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International management of North Atlantic pelagic fisheries – The role of competing species and exploiters

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ABSTRACT

This paper explores the economic and biological effects of exploiter and species interactions in a multiplayer, multispecies fishery. To this end, a partial ecosystem model for three key pelagic species in the Northeast Atlantic (Norwegian spring-spawning herring, mackerel and blue whiting) is developed and coupled with an economic model describing harvesting behavior of three major exploiters. We explore the effects on the fishery under assumptions on plausible interaction parameters between the harvested species and the type of management adopted by the exploiting countries. Single-species management is modeled by using three single-species models of the pelagic complex. Net present value is increased by over 20% when applying multispecies management in the cooperative case. Under non-cooperation there is always overfishing of all species compared to the global optimum, resulting in depletion of the mackerel stock and an almost 50% loss in net present value attainable from the aggregate fishery. Interestingly, under non-cooperation the effect of exploiters applying either single-species or multispecies management is rather small on the health of the stocks and on economic benefits.

1. Introduction

In shared multispecies fisheries interactions can occur between both harvesters and the exploited fish populations that have potential to cause economic inefficiencies and be ecologically damaging. In a fishery shared among several exploiters the harvesting of each exploiter will affect the population dynamics of the fish stock, and thus the harvest and future profits of all other exploiters. In an open-access or non-cooperative fishery this will lead to excess effort, overfishing and suboptimal economic and biological performance. If the species of a multispecies fishery are ecologically interdependent, there will also be interactions between the harvested populations. Also biological interdependencies have the potential to significantly influence a fishery's socio-ecological outcome. The effect of biological interactions will depend on the ecosystem in question and on the management regime in place. The ecosystem defines the type of biological interaction between the species, which can be competition for food and other resources, predator-prey interactions or various types of symbiotic relationships. The management regime determines whether species interactions are taken into account (multispecies management) or ignored (single-species management), and whether fishing is cooperative or competitive among the exploiters.

This paper studies the joint effect of exploiter and biological interactions on a Northeast Atlantic assemblage of pelagic fish, consisting of Norwegian spring-spawning (NSS) herring[1] (*Clupea harengus*), mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*). The analysis considers three major exploiters of these fisheries, Norway, the European Union (EU) and Iceland, which differ in harvesting costs and prices for fish. To perform this task an empirically based bioeconomic model is developed, which allows for interaction between both species and exploiters. This implies three types of interaction:

(i) Exploiters interact with species through the harvesting process,
(ii) Species interact with each other through different ecological relationships, and
(iii) Exploiters interact with each other by either cooperating or competing in the fishery.

We compare different management scenarios, where the exploiters either cooperate or compete in all fisheries, and employ either single-species (SSM) or multispecies management (MSM) when making harvesting decisions. MSM is modeled by using a multispecies model of the three-species fishery. This model includes explicit relationships between the harvested species, i.e. species interactions are taken into account in fisheries management. In SSM the agents optimize three single-species models, which do not include interspecific interactions. Consequently fisheries management ignores interactions between species. Under cooperation the three exploiters are maximizing joint benefits from the fishery, while under non-cooperation the agents are

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[1] Also known as Atlanto-Scandian herring.

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Table 1
Scenarios.

1. Cooperation Multispecies management (MSM)
2. Cooperation Single-species management (SSM)
3. Non-cooperation Multispecies management (MSM)
4. Non-cooperation Single-species management (SSM)

Note: Cooperation or non-cooperation apply to the whole pelagic complex, i.e. all three fisheries.

playing a competitive game against each other. The four corresponding scenarios considered are shown in Table 1.

Because the fisheries are closely intertwined through ecological factors, they are sometimes referred to as the pelagic complex of the Northeast Atlantic. There are two features of the pelagic complex fishery which are central for this study. First, from time to time there has been a failure to reach or maintain agreements on quota sharing in each of the fisheries in question (Bjørndal and Ekerhovd, 2014), therefore opening way for non-cooperative harvesting. Second, the single-species management used nationally and internationally neglects ecosystem considerations, such as ecological interactions between the species. Thus, there are important exploiter and species interactions present in this fishery, which should be accounted for when making predictions on the effect of different management decisions.

Very few empirically based studies exist that study interactions between both exploiters and harvested species. The current paper aims to fill this gap in the literature. We contribute to two important areas in the fisheries economics literature. The first is the use of ecosystem models instead of the traditional single-species model in bioeconomic analysis of fisheries. The second is the use of game theory to analyze the strategic interactions between, for example, several countries participating in international fisheries. The importance of moving towards an ecosystem based fisheries management has been widely acknowledged (e.g. Arnason, 1998; Sinclair et al., 2002), while game theory has become a standard tool in the analysis of fisheries with more than one stakeholder (Munro, 2009). In an empirical study by Hjermann et al. (2004) it is shown that Barents Sea capelin can collapse as a result of overexploitation by competing fishermen and predation by herring, whereas predation by cod is shown to slow recovery of the collapsed capelin stock. These findings illustrate the importance of taking into account broader ecological aspects when assessing fisheries management outcomes.

1.1. Related literature

Our empirical application is the same as in Ekerhovd and Steinshamn (2016), who develop a multispecies model of the pelagic complex, where species growth is limited by a common environmental carrying capacity. The model is optimized from a sole owner perspective. Existing literature combining game theoretic tools and multispecies modeling is fairly scarce. Fischer and Mirman (1996) compare cooperative and non-cooperative solutions in a model, which incorporates interactions between two species of fish. The catch ratios are compared to results from earlier studies, where only competing exploiters (Levhari and Mirman, 1980) or biological interactions (Fischer and Mirman, 1992) have been studied.[2] Kronbak and Lindroos (2011) is another analytical study in a similar vein. They study a two-species ecosystem with different ecological interactions and derive the maximum number of non-cooperative exploiters that preserve all species in the ecosystem. The current study differs from these previous papers that it is an application to a real world fishery, and focuses on impacts on economic performance in addition to exploring threats to biological viability.

Sumaila (1997) is an empirical application that combines strategic interaction between exploiters and biological interaction between species. This study is an application to the Barents Sea with two exploiters and two species, cod and capelin, which are in a predator-prey relationship. One player harvests only cod and the other player only capelin. The study concentrates on the inefficiencies arising from the separate fishing of two interlinked species of fish by non-cooperating exploiters. Our study differs from this in that all exploiters participate in all fisheries. A more recent empirically based study is Nieminen et al. (2015), who combine multispecies modeling (cod, herring and sprat in the Baltic Sea) with game theory, specifically stability analysis of international fisheries agreements. In the current paper we are not concerned with if and how the cooperative solution is reached. Rather, we focus on the comparison of the long-run solutions of cooperation and non-cooperation and the economic and biological ramifications of these solutions.

2. The pelagic complex fishery in the Northeast Atlantic

Species interactions between NSS herring, mackerel and blue whiting include spatial and dietary overlap, as well as interspecific predation on eggs, larvae and juveniles (Huse et al., 2012; ICES, 2015).[3] There is strong evidence of interspecific competition for food between the species of the pelagic complex, in particular between NSS herring and mackerel. The herring is thought to be more negatively affected from this competition, because mackerel is a faster and more effective predator (ICES, 2015, and references therein). Furthermore, mackerel predating on herring larvae may have a regulatory effect on the herring population by influencing recruitment (Skaret et al., 2015). Mackerel also feeds on blue whiting eggs, larvae and juveniles, to the extent that it may have a regulatory impact on the juvenile blue whiting population. For example, studies have found that juvenile blue whiting constitutes the main prey of mackerel of the coast of Portugal. (Payne et al., 2012). Thus, ecological interactions between the small pelagic species of the Northeast Atlantic may be an important determinant of the dynamics of these fisheries. For example, in the North Sea it has been shown that pelagic fish feeding on other pelagic fish has a larger potential to influence population dynamics than removal by the fishery, or than predation by e.g. marine mammals and sea birds (Furness, 2002). Fig. 1 shows the spatial overlap of feeding areas for species in the pelagic complex.

The main exploiters of the pelagic complex are the EU, Norway, Iceland, Faeroe Islands, Russia and more recently Greenland. The migratory nature of the pelagic complex poses a challenge to international management. During their annual migrations the stocks enter the Exclusive Economic Zones (EEZs) of several coastal states and they are also present in international waters (high seas). When distribution is variable, it is difficult to agree on the share of a fish stock each party is entitled to. Indeed, for all fisheries considered here reaching and maintaining international fisheries agreements (IFAs) has proved challenging from time to time. Reaching an IFA often means that the exploiters agree on a total allowable catch (TAC) and how to share that catch between them on an annual basis. Mackerel began entering the Icelandic EEZ during its summer migrations in mid-2000, and the fishery has been under dispute ever since. Parties have not been able to agree on how to share the harvest and have been setting unilateral

[2] The aforementioned authors call these interactions a dynamic and biological externality, respectively. Levhari and Mirman (1980) also acknowledge a third type of interaction, which they call a "market" externality. This occurs when the market price for fish is affected by the landings of all exploiters. We do not consider this last effect in our analysis, because we assume constant prices.

[3] Trenkel et al. (2014) provide a good overview of the comparative ecology of NSS herring, mackerel, blue whiting and other pelagic species in the North Atlantic.