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The relation between the spatial distribution of early juvenile cod (*Gadus morhua* L.) and zooplankton biomass in the Barents Sea

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Abstract

The year class strength of Arcto-Norwegian cod (*Gadus morhua* L.) in the Barents Sea is extremely variable. One of the key indicators for a possible strong year class is water temperature since good year classes may be produced in warm years while they seldom if ever occur in cold years. Water temperature alone is not sufficient to produce a good year class. Thus it is conjectured that when there is a strong flow of Atlantic water from the Norwegian Sea into the Barents Sea it not only warms the water but transports large quantities of zooplankton and hence provides better survival conditions for cod. Survey data from the Barents Sea for the years 1977 through 1984 are examined to determine the relation between zooplankton abundance and the spatial distribution of juvenile cod and to investigate if zooplankton abundance is associated with the flow of Atlantic water. For all years, more zooplankton on average were found in areas with cod than in those without cod. Total zooplankton abundance increased significantly in the Barents Sea concurrently with an increased inflow of Atlantic waters in 1981.

Key words: Early juvenile cod, temperature, year class strength, zooplankton biomass.

Introduction

Many factors may influence the growth, survival and abundance of early juvenile cod in the Barents Sea. These include spawning stock biomass, maternal effects, climatic conditions, predation and zooplankton abundance. The main indicator for the production of a good yearclass (abundance at age three) of Arcto Norwegian cod appears to be water temperature during their first year of life (Sætersdal and Loeng 1987; Sundby *et al.*, 1989). Good year classes only occur during warm periods, but warmer temperatures do not guarantee a good year class (Ellertsen *et al.*, 1987). Changing water temperature in the Barents Sea is a result of a variable influx of warm Atlantic water and an upward trend in temperature signals an increasing rate of flow (Ådlandsvik, 1989). The inflowing Atlantic water transports the calanoid copepod, *Calanus finmarchicus*, which is the primary food for juvenile cod (Wiborg 1948; Sysoeva and Degtereva, 1965; Ellertsen *et al.,* 1984; Helle 1994), from their main overwintering and spawning grounds in the Norwegian Sea to the Barents Sea (Skjoldal and Rey, 1989). The total zooplankton biomass in the Barents Sea can vary yearly by a factor of ten and the changing inflows of Atlantic water seem to play an important role in this phenomenon (Skjoldal and Rey, 1989).

The question naturally arises whether there is a connection between the abundance of zooplankton and the survival and abundance of juvenile cod. The spatial distributions of zooplankton and juvenile cod are highly patchy and thus it is unlikely that a deterministic relation would be observable in the field between the amount of zooplankton and the abundance of juveniles at a station. For it is a matter of chance that a patch of juveniles drifting northward from the spawning grounds around Lofoten (Figures 1 and 2) is in or reaches an area of high zooplankton abundance. Conversely, an area rich in zooplankton may by chance be devoid of juveniles. Thus the amount of zooplankton and juveniles that are at a station initially is due to a dynamic classical 'match-mismatch' process. Furthermore, it is also a probabilistic event, which will depend on factors such as predation, starvation and the number of juveniles that originally drifted into an area, whether any juveniles survive to be observed.

Even though the factors affecting juvenile cod survival in the Barents Sea are highly stochastic, one would expect to find juveniles in areas that have, on average, larger quantities of zooplankton if greater zooplankton abundance does enhance the survival capability of juveniles. Helle (1994) found, based on survey data, that in 1989 average zooplankton abundance was significantly higher in areas where juvenile cod occurred in the Barents Sea than in those areas where juveniles were not observed.

Surveys of juvenile cod and zooplankton were conducted by the Institute of Marine Research (IMR), Bergen, in the Barents Sea from 1977 through 1984. During this period the water in the Barents Sea was relatively cold through 1982. However in 1981 the temperature started to rise signalling an increased inflow of Atlantic water (Loeng *et al.*, 1992). In this study we found that juvenile cod tended to be in areas of higher zooplankton abundance in all the years 1977 through 1984, as was the case in 1989, and that total zooplankton abundance rose concurrently with the increased inflow of Atlantic water into the Barents Sea that began in 1981.

Materials and methods

The IMR conducted early juvenile pelagic trawl surveys from 1977 to 1991 along the coast of northern Norway and in the western Barents Sea (Figure 1). The primary objective of the surveys was to estimate the abundance of early juvenile fish with particular emphasis on early juvenile cod (ages 2-3 months). The survey design was adapted yearly to cover the geographical distribution of the early juvenile cod and, therefore, the region surveyed varied slightly from year to year. The surveys were conducted in June and July except for the survey in 1977 which was in July and August (for details on the design of the surveys see Bjørke and Sundby, 1987). In order to make the survey region uniform over the time series and to cover the major drift area of juvenile cod, the survey region for this paper was restricted to the area off shore and north of 67° N (Figure 1).

The early juveniles were sampled with a Harstad midwater trawl in all years except in 1977 when an Asterias midwater trawl was used. The codends contained a 4 meter long inner net which had a 5 mm mesh size (stretched hexagonal meshes). At each station juvenile cod were sampled at three depths; 40m, 20m and at the surface (for details on sampling techniques see Bjørke and Sundby, 1987).

Zooplankton samples were also taken at a most stations from 1977 to 1984. A Juday net, with an opening diameter of 36 cm and a mesh size of 180 μm, was lowered to 20 or 200 m and then raised vertically to the surface. Zooplankton samples from 20m were taken in 1977, 1980 and from 1982 to 1984. Samples from 200 m were made in all years except in 1980. The zooplankton samples were hosed down into the codend, the surplus water was drained and the volume of the zooplankton measured to the nearest ml. The data were recorded as ml of zooplankton per square meter of surface area. The

20m data were used to interpolate a value for 200m in 1980 in order to have a continuous time series of 200m zooplankton estimates for the entire period.

The sampling distributions of zooplankton values have large variances and are skewed to the right, which are typical characteristics of marine data. The lognormal distribution often provides a good approximation to the sampling distribution of skewed marine survey data (Pennington, 1996). Estimators based on the lognormal distribution tend to be more efficient for marine data and, perhaps more importantly, the associated confidence statements are more accurate (McConnaughey and Conquest, 1992; Pennington, 1996). Therefore estimators based on lognormal theory were used to estimate the abundance of zooplankton and its variance (see Pennington, 1996 for details).

The presence or absence of juvenile cod at a station was used as an indicator variable to define the two subareas of interest in this study (or 'domains of study', see Cochran, 1977); the subarea of the survey region containing juvenile cod and the subarea where they did not occur. The mean abundance of zooplankton, based on lognormal theory, was estimated in each subarea for every year. The abundance estimates for the two domains are unbiased and uncorrelated (Cochran, 1977).

Results

For the years 1977 through 1984, the spatial distributions of zooplankton were similar in nature. In each year a region with high zooplankton densities was observed on the Tromsøflaket bank with a branch extending north toward Bear Island along the West Spitsbergen Current and another branch following the North Cape Current into the Barents Sea (Figures 1 and 2). Before the water began to warm in 1981 (Loeng *et al.*, 1992), the highest concentrations of zooplankton were in the southern and western parts of the survey area and afterward the highest zooplankton densities were observed more to the north and east. The spatial distributions of juvenile cod during this period were generally similar to those for zooplankton (for detailed maps of the spatial distribution of the juveniles, see Bjørke and Sunby, 1987).

Figure 3 shows the estimated mean levels, along with 80% confidence intervals, of zooplankton biomass (ml m^{-2}) within 200m of the surface in the survey area for the years 1977 through 1984. The estimated mean zooplankton biomass was lowest in 1977, the beginning of a cold period (Loeng *et al.*, 1992), and rose steeply and significantly ($p < .05$) in 1981, the year the water temperature began to increase. The average zooplankton abundance during the years before the warming trend began in 1981 was 61.3 ml m^{-2} and afterwards the average abundance was 85.1 ml m^{-2}. Though not statistically significant, the zooplankton biomass appeared to fluctuate at a higher level in the years 1981 through 1984 than in the period before the warming trend began. The estimated zooplankton abundance was consistently and significantly higher ($p < .01$) in areas where juvenile cod were observed than in areas without cod (Figure 4). The estimated fraction of the survey area occupied by juvenile cod was .81 when the cold period began in 1977 and then continuously declined to a low of .35 in 1980 (Figure 4). During this period, 1977 to 1980, when the area occupied by the juveniles declined, the average abundance of zooplankton in areas with juveniles increased to a peak in 1980 (Figure 4). In 1979 and 1980 the area occupied by the juveniles was significantly smaller than it was in the other years ($p < .01$), and for these two years the spatial distribution of zooplankton was considerably more patchy than in the previous and subsequent years. After warming began in 1981, the fraction of the area occupied by juvenile cod stabilised at around .8.

Discussion

For all the years in this study, the average biomass of zooplankton in areas where juvenile cod were observed was higher than in areas without juveniles. This result is consistent with similar observations in the Barents Sea for the period 1959 through 1961 (Sysoeva and Degtereva, 1965) and for 1989 (Helle, 1994).

Early juvenile cod have a limited ability to move on their own over large distances (Sundby 1995). The tendency for juveniles to be in areas of higher zooplankton abundance may be due to enhanced survival as a result of currents bringing the two together by chance or it may simply indicate better survival of cod in the original drifting patch of zooplankton and juveniles.

No relation was detected in any year between the number of juveniles at a station and the abundance of zooplankton. This may be due to sampling variability or because the survival probability of an individual is, for the most part, only a function of zooplankton density. That is there may be little competition for food amongst individual juveniles since, perhaps, the density of juveniles is relatively low compared with the abundance of zooplankton at a station. The basic difficulty in detecting a direct relation between juvenile abundance and the absolute level of zooplankton in the field is that only the juveniles that survive are observed and the number of juveniles that were originally (or at an earlier time) in an area is usually unknown.

Estimates of the total zooplankton abundance in terms of volume is an approximate measure of the amount of suitable prey available for the juveniles. *Calanus finmarchicus* is the most important item in the diet of juvenile cod (Wiborg 1948; Sysoeva and Degtereva, 1965; Ellertsen *et al.*, 1984; Helle 1994) and around 80% of the zooplankton biomass in the Barents Sea is composed of *C. finmarchicus* (Dragesund and Gjøsæter, 1988). Helle (1994) found that the total biomass of zooplankton was higher in the Barents Sea, on average, in areas where juvenile cod occurred in 1989 than in areas without juveniles, but the strongest relation was between the amount of *C. finmarchicus*, copepodite stages IV and V, and the occurrence of juvenile cod. Thus Figure 4 may understate the strength of the relation between (suitable) prey density and the survivability of juvenile cod.

A cold period started in 1977 and the first six years are considered cold years while 1983 and 1984 are classified as warm years (Loeng *et al.*, 1992; Ottersen *et al.*, 1994). The temperature started to increase sharply during the summer of 1981 (Loeng *et al.*, 1992) indicating an increased inflow of warm Atlantic water during 1981. The estimated abundance of zooplankton in 1981 was at the highest level observed during the eight year period while the abundance in 1977, the start of the cold period, was significantly lower than all the other years (Figure 4).

The relative importance of the inflow warm Atlantic water into the Barents Sea as a carrier of zooplankton or as an enhancement for the primary production of plankton in the Barents Sea is unknown (Skjoldal and Rey, 1989). Given that the estimated zooplankton biomass was highest in 1981, the year the inflow of Atlantic water appeared to be greatest, supports the hypothesis that transport plays an important role, especially since in the three subsequent warmer years zooplankton biomass was lower than in 1981.

In addition to transporting zooplankton into the Barents Sea, the inflow of Atlantic waters will have an overall warming effect that should enhance the growth rate and hence the survival of the juveniles (Sundby *et al.*, 1989; Loeng *et al.*, 1995). Though temperature is an important factor, temperature is not the only environmental condition that determines the growth rate of juveniles (Loeng *et al.*, 1995) or adult cod (Nakken and Rakness, 1987) in the field.

Loeng *et al.* (1995) estimated the growth rates of cod in the Barents Sea from the early juvenile period to the 0-group stage for the years 1977 through 1991. The estimated average growth rate from 1977 through 1980 was 0.62 mm day $^{-1}$, the rate increased sharply from 0.67 mm day $^{-1}$ in 1980 to 0.81 mm day $^{-1}$ in 1981 (the year zooplankton biomass peaked, Figure 3) and averaged 0.79 mm day $^{-1}$ during the years 1981 through 1984 (see Table 1 in Loeng *et al.*, 1995). Hence in spite of the fact that the water temperature in the Barents Sea was relatively cold until 1983, the growth rate increased parallel with the increase in zooplankton biomass in 1981. Loeng *et al.* (1995) observed that even though growth rate and temperature were positively correlated ($r = 0.70$), the growth rate in 1985, a cold year, was relatively high (0.95 mm day $^{-1}$). They conjectured that a high inflow of Atlantic water into the Barents Sea in early 1985 had transported large amounts of zooplankton into the sea which provided favourable conditions for growth (Loeng *et al.*, 1995).

The increased inflow of Atlantic water in 1981 appears to have signaled a more suitable climate for the production of cod. In Table 1 are the average abundance indices for zooplankton biomass, juvenile cod, 0-group cod, and their ultimate abundance as three year olds for the years 1977 through 1980 and the period 1981 through 1984. Not only was the average abundance of zooplankton higher in the latter period than in the earlier one but so was the estimated abundance of cod as juveniles, two months later at the 0-group stage, and even three years later as recruits (Table 1).

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Table 1. Comparison of the average abundance indices for zooplankton, juvenile cod, 0-group cod (Anon. 1996a) and as 3 year olds (Anon., 1996b) in the Barents Sea for the years 1977 through 1980 and 1981 through 1984.

	Average zooplankton biomass (ml m^{-2})					
Years	Total area	Area with cod	Area without cod	Relative abundance of juvenile cod	Relative abundance of 0-group cod	Relative abundance as 3-year olds
77-80	61.3	80.4	44.4	105.1	105.5	156.3
81-84	85.1	91.2	61.7	632.4	262.8	541.5

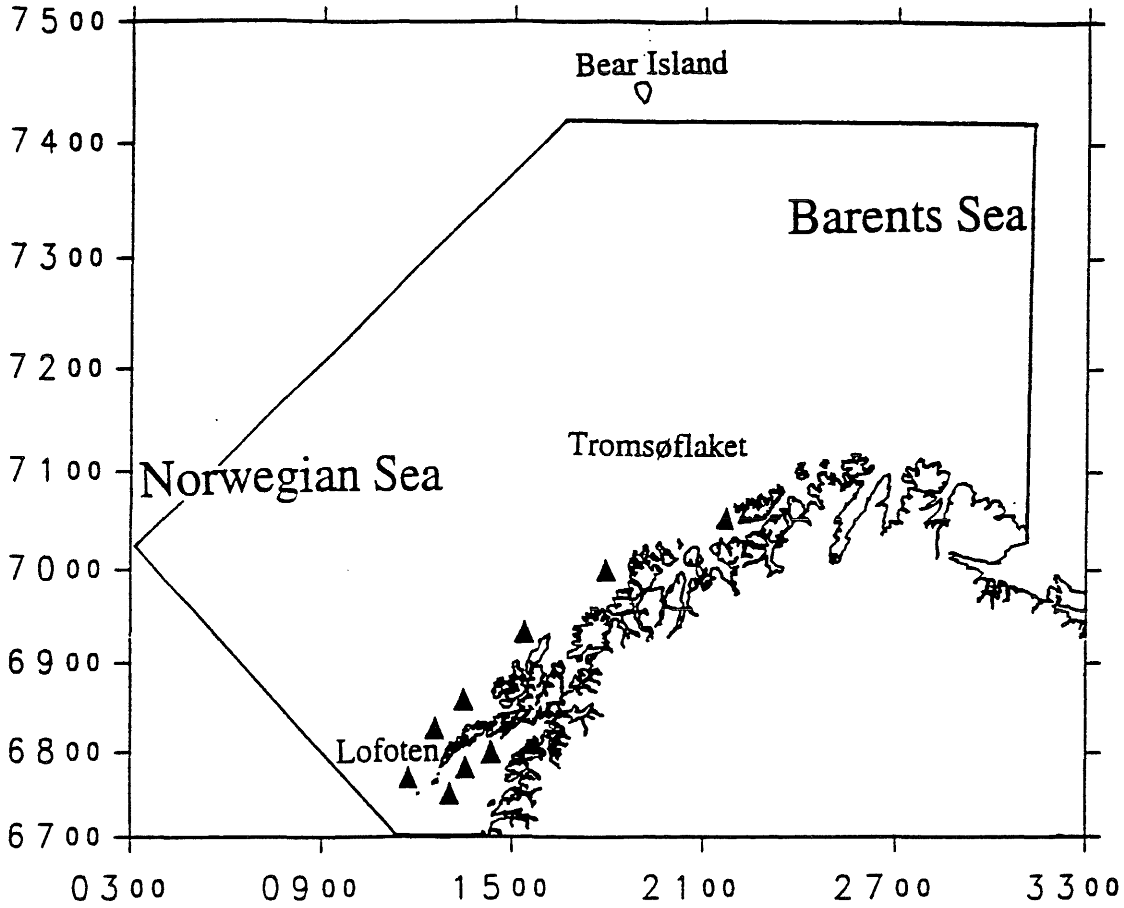

Figure 1. Early juvenile cod survey region is within the marked boundaries and seaward from the coastal islands. The main spawning areas for Arcto Norwegian cod are denoted by ▲. (Adapted from Godø and Sunnanå, 1984; Sundby and Bratland, 1987).

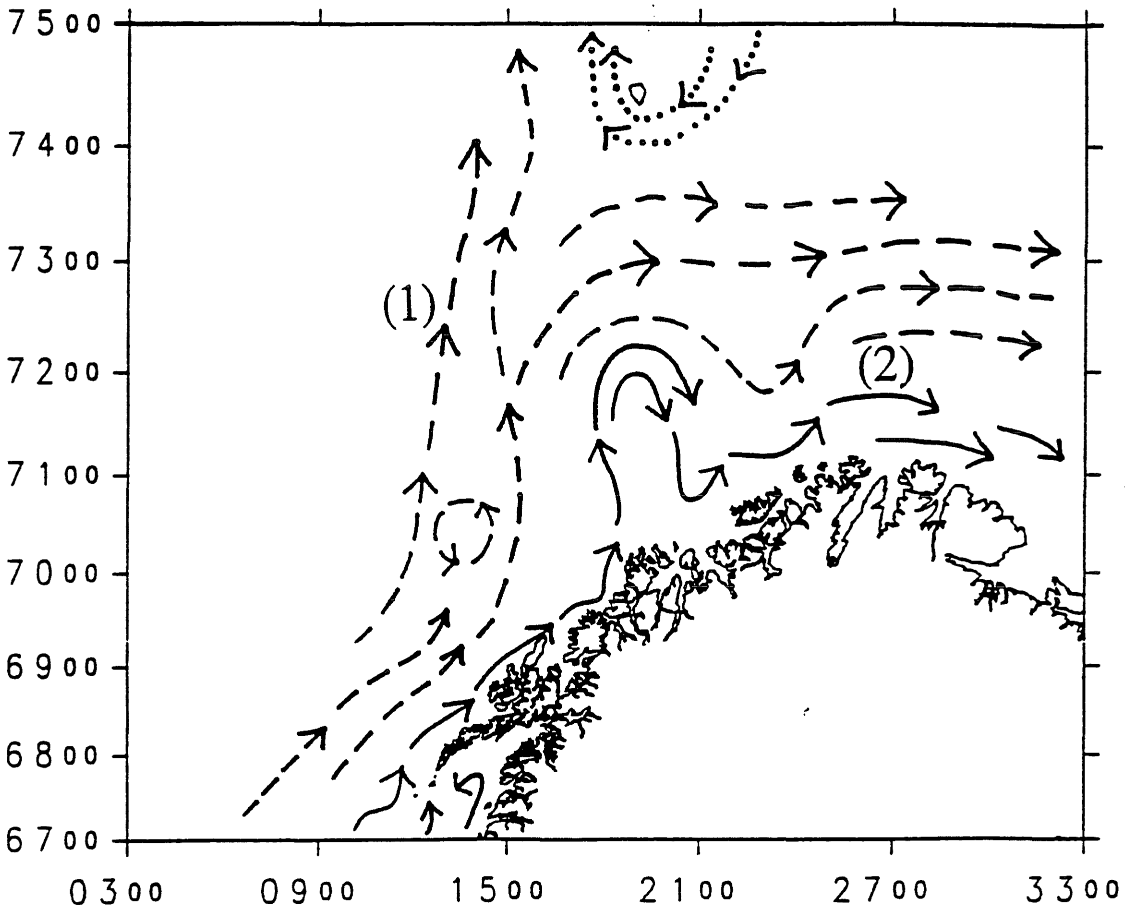

Figure 2. General system of water currents in the Norwegian Sea and the Barents Sea. Solid arrows denote the Norwegian Coastal Current, dashed arrows the Atlantic Current, and dotted arrows the Arctic Current. The West Spitsbergen current branch is denoted by (1), and (2) is the North Cape branch (modified after Loeng, 1989; Suthers and Sundby, 1993).

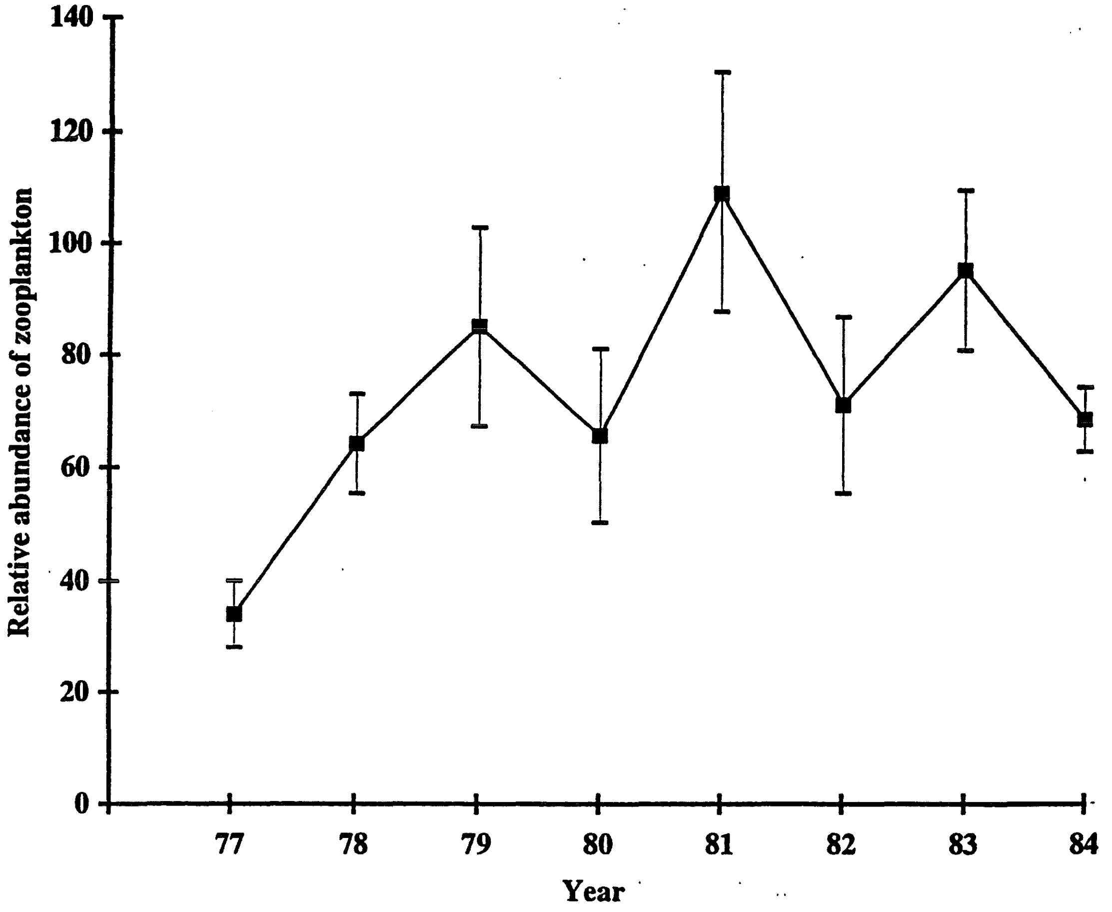

Figure 3. The estimated average zooplankton biomass (ml m^{-2}) in the Barents Sea based on surveys conducted from 1977 through 1984. Bars denote the 80% confidence intervals.

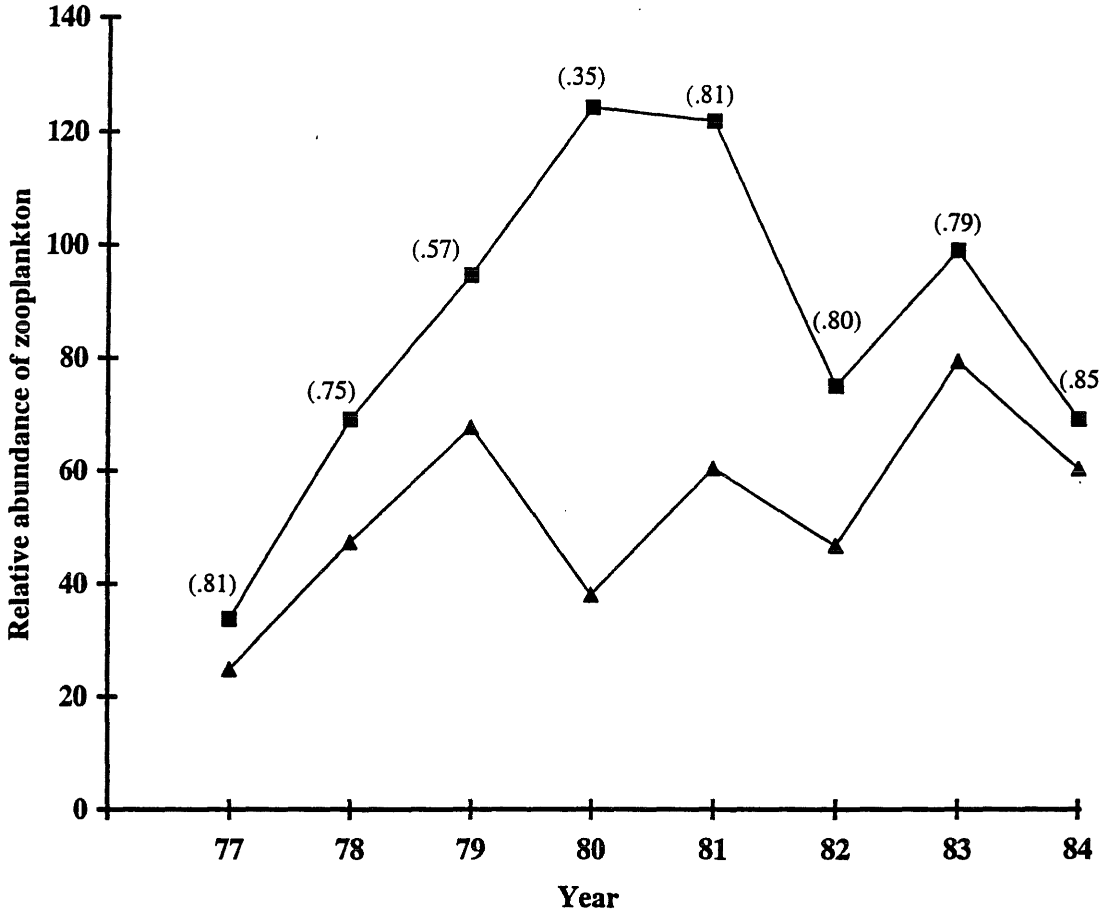

Figure 4. Estimates of the average zooplankton biomass in areas with (squares) and without (triangles) cod. In parentheses are yearly estimates of the fraction of the total survey area occupied by juvenile cod.