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ORIGINAL RESEARCH ARTICLE

Ecosystem maturation process follows the warming of the Arctic fjords

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Summary Two fjords in West Spitsbergen (Hornsund 77°N and Kongsfjorden 79°N) differ with regard to their exposure towards increasingly warm Atlantic water inflow. Hornsund remains in many respects cooler than Kongsfjorden (on average 2°C SST in summer) and is less influenced by warmer and more saline Atlantic waters. Reported changes in the physical environment (temperature rise, freshwater inflow, salinity drop, turbidity, fast-ice reduction, coastal change) are discussed in the context of biological observations in the pelagic and benthic realms with special reference to krill (Euphausiacea). We conclude that well-documented changes in the physical environment have had little effect on the fjord biota and that both organisms and their ecological functions in the fjords are well adapted to the scale of ongoing change. The observed changes fit the definition of ecosystem maturation, with greater diversity, a more complex food web and dispersed energy flow at the warmer site.

1. Introduction

Currently observed environmental changes — specifically those in the marine ecosystem reported in the last IPCC document (2014) — are well documented, yet their predicted consequences are a matter for debate. We selected two Svalbard fjords as a case study, since they are among the best studied Arctic regions (Hop et al., 2002; Svendsen et al., 2002), and because the archipelago lies in the centre of reported environmental change (ACIA, 2004; Pavlov et al.,

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2013; Walczowski and Piechura, 2006). Public concern about Arctic change is understandable, as the visible element – ice, disappears before our eyes (Duarte et al., 2012). When traditional marine biogeography came into being (Ekman, 1953), the Arctic was given the status of a fully "independent province", owing to the obvious ice cover and its cold character, not because of its faunistic or functional uniqueness. This stands in stark contrast to the other polar area, the Antarctic, which is a hydrologically separate entity with a rich endemic fauna and long evolutionary history (McIntyre, 2010).

The Svalbard archipelago has most often been placed at the boundary between the High Arctic and Arctic or the Arctic and Sub-Arctic, with the borderline along the west coast of the island of Spitsbergen (Backus, 1986; Ekman, 1953; Sherman et al., 1990). Some authors have used the more general expression "temperate and cold waters of the Northern Hemisphere" (Golikov et al., 1990). The present paper summarizes and reviews data recently acquired within the GAME (Growing of Arctic Marine Ecosystem) project. We are going to demonstrate that most of the changes to the fjord ecosystem, reported from Spitsbergen, are in fact shifts within one large system. The changes resemble the process of ecosystem maturation as described by Odum (1969), namely, the development of more complex and balanced food webs and a higher level of carbon metabolism.

2. Material and methods

The data discussed below were collected from r/v OCEANIA during late July–early August surveys in 2013–2015, in the central basins of Hornsund (77°N) and Kongsfjorden (79°N), on a flat, even seabed of 100 m depth as part of the GAME project. There, an array of multidisciplinary observations were gathered from the water column and seabed, relating to hydrography, water column optics, water chemistry, plankton (from piko- to macroplankton), fish, as well as sediment biogeochemistry, bacteria, and meio- and macrofaunal assessments. The oxygen consumptions of the sediment and dominant taxa were also measured. In order to ensure the best possible comparability of the data, the same group of people made the observations, within a short time window, using the same equipment and measuring techniques. The specific methodologies are described in separate papers. Archival hydrographic data, collected in the two fjords between 2000 and 2015, were also used as background to give the fresh data a long-term environmental perspective (specific data are cited in the paper). All the data are accessible on the project's website and an illustrated summary can be found at http://www.iopan.gda.pl/projects/Game/deliverables.html.

To place the above-mentioned observations in a wider perspective, we took the case study of the expansion of Euphausiacea to the Spitsbergen fjords, studied by the second author (literature cited in the text).

3. Results and discussion

3.1. Environmental drivers

Table 1 shows that the two fjords (Hornsund at 77°N and Kongsfjorden at 79°N) are similar in size (300 and 210 km^2 respectively), volume (25 km^3) and shape with semi-separated inner fjord branches (Fig. 1) http://www.iopan.gda.pl/projects/Visual/index.html. The general circulation pattern is also similar, with shelf waters entering the fjord along the southern shore and flowing back out along the northern (Jakacki et al., 2016; Svendsen et al., 2002). Both fjords lack a sill at their entrances, yet depth is the important difference: Hornsund is shallower (max. depth 220 m) with a flat bottom profile, whereas Kongsfjorden is deep (max. depth 350 m) with a V-shaped bottom profile. Kongsfjorden's bathymetry links it directly to the outer shelf and slope via the Kongsfjordrenna (Wlodarska et al., 2009). Hornsund is colder, fresher and less influenced by Atlantic shelf waters than

Table 1 Observed physical differences between "cold" Hornsund and "warm" Kongsfjorden; data from cruises of r/v OCEANIA in 2010–2013 and Urbański et al. (1980), Swerpel (1985), Beszczynska-Möller et al. (1997), Blaszczyk et al. (2013), Drewnik et al. (2016), GAME project web page http://www.iopan.gda.pl/projects/Visual/index.html.

Factor	Hornsund	Kongsfjorden
Average near-bottom temperature in summer at 100 m depth (°C)	2	4
Average summer surface temperature	4	6
Fast ice: % of fjord area	20–25%	5–10%
Fast ice duration	3–5 months	1–3 months
Freshwater (glacial melt) volume in summer	0.7 km^3	0.3 km^3
Coastal change (new areas uncovered by glaciers between 1936 and 2000)	8% increase in sea bed shallower than 50 m	13% increase in sea bed shallower than 50 m
Winter cooled water retention in summer, volume	Always, usually 0.2–0.45 km^3	Seldom, 0–0.02 km^3 at best
Wind pattern	High percentage of local easterly winds driving freshwater out of the fjord	High percentage of westerly winds driving shelf water into the fjord
Atlantic core water inflow from shelf	Rare, outer part of fjord only	Regular in summer, deep into the fjord
Fjord topography	Shallow (max. depth 220 m)	Deep (max. depth 350 m)
Fjord area	300 km^2	210 km^2

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