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INTRODUCTION

Subarctic fish and crustacean populations — climate effects and trophic dynamics

Franz J. Mueter[1,]*, Earl G. Dawe[2], Ólafur K. Pálsson[3]

[1]School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Juneau, Alaska 99801, USA
[2]Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, PO Box 5667, St. John's, Newfoundland and Labrador, A1C 5X1, Canada
[3]Marine Research Institute, Skúlagata 4, PO Box 1390, IS-121 Reykjavík, Iceland

ABSTRACT: This Theme Section reviews the ecological role of large marine decapods, presents selected case studies, and features comparative analyses of the dynamics of fish and crustacean populations and their interactions across several subarctic ecosystems. Collectively, the studies described here highlight the role of climate and predation in regulating fish and crustacean populations in these systems. The Theme Section has resulted from the activities of ESSAS (Ecosystem Studies of Sub-Arctic Seas) Working Group 4 on 'Climate Effects at Upper Trophic Levels'.

KEY WORDS: Subarctic · Crustacea · Gadoids · Climate · Predation · Trophic dynamics

Background

The Ecosystem Studies of Sub-Arctic Seas (ESSAS) program was established in 2005 to examine how climate change affects marine ecosystems of the Sub-Arctic Seas. The hallmark of ESSAS has been a comparative approach that seeks a better understanding of subarctic ecosystems by identifying commonalities and differences among multiple systems. This Theme Section is the product of ESSAS Working Group 4 (WG4) 'Climate Effects at Upper Trophic Levels', which assesses the effects of climate variability, predation, and fishing on major commercial fishes and crustaceans across multiple subarctic marine ecosystems.

Gadoid fishes, flatfishes and crustaceans are integral parts of subarctic ecosystems (Livingston & Tjelmeland 2000, Aydin & Mueter 2007) and support important commercial and subsistence fisheries, as well as large populations of marine birds and mammals (Hunt & Drinkwater 2007). Sustainability and management of these fisheries in a changing climate requires a better understanding of the effects of climate variability on the target stocks, on interactions among stocks, and on the ecosystems of which they are a part.

Observations from several high-latitude marine ecosystems in both the Atlantic and Pacific oceans indicate the existence of alternating states dominated by crustaceans or large predatory fishes (primarily gadoids and flatfishes), respectively (Anderson & Piatt 1999, Choi et al. 2004, Lilly et al. 2008). However, the effects of climate variability, exploitation, and predation on the transition between states remain controversial.

To address this issue, WG4 brought together experts on fishes and crustaceans in 8 subarctic ecosystems. Initial workshops were held in conjunction with the ESSAS Annual Science Meetings in Seattle, USA, in September 2009 and in Reykjavik, Iceland, in September 2010. These workshops featured case studies from selected subarctic seas and laid the foundation for collaborative analyses of long-term fishery and survey data, as well as time series of ocean climate variables. A third workshop to focus on cross-system comparisons was held in conjunction with the second ESSAS Open Science Meeting (OSM) in Seattle in

*Email: fmueter@alaska.edu

May 2011 on 'Comparative studies of climate effects on polar and sub-polar ocean ecosystems: progress in observation and prediction' (Drinkwater et al. 2012). Members of WG4 chaired a scientific session on 'Interactions between gadoids and crustaceans: the roles of climate, predation and fisheries' during the OSM.

Major findings

This Theme Section includes a review of the ecological role of large marine decapods and several case studies, as well as comparative analyses of trophic interactions between predatory fishes and crustaceans and comparisons of recruitment dynamics of snow crabs *Chionoecetes opilio* across several subarctic ecosystems. Boudreau & Worm (2012, this volume) conclude that more experimental studies and long-term observations are needed to understand the mechanisms driving variability in large marine decapods and to manage their fisheries sustainably. Other papers in the Theme Section draw on long-term observations, often from multiple systems, to shed new light on the dynamics of, and interactions between, predatory fishes and crustaceans. Diet studies in the Gulf of Alaska indicate that Tanner crabs *Chionoecetes bairdi* are the most important prey of Pacific cod *Gadus macrocephalus*, whereas shrimp represent an important component of the diet of walleye pollock *Theragra chalcogramma* (Urban et al. 2012, this volume). Pandalid shrimp are important in the diet of Atlantic cod *Gadus morhua* off Iceland, but their prevalence varies greatly between inshore and offshore waters (Jónsdóttir et al. 2012, this volume), highlighting the importance of spatial considerations in analyses of trophic dynamics. The diets of Atlantic cod off Newfoundland and Labrador and of Greenland halibut *Reinhardtius hippoglossoides* in the Gulf of St. Lawrence both shifted from capelin *Mallotus villosus* in the 1980s to shrimp since the mid-1990s, following the collapse of capelin and other fish stocks (Dawe et al. 2012a, this volume). Snow crabs are of lesser importance in the diets of predatory fishes, consistent with evidence across systems that predation does not control their dynamics (Marcello et al. 2012, this volume, Dawe et al. 2012a), although spatial interactions between cod and crustaceans off Newfoundland were locally stronger for snow crabs than for northern shrimp (Windle et al. 2012, this volume).

Climate variability has important effects on the dynamics of snow crab and shrimp populations in a number of subarctic systems. Warm temperatures have consistent negative effects on the survival of early benthic stages of snow crabs (Boudreau et al. 2011, Marcello et al. 2012, this volume), but adults achieve a higher molting frequency and larger size at terminal molt under higher temperatures (Dawe et al. 2012b, this volume). These effects on growth imply that low temperatures reduce recruitment into the fishery because fewer males recruit to harvestable size. However, the overall effect of lower temperatures on recruitment is positive (Marcello et al. 2012), implying that positive effects on early survival dominate recruitment dynamics. In contrast, northern shrimp off West Greenland benefit from warmer surface layer temperatures, presumably due to enhanced food availability for the larvae, as long as bottom temperatures are also warmer to ensure a match between the time of hatching and the plankton bloom (Koeller et al. 2009, Ouellet et al. 2011, Wieland & Siegstad 2012, this volume).

Conclusions

Collectively, papers in this Theme Section provide new evidence for the importance of climate effects on the dynamics of subarctic crustacean populations. In particular, there is strong evidence that climate controls snow crab populations (Marcello et al. 2012), although predation may impede recovery when abundances are low (Orensanz et al. 2004). Climate also interacts with predation in regulating some northern shrimp populations (Wieland & Siegstad 2012). Spatial dynamics regulating the relative overlap of predatory fishes and crustaceans are key to understanding the temporal dynamics of crab and shrimp stocks (Orensanz et al. 2004, Wieland et al. 2007, Parada et al. 2010, Wieland & Siegstad 2012, Windle et al. 2012). These findings will contribute to the sustainable management of fish and shellfish populations in subarctic ecosystems.

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