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The effect of recent warming on polar cod and beaked redfish juveniles in the Barents Sea

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ABSTRACT

During 1980–2008, climatic conditions in the Barents Sea changed from cold to warm. This recent warming has led to a greater area of Atlantic water and a smaller area of Arctic water within the Barents Sea, which influences suitable habitats for arctic and boreal fish. Using extensive survey observations of temperature and the presence of juvenile polar cod (arctic) and beaked redfish (boreal), we defined a core thermal habitat for these species and studied how climate variability has influenced abundance indices, fish density and length, and geographical distribution. The distribution of polar cod has often been split into western (Svalbard) and eastern (Novaya Zemlya) components, which correspond to spawning sites. Most polar cod were found in a temperature band of 2–5.5 °C (core thermal habitat, CTH). Higher temperatures will lead to worse conditions (less CTH) for polar cod, which will result in decreased fish density and distribution for this species in the Barents Sea. Decreased ice cover provides less suitable spawning sites for polar cod, which may result in reduced abundance (0-group index). Redfish were primarily distributed in the western and central parts of the Barents Sea and were seldom observed east of 30°E. The majority of beaked redfish were found in a temperature band of a 5.5–8.5 °C. For redfish, higher temperatures resulted in better conditions (larger CTH), but redfish did not seem to utilise the increased habitat. The abundance of redfish (0-group index) seemed to depend more on exploitation than on CTH. Thus, recent warming negatively influenced polar cod recruitment due to a shrinking habitat, but it positively affected redfish recruitment.

1. Introduction

The climate in the Barents Sea has varied from cold during the 1980s to intermediate during the 1990s to warm during the 2000s, and there has been an increasing trend in both oceanic and atmospheric temperatures over this time period (Ingvaldsen et al., 2003; Johannesen et al., 2012). The temperature increase has been particularly strong in the last two decades, which have been the warmest decades on record (Levitus et al., 2009; Boitsov et al., 2012). Strong inflow is associated with a wide area of Atlantic water and a push-back of sea-ice with a lower extent of sea-ice cover in the winter (Boitsov et al., 2012; Johannesen et al., 2012). The ice has retracted further north, decreasing the area influenced by Arctic water in the Barents Sea. These changes have influenced the distribution, abundance and trophic interactions of true arctic species (Fossheim et al., 2015). Most boreal species followed the redistribution of warm Atlantic water, and thus, spatial distributions of zooplankton and several fish species have extended northwards in the last decade (Rass, 1968; Fossheim et al., 2015). Variable inflow of Atlantic water and changing temperature conditions have in turn been found to affect the recruitment variability of all the major fish stocks in the Barents Sea, including Atlantic cod, haddock, herring and capelin (Rass, 1968; Borkin, 1979; Monstad and Gjøsæter, 1987; Sundby, 2000; Korshunova, 2012; Eriksen et al., 2012). Water temperature influences larvae and juveniles directly through metabolism and indirectly through food availability and habitat conditions (Brett, 1979). Planktonic crustaceans (e.g., copepods) constitute the majority of the diet of polar cod and redfish juveniles (Dolgov and Drevetnyak, 1995; Orlova et al., 2008). In mid-summer, the biomass of *Calanus finmarchicus* in Atlantic water and *Calanus glacialis* in Arctic waters can reach 4.0 and 3.8 g dry weight per square meter respectively (Arashkevich et al., 2002). The biomass of *C. finmarchicus* has increased in recent years (Drobysheva, 1994; Skjoldal and Rey, 1989; Dalpadado et al., 2003; Orlova et al., 2005) due to increased advection of warm, plankton-rich Atlantic water into the Barents Sea

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(e.g., Skjoldal and Rey, 1989; Sundby, 2000; Dalpadado et al., 2003; Orlova et al., 2005). A decrease in the area influenced by Arctic water and a reduction in the associated arctic plankton community (e.g., the calanoid copepods *C. glacialis* and *Calanus hyperboreus*) may result in some species of arctic plankton and fish "running out of shelf" (Ponomarenko, 1968; Wassmann, 2006).

In this study, we studied 0-group polar cod (*Boreogadus saida*) and redfish (*Sebastes mentella*) and their thermal habitats using pelagic trawl catches and temperature observations from the upper 50 m. All samples were collected during standard fishery-independent surveys from 1980–2010. We also examined how variation in the distribution and abundance of the 0-group were related to recent warming. If temperature is an important controlling factor for juvenile abundance, distribution and growth, then we expected that increasing temperatures would have positively influenced the abundance, fish length and distribution of redfish, which were associated with Atlantic water, and negatively influenced polar cod, which were associated with Arctic water.

2. Materials and methods

2.1. Study area

The Barents Sea is a high-latitude, arcto-boreal, shallow shelf sea. The water masses in the Barents Sea are dominated by warm water from the Atlantic Ocean flowing into and across the Barents Sea. The flow of Atlantic water into the Barents Sea is influenced by the atmospheric pressure and winds. Cold water from the Arctic Ocean is found overlying the Atlantic water in the northern Barents Sea. Some of the Arctic water of the northern Barents Sea may circulate around the Svalbard and Franz Josef Land archipelagos. The inflow of Atlantic water results in boreal conditions in the western, central and southern part of the Barents Sea, while the influence of water from the Arctic leads to sub-arctic and arctic conditions in the northern part of the sea (Boitsov et al., 2012). There is a biogeographical transition zone between the boreal and arctic communities.

2.2. Studied species

Polar cod is a small, relatively short-lived (5–7 years) circumpolar species that is widely distributed in cold waters. In the Barents Sea, this species occurs in the northern and eastern areas. Spawning of polar cod is associated with the ice in the southeastern Barents Sea during the winter (primarily from January–February) (Ponomarenko, 1968; Hop and Gjøsæter, 2013). Pre-spawners and fry have been observed in the northern and western parts of the Spitsbergen archipelago, indicating that spawning may occur in that region during February and March (Korshunova, 2012). Female polar cod are able to spawn more than once, whereas males (who have a high-energy investment in maturation and sex products) most likely suffer post-spawning mortality (Hop and Gjøsæter, 2013). Polar cod produce large, floating eggs (1.5–1.9 mm), which are widely distributed in the Pechora Sea and along the west coast of Novaya Zemlya (Rass, 1968; Ponomarenko, 1968). The incubation period of the eggs may last for 1.5–3 months, and both eggs and small larvae are found in high concentrations below the ice or in the upper water layers after ice melt (Rass, 1968; Ponomarenko, 1968; Hop and Gjøsæter, 2013). Young-of-the-year (hereafter referred to as 0-group) polar cod have been found in the autumn near Svalbard, in the northern Barents Sea and along the Novaya Zemlya (Hop and Gjøsæter, 2013). In some years, the distribution of polar cod is discontinuous, with western (around Svalbard) and eastern (along Novaya Zemlya) components (Hop and Gjøsæter, 2013).

Beaked redfish is a slow-growing, long-lived boreal species. While the species can live for more than 70 years, the maximum confirmed age in the Barents Sea is more than 40 years old (Drevetnyak and Nedreaas, 2009). Adult beaked redfish (hereafter referred to as redfish) are distributed in the northeastern Atlantic from approximately 62°N in the south to the Arctic ice in the north and from the east side of the Spitsbergen archipelago to 35°E. Redfish larvae are transported by currents from the spawning grounds along the continental slope to the Norwegian Sea and into the Barents Sea towards the Svalbard (Spitsbergen) archipelago region. 0-group redfish occupy the western and northwestern regions of the Barents Sea, while other year-classes occupy the central Barents Sea, particularly near the Hopen Deep (Drevetnyak and Nedreaas, 2009; Ajiad et al., 2011). When redfish reach 5–6 years of age, they migrate to sites along the continental slope, where mature individuals of the population aggregate (Ajiad et al., 2011).

2.3. Survey

The joint Norwegian–Russian 0-group fish survey (operated since 2004 as part of the joint Norwegian–Russian ecosystem survey; see below) has been annually conducted during August and September in the Barents Sea. The standard trawling procedure, used on both Norwegian and Russian vessels, consists of stepwise tows at three depths, with the head-line at 0 m, 20 m and 40 m. At each depth level, the trawl is towed for 10 min at a speed of 3 knots (corresponding to a tow length of 0.5 nm or 0.93 km). Additional tows with the head-line at 60 and 80 m are occasionally made if dense concentrations of fish are recorded at depths greater than 60 m on the echo-sounder. Further trawling details and procedures are provided in Anonymous (2004) and Eriksen and Prozorkevich (2011).

Since 2004, the 0-group fish survey has been part of a Joint Norwegian–Russian ecosystem survey, designed and jointly carried out by the Institute of Marine Research (IMR, Norway) and the Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO, Russia) (Eriksen and Gjøsæter, 2013). The area covered by the survey has become larger over time due to reduced ice-coverage and has expanded into the northern and northeastern regions of the Barents Sea. Survey details are available at http://www.imr.no/tokt/okosystemtokt_i_barentshavet/sampling_manual/nb-no.

2.4. Biotic data

During the study period (1980–2008), approximately 8851 stations were sampled for 0-group fish. The 0-group fish were caught by pelagic trawling in the upper 50 m. 0-group fishes were identified to the species level. Body lengths were measured to a precision of 1 mm on Norwegian vessels and 0.5 mm on Russian vessels and were thereafter aggregated into length groups of 0.5 cm intervals. The data were obtained from the joint Norwegian–Russian 0-group database, which underwent a complete revision and quality check in 2006–2009 (Eriksen et al., 2009).

The surveyed area has increased in recent years due to reduced ice coverage in the north (Prokhorova, 2013; Eriksen and Gjøsæter, 2013); thus, to make our results comparable across all years, we excluded the areas east of Spitsbergen and north of 78°N and the areas east of 35°E and north of 76°N.

2.5. Abiotic data

Temperature data were acquired from CTD samples taken at each 0-group trawl station. The CTD profiles were collected either before or after trawling. Here, we used the temperatures averaged to standard depths (5, 10, 20, 30, 40, and 50 m), corresponding to