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## **Spatial patterns in growth rate variability of Arctic cod in Disko Bay, West Greenland.**

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### ABSTRACT

The Disko Bay at the West Greenland is a highly productive area of great fishery importance. The hydrography shows marked temporal and spatial variability, which is reflected in the plankton dynamics. In June 1997 we carried out a field study in the bay focusing on characteristics of the frontal hydrography and its potential influence on the life traits of fish larvae distributed in the Bay. We found the larvae of Arctic cod (*Boreogadus saida*) widely distributed in the Bay, with major concentrations coinciding areas of enhanced abundance's of the preferred prey (copepod nauplii and eggs). We estimated larval growth rates in the order of 10% (SGR in weight), with marked differences between estimates from closely spaced stations. Findings indicate that attainable growth rates are linked to frontal hydrography and the productivity at lower trophic levels, and point to a conspicuous environmental influence on fish recruitment processes in the bay.

## INTRODUCTION

The number of survivors from a given cohort of spawned eggs is a function of both the mortality and the growth rates experienced during the early life. The importance of the linkage between rates of mortality and growth rates is stressed in a number of studies (e.g. Pepin, 1991; Houde, 1997), and simulations of cohort survivals as a consequence of imposed variability in growth and mortality rates demonstrate a marked large contribution from the growth rate component (Beyer, 1989; Houde, 1987). Moreover studies show that increasing variances in growth rates could enhance cohort survival (Pepin 1989, Cowan et al 1996). Thus, the exploration of growth rate variability among cohorts of fish larvae is a requisite for the understanding of recruitment processes. For this exploitation the microstructure analysis of larval fish larval otoliths has shown to be a promising technique, and during the last two decades an increasing number of studies use of this technique for the investigation of growth variability of given fish species.

Below, we will summarize preliminary results of the study of Arctic cod (*Boreogadus saida*) growth performance focused on the spatial variability in growth and its potential linkage to hydrographical patterns. This study was part of a larger co-operative investigation carried out in the Disko Bay, a deep embayment at West-Greenland coast of high biological productivity and of great local fishery importance.

During the period 1995-1998 the temporal and spatial variability in hydrography and plankton dynamics were investigated by a number of field campaigns (Nielsen and Hansen, 1999). In June 1997 concentrations of Arctic cod larvae were sampled across the bay, and the otolith microstructure of sampled larvae were analysed with the aims of estimating the extent and spatial relationships of growth rate variability.

## MATERIALS AND METHODS

The geographical position of Disco Bay is shown in Figure 1. The Bay is up to 500 meters deep and of a size of approximately 6000 square kilometre. North-flowing currents along the coast of west-Greenland enters the Bay in the south-western part and leaves through narrow straits in the north-east and the north-west. During the period June 10-15, 1997 hydrographic measurements and plankton sampling were carried out along four transects extending from northern to southern coasts of the Bay (Figure 1). Of these the two westernmost transects crossed shallower, skerry parts at the entrance to the Bay.

Distance between sampling stations varied from about 4 to 15 kilometres. At each station the hydrography (temperature, salinity) and chlorophyll *a* concentration were profiled using a CTD (Seabird 25-01) with a mounted fluorometer. Measurements were averaged within  $\frac{1}{2}$  m intervals. The fluorometer were calibrated by a comparison between fluorescence measurements and

chlorophyll *a* estimates from water samples taken in the surface and in the layer of maximal fluorescence. The CTD cast and water bottle sampling were followed by zooplankton sampling using a submersible pump (capacity approx. 0.5 m<sup>3</sup> min<sup>-1</sup>) equipped with a conical net of 50 µm mesh size. The pump was lowered to 50 meter depth, started and retrieved slowly to the surface. At deck the net was washed down and the zooplankton were preserved in 4 % formaldehyde. The final procedure at a given station was sampling for larger plankton using a ring-net of 2 meter diameter equipped with a black netting of 1 mm mesh size. The haul was oblique from surface to 90 m depth, or at shallower depths to 10 m above bottom. All fish larvae were immediately sorted from the sample and preserved in 96% alcohol, a subsample of 5-10% of the remaining plankton was subsequently preserved in 4% formaldehyde.

After the cruise subsamples of the pumped plankton were sorted and the copepods were identified to species, staged and length measured. Based on copepod lengths and species- and stage-specific length-weight keys, the copepod biomass per volume water was estimated.

The fish larvae from the ring-net sampling were identified to species and length measured in 0.5 mm intervals. Fifteen to twenty larvae of Arctic cod from each station were used for otolith analysis. The lapilla were dissected with fine needles under a dissection microscope and transferred to thermoplastic resin on microscope slides. They were then ground with 1 µm lapping film, and the ring structure were investigated using a light microscope (63X objective) with connected camera and image analysis system. The ring pattern was counted from the inner prominent ring (the hatch check) towards the periphery. Two counts were made on each otolith and the average of the four counts used as estimate of larval age in days. The length/age relationship of larvae caught at same station was analysed assuming exponential growth during the period from hatch (assumed 6 mm length, from Fortier et al 1995) to sampling. Hence a non-linear fit of data to the relationship  $\text{Length} = 6 \cdot \exp(b \cdot \text{Age})$  was carried out and the slope at a given length (*L*) used as descriptor of growth rate (GRL) at station. Specific growth rate in weight was found from  $\text{SGRW} = 3.1 \cdot (\text{GRL} / L)$  where 3.1 is the exponent in the length-weight relationship (from Ponomarenko 2000)

## RESULTS

The characteristics of the hydrography in the Bay are illustrated by vertical profiles for transects 2-4 (Figure 2). The water was thermally stratified in the upper 20 m of the water column while in the deeper parts of the water column we observed a relatively homogeneous water mass of below-zero temperature (°C). This water mass covered central/northern parts of the Bay (Figure 3), but we observed a marked inclination of both isotherms and isohalines in the coastal regions and in the skerry regions at the entrance to the Bay (Figure 2). In these transition areas the chlorophyll peaked at about 30 m depth (upper panel graphs of Figure 4).

The zooplankton was dominated by the three copepod species *Calanus finmarchicus*, *C. hyperboreus* and *C. glacialis*. The copepodite stages of these species dominated by biomass, while the naupliar and egg stages dominated by number. Only the naupliar and egg stages are potential prey items of the smaller fish larvae and only these will be dealt with here. In Figure 5 (a-b) the abundance and the biomass of *Calanus* eggs and larvae are illustrated. Of the other copepod species only *Pseudocalanus* spp, *Oithona* spp. and *Microsetella* spp. were abundant, the biomass of these in stages of lengths <0.5 mm (potential prey items for Arctic cod larvae found in this study, see below) is illustrated in Figure 5 (c). The biomass estimates varied across the bay, with a tendency to show their highest values in areas of intermediate water depth (at approx. 150 m, this isobath marked in Figures 5 a-c)

A number of different larval species were caught by the ring-net sampling, among these the species Arctic cod (*Boreogadus saida*), sand lance (*Ammodytes* sp.), Atlantic poacher (*Leptagonus decagonus*), snake blenny (*Lumpenus lumpretaeformis*) and Arctic shanny (*Stichaeus punctatus*) were the most abundant. Only Arctic cod will be dealt with here. Figure 6 illustrate the observed abundance of this species in the Disko Bay, the larvae were predominantly distributed in the central/northern parts of the bay and at the northern entrance to the bay. Larval distribution showed no apparent relation to bottom topography of the bay. Larvae were of a size range from 8 to 14 mm.

The size at age estimations of Arctic cod are illustrated for two of the stations in Figure 7. Inserted curves are the respective fit of the exponential model to data. Growth estimates are available for station along three of the transects in the study, the bar charts in the lower panel of Figure 4 show the estimates of specific growth rate in weight for these stations (estimated for 11mm larvae). These preliminary estimates are too sparse to support firm conclusions, however they indicate enhanced growth in frontal regions. For example larval growth rates showed a peak at the second station from the northern coast of the bay, coinciding the area of frontal characteristics and of enhanced productivity (Figure 4), while high growth rates are also estimated for larvae in the frontal areas around the skerry parts at the bay entrance

## DISCUSSION

The present findings show that the biological productivity in the Arctic Disko Bay is of a magnitude that match temperate areas of well-known high productivity, e.g. the North Sea. The algal and copepod (nauplii+eggs) abundance reach 6 mg Chl. a m<sup>-3</sup> and 8 mg C m<sup>-3</sup> respectively, which approach maximal values measured in frontal areas of the North Sea (e.g. Nielsen and Munk 1998). Accordingly, a high egg production rate (up to 30 eggs female<sup>-1</sup> d<sup>-1</sup>) was measured for the *Calanus* species in the period of investigation (Nielsen and Hansen unpubl. results).

The enhancement of algal biomass appeared at depths between 20 and 30 meters, horizontally restricted to frontal regions between water masses of different characteristics. There was not an

evident (significant) relationship between measured algal and copepod biomasses at stations, however, the copepod biomass' showed their highest values in areas of intermediate water depth, in the vicinity of the frontal zones. Arctic cod larvae showed their highest abundance in the central regions of the Bay, i.e. there was no evident connection between larval abundance and frontal zones. Our estimation of larval ages (range 6 to 23, mean 15 days) indicate that peak hatching of Arctic cod in the Bay had taken place in late May. Other studies also find indications of peak hatching of Arctic cod in the late May (Fortier et al., 1995: Hudson Bay, Canada; Michaud et al., 1996: Northeast Polynia Greenland Sea; Ponomarenko, 2000: Barents Sea). Only sparse information are, however, available on Arctic cod larvae in the older stages.

Our preliminary analysis of larval growth, showed growth rates in the order of 10 % weight increase per day. This magnitude of growth is comparable to growth rates described for other gadoid species in temperate waters (e.g. Meekan and Fortier 1996, Bailey et al 1996). The variability in growth rate estimations by the present study ranged from 9.5 % d-1 to 11.5 % d-1, and the growth estimations as well as our measurements of productivity and potential prey biomass varied markedly within relatively short distances. Thus, the displacement of the haul for larval sampling, started at the given station, but towed away from the station, might have confounded our possibility to trace a linkage between larval growth estimates and the measured biomass of potential prey.

The observed spatial variability in growth rates of Arctic cod, for example of a 20% increase in attained growth rate (from 9.5 to 11.5 % d-1) within distances of only 15 km, signify an influence from the hydrographic variability connected to frontal characteristics in the Disko Bay. The findings and modelling of e.g. Meekan and Fortier (1996) and Fortier and Quinones-Velazques (1998) indicate that a growth rate variation of the magnitude observed during the present study, could potentially lead to a three-fold change in survival. Thus, our findings of spatial growth rate variability point to a conspicuous environmental influence on fish recruitment processes in the Disko Bay.

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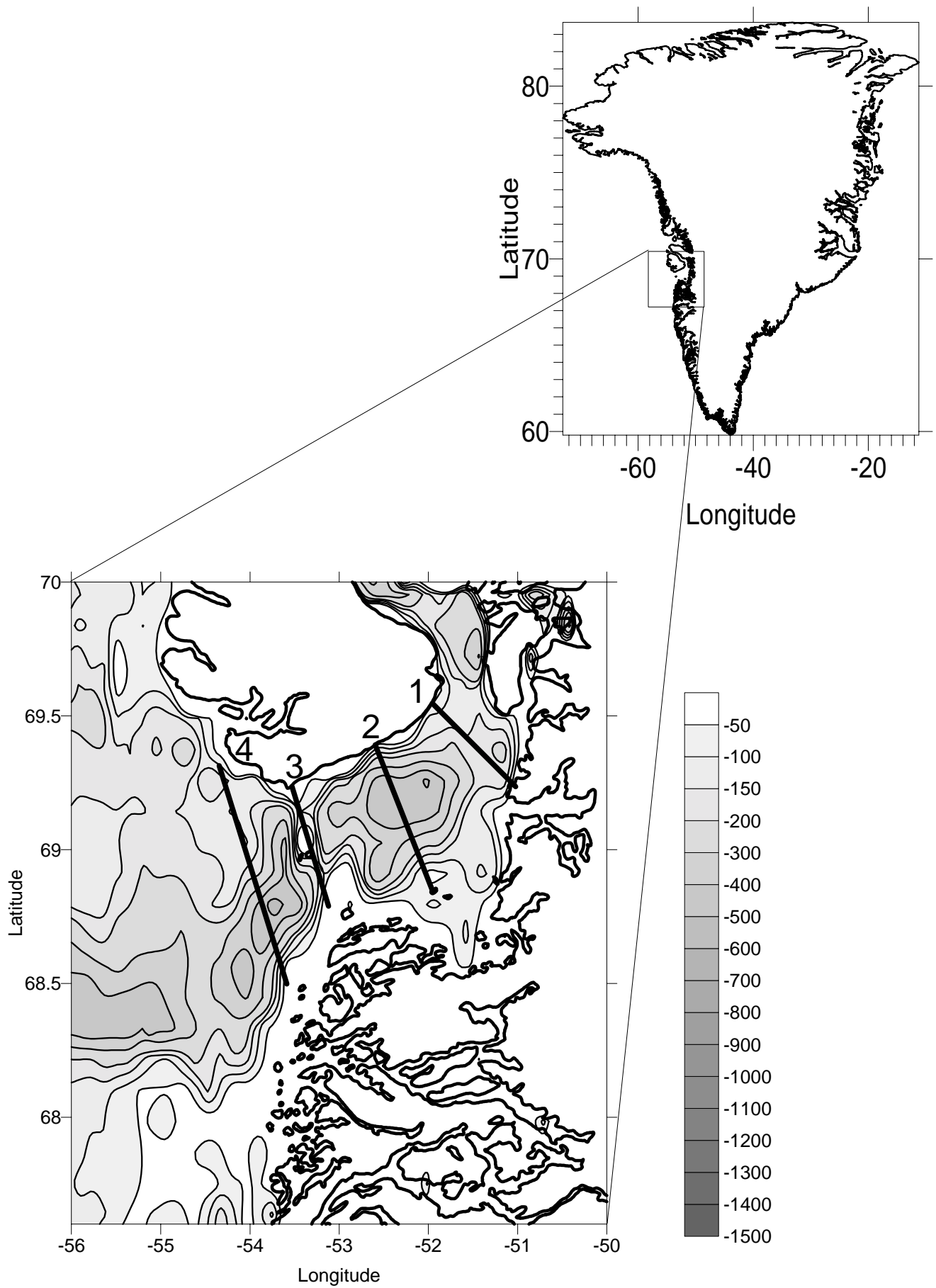


FIGURE 1. Geographical position of Disko Bay at the west-coast of Greenland. The four primary transects are indicated

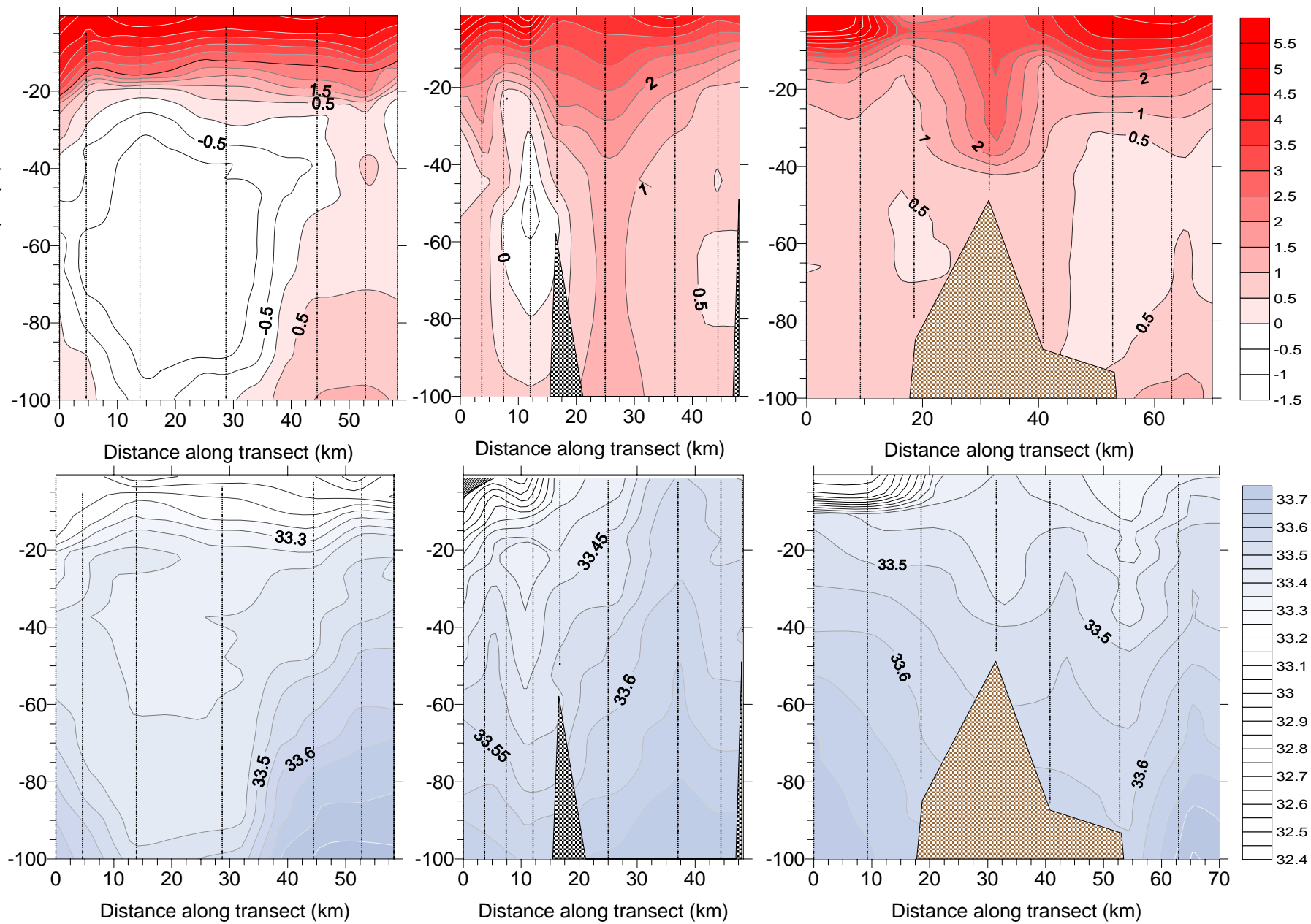


FIGURE 2. Profiles of temperature (upper panel) and salinity (lower panel) for transects 2-4 (transect 2 is the first one to the left). Temperature in  $^{\circ}\text{C}$ ; salinity in ppt.



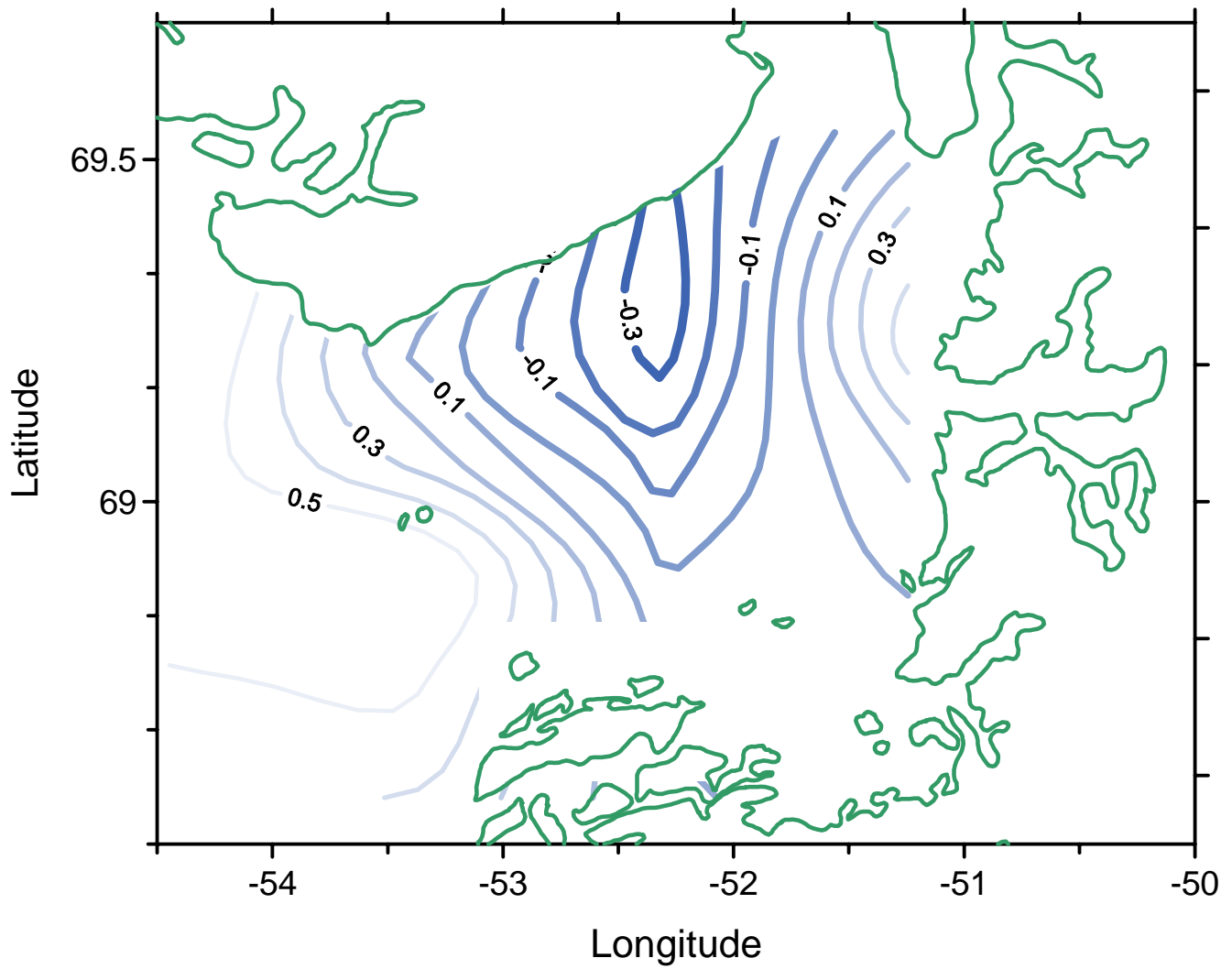


FIGURE 3. Illustration of the cold water mass in the central bay. Contour lines show temperature at 50 meters depth. ( $^{\circ}\text{C}$ )

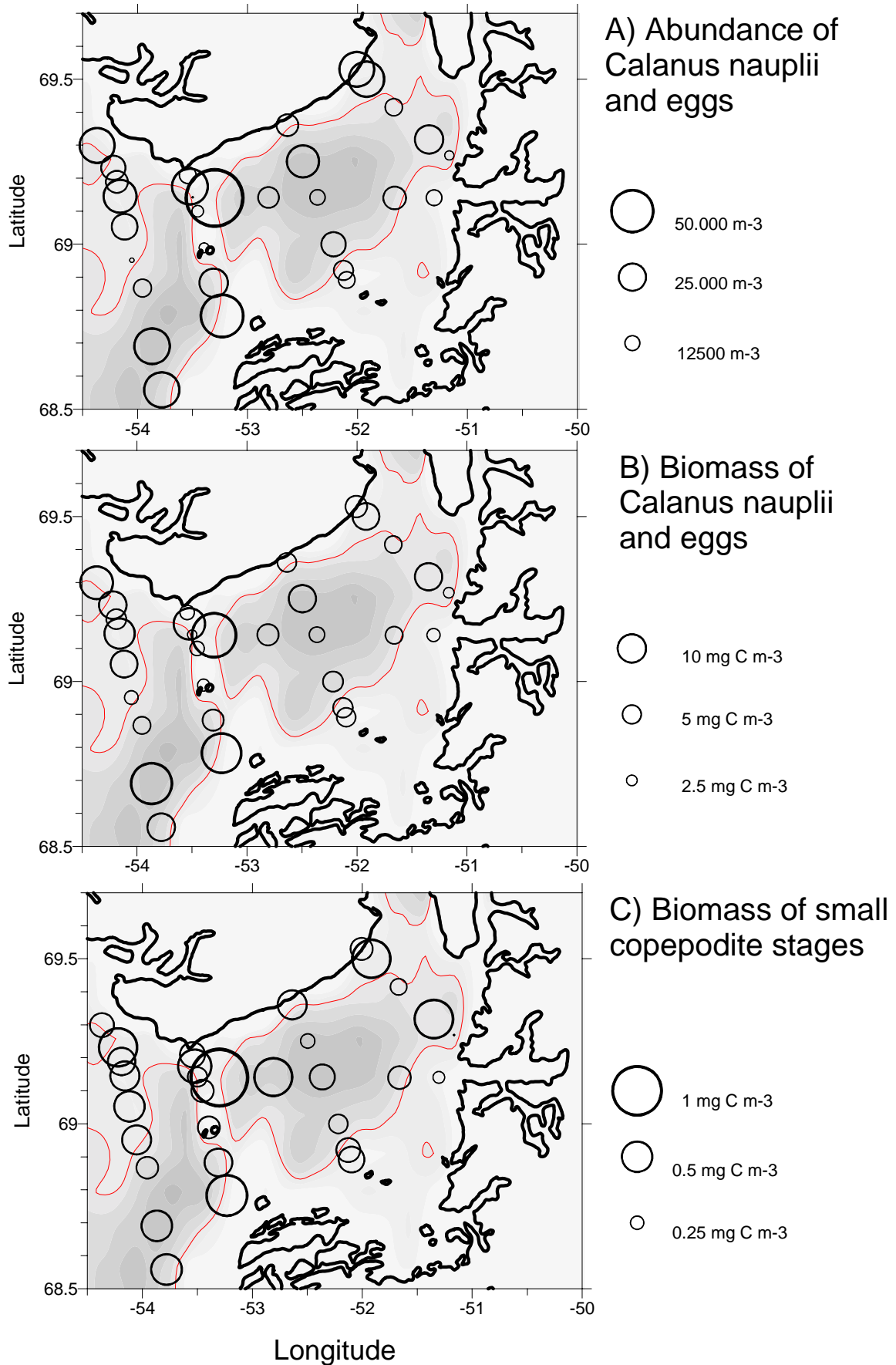


Figure 5 (a-b) . Abundance and biomass estimates of *Calanus* spp. nauplii and eggs (a and b), and biomass estimates of copepodites smaller than 500 $\mu$ m. Area of circles illustrate values as indicated to the left of figures. Contouring line illustrate water depth of 150 m.

## Abundance of Arctic cod *Boreogadus saida*

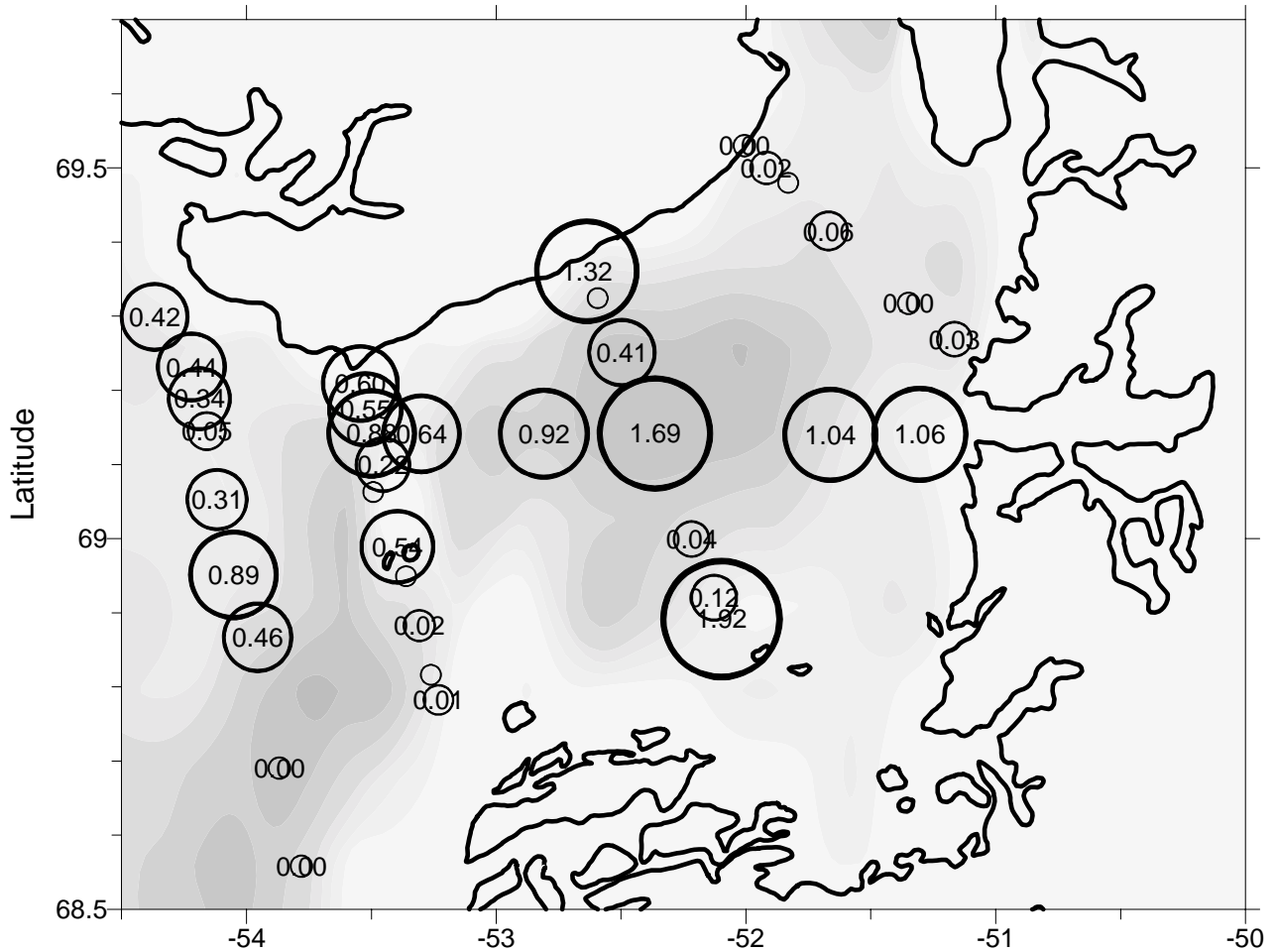


Figure 6. Abundance estimates of Arctic cod (*Boreogadus saida*), illustrated by area of circles and labelled in  $\text{no m}^{-2}$ .

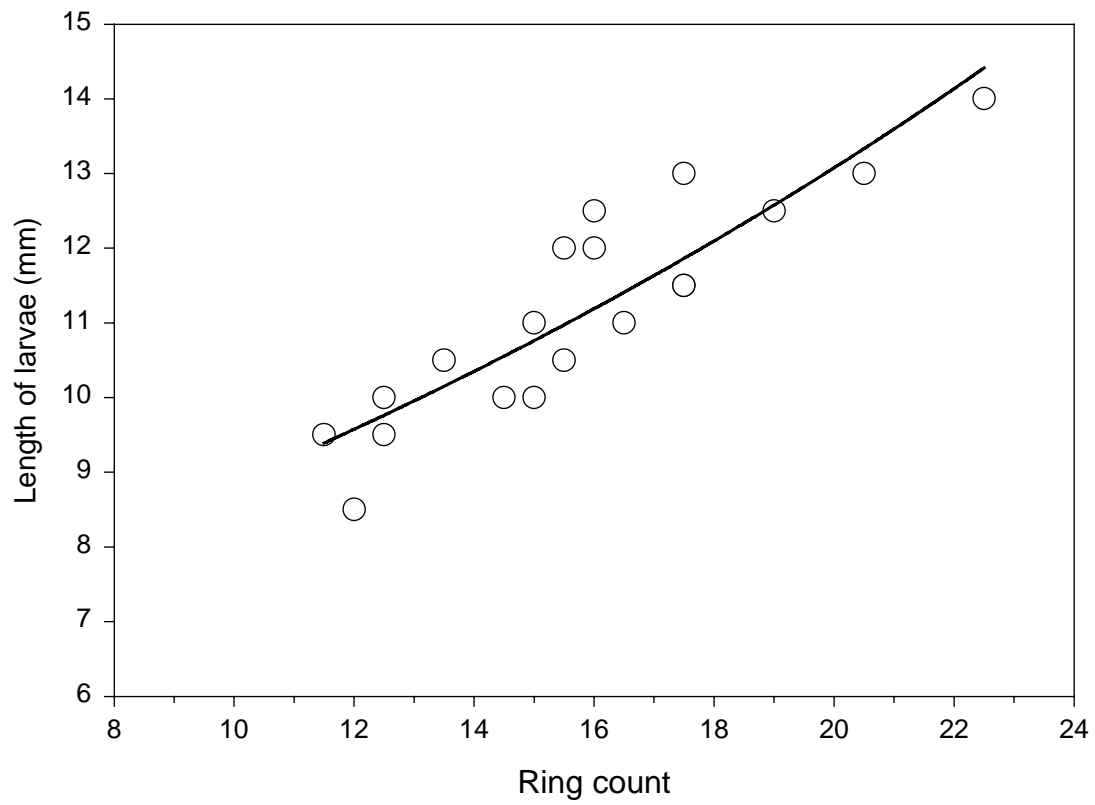


Figure 7. Example of lengths at age for Arctic cod at a station in the Disko Bay. Curve illustrates fit of exponential model to the data.