Journal of Marine Systems 84 (2011) 78–84

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Distribution and diet of larval and juvenile Arctic cod (*Boreogadus saida*) in the shallow Canadian Beaufort Sea

Wojciech Walkusz [a,b,*], Joclyn E. Paulic [b], William J. Williams [c], Slawomir Kwasniewski [a], Michael H. Papst [b]

[a] Polish Academy of Sciences, Institute of Oceanology, Powstancow Warszawy 55, 81-712 Sopot, Poland
[b] Fisheries and Oceans Canada, Freshwater Institute, 501 University Crescent, Winnipeg, MB, R3T 2N6, Canada
[c] Fisheries and Oceans Canada, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, BC, V8L 4B2, Canada

ARTICLE INFO

Article history:
Received 22 April 2010
Received in revised form 16 September 2010
Accepted 20 September 2010
Available online 29 September 2010

Keywords:
Arctic cod
Larvae
Diet
Feeding
Boreogadus saida
Arctic
Beaufort Sea

ABSTRACT

The distribution and diet of larval and juvenile Arctic cod (*Boreogadus saida*) were studied during summer 2005 in the coastal Canadian Beaufort Sea. A total of 275 individuals were captured and the highest abundance was observed at station depths of 20–30 m. This corresponds well with the location of the frontal zone where the Mackenzie River plume water and open sea water meet. Diet examinations were performed on 220 Arctic cod, which were found undamaged from sampling. We observed a gradual decrease in prey number per fish and increase in prey size as larvae grew which corresponded to a shift from Rotifera and nauplii towards larger copepodid stages. However, at all sizes, the larvae remain generalists and feed on a broad range of organisms. Environmental changes due to climate warming could have a two-fold impact on fish larvae feeding in the studied region. First, the potential for increased primary production may lead to increased zooplankton production that may impact the feeding and nutrition positively. On the other hand, greater discharge of turbid water from the Mackenzie River may reduce light penetration in the water column that may negatively influence the ability of visual predators to successively forage.

1. Introduction

Arctic cod (*Boreogadus saida*; Lepechin, 1774) is a key component of Arctic marine food webs (Craig et al., 1982; Welch et al., 1992) as it is a major food source for marine mammals (ringed and harp seals, narwhals and belugas) and sea birds (thick-billed murres, fulmars and black-legged kittiwakes). It is also a major consumer of zooplankton and therefore plays a crucial role in both the carbon cycle and energy transport (Welch et al., 1992). Arctic cod are believed to be associated with ice cover (Lønne and Gulliksen, 1989), however, they are also found throughout the water column in ice-free areas. They spawn in winter and achieve sexual maturity at age 2+ (males) and 3+ (females) after reaching 12–15 cm fork length (Craig et al., 1982). The larval period lasts for three to four months at the end of which the 27–35 mm long larvae transform into juveniles. However, size and weight of larval specimens are greatly dependent on the time of pre-larval hatching (Ponomarenko, 2000). Sparse records of Arctic cod larvae feeding showed that copepod nauplii and eggs are the main food components (Gilbert et al., 1992; Ponton et al., 1993; Michaud et al., 1996), while Chiperzak et al. (2003a,b,c) reported Copepoda and Rotifera to be important in the diet. It has been suggested that young-of-the-year Arctic cod will typically feed on the groups and species that are locally abundant rather than limit their feeding to a specific group or species (Bradstreet et al., 1986).

The near-shore region of the Canadian Beaufort Sea is a unique estuarine environment due to the outflow from the Mackenzie River. The region can be characterized by the presence of two opposite regimes and a transitional zone — riverine, marine and intermediate, respectively (Retamal et al., 2007; Walkusz et al., 2010). The Mackenzie River outflow plays an important role in the structuring of the ecosystem: the buoyant discharge carries large loads of sediment, limiting light penetration in the water column, and brings terrestrial nutrients into the area (Retamal et al., 2007) whereas the clear marine waters allow for increased primary production in spring and transport marine nutrients to the system (Macdonald et al., 1987). Such a dynamic environment leads to an overall increase in productivity (phytoplankton and zooplankton), creates conditions for foraging by a variety of fish and marine mammal species during spring and summer and enhances larval fish growth and survival (Cushing, 1975; Heath, 1992).

Relatively little is known about the ecology of the Arctic cod, despite its importance to the Arctic ecosystem. Knowing that the diet of this fish is highly variable and dependent on local conditions, we examined the diet and distribution of Arctic cod larvae in the shallow Canadian Beaufort Sea during summer, 2005.

* Corresponding author. Polish Academy of Sciences, Institute of Oceanology, Powstancow Warszawy 55, 81-712 Sopot, Poland. Tel.: +1 204 984 5541; fax: +1 204 984 2403.
E-mail address: walwo@iopan.gda.pl (W. Walkusz).

0924-7963/$ – see front matter. Crown Copyright © 2010 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.jmarsys.2010.09.001

2. Material and methods

Arctic cod larvae and juveniles were sampled at 16 stations located along two transects (Toker and Paktoa) in the coastal Canadian Beaufort Sea during summer 2005 (29 July–17 August) (Fig. 1). At each station two 20-minute tows were performed using a 500 µm Bongo net that was towed obliquely between the surface and the near-bottom. Fish were removed immediately from the net and preserved in 4% formaldehyde solution in filtered sea water. Measurements of length and weight were done in the laboratory within approximately 1 month after sampling. The potential impact of formaldehyde preservation on shrinkage/expansion of larvae had likely a marginal effect on the measurements in our case (Fox, 1996). Developmental stages of all fish were determined based on the morphology and meristics of the larvae according to method proposed by Moser et al. (1984). For examination of the diet the entire gut (including stomach and intestines) of all undamaged fish were opened and examined under a stereomicroscope. All recognizable diet items were identified to the lowest possible taxonomical level. In order to compare food abundance between larvae developmental stages, analysis of variance was performed (ANOVA; one-way, post-hoc test: Tukey, $\lambda = 0.05$, ordinary least-square linear regression; SYSTAT 11, Systat Software Inc.). The estimates of fish larvae and juvenile abundances (individuals 100 m^{-3}, later ind. 100 m^{-3}) were based on filtered water volume data obtained by flow meters attached inside each net opening.

Data on zooplankton distribution and density on the two transects were based on samples collected with a conical net (153 µm mesh; 0.5 m opening diameter) which was towed vertically from ~1 m above the bottom to the surface. Two net tows (replicates) were collected at each station. All samples were fixed in 4% borax buffered formaldehyde solution in sea water. The abundance of zooplankton is presented as the number of individuals per m^3, and it is the mean of the abundance in the two replicates, calculated using the filtered water volume obtained from the net mouth area and the depth of the tow. Prior to taxonomical identification samples were rinsed in fresh water and divided into subsamples with the 1 dm^3 Folsom splitter. Taxonomical identification of the samples was performed to the lowest possible level. Larger copepods were also discriminated by developmental stage. For the discrimination of *Calanus* developmental stages the procedures given in Walkusz et al. (2010) were applied. Only zooplankton taxa found in the larval diet are presented.

Before each Bongo net tow a CTD profile was made using a Seabird SBE25 that was lowered from approximately 1 m off the surface to within 2 m off the sea-floor. Additional CTD profiles were also made between Bongo net stations in order to obtain finer cross shelf resolution in temperature and salinity. The CTD profiles that comprise the Paktoa section (Fig. 3) were taken over a period of 3 days and, in the absence of strong wind forcing, can be considered contemporary. The CTD profiles that comprise the Toker section were taken over a period of two weeks and there are temporal discontinuities in the section immediately onshore of TOK 4 and immediately offshore of TOK 5 and TOK 6. The Toker section should be viewed with this in mind.

3. Results

The Toker and Paktoa cross shelf sections presented in Figs. 2 and 3 show the strong influence of the Mackenzie River plume across the Canadian Beaufort Shelf. Typically, the warm and fresh Mackenzie River water dominates onshore and spreads offshore in a brackish layer that is less than 10 m thick and has large salinity and temperature gradients at its base (Carmack and Macdonald, 2002). On traversing the shelf from near-shore to offshore, these near surface plume waters transition from warm (temperatures of 10 and 12 °C, at the surface of TOK 1 and PAK 2, respectively), fresh (salinities of 15 and 6 psu, at the surface of TOK 1 and PAK 2, respectively) and extremely turbid Mackenzie River water to the clear waters of the cooler and less-fresh polar surface mixed-layer (temperatures of 4 and 9 °C, at the surface of TOK 11 and PAK 9, respectively; salinities of 28 and 14 psu, at the surface of TOK 11 and PAK 9, respectively). The transition occurs both gradually, as marine water mixes with the Mackenzie River water, and rapidly at sharp frontal features where horizontal temperature and salinity gradients are high.

In total 275 Arctic cod individuals were collected during the study. No fish were caught less than 10 m deep — TOK 1 and TOK 2 and PAK 2 and 3, while only one Arctic cod larva was collected at TOK 3. The greatest number of larval and juvenile Arctic cod was found at station TOK 6 — 95 fish were caught; 6 ind. 100 m^{-3}, followed by TOK 8 and

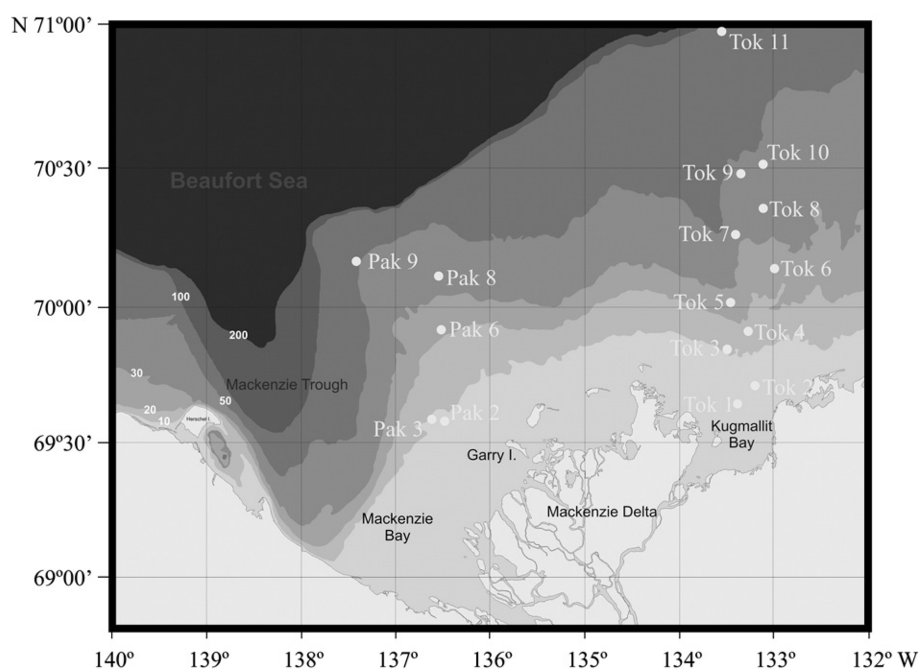

Fig. 1. Western end of the Canadian Beaufort Shelf with sampling stations along the Paktoa (Pak) and the Toker (Tok) transects.