (Linnaeus, 1758)	Witch	1.44	47.7
	Microstomus kitt (Walbaum, 1792)	Lemon Sole	2.02	56.4
	Limanda limanda (Linnaeus, 1758)	Dab	2.23	30.8
	Platichthys flesus (Linnaeus, 1758)	Flounder	0.07	1.7
	Pleuronectes platessa (Linnaeus, 1758)	Plaice	0.05	2.9
	Hippoglossoides platessoides (Fabricius, 1780)	Long rough dab	0.66	12.2
Scombridae	*Scomber scombrus* (Linnaeus, 1758)	Mackerel	20.81	55.8
Scorpaenidae	*Helicolenus dactylopterus* (Delaroche, 1809)	Red bream	0.31	16.9
Serrandiae	*Dicentrachus labrax* (Linnaeus, 1758)	Bass	0.01	0.6
Soleidae	*Solea sp.* (Quensel, 1806)		0.02	2.3
	Buglossidium luteum (Risso, 1810)	Solenette	0.01	0.6
	Solea solea (Linnaeus, 1758)	Common sole	0.22	8.7
	Microchirus variegatus (Donovan, 1808)	Thick back sole	1.32	30.8
Stichaeidae	*Chirolophius ascanii* (Walbaum, 1792)	Yarrell's blenny	0.01	0.6
Stomiatidae	*Stomias boa ferox* (Reinhardt, 1843)	Boa dragonfish	0.05	4.7
Trachinidae	*Trachinus vipera* (Cuvier, 1829)	Weever	0.01	1.2

Table 1cont. Relative percentage abundance and occurrence of all species found.

* previously only described in tropical waters

4 Conclusions

- The MI-NOAA 2000 ichthyoplankton survey was the first dedicated survey that covered waters around Ireland from the inshore to the shelf edge, south, west and north of Ireland. As a result it has provided important baseline data on the distribution of fish larvae around Ireland.

- The timing of the survey was adequate in covering the spawning and early larval stages of most species studied. This was evident from the size distribution of the different larvae and from comparisons to previously published data. Results of the survey did however not allow the identification of peak spawning events for different species, as this would require continuous monitoring of the spawning grounds between January and July and the construction of spawning curves.

- Results of the survey have shown that some species exhibit distinct distribution patterns and occur in patches of high abundance while other species are more widespread and discrete spawning grounds cannot be identified. Some of the areas of high larval concentration have been reported in the past indicating that the locations of spawning and larval habitats can be persistent over long periods of time.

- The survey identified two areas of high larval abundance and diversity: the eastern Celtic Sea close to St. George's Channel and the western Celtic Sea near the shelf edge.

- In the eastern Celtic Sea an area of high larval concentration was around Nymph's bank and west of St. George's Channel. Nearly all the cod larvae were found here, as well as whiting, haddock, pollack and saithe. The area also contained the highest number of gadoid eggs (unpublished results). On the southeastern side of St. George's Channel, close to Land's End, larvae also increased in numbers and in addition to the gadoid species flat fish such as sole and plaice were more abundant than elsewhere. SeaWIFS images indicate that primary production is enhanced in this area and so is the standing stock of plankton (McCarney, 2001), making this a potentially suitable area for successful larval survival and growth.

- The western and southern Celtic Sea along the shelf edge was also identified as a region of high larval abundance and diversity. It harbours high numbers of hake, megrim and mackerel. Satellite images suggest that in this area oceanic waters mix with shelf waters. In the first three weeks of the survey, primary production as shown by the SeaWIFS images was high in the north-western

Celtic Sea, where the shelf edge is closely situated to the coast. Later on during the survey, production also increased along the shelf edge further south suggesting the formation of a phytoplankton bloom. Higher levels of physical mixing due to upwelling and internal waves at the shelf edge are likely explanations for raised surface nutrient levels which in turn stimulated primary production (Pingree and Mardell, 1981). These productive waters provide good feeding conditions for the larvae thus improving their chance of survival.

- This report has focused on the larval rather than the egg distribution of fish. In order to identify the exact location of spawning grounds with confidence, the distribution of the earliest egg stages have to be used thus minimising the effects of dispersion over time. Deductions from egg distributions are, however, often hampered by the difficulties of positive species identification during the early egg stages. The eggs of gadoid species such as cod, haddock and whiting overlap in size range and can only be identified visually at late stages, while egg and oil globule sizes of mackerel, horse mackerel, megrim and hake also overlap, causing visual identification difficulties at early stages. The study of larvae and late egg stages is therefore a more reliable way of assuring accurate species identification. The relative distance of larvae from the spawning ground depends however on the degree of drifting and retention and conclusions about spawning grounds from larval distribution maps are only possible if the prevailing hydrography is properly understood. This emphasises the importance of including the study of ocean circulation in fisheries science. The development of a new Irish shelf circulation model that is being undertaken under the Marine Institute-NOAA project will greatly facilitate and improve the study into the early life stages of fish in Irish waters.

5 Acknowledgements

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