Growth of Atlantic herring larvae (Clupea harengus L.) in response to climatic long term trends (NAO) and to hydrographical features in the northern North Sea in the period 1990-1997.

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Abstract

Herring larvae were sampled during the IHLS in the ICES area IVa from 1990 to 1997. Larval growth was determined based on otolith microstructure analysis from larvae of 7-25mm standard length. The data were correlated to the North Atlantic Oscillation (NAO) and the inflow of Atlantic water (AW) at the same period. The study showed a strong correlation between positive NAO years with a higher inflow of AW and subsequently higher larval growth rates, which could be an indication of favorable growth conditions.

Introduction

The prospects of global warming and climatic change have reawakened the interest of many fisheries biologists in detectable correlations between recruitment and abiotic factors. Climatic change may be a cause of long term alterations in a particular fish stock abundance or in its geographical distribution, while shorter period environmental changes may be responsible for year-to-year variability in the recruitment of the young fish (Sheperd et al. 1984). The mechanisms whereby environmental change might affect recruitment include direct physiological responses in the young fish to changes in temperature and salinity or alteration of timing of food production cycles in relation to the feeding requirements of the young fish (Turrel 1992).

The North Atlantic Oscillation (NAO) is one of the major modes of climatic variability of the Northern Hemisphere. It exerts a strong control on the climate, especially in the winter months. The NAO has strengthened during the last years, reaching a historical maximum in the early 1990's. It has kept a positive tendency until 1996, when one of the most negative indexes of the last years was observed (Jones et. al 1997).

The hypothesis that changes on the sea surface temperatures (SST) in the North Sea occur as a result of local atmosphere-ocean processes was investigated by Becker & Pauly (1996). They found a coefficient of correlation between NAO and SST of 0.6 for the Central North Sea and 0.4 for the northern North Sea. It means that changes in SST are largely explained by the local air-sea changes that are depending on the North Atlantic atmospheric circulation. However, the most part of the heat obtained in the northern North Sea is from oceanic origin. During an investigation on the North Sea heat budget, Becker (1981) derived an average heat gain of 8 Wm^{-1} due to the advective transport from the North Atlantic. Thus, any change in strength and position of the North Atlantic current system will therefore influence the oceanographic conditions in the North Sea. Consequently, we can expect that changes in environmental conditions through the years of the study period might affect to the growth conditions and to the success of a given cohort.

Sheperd et al. (1984) found a correlation between recruitment and temperature for nine species in the North Sea. Corten (1990) suggests that most of the observed changes in fish stocks could be explained by the theory assuming a long term reduction of the inflow of Atlantic Water (AW) to the North Sea during the period 1960-1980, and an increase of this inflow in later years. Success in recruitment is related to the circulation patterns in the North Sea due to the larval transport process for herring (Bartsch et al. 1989).

Svendsen et al (1991) showed that an anomaly in large scale atmospheric climate, causing local anomalies of climate parameters such as air-sea heat exchange, combined with physical and oceanic parameters may be of prime importance for the recruitment success partly indirectly through their effect on primary and secondary production. Changes in the residual circulation of a shelf sea may influence the composition of the available food to the larvae by altering the advection of the planktonic stages, for example.

The eggs and larvae of fishes are of particular interest because it is generally held that younger stages are more susceptible to potentially harmful environmental effects than older individuals, and because they are so important for the recruitment of new fish into the population (Blaxter 1992). The larval phase of many marine fishes is characterized by a very high mortality. The transition period from endogenous to exogenous feeding has been considered a particularly critical period in the fish life history. If the larvae do not encounter sufficiently high densities of food during this period, they are bound to die from starvation (Hjort 1914).

According to the hypothesis linking growth and mortality rates in young fish (Sheperd & Cushing 1981, Houde 1987, 1989, Miller et al. 1988, Rice at al. 1993, Cushing and Horwood 1994) a survival advantage is accrued to fish which move quickly through a "mortality window" that is a period of several months during which as much as 99,99% of a cohort may die. A rapid growth rate through the larval and juvenile stages is thought to increase the probability of survival due to an enhanced ability to feed and avoid predators (Rice et al. 1993, Cushing & Horwood 1994).

In this study, growth rates were estimated based on the otolith microstructure analysis, which has proven a valuable tool in growth studies (Campana and Jones 1992). Herring larva otoliths (sagitta) deposit an increment (ring) daily (after the yolk sac consumption), which permits somatic and otolith growth rates estimation. As increment width (distance between two consecutive increments) reflects the growth pattern of fish (Geffen 1982, Moksness & Wespestad 1989, Moksness 1992) individual growth rates can be calculated.

The proposal of this study was to investigate the possible connection between variations in the North Atlantic Oscillation, the inflow of Atlantic Water into the northern North Sea, hydrographical conditions and their possible influences on herring larval growth.

Material and Methods

Herring larvae were collected during the International Herring Larvae Surveys (IHLS) at Shetland-Orkneys area (ICES area IVa) from 1990 to 1997. The samples were taken using

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a "Nackt-Hai" plankton sampler with a mesh size of 300μm (Nellen & Hempel 1969) at geographically fixed stations in the northern North Sea (Fig.1). Temperature and salinity were recorded by a sensor attached to the gear. Herring larvae were preserved in 96% ethanol. The standard length (from the snout to the end of the notochord) was measured under a stereo-microscope to the nearest 0.1 mm. No correction for larval shrinkage due to preservation in ethanol was made. The otoliths (*sagitta*) of 50 larvae per sampled year, in the size range of 7-23 mm, were removed and placed on glass slides (Campana 1992). Measurements on the otoliths were performed using a digitized computer video system (Leuttron) with a CCD camera (Sony XC-77CE) connected to a microscope (Leitz Labor Lux S) at 1000x magnification and immersion oil. Otolith readings were analyzed using an adaptation of the "Oto program" by Herwig Heilmann (IFM Kiel) (Campana & Neilson 1985, Jones 1986, Munk et al. 1991, Bühler & Clemmesen in prep.).

Somatic growth rates and otolith growth rates were analyzed by linear regressions based on larval aging, length and otolith radius measurements. Individual otolith growth rates were calculated based on daily mean increment width. Biological data were associated to the hydrographical features recorded during the sampling stations, the inflow of Atlantic water (AW) and North Atlantic Oscillation (NAO) data.

The NAO data presented in this study were kindly supplied by Dr. Phil Jones (Jones 1997). The inflow of Atlantic water (AW) in the northern North Sea was calculated based on a 3D-model from the Norwegian project NORWECON (Skogen 1993) and was kindly provided by Dr. Einar Svendsen (Skogen & Svendsen unpubl.). In order to evaluate the effect of the strengthening of the NAO in the last years on the hydrographical elements in the North Sea, a comparison between the NAO and inflow of Atlantic water (AW) was performed.

Results

NAO and the volume of AW inflow appear to be strongly correlated (Fig.2). A high positive NAO seems to be associated with a higher inflow of AW in the northern North Sea while a negative NAO is associated with a lower inflow of AW. There is an indication that the NAO feature (positive or negative) during the winter months regulates the amount of AW which enters in the North Sea (Fig.3). The years 1990, 1993 and 1997 showed a winter period marked by a positive NAO index and, consequently, a higher inflow of AW, which also could explain the high inflow in 1997 in spite of the negative annual mean. On the other hand, 1991 and 1996 were characterized by a winter period with negative NAO index values and distinguished by relatively lower inflows.

Analysis of STD (Salinity and Temperature vs. Depth) profiles (Fig.4) showed a relatively homogenous temperature distribution over the study period with exception of 1991, which was a warmer year. In 1990, 1993 and 1997 there was a notable presence of a thermocline although a mixed water column would be normally expected for this period (i.e. the thermocline breaks up at the beginning of autumn (Levitus 1989).

Comparisons between the sampling years showed a slight trend for a higher somatic growth rates (Fig.5a) as well as larger larval sizes in the years 1990, 1993 and 1997. This trend was stronger for the otolith growth rates, where growth rates were much higher in the years 1990, 1993 and 1997, but low in 1991 (Fig.5b).

The hatch check (first ring) was wider (about 1.2 μm) in the year-classes 1990, 1993 and 1997. These years showed an average otolith daily deposition increasing from 1.2μm at the centre to 2.1μm at the outer edge, while in 1992 and 1994 the increment width increased from 1.1 to 1.6 μm. In 1991 the mean increment width was approximately 1.1μm with practically no daily increase in increment width (fig.6).

Comparison of the NAO and inflow values and larval herring growth rates showed a clear link between years of a strongly positive NAO and a higher inflow with a tendency for higher larval growth rates.

Discussion

The present study revealed a strong correlation between NAO and the inflow of AW in the northern North Sea throughout the years. The strengthening of the westerly winds due to a positive NAO in winter months seems to promote the oceanic transport into the North Sea. A weakening of the westerlies due to a negative NAO may be related to a lower inflow.

Many authors would agree that a higher inflow of AW is advantageous for the North Sea. The AW contributes not only to the heat storage but also indirectly to the high productivity of this area. The relationship between strongly negative NAO indexes and the low inflow of AW is not clear. One could suggest that the weakening of the westerlies could influence the oceanic transport by changes in the current system. Levitus (1989) observed that during the negative phase of the NAO in the 1970s, the temperature and salinity changes implied base-wide rearrangement in the water density as a function of depth leading to a weakening of the Gulf Stream transport. Temperature anomalies can cause changes in timing of peak spawning and dislocation of spawning from traditional spawning grounds. Studying the pre-spawning herring movements in the Shetland-Orkneys area, Maravelias (1997) found that regions of deep thermocline (> 30m) were associated with high herring biomass and

that the highest average of pre-spawning herring abundance was mainly observed in waters with SST between 11° and 12°C. These observations support the hypothesis that the temperature profile of the water column and the geographic location are significant factors that might modulate presence and relative abundance of herring larvae within the northern North Sea ecosystem.

STD profiles recorded during the sampling stations for otolith analysis indicated the presence of a thermocline in 1990, 1993 and 1997. As the thermal stratification develops during the summer months (April - August) one might expect that such hydrographical features have already developed prior to the sampling. The later presence of stratification during these years compared to the well mixed water column found in other years could indicate that intense processes of breaking of thermal stratification and upwelling were still taking place, which could mean an increase of the primary production and slower decreasing of the transition zones between isothermally mixed and stratified waters. In other words, it is possible that the seasonal degeneration of the front, which varied in timing from year to year depending on the local weather conditions, was delayed in the years 1990, 1993 and 1997, which seemed to be advantageous for the larvae from these areas. Probably, the continuance of the stratification over a longer period was related to the inflow of AW. The northern North Sea bottom water is surrounded by a discrete and persistent inflow during the summer. In autumn, when the vertical mixing increases across the northern North Sea, little of the original bottom water remains. The temperature of the North Sea bottom is related to the degree of Atlantic inflow which occurs prior and during the winter (Turrel 1992).

The biological relationship between the larger larval sizes at hatching, wider hatch-checks and higher growth rates found in the year-classes 1990, 1993 and 1997 and the stratified water layer found at this area, in the same years, is not clear. It has been suggested that pre-spawning aggregations of herring follow the movements of zooplankton to deeper and cooler waters beneath the thermocline during summer (Maravelias & Reid 1997) and it is possible that such areas are used by repeated spawners not only due to the presence of food resources but also for spawning. The larval sizes at hatching are related to the egg sizes, which are directly influenced by the size of the mother. First time spawners produce smaller low quality eggs and have different spawning times than repeated spawners (Solemdal 1997), since recently mature and middle aged fish invest proportionally more energy resources into growth than into reproduction (Calow 1979). In contrast, larger females (repeated spawners) spawn larger eggs from which larger larvae hatch. Additionally, the temperature exerts influence on egg's incubation time and on larval size at hatching, thus lower temperature will produce slightly larger larvae at hatching and higher temperatures will produce slightly smaller larvae (Blaxter 1992, Bühler & Clemmesen in

prep.). Larger eggs produce larger larvae which tend to have higher survival changes because mortality in the sea is inversely related to body size (Peterson & Wroblenski 1984).

In conclusion, the present study showed that the strengthening of the positive NAO indexes in the last years has contributed to higher inflow of Atlantic water into the northern North Sea. Consequently, this may have contributed to an improvement of the hydrographical conditions in the herring's spawning area in the northern North Sea in 1990, 1993 and 1997. These may be responsible for the increased larval otolith and somatic growth rates, which could be indicative of better larval condition .

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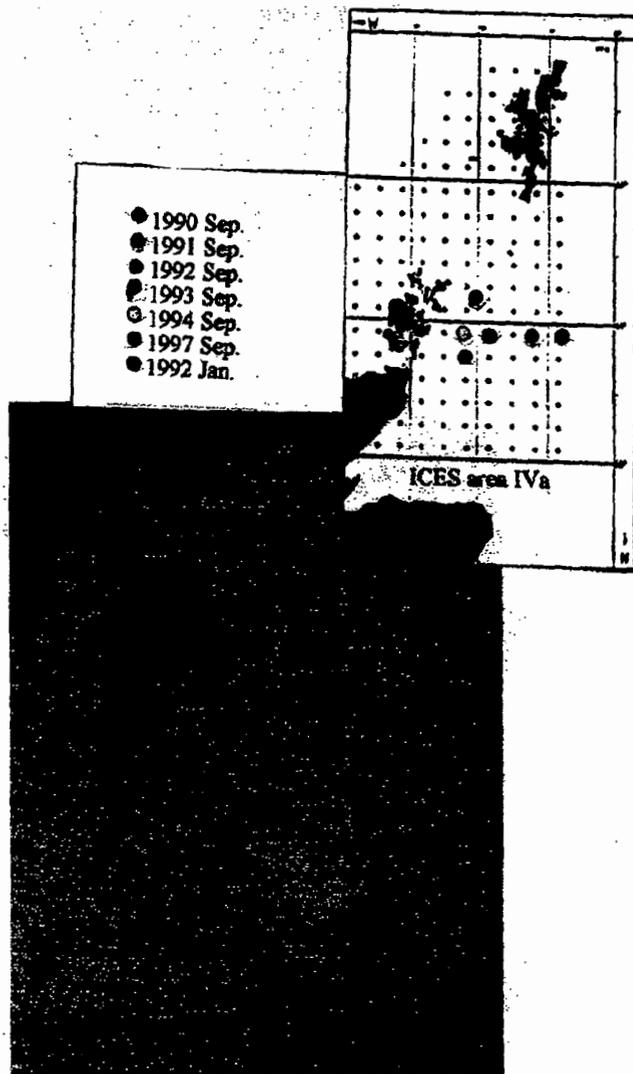
Fig 1. Sampling stations of herring larvae for otolith analysis in the North Sea. Legend:points represent the geographical position of the stations and colours the respective sampling years.
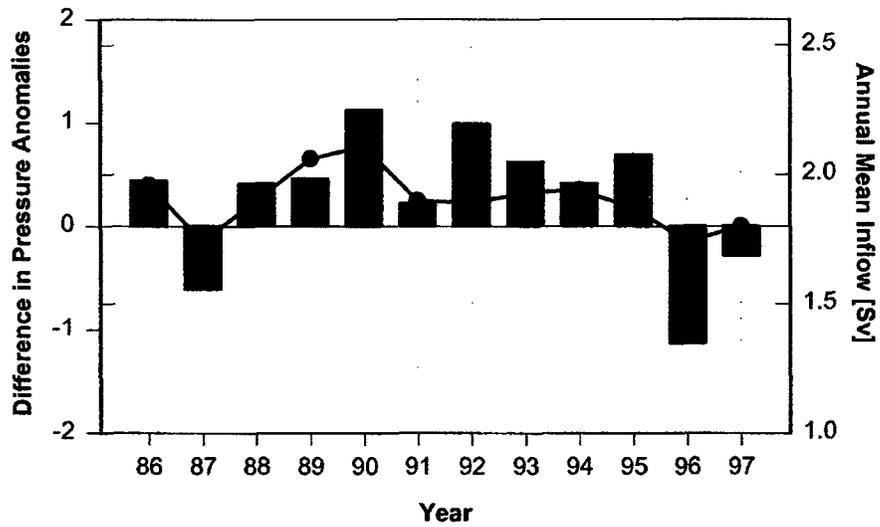
Fig 2. Bars show annual mean values for the NAO index during the period 1986 to 1997. Line and symbols represent the respectively annual mean inflow of Atlantic water.
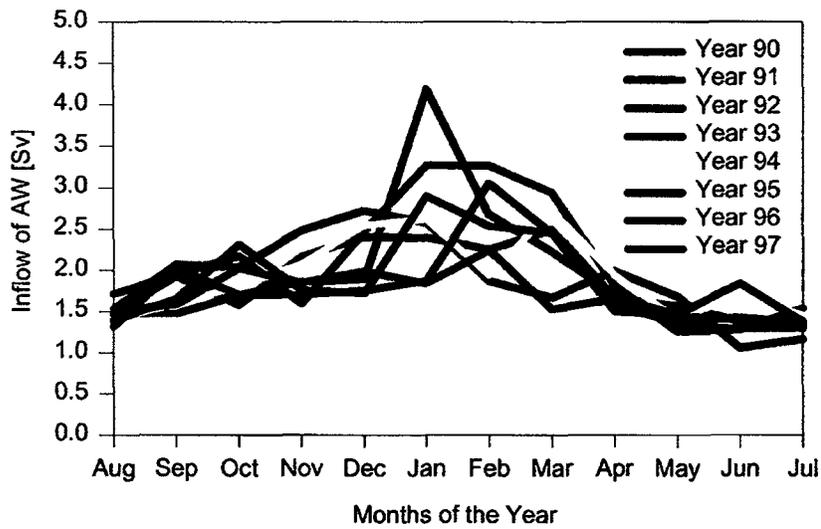

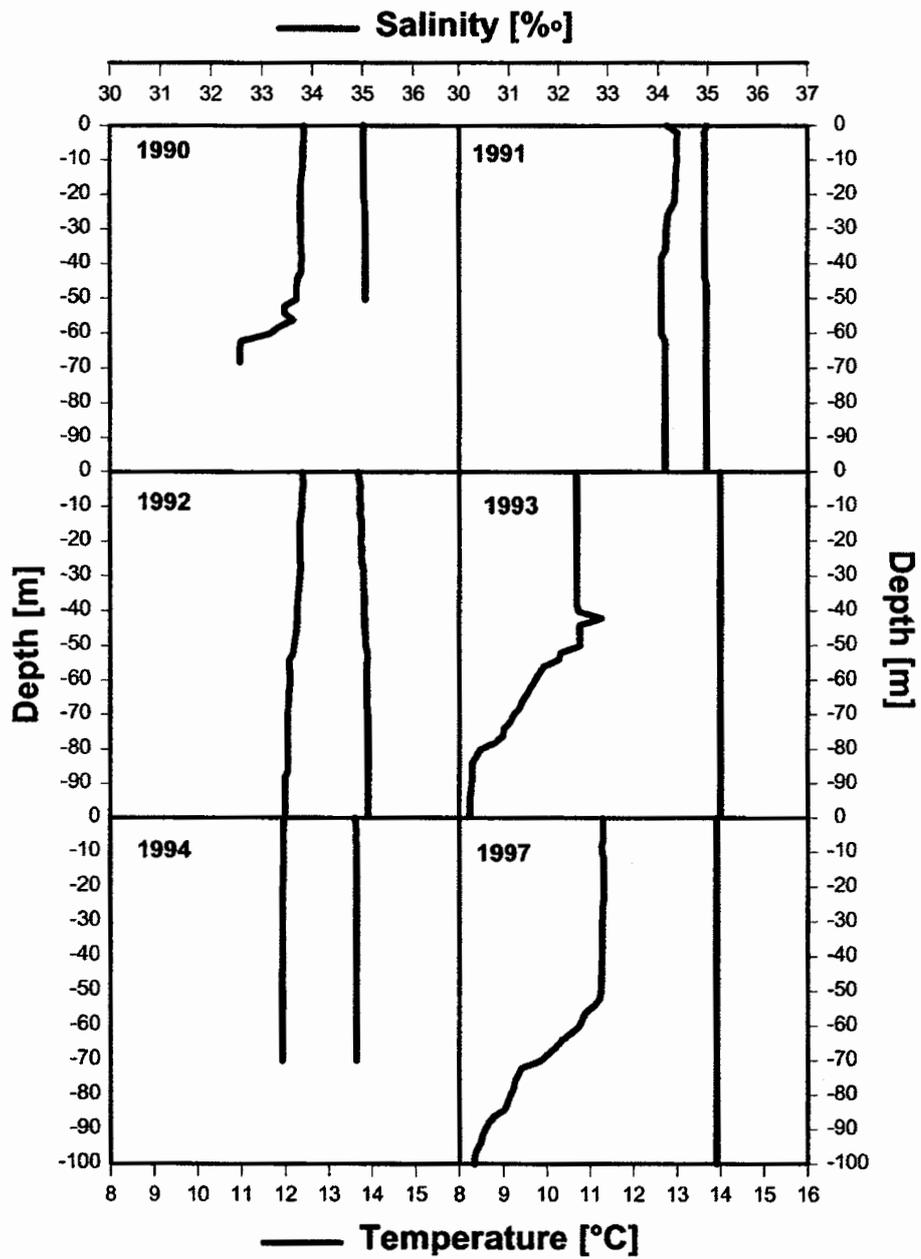Fig 3. Lines represent the monthly inflow of Atlantic water in the northern North Sea in 1990-1997.

Fig 4. Profiles indicate hydrological conditions at the stations during the herring larval sampling.
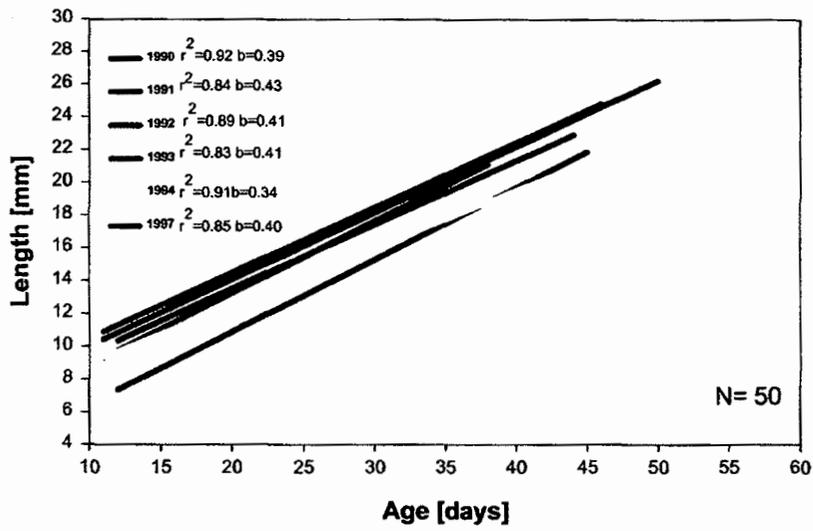
Fig 5a. Somatic growth rate estimates for the different year-classes of herring larvae are given by the slope (b) from the linear regressions (L=a+ bx), in mm/d.
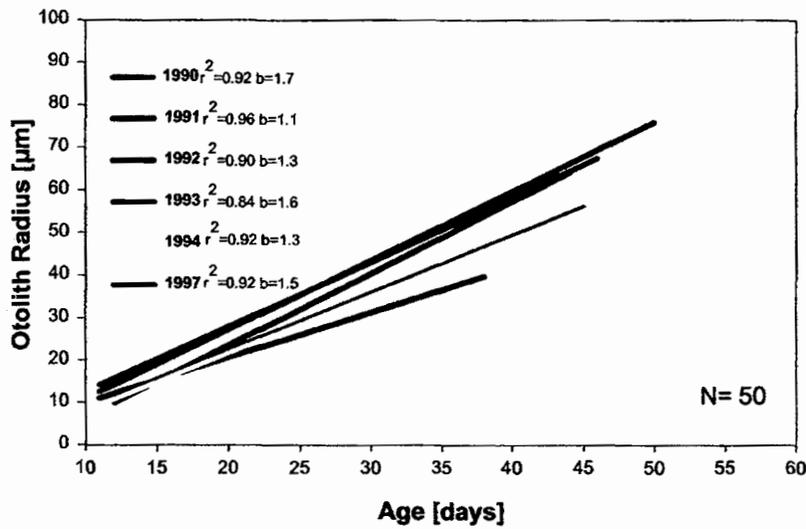

Fig 5b. Otolith growth rate estimates are given by the slope (b) from the linear regressions (L=a+bx) for each year-class, in μm/d.
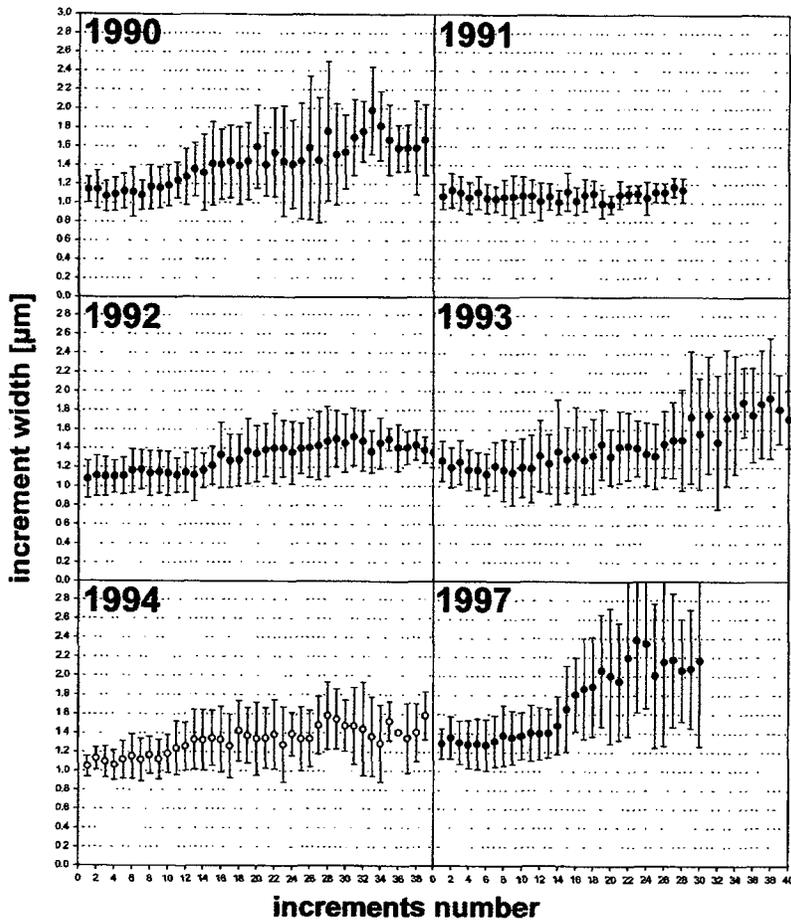
Fig 6. Mean increment width of each increment (1st,2nd,3th...) of
herring larvae otoliths for the years of the study period. Error bars
give the standard deviation. Measurements were done for N= 50
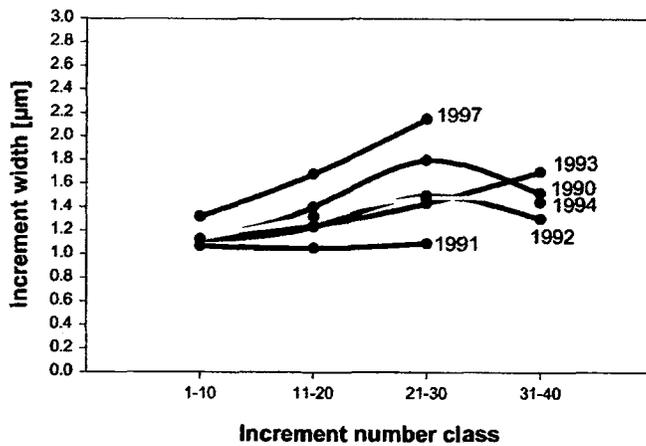larvae per year-class.

Fig 7. Mean increment width vs. increment number classes
(ten increments per class) compared among the years of
the study period.