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Mesoscale physical variability affects zooplankton production in the Labrador Sea

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ABSTRACT

Surface distribution (0–100 m) of zooplankton biomass and specific aminoacyl-tRNA synthetases (AARS) activity, as a proxy of structural growth, were assessed during winter 2002 and spring 2004 in the Labrador Sea. Two fronts formed by strong boundary currents, several anticyclonic eddies and a cyclonic eddy were studied. The spatial contrasts observed in seawater temperature, salinity and fluorescence, associated with those mesoscale structures, affected the distributions of both zooplankton biomass and specific AARS activity, particularly those of the smaller individuals. Production rates of large organisms (200–1000 μm) were significantly related to microzooplankton biomass (63–200 μm), suggesting a cascade effect from hydrography through microzooplankton to large zooplankton. Water masses defined the biomass distribution of the three dominant species: *Calanus glacialis* was restricted to cold waters on the shelves while *Calanus hyperboreus* and *Calanus finmarchicus* were widespread from Canada to Greenland. Zooplankton production was up to ten-fold higher inside anticyclonic eddies than in the surrounding waters. The recent warming tendency observed in the Labrador Sea will likely generate weaker convection and less energetic mesoscale eddies. This may lead to a decrease in zooplankton growth and production in the Labrador basin.

1. Introduction

Zooplankton plays a central role in the transfer of energy from primary producers to fish populations. Their distribution and production are important to the main fisheries of the North Atlantic. One species, the copepod *Calanus finmarchicus*, has a particularly significant role. It accounts for >70% of the mesozooplankton biomass on the North Atlantic continental shelves in spring (Head et al., 2003), where its young stages (eggs and nauplii) provide an important food source for larval groundfish (e.g. haddock, Gaard and Reinert, 2002; cod, Heath and Lough, 2007) and its later stages for pelagic fish (e.g. herring, Prokopchuk and Sentyabov, 2006; mackerel, Olsen et al., 2007) and baleen whales (e.g. right whales, Laidre et al., 2007). Despite its dominance on the continental shelves in spring, *C. finmarchicus* is generally regarded as an oceanic species; being less abundant in fall because it retreats to depth to overwinter in a dormant state (Heath et al., 2008). In the Northwest Atlantic *C. finmarchicus* dominates the mesozooplankton biomass of the central Labrador Sea (Head et al., 2003), which is thought to serve as a distribution centre to the adjacent shelves (Wiebe, 2001). To understand and predict the dynamics of zooplankton production in general, and *C. finmarchicus* production in particular, we need to know how environmental factors (physical mesoscale features, food availability) affect the distribution of planktonic biomass and growth rates. Some key habitats have a

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special interest as they present hydrological structures like fronts and eddies, in which fish larvae obtain nourishment from enhanced concentrations of zooplankton (Rodriguez et al., 2004). Despite the Labrador Sea being a region of high physical variability, there are only a few studies on the effects of hydrography on zooplankton populations in the area (Kielhorn, 1952; ICNAF, 1968; Head et al., 2003), mainly focused on *C. finmarchicus* (Head et al., 2000; Heath et al., 2004).

The western region of the Labrador Sea is dominated by the Labrador Current which is divided into two branches (Lazier and Wright, 1993): a smaller inshore branch at the upper continental slope and over the Labrador shelf, and an offshore branch which forms the front between the cooler, fresher coastal waters and the warmer, saltier open ocean waters. East of the offshore branch there is a cyclonic circulation bordered by the North Atlantic Current (NAC) in the south. The NAC reaches the Labrador Sea as the relatively warm Irminger Current (Veron et al., 1999). Along the west shelf of Greenland, the West Greenland Current (WGC) flows north (Lazier and Wright, 1993), transporting fresh, cold water from the Nordic seas (Clarke, 1984; Dickson et al., 2007) and also small icebergs. The branch of the WGC that joins the Labrador Current shows high variability in its salinity (Dickson et al., 1984). It is most variable near the shelf break between Greenland and the Labrador Sea because of eddies or shelf waves of about 30 km in diameter that last for several days (Myers et al., 1989). Mesoscale physical phenomena such as fronts and eddies are common features in the Labrador Sea. Their presence depends on the seasonality of the interacting currents. Lazier and Wright (1993) found seasonal variation in upper level circulation (400 m and up) but not at greater depths (1000 m). Minimum velocities ($0.06\,\mathrm{m\,s^{-1}}$) were in March and April while maximal ones ($2.7\,\mathrm{m\,s^{-1}}$) were observed in October. However, Chanut et al. (2008) observed higher formation of eddies, known as Irminger Rings (Eden and Böning 2002), between December and March, followed by a strong seasonal peak of eddies originating from the West Greenland boundary current system in March and a later peak of convective eddies in April.

In this study, we examine the contrasting hydrography in winter (December 2002) and spring (May 2004) and the effects of mesoscale physical structures on the distribution of zooplankton biomass, growth and production rates. We use aminoacyl-tRNA synthetases (AARS) activity as an index of zooplankton growth (Yebra and Hernández-León, 2004) and also, in spring, *C. finmarchicus* egg production rates (EPR). The biochemical approach allowed us to study for the first time growth rates of mixed zooplankton in the area (not just the dominant *C. finmarchicus*) during spring and winter.

2. Methods

2.1. Hydrography

From 1st to 9th December 2002, 17 stations were sampled across the Labrador Sea, following the World Ocean Circulation Experiment (WOCE) line AR7W/L3 (Fig. 1). From 15th to 30th of May 2004, 21 stations were sampled along the same transect. A Seabird 9 CTD was used to obtain profiles of temperature, salinity and fluorescence during both cruises. In addition, during the spring cruise, 129 XBTs were deployed to increase resolution of the temperature profiles.

2.2. Zooplankton sampling

Vertical hauls (0–100 m, $0.5\,\mathrm{m\,s^{-1}}$) were made from the CCGS Hudson (cruises 2002-075 and 2004-016) with a double Bongo net (63 μm mesh, 0.34 m diameter) and a ring net (200 μm mesh, 0.75 m diameter). Zooplankton from the ring net hauls were fractionated with sieves to obtain 200–450, 450–1000 and >1000 μm size classes. The <200 μm size fraction was obtained from the Bongo hauls after sieving through a 200 μm sieve to remove larger organisms. On the May 2004 cruise, the 63 μm double net was substituted for a single 76 μm mesh net (0.50 m diameter) to collect the <200 μm fraction. Each fraction was quickly rinsed with filtered sea water on corresponding mesh (to remove phytoplankton and smaller than desired zooplankton) and stored in liquid nitrogen ($-196\,^{\circ}\mathrm{C}$) for later measurement of protein content and aminoacyl-tRNA synthetases activity (AARS, Yebra and Hernández-León, 2004).

On the May 2004 cruise additional ring net hauls (0.75 m diameter) for taxonomic analysis were towed vertically (0–100 m) at every station of the transect. On the December 2002 cruise at stations with a water column depth of >500 m, zooplankton samples for taxonomic analysis were collected using a Hydro-bios Multi-net system (0.5×0.5 m mouth) towed vertically (0–200 m). Both nets were fitted with 200 μm mesh and retrieved at $\sim1\,\mathrm{m\,s^{-1}}$. Samples were preserved in 4% formalin. In spring all zooplankton categories were counted (copepods, chaetognats, amphipods, medusae, etc., data not shown), including individual stages of three *Calanus* species (*C. finmarchicus*, *C. glacialis*, *C. hyperboreus*). In winter *Calanus* species were also counted but other zooplankton taxa were not enumerated. Due to poor sample condition, *C. finmarchicus* copepodite stages IV–VI were enumerated separately, while stages I–III were pooled together. We used these spring and winter taxonomic data to compare *Calanus* abundances distribution between seasons. Previously, Head and Pepin (2007) obtained significantly similar *C. finmarchicus* abundances when using both gears at the same stations, even though depth ranges were somewhat different (Multi-net: 0–100 or 0–200 m versus ring net: bottom to surface, maximum depth range sampled 0–1000 m; *t*-Student, $t = 0.78$, $n = 84$, $p = 0.43$).

2.3. *Calanus finmarchicus* metabolism

We use metabolism here to refer to synthesis processes such as protein synthesis and egg production. When possible, additional ring nets were deployed (0–100 m) to obtain *C. finmarchicus* stages IV–VI copepodites from both