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Krill, Climate, and Contrasting Future Scenarios for Arctic and Antarctic Fisheries

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Summary

Arctic and Antarctic marine systems have in common high latitudes, large seasonal changes in light levels, cold air/ sea temperatures, and sea ice. In other ways they are strikingly different, including: geological structure; ice stability; and food webs. Both regions contain rapidly warming areas; reported climate impacts and future projections are dramatic. Effects of changing climate on oceanographic processes and food webs influence their fisheries in different ways. Life-history strategies of zooplankton (Antarctic krill and *Calanus* copepods in the Arctic) may affect future fisheries productivity. To explore potential future scenarios for each region; this paper: 1) considers characteristics (geographic, physical, biological) defining these ecosystems, and reviews impacts of climate change on key zooplankton; 2) summarizes existing fisheries; 3) synthesizes this information to envisage future scenarios; 4) considers implications for management. Published studies suggest that in the Arctic increased open water and primary/ secondary production may benefit fish stocks. Fisheries may see new mixes of species and enhanced biomass. In contrast, studies in the Southern Ocean suggest the potential for existing species to adapt is mixed and potential for invasion of pelagic finfish is low. Future fisheries may depend on currently existing species. Management approaches should anticipate climate-induced changing dynamics in these regions.

Introduction

Climate is impacting the physics, chemistry, and biology of world oceans. Projected future changes in physical features (ocean temperature, ice conditions, stratification, and currents) will have further impacts on marine ecosystems. In highly sensitive Polar Regions climate change is affecting the flow of energy from lower (phytoplankton and zooplankton) to higher (fish, seabirds, and marine mammals) trophic levels. Direct affects on fish stocks may cause geographic shifts in distribution and abundance. Combined direct and indirect impacts on fished species may have economic implications for fisheries, although uncertainty remains regarding magnitude of impacts and mechanisms that underlie them. In Arctic and Antarctic marine food webs copepods/ krill/ amphipods and Antarctic krill, respectively, contribute significantly to zooplankton production, and link phytoplankton to higher trophic levels. Spatial and temporal changes in zooplankton distribution and abundance can have consequences for recruitment of commercially important fish. This response in Polar marine ecosystems has been the topic of international research; understanding has improved as result. Further improving the ability to determine how climate change will affect physical and biological conditions in these systems, and mechanisms that shape recruitment variability and production, is essential to develop sound management policies. This review questions: How will the response to climate change of marine systems within Arctic and Antarctic regions affect their future fisheries?

Materials and Methods

Published studies were reviewed to determine: 1) how and why Arctic and Antarctic marine systems differ; and how they are responding to climate forcing, particularly regarding food webs and fishery productivity; 2) currently exploited fishery resources in both regions; 3) future prospects for fisheries productivity in both regions; and 4) important considerations for ecosystem-based management of future fisheries in these regions. Focus is on the effects of climate change on key zooplankton species linking primary producers and upper-trophic levels in both regions. We compare and contrast their fundamental differences, geological and evolutionary histories, patterns of ocean circulation, extent of pelagic-benthic coupling, levels of primary and secondary production (its importance for food webs), and existing fish fauna and biodiversity**.** To consider future prospects for fishery productivity in both regions, we focus on: rates of vanishing sea ice; degrees of ocean acidification; food web responses in key zooplankton; responses in fished species (movement toward the poles); circumpolar contrasts; and efforts to model future scenarios. We conclude by discussing considerations for ecosystem approaches to management of fishery resources.

Discussion

Prospects for expanded fisheries productivity in Arctic and Antarctic regions differ and are tentative. In the Arctic/sub-Arctic, changing conditions may increase fisheries productivity and foster a northern shift in geographical distribution. This will largely depend on reductions in the extent of sea ice, sufficient nutrient availability, and favourable temporal match-mismatch between plankton blooms and secondary producers. There may be greater elasticity at the level of secondary productivity in the Arctic/sub-Arctic where three species of *Calanus* copepods typically dominate the zooplankton community (Parent *et al*., 2012). The three show marked differences in lifespan, body size, and lipid content; and display a range of adaptations to highly seasonal Arctic/sub-Arctic environments (Berge *et al*., 2012). Recent studies indicate that two of these *Calanus* species are able to hybridize and produce fertile and reproductive offspring (Parent *et al*., 2012). This evolutionary development improves their chances of survival with positive effects at upper trophic levels. There also is a broad assemblage of non-copepod plankton organisms which may be of trophic importance (Hopcroft, 2009). The northward expansion of warmer waters from the Atlantic into the Arctic may alter the distribution of suitable habitat for many fish species. A number of fish stocks have high potential to establish viable resident populations, or to expand or move into the Arctic. These stocks exhibit life history characteristics allowing them to survive challenging environmental conditions that will continue to prevail in the north (Hollowed *et al*., 2013).

In the Southern Ocean, there may be less elasticity at the level of secondary productivity. Reduction of winter sea ice and ice-shelves could open new areas of potential primary production (Peck *et al*., 2010), help generate new food webs, and potentially enhance demersal and semi-demersal fish production. However, these high-latitude habitats will remain highly seasonal and ice covered in winter, so large increases in production are unlikely. Further north, around islands where natural iron fertilization occurs, productivity is already high (Murphy *et al*., 2007). These regions have large numbers of higher trophic-level predators and, historically, have had concentrated fishing effort. Reductions in numbers of predators on krill populations in such areas may also release some top-down pressure on fish populations allowing them to increase. However, the presence of a wide range of predators, with different diet compositions, suggests that such an outcome is unlikely. The Southern Ocean Polar Front forms a significant circulatory and thermal barrier to poleward movement of pelagic fish species. The associated lack of connectivity between ocean currents at high and low latitudes may inhibit pelagic fish species from completing their life cycles within the different habitats found north and south of the Front. Other factors make it difficult for pelagic fish species found north of the Polar Front to successfully colonize the Southern Ocean, where ecosystems are highly seasonal, temperatures are low, habitats are heterogeneous and variable, and there is relatively little highly-productive shelf area. Some combination of these factors has acted as a barrier to colonisation of the Southern Ocean by truly pelagic fish species, and has constrained the evolution of endemic species.

Conclusion

As the sea-ice edge moves northward in the Atlantic-influenced Arctic region so will distribution of zooplankton (copepods, krill, and amphipods) and their fish predators. An increase in open water, and subsequent increases in primary and secondary production south of the ice edge, will likely benefit important commercial fish stocks in Arctic and sub-Arctic seas. Accordingly, fisheries may see new mixes of species and enhanced biomass for presently targeted species. However, the Pacific-influenced shallow northern Bering and Chukchi Seas are expected to continue to be ice covered in winter; waters there will continue to be cold in winter and spring, and remain a barrier to movement of temperate fish species into the Chukchi Sea (Hunt *et al*., 2013).

Significant changes in sea-ice, and air and ocean temperatures in regions of the Southern Ocean in recent decades are believed to have impacted krill abundance. Future reductions in sea ice may lead to further changes in distribution and abundance across the region, with consequent impacts on food webs where krill are currently key prey items for many predator species, and where krill fishing also occurs. Projections of impacts are uncertain, but this will likely affect the reproduction, growth, and development of krill and its fish predators, leading to further changes in population sizes and distributions. Published studies suggest that the potential for existing species to adapt is mixed, and that potential for invasion into the Southern Ocean of large, highly productive pelagic finfish species appears to be low. Thus, future fisheries in the Southern Ocean may largely be dependent on currently existing species.

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