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Review

Future harvest of living resources in the Arctic Ocean north of the Nordic and Barents Seas: A review of possibilities and constraints

Tore Haug[a,*], Bjarte Bogstad[b], Melissa Chierici[a], Harald Gjøsæter[b], Elvar H. Hallfredsson[a], Åge S. Høines[b], Alf Håkon Hoel[a], Randi B. Ingvaldsen[b], Lis Lindal Jørgensen[a], Tor Knutsen[b], Harald Loeng[b], Lars-Johan Naustvoll[b], Ingolf Røttingen[b], Knut Sunnanå[a]

[a] Institute of Marine Research, PO Box 6404, NO-9294 Tromsø, Norway
[b] Institute of Marine Research, PO Box 1870 Nordnes, NO-5817 Bergen, Norway

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ABSTRACT

Global warming drives changes in oceanographic conditions in the Arctic Ocean and the adjacent continental slopes. This may result in favourable conditions for increased biological production in waters at the northern continental shelves. However, production in the central Arctic Ocean will continue to be limited by the amount of light and by vertical stratification reducing nutrient availability. Upwelling conditions due to topography and inflowing warm and nutrient rich Atlantic Water may result in high production in areas along the shelf breaks. This may particularly influence distribution and abundance of sea mammals, as can be seen from analysis of historical records of hunting. The species composition and biomass of plankton, fish and shellfish may be influenced by acidification due to increased carbon dioxide uptake in the water, thereby reducing the survival of some species. Northwards shift in the distribution of commercial species of fish and shellfish is observed in the Barents Sea, especially in the summer period, and is related to increased inflow of Atlantic Water and reduced ice cover. This implies a northward extension of boreal species and potential displacement of lipid-rich Arctic zooplankton, altering the distribution of organisms that depend on such prey. However, euphausiid stocks expanding northward into the Arctic Ocean may be a valuable food resource as they may benefit from increases in Arctic phytoplankton production and rising water temperatures. Even though no scenario modelling or other prediction analyses have been made, both scientific ecosystem surveys in the northern areas, as well as the fisheries show indications of a recent northern expansion of mackerel (*Scomber scombrus*), cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and capelin (*Mallotus villosus*). These stocks are found as far north as the shelf-break north of Svalbard. Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes* spp.) and shrimp (*Pandalus borealis*) are also present in the slope waters between the Barents Sea and the Arctic Ocean. It is assumed that cod and haddock have reached their northernmost limit, whereas capelin and redfish have potential to expand their distribution further into the Arctic Ocean. Common minke whales (*Balaenoptera acutorostrata*) and harp seals (*Pagophilus groenlandicus*) may also be able to expand their distribution into the Arctic Ocean. The abundance and distribution of other species may change as well – to what degree is unknown.

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* Corresponding author.
E-mail address: toreha@imr.no (T. Haug).

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1. Introduction

The marine Arctic comprises the Arctic Ocean, including the deep Eurasian and Canadian Basins, and the surrounding continental shelf seas (Barents, Kara, Laptev, East Siberian, Chukchi, and Beaufort Seas and the Canadian Archipelago (Fig. 1)). The Arctic Ocean has a distinct natural climate variability occurring on time scales ranging from seasonal to multi-decadal (Overland et al., 2008). Dramatic reduction in the Arctic sea-ice mass and coverage (Overland, 2011; Comiso, 2012) is observed for the summer period, and growing also in winter. The speed of these changes has been underestimated in global models (Stroeve et al., 2012; IPCC, 2013). The sea-ice changes have resulted in large areas of the Arctic Ocean becoming more accessible, allowing for increased human activity. Other observed environmental changes include warming and freshening of surface waters due to increased river runoff and ice melting. This can alter the Arctic Ocean's stratification, acidification state, light regime, carbon cycle and nutrient availability. The combination of increased human activity and environmental perturbations is likely to affect the Arctic Ocean ecosystems and may pose challenges to their management (ACIA, 2005).

The Fram Strait is the only main deep gateway for the exchange of deeper waters out of the Arctic and warm Atlantic Water and heat into the Arctic Ocean (Schauer et al., 2002). An increase in this heat transfer will have profound implications for the marine environment and the living marine resources. Colonization of new regions by immigrating species is more likely on the Atlantic side of the Arctic Ocean than on the Pacific side (Drinkwater, 2011; Hollowed et al., 2013a,b). But the number of well-documented, climate-related changes in plankton, fish and benthic communities in the Arctic Ocean's marine ecosystems is low, and there is substantial uncertainty regarding current and future productivity (Wassmann et al., 2011).

Large-scale commercial harvesting of mammals (since 1611, see Christensen et al., 1992a; Allen and Keay, 2006) and fish (since the 1870s, see Iversen, 1934) already occurs in the sub-Arctic Barents and Norwegian seas adjacent to the Arctic Ocean. The harvesting potential of marine sub-Arctic regions is predicted to increase with global warming (Cheung et al., 2011). Some species currently targeted in fisheries in these regions may expand into the Arctic Ocean (Hollowed et al., 2013a,b). In addition, currently unexploited species may become harvestable, either in conventional fisheries or in new fisheries, as technology develops (e.g. zooplankton harvest; Grimaldo et al., 2010; Nicol et al., 2012) or because of marine bioprospecting (Svenson, 2012). Also, new species are emerging in these areas, either as a result of artificial introduction or bio-invasion (Ware et al., 2013; Sundet and Hoel 2016). Moreover, due to warming, species that are more southerly may enter Arctic waters, extend their distributional range northwards and reproduce (Buchholz et al., 2012; Berge et al., 2015a; Fossheim et al., 2015; Misund et al., 2016).

Climate change projection scenarios of how some of the key stocks would respond (e.g. Cheung et al., 2009; Wisz et al., 2015) are often used to evaluate future harvesting opportunities. However, central to such projections are correct predictions of propagation limits of the individual species. Such projections call for suitable physical model forcing as input (Ingvaldsen et al., 2015) as well as real data for understudied Arctic seas (Christiansen et al., 2016). Even more important, climate change affects a multitude of environmental factors that may affect various processes at different levels of biological organization (e.g. Rijnsdorp et al., 2009; Hollowed et al., 2013a,b), and regional-scale variation in climate-demographic functions make range-wide population dynamics challenging to predict (Sydeman et al., 2015). In this paper we review the possibilities and constraints regarding future harvest in the Arctic Ocean north of the Nordic and Barents Seas. We examine how changes in the physical and chemical conditions influence the biological production, and affecting possible future harvesting of marine biological resources on the Northeast Atlantic side of the Arctic Ocean. We will focus on fundamental conditions for harvestable populations to occur: (1) beneficial oceanographic conditions; (2) adequate primary, secondary and benthic production; and (3) plasticity in life cycles, migration and drift patterns of potentially harvestable stocks.

2. Advection, stratification and nutrients

The region west and north of the Svalbard archipelago (>80° N), the northernmost extension of the northern North Atlantic, is of particular interest with regard to the biological production of the Arctic Ocean. Atlantic Water carried northwards brings heat, thereby affecting thermal conditions as well as the sea ice cover (e.g., Beszczynska-Möller et al., 2012; Onarheim et al., 2014). The Atlantic current also supplies the region with nutrients and drifting organisms like zooplankton (Kosobokova and Hirche, 2009) and micronekton (Knutsen et al., in press). This advective regime fuels life in the Arctic Ocean (Bluhm et al., 2015; Wassmann et al., 2015; Hunt et al., 2016).

This region is a transition zone between Atlantic and Arctic conditions. Typically, the Arctic Ocean is strongly stratified due to the ice freezing and melting cycle combined with the large volumes of river runoff, and there are horizontal layers of water associated with the large-scale circulation and these local processes (e.g., Rudels, 2012). Biological production in Arctic regions experiencing seasonal ice melt are usually nutrient limited (e.g. Tremblay and Gagnon, 2009), nutrient availability depending on the strength of the stratification and the depth of the surface mixed layer. Comparing the deep Arctic Ocean with the Barents Sea shows substantial