Fisheries Research 201 (2018) 109–119

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Fisheries management under nutrient influence: Cod fishery in the Western Baltic Sea☆

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ARTICLE INFO

Handled by George A. Rose

Keywords:
Bio-economic modelling
Fisheries
Emissions
Nutrients

ABSTRACT

A fisheries management model that identifies the economic optimal management of fisheries under the influence of nutrients is presented. The model starts from the idea that growth in fish biomass increases with increasing availability of nutrients owing to higher food availability up to a peak, after which growth falls due to eutrophication. The model is applied to Swedish and Danish cod fisheries in the Western Baltic Sea and identifies the welfare contribution of the fisheries, measured as the sum of resource rent and producer surplus. In 2010, the welfare contribution was −28% of the landing value. Maximizing the model with respect to effort alone and additionally over nitrogen concentration increases the contribution to 11% of the landing value in 2010. The analysis shows that the welfare effect of reducing fishing effort through management reforms is large, but that the effect of incorporating nitrogen in fisheries policy is small.

1. Introduction

In recent years several policy initiatives have been taken to integrate different sector policies that affect marine areas, acknowledging that different human activities in the marine area affect each other. In the European Union these initiatives include the Marine Strategy Framework Directive (European Commission, 2008), the Marine Spatial Planning Directive (European Commission, 2014) and the Habitat Directive (European Commission, 1992). Successful implementation of such integrated policies requires knowledge on how sector activities interact and affect each other.

Two such sector activities are fisheries that are regulated via fisheries policies and marine pollution that is regulated trough environmental policies. Fisheries policies typically focus on the sustainable use of fisheries resources, although implementation differs depending on different biological, economic and social sustainability objectives. Environmental policies focus on ensuring a good environmental status of the marine ecosystems. Hence, fisheries and marine pollution have historically been regulated independently of each other in policies with different purposes.

An example of interactions is how fisheries are affected by nutrient discharges, mainly from land-based sectors such as agriculture and industry. Different nutrient concentrations will affect the growth of fish stocks and thus the socio-economic outcome of the fishing sector. When such interactions exist, fisheries- and environmental policies are also interrelated with each other. Therefore, if policy purposes in both areas shall be achieved simultaneously, coordination is necessary.

The purpose of this study is to identify the optimal management of fisheries taking both fisheries policies and policies for nutrient discharges into account. Further, we analyze how the optimal fishery is affected by nutrient policies that do not take fisheries into account (e.g. when nutrients are reduced for other environmental purposes such as water quality). To do this, a model for identifying welfare-optimal management of fisheries under the influence of marine nutrients such as nitrogen and phosphorous is developed. The model is applied to the Swedish and Danish cod fisheries with passive gears in the Western Baltic Sea. Focus is on nitrogen concentrations since these are a major cause of eutrophication in the Baltic Sea (Helcom, 2007, 2014). The approach is based on a comparative-static bio-economic model, extended with a biological growth function that depends not only on fishing effort, but also on nutrient concentrations in the sea. The model

☆ Funding from the Fisheries Cooperation of the Nordic Council of Ministers for the project "Potential for green growth in Nordic fisheries and aquaculture through reduced discharges of nitrogen" no. 60:2012-2014 is gratefully acknowledged.
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https://doi.org/10.1016/j.fishres.2018.01.012
Received 22 November 2016; Received in revised form 18 January 2018; Accepted 19 January 2018

takes into account that more nutrients lead to higher food availability, which potentially leads to higher growth of the cod stock. It further takes into account that a level of nutrient concentration exists that maximizes the sustained harvest. At higher nutrient concentrations, eutrophication reduces the life of benthic ecosystems through oxygen deficiency, and thereby limits the cod stock. Finally, a socio-economic analysis focusing at the contribution of fisheries to welfare is chosen, instead of only focusing on the economy of the vessels.

The issue of taking the effect of nutrient concentrations on the Western Baltic cod stock into account is important, since it might change the optimal fisheries policy both from a biological and a socio-economic point of view. If nutrient concentration is higher than optimal, a reduction could improve the growth conditions for the Baltic cod stock. Conversely, if the nutrient content is below the optimal level, a reduction could limit potential growth of the stock. With changed stock conditions, the socio-economic optimal fisheries policy is affected, implying that the fisheries policy can gain from knowledge on how nutrient concentrations affect fish stocks and socio-economy.

A number of studies have incorporated environmental externalities into bio-economic models of fisheries (Barbier and Strand, 1998; Simmonit and Perrings, 2005; Foley et al., 2009; Udumyan et al., 2010; Foley et al., 2012; Nguyen, 2013; Smith et al., 2014; Nguyen et al., 2015). Barbier and Strand (1998) study the effect of changes in mangrove areas on the carrying capacity of shrimp stocks in Mexico, while Simmonit and Perrings (2005) look at effects of eutrophication on growth of fish in Lake Victoria. Foley et al. (2012) identify the effect of habitat quality on carrying capacity and growth rates in a theoretical set-up. All depart from the Gordon-Schaefer model (Gordon, 1954; Schaefer, 1957). Using micro-data, Huang et al. (2010) analyze the effects of hypoxia and estimate that it has reduced North Carolina brown shrimp catches with about 13% between 1999 and 2005 which corresponds to revenue losses of $1.25 million per year. However, Huang et al. (2012) find that the welfare effect is considerably smaller (only 25% of revenue losses) due to fishermen being able to adjust their fishing activities. Smith et al. (2014) study the Gulf of Mexico brown shrimp and argue that hypoxia will decrease harvest due to lower growth and higher mortality, but that the catchability will increase. Other studies investigating the effects of hypoxia are Lipton and Hicks (2003), Mistiaen et al. (2003) and Massey et al. (2006). Nguyen (2013) and Nguyen et al. (2015) maximize the net present value of profits of the Eastern Baltic cod fishery under the influence of eutrophication by applying a dynamic empirical model. They show that the marginal damage to the fish stock is small compared with the marginal abatement cost of land-based polluters.

We contribute to the literature by explicitly modelling the interaction between environmental policies reducing nitrogen concentrations and fisheries policies improving fisheries management. In the model, intrinsic stock growth and carrying capacity depend on nitrogen concentrations.

The remainder of the paper is organized as follows: In Section 2, nutrient regulations and the cod fishery of the Western Baltic Sea are described. In Section 3, a model for optimal management of fisheries under the influence of nutrients is developed. Section 4 present data and Section 5 the calibration of the model. Section 6 contains the results. Section 7 contains a sensitivity analysis of the results. The results are discussed and concluded in Section 8.

2. Nutrients, regulations, and the cod fishery in the Western Baltic Sea

In the 1990s, increasing concerns about the negative effects of eutrophication of European waters resulted in two EU directives. Council Directive 91/676/EC focused on protection of waters against emissions of nitrates from agricultural sources and required all member states to identify vulnerable zones, establish action plans for limiting nitrogen losses from agriculture, and promote good agricultural practices (European Commission, 1991). Around ten years later, the EU Water Framework Directive (Directive 2000/60/EC) was established, taking a wider perspective on the environmental problems in the field of water policy (European Commission, 2000). For the Baltic Sea countries, limiting eutrophication in the Baltic Sea has become a major issue in order to meet the objectives of the directive. More recently, in 2008, a marine strategy framework (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008) for community action in the field of marine environmental policy was issued (European Commission, 2008) with the purpose to increase the ecosystem approach in the management of marine resources and to further protect marine biodiversity (European Commission, 2016).

In addition to the EU directives, HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) is working through intergovernmental cooperation to protect the marine environment of the Baltic Sea. In 2007, HELCOM established the Baltic Sea Action Plan with the objective of achieving "good environmental status" for the Baltic by 2021. The plan establishes the level of reduction in nitrogen and phosphorus emissions that is required from each country. In total, HELCOM requires that emissions of nitrogen and phosphorus in the Baltic Sea be reduced by 118,000 and 15,000 tons, respectively (Helcom, 2013a). More specifically, the latest Ministerial declaration of the Helcom (2013a, 2013b, 2013c) required reductions for the Baltic Proper but not for the Danish Straits (which covers the Western Baltic Sea) (Helcom, 2013b). However, the declaration specified oxygen debt targets and an agreement that oxygen concentration in the Danish Straits must exceed 2 mg/l (Helcom, 2013a).

Although the framework of the legislation is established in the EU directives and the Baltic Sea Action Plan, it is up to individual states to implement the regulations to meet the objectives. In Denmark, environmental water action plans have been in place since 1985, with the objective of reducing losses of nitrogen and phosphorus to Danish waters (Dalgaard et al., 2014). It has been relatively easy to reduce phosphorus losses to Danish waters, whereas reducing losses of nitrogen has been somewhat more difficult, since its sources are more diffuse (Dalgaard et al., 2014). In Sweden, 15 national environmental quality objectives were established in 1999 and one of these, "no eutrophication", is related to loss of nutrients to waters. The overall objective is for eutrophying substances in soil and waters to be reduced to a level where they do not affect health, biological diversity, or the use of soil and waters (Swedish Environmental Protection Agency, 2013).

Evidence from a large number of coastal and semi-enclosed systems shows that increased nutrient concentrations and organic enrichment generally enhance overall fish biomass production (Nixon and Buckley, 2002; Nagai, 2003; Oczkowski and Nixon, 2008). A positive relationship between nutrient concentration and fisheries yields is often observed over large spatial scales and considering the entire harvested biomass spanning across different trophic levels (Breitburg et al., 2009). Eero et al. (2011) discuss the positive effects of eutrophication on the cod stocks in the Baltic, and concludes that eutrophication can be related to higher food availability, growth and survival conditions for larvae and juvenile stages of cod, and that the increased nutrient concentration to the Baltic Sea from the 1940s to the 1980s is associated with higher cod recruitment. However, nutrient concentration can cause oxygen deficiency which has negative implications for a number of fish and macro-invertebrate species, affecting their physiology (Claireaux and Dutil, 1992) and behavior (Baden et al., 1990), and fragmenting and reducing essential habitats necessary for their reproduction and food (Breitburg, 2002). Eggs and early life stages are particularly vulnerable to oxygen deficiency because of their low ability to avoid adverse conditions and because of their generally higher oxygen requirements (Vallin and Nissling, 2000). Moreover, the reproductive habitat of cod can shrink due to oxygen deficiency, with negative consequences on its recruitment (Vallin and Nissling, 2000). Temporary, moderately hypoxic conditions may increase predation rates of benthivorous species (Neuenfeldt et al., 2009), but experimental tests on juvenile cod have shown that prolonged exposure compromises physiological functions (Claireaux and Dutil, 1992) and has negative effects on