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ORIGINAL RESEARCH ARTICLE

Age, growth rate, and otolith growth of polar cod (*Boreogadus saida*) in two fjords of Svalbard, Kongsfjorden and Rijpfjorden

Dariusz P. Fey [a,*], **Jan M. Węsławski** [b]

[a] *National Marine Fisheries Research Institute, Gdynia, Poland*
[b] *Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland*

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Summary This work presents biological information for polar cod (*Boreogadus saida*) collected with a Campelen 1800 shrimp bottom trawl in Kongsfjorden (two stations located in the inner part of the fjord adjacent to the glacier) and Rijpfjorden (one station at the entrance to the fjord) in September and October 2013. The otolith-based ages of polar cod collected in Kongsfjorden (6.1–24 cm total length TL; $n = 813$) ranged from 0 to 4 years. The growth rate was relatively constant at approximately 4.7 cm year^{-1} between years 1 and 4, which indicates that growth was fast in the glacier area. The ages of polar cod collected in Rijpfjorden (8.6–15.9 cm TL; $n = 64$) ranged from 2 to 3 years. The fish from Rijpfjorden were smaller at age than those from Kongsfjorden, and their growth rate between years 2 and 3 (no other age classes were available) was approximately 3.3 cm year^{-1}. In both fjords, males and females were of the same size-at-age and the same weight-at-TL. The small sampling area means that the results on growth rate are not representative of the entire fjords. Instead, the results can be discussed as presenting the possible growth rates of some populations. A strong relationship was identified between otolith size (length and weight) and fish size (TL and TW), with no differences between males and females or the fjords. A significant, strong relationship was also noted between fish and otolith growth rates.

* Corresponding author at: National Marine Fisheries Research Institute, Kołłątaja 1, 81-332 Gdynia, Poland. Tel.: +48 587 356 232; fax: +48 587 356 110.
E-mail addresses: dfey@mir.gdynia.pl (D.P. Fey), weslaw@iopan.gda.pl (J.M. Węsławski).
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1. Introduction

Polar cod (*Boreogadus saida*) is both a pelagic and demersal gadoid species that plays a key role in the Arctic shelf seas (Hop and Gjøsæter, 2013). It is distributed in open and ice-covered waters, and it provides a link between the lower (mainly zooplankton) and higher (seabirds and mammals) trophic levels (Christiansen et al., 2012; Hop and Gjøsæter, 2013). Closer association with ice, however, occurs particularly during the larval and juvenile stages (Bouchard and Fortier, 2011), whereas adult fish are primarily distributed in open or deeper waters below the ice (Geoffroy et al., 2011, 2016). From the point of view of population ecology, polar cod as an abundant planktivorous species could be a significant food competitor for other species (Renaud et al., 2012) such as capelin (*Mallotus villosus*) (Hedeholm et al., 2012). The level of competition depends, of course, on polar cod life stages. Additionally, the poleward expansion of Atlantic cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) observed in recent years (Fossheim et al., 2015; Haug et al., 2017; Misund et al., 2016; Szczucka et al., 2017) increases the risk of predation by these species on polar cod. Another potential risk involves increased food competition between the young stages of Atlantic cod and haddock and polar cod, even if competition currently seems still to be at a low level (Renaud et al., 2012).

As the temperature is predicted to rise in the Arctic, further changes in species composition, their requirements, and processes such as predation and food competition are expected in the future (Berge et al., 2015; Fossheim et al., 2015; Haug et al., 2017; Misund et al., 2016). In regions such as Svalbard, these changes are likely to have serious consequences for the polar cod population. Therefore, obtaining a good understanding of polar cod life history strategies, biology, and ecology, including, for example, information on size range, growth rate, and length-weight relationship, is crucial. The amount of information of this kind for polar cod remains insufficient.

Otoliths are a useful tool in research on fish ecology. Information on the relationship between somatic growth and otolith growth as well as between otolith size and fish size is important for many applications, such as back-calculating growth rates (Francis, 1990), size estimates of fish from the guts of predators (Dietrich et al., 2006; Fritts and Pearsons, 2006; Takasuka et al., 2004), and age prediction (Boehlert, 1985; Fey and Linkowski, 2006). Although literature data on otolith size-fish size are available for polar cod (Christiansen et al., 2005; Frost and Lowry, 1981; Lidster et al., 1994), no data on the somatic growth-otolith growth relationship are available for this species except in a publication by Bouchard and Fortier (2008), who show that otolith growth is a reliable estimator of somatic growth for age-0 polar cod. Validating this assumption is necessary if growth back-calculation from otoliths or relative growth estimates from annual ring widths are to be conducted. The above-mentioned applications make otoliths a useful tool in research on the ecology of polar cod especially in light of the processes occurring in the Arctic ecosystems – increasing temperature and changes in community structure of different groups of sea animals (Fossheim et al., 2015; Haug et al., 2017; Misund et al., 2016) including mammals (Haug et al., 2017) that prey on polar cod.

This study determines the sex-specific size frequency, growth rate, and weight at length relationship for polar cod collected in two fjords – Kongsfjorden and Rijpfjorden. Because of the small sampling areas, we cannot treat the growth rate results as representative of the entire fjords. Instead, the results can be considered as indicative of the possible growth of some populations in the fjords analyzed. Additionally, the otolith size-fish size relationship as well as the fish growth rate-otolith growth rate relationships were analyzed to verify the usefulness of polar cod otoliths for their size and growth back-calculation. Possible sex and fjord effects were considered in these relationships.

2. Material and methods

2.1. Study area

Kongsfjorden is approximately 25 km long and 5–10 km wide and is located on the northwest coast of Svalbard (79°N, 12°E) (Fig. 1). Because it is an open fjord with no sill at the entrance, the influence of warm, saline Atlantic waters carried with the North Atlantic Current makes it sub-Arctic rather than Arctic. However, at the head of the fjord is an active tidal glacier that causes marked environmental gradients in salinity, temperature, and sedimentation rates (Walkusz et al., 2009). Rijpfjorden is approximately 40 km long and 12 km wide and is located in the high-Arctic on the northern side of Nordaustlandet, Svalbard (80°N, 22°30′E) (Fig. 1). The fjord is open toward the Arctic Ocean, and, because of the limited influence of warm Atlantic waters, its environment is truly arctic (Walkusz et al., 2009). The fjord is ice-covered for six to eight months annually (Wallace et al., 2010).

2.2. Fish collection

Polar cod (*B. saida*) were collected in Kongsfjorden and Rijpfjorden (Svalbard, Norway) between September 29 and October 4, 2013 during a cruise of the R V^{-1} *Helmer Hanssen* using a Campelen 1800 shrimp bottom trawl. The horizontal and vertical openings were 17 m and 4–5 m, respectively, and the door spread was about 45–50 m. Mesh size was 80 mm in the front and 22 mm in the cod end. The gear was towed on the bottom for approximately 10–15 min at 3 knots/h. The fish were collected at two stations in Kongsfjorden (depth: 134 m and 52 m) and at one in Rijpfjorden (depth: 280 m) (Fig. 1). Random sub-samples of polar cod were collected, and a total of 813 fish from Kongsfjorden and 64 from Rijpfjorden were used for the biological analysis, which included determining total length (TL, ±0.1 cm), total wet weight (TW, ±0.1 g), and sex. The fish were stored frozen before the measurements were taken. All the fish from Rijpfjorden (n = 64) and a sub-sample (n = 358) of fish from Kongsfjorden were used for otolith extraction (Fig. 2).

2.3. Otolith analysis

The sagittal otoliths were extracted from each fish non-randomly to cover the size range and to represent the fish size frequency in a given sample. The otoliths were cleaned

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