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Forage Fish Interactions: a symposium on "Creating the tools for ecosystem-based management of marine resources"

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Forage fish (FF) have a unique position within marine foodwebs and the development of sustainable harvest strategies for FF will be a critical step in advancing and implementing the broader, ecosystem-based management of marine systems. In all, 70 scientists from 16 nations gathered for a symposium on 12–14 November 2012 that was designed to address three key questions regarding the effective management of FF and their ecosystems: (i) how do environmental factors and predator–prey interactions drive the productivity and distribution of FF stocks across ecosystems worldwide, (ii) what are the economic and ecological costs and benefits of different FF management strategies, and (iii) do commonalities exist across ecosystems in terms of the effective management of FF exploitation?

Keywords: forage fish, introduction, symposium.

Introduction

Forage fish (FF) are small, often pelagic and schooling fish that are a main pathway for energy to flow from plankton to higher predators in marine ecosystems. Because they maintain this trophodynamic role throughout their life, their population fluctuations may produce notable ecological effects and, therefore, the sustainable management of forage fisheries is critical to maintaining ecosystem functioning. This special issue of the *ICES Journal of Marine Science* contains 12 articles stemming from the ICES-PICES Forage Fish Symposium. These papers largely reflect the major themes of the symposium which included: (i) key processes affecting FF recruitment, (ii) important trophodynamic roles of FF, (iii) quantifying the bioeconomic costs and trade-offs of FF fisheries, and (iv) management of FF resources. In the following, we briefly summarize the presentations and discussions at the conference as well as some of the take home messages from this symposium and papers in this special volume.

Climatic and biotic forcing on FF recruitment

One characteristic of FF populations is that they display large fluctuations in abundance associated with climate variability (Fréon *et al.*, 2005; Peck *et al.*, 2012; Litz *et al.*, 2014; Tian *et al.*, 2014). In some ecosystems, shifts in species dominance and productivity are regular features which often synchronously occur across large spatial scales. An understanding of the properties of this variability in productivity (primarily through variable recruitment) is a cornerstone to the effective management of FF. Changes in early growth and reproduction can amplify subtle environmental variability and cause dramatic fluctuations in survival and year class success. Case studies presented at the symposium illustrated how the trophodynamic role of FF is modulated by a range of factors including changes in bottom-up (physical) forcing (Litz *et al.*, 2014; Tian *et al.*, 2014). The tight coupling between FF and their prey was evinced from the estimates of changes in growth of North Sea sandeels and climate-driven changes in zooplankton (van Deurs *et al.*, 2014). A study from the western North Pacific reported strong trophic overlaps throughout the life history among three clupeids, in contrast to the prevailing "trophic dissimilarity" hypothesis that attributes alternations in the abundance of these anchovy and sardines to different feeding strategies and regime-like changes in prey field characteristics (Yasue *et al.*, 2014). An important, but thus far understudied, aspect of FF in marine foodwebs is potential climate-driven change in trophic transfer efficiency. One presentation highlighted contrasting lipid (fatty acid) profiles of Baltic Sea sprat and herring that emerge from differences in dietary preferences for zooplankton species (Røjbek *et al.*, 2014). Climate-driven changes in zooplankton species composition and availability may lead to lipid profiles in these FFs that are nutritionally suboptimal for maturation of Atlantic cod, one of their main predators in that system.

An emerging theme at the symposium was the role of intra-guild predation (including cannibalism) and competition in population dynamics, often amplifying impacts of external drivers (e.g. environment and fishing). In some systems, mortality of FF due to intra-guild predation may be an important contributor to the regulation of recruitment (Irigoien and de Roos, 2011). A presentation of research conducted in the Bay of Biscay suggested that predation on European anchovy eggs by European sardine can substantially contribute to fluctuations in recruitment and affect the relative abundances of those two FF species in that system. Stock rebuilding management strategies should consider intra-guild predation as a potential factor, impacting on species composition and productivity. In general, climate-driven fluctuations at lower trophic levels (bottom-up processes) and competitive/predatory interactions among FFs can be complex and system-specific, complicating efforts to understand and project changes in FF distribution and abundance.

Predator–prey dynamics in global marine ecosystems

Predation by piscivorous fish and top predators (such as birds and marine mammals) can extract as much or more FF biomass as fishing does in many ecosystems (Bax, 1998; Barrett *et al.*, 2002; Tyrrel *et al.*, 2011). For central-based predators, the local availability of FF is often more important than overall abundance, although equivocal results were presented at the symposium for marine mammals and seabirds in the NE Atlantic. On the one hand, changes in the sizes of female North Sea grey seal after birth were correlated with the abundance of sandeel. Larger post-birth maternal mass is an important characteristic affecting pup mass, growth rate, sucking time, and weaning mass, which affects survival and future growth. On the other hand, a study examining common guillemot indicated that energy delivered to chicks was broadly constant over time and apparently, independent of FF total availability. Thus, a range of responses has been observed.

It was widely accepted that changes in spatial overlap at local scales between FF and predator populations (caused by predation, fishing, behaviour, and/or the environment) have the same effects as large-scale (system-wide) changes in population density. Shoaling may not reduce individual mortality but lead to higher losses if predators target schools. Given the importance of local (small-scale) processes, spatially-explicit modelling of predator–prey dynamics would help us better understand the post-recruitment processes affecting FF, especially as distributional changes and/or abundance of FF can have important trophodynamic consequences. An example of this is presented in Smout *et al.* (2014), who modelled the consumption of FF by grey seals, suggesting that prey switching behaviour could make some prey species vulnerable to predator pit effects. In a second example, cannibalism in Barents Sea cod increases (and growth declines) during periods of low spatial co-occurrence with capelin (Howell and Filin, 2014). Thus, successful, sustainable management of FF fisheries requires understanding of not only predator–prey interactions (who eats what and how much), but also of the spatial and temporal dynamics of these interactions.

Links between biology and economics

The provision of ecosystem services arise from the interaction between ecological and economic systems with the latter often impacted by factors which are external to the former (Tschirhart, 2009). The symposium investigated how FFs fit into this broad perspective. In this case, external factors are the costs or benefits not transmitted through prices; in the ecosystem context, this could include uncompensated environmental effects on production and result in the private costs being lower than the social costs. Fisheries alter the strength of foodweb associations and thus impact other fisheries exploiting other parts of the foodweb. The measurement of the feedbacks in these coupled ecological-economic systems is difficult because of spill-over between markets and fisheries but can be approximated using general equilibrium tools. Presentations at the symposium highlighted how single-stock FF collapses may not always be detrimental for predators in the long term. To measure the links between FF and economics, the concept of shadow interest rates was introduced, i.e. how much a marginal investment in forage stocks would return in the form of future predator harvest of a fishery. A presentation on European fisheries suggested that most shadow interest rates varied between 30 and 70%, suggesting marked overexploitation as these values are higher than inflation.

A recurring theme was that managing FF fisheries broadly hinges on striking a balance between utilizing different parts of the system and balancing biological and economic trade-offs (Dickey-Collas *et al.*, 2014). Several ecosystem services are derived from FF; e.g. landings, supporting ecosystem structure, and maintaining energy flow. Apart from the landings, most services are difficult to evaluate and compare. The cost not included in prices (externality) of harvesting FF has to be taken into account and compared with the direct utility (the satisfaction gained directly from a service). Presentations at the symposium highlighted that, for the North, Baltic, and Barents Seas, the indirect utility of FF is probably greater than the direct utility, a message echoed in a recent assessment of the value of FF to world fisheries (Pikitch *et al.*, 2012a). This conclusion, however, did not consider the value of FF as providers of important fatty acids to the world aquaculture industry.

Ecosystem-based management

Although several indicators, models, and management approaches have been advanced to support ecosystem-based management of FFs, symposium presentations also revealed many uncertainties about the nature of trade-offs among different management objectives. Although we have the tools to estimate who takes FF, we have considerably less information on "who needs" FF and how much (i.e. which species are specialists that are vulnerable to depletion and which are generalist and are thereby less singly dependent on particular forage stocks). Moreover, much of our understanding of trade-offs between management objectives derive from testing simulation models, so there is a need to test the predictions of those models against data (Essington and Plagányi, 2014).

Community indicators, such as the ratio of large- to smaller fish or the pelagic to demersal ratio (Methratta and Link, 2006), might indicate when communities have been pushed beyond a natural range of variability. New model analyses were presented to evaluate cost and benefits of FF fisheries in size-structured foodwebs and to explore conditions in which FF communities may shift into alternative regimes. An example from Puget Sound highlighted the potential importance of management measures to protect critical habitats for FF but concluded that these management measures may also result in unanticipated effects in a highly connected foodweb. Information about predation rates on FF are already being used to improve stock assessment by providing better estimates of FF natural mortality. These have resulted in more robust estimates of biological reference points that explicitly account for the large, direct removal of FF biomass by predators. Explicit consideration of the age and size structure of these removals may be critical for providing scientific advice and projecting impacts of alternative harvest levels. Moreover, the embedding of FF in the middle of complex foodwebs and the regulation of FF populations by various top-down and bottom-up processes indicate that the ecosystem-level impacts of FF exploitation will only be fully appreciated by incorporating estimates from models simulating a large part of the foodweb (Lassalle *et al*., 2014).

From the presentations and discussions at the symposium a wide range of management strategies emerge to achieve FF ecosystem management objectives in the face of uncertainty about populations and foodwebs (Pikitch, *et al*., 2012b; Dickey-Collas *et al*., 2014). These strategies include (i) precautionary buffers that are included in scientific catch advice, (ii) more specified harvest control rules that aim to minimize the "troughs" of population cycles, and (iii) spatial management to preserve the availability of FF for top predators that require these fish at critical times and locations. Many of these strategies are already being applied in fisheries around the world, but additional management strategy, model, and empirical evaluations are needed to evaluate the effectiveness of each on a case-by-case basis. Additionally, it will be important to determine the level of generality that can be assumed to exist in the role of FF in different ecosystems. This will help determine whether generic tools (e.g. size-spectrum models, qualitative foodweb models) can offer viable alternatives to managers charged with examining the ecosystem-level impacts of various FF exploitation strategies, as suggested by results presented at the symposium.

Take-home messages

Many contributions to the ICES-PICES Forage Fish Symposium concluded that, for different and sometimes opposite reasons, a higher degree of risk aversion is necessary in the management of fisheries on forage species. Some studies of top-down processes concluded that the dietary requirements of marine mammal and seabird predators may not be met if fisheries substantially reduce the abundance of forage species because of the high energetic value of forage species as prey. On the other hand, some studies concluded that, in part due to the reduction of abundance of piscivorous predators by fisheries, forage species population dynamics are now dominated by environmentally driven bottom-up processes (Engelhard *et al*., 2014). These processes can cause abrupt changes in the abundance of forage species, requiring both swift responses by management to appropriately adjust fishing mortality and maintain a large standing stock after harvest to provide spawners in the coming years. A number of alternative management strategies have been proposed to achieve the desired risk aversion, but there have been few comparative evaluations of their performance (Link, 2010; Pikitch *et al*., 2012b).

An overarching question was whether objectives for the management of FF are well defined and if scientists and managers can adequately address the trade-offs among these objectives with the knowledge and tools at hand (Rice and Duplisea, 2014). At least six management objectives were listed at the symposium: (i) maintain human food-security via direct and indirect utilization of forage species, (ii) conserve and restore protected, threatened, or endangered species, (iii) promote the productivity of commercially important predators, (iv) satisfy goals and interests of a profitable fishing industry, (v) maintain cultural identity, and (vi) maintain ecosystem structure and function (Fréon *et al*., 2005; Cury *et al*., 2011; Dickey-Collas *et al*., 2014; Rice and Duplisea, 2014). Although some of these objectives are common to most fisheries, all are particularly relevant for fisheries on FFs. Priorities will change over time, but the crucial role of FF and their interactions should always be addressed in the ecosystem approach to fisheries management.

We hope that you enjoy reading the articles published in this special issue of the *ICES Journal of Marine Science*.

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