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Analysis

Maximum Economic Yield Fishery Management in the Face of Global Warming

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A B S T R A C T

This paper deals with fishery management in the face of the ecological and economic effects of global warming. To achieve this, a dynamic bioeconomic model and model-based scenarios are considered, in which the stock's growth function depends on the sea surface temperature. The model is empirically calibrated for the French Guiana shrimp fishery using time series collected over the period 1993–2009. Three fishing effort strategies are then compared under two contrasted IPCC climate scenarios (RCP 8.5 and RCP 2.6). A first harvesting strategy maintains the Status Quo in terms of fishing effort. A more ecologically-oriented strategy based on the closure of the fishery is also considered. A third strategy, which relates to Maximum Economic Yield (MEY), is based on the optimisation of the net present value derived from fishing. The results first show that 'Status Quo' fishing intensity combined with global warming leads to the collapse of the fishery in the long run. Secondly, it turns out that the Closure strategy preserves stock viability especially under the optimistic climate scenario. Thirdly, the MEY strategy makes it possible to satisfy bioeconomic performances requirements with positive stock and profit, once again, especially under the optimistic warming scenario. Consequently, MEY emerges as a relevant bioeconomic strategy in terms of adaptation to climate change but only in connection with climate change mitigation.

1. Introduction

Marine biodiversity and ecosystems are under pressure worldwide. According to Moffitt and Cajas-Cano (2014), around 25% of world's commercial fish species are overexploited. Climate change complicates and exacerbates the issues by inducing new - or intensifying existing - risks, uncertainties and vulnerabilities.

Recognition that global warming affects the ecological functioning of marine ecosystems and fisheries is increasing. Lehodey et al. (2006), Steinmetz et al. (2008) and Garza-Gil et al. (2011) analyse the effects of climate on fisheries. More specifically, Brander (2007) and Cheung et al. (2009) argue that climate change and global warming, in particular through their effect on sea temperature, may be the strongest drivers of stock dynamics and harvest levels in the future. As rapid and persistent rises in temperature are expected to occur during the next decades (Levitus et al., 2000), there is a clear need to take this phenomenon into account in management strategies and public policies.

In that context, the European Union explicitly includes the objectives of climate change mitigation and adaptation in its policy relating to maritime spatial planning and integrated coastal zone management. Thus, the Common Fisheries Policy (Reg. UE 1380/2013 11/12/2013) reaffirms the obligations associated with international commitments on sustainable management of fisheries. It also puts forward a more regional approach for optimising various ecological and socio-economic objectives in order to reach, in particular, Maximum Sustainable Yileds (MSY) by 2020. Positive economic and social benefits as well as food security are also targeted. Moreover, the Marine Strategy Framework Directive (MSFD), which requires "Good Environmental Status" including descriptors on biodiversity (gains in fish community, status of the assessed stock, indicators of individual size, etc.) has to be applied as well. This is challenging for the EU overseas entities, where to date

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the MSFD has not been applied.

As a consequence of the above-mentioned difficulties, designing quantitative tools to guide public policies and ensure the long-term bioeconomic sustainability and resilience of marine fisheries in the face of global warming is a major challenge (Moffitt and Cajas-Cano, 2014). In response, an increasing number of marine scientists and experts advocate the use of ecosystem-based fishery management (EBFM) which takes into account the various ecological and economic complexities involved, including habitat and climate drivers (Pikitch et al., 2004, Thébaud et al., 2014, Link et al., 2017, Doyen et al., 2017). However, operationalising the EBFM approach remains difficult (Sanchirico et al., 2008, Doyen et al., 2017) especially from a bioeconomic viewpoint. In particular, question arises as to how to adapt current management strategies including MSY when adopting an ecosystem approach. Many fish stocks are currently managed to reach their MSY, through limitations on fishing quotas or effort (Mace, 2001, Worm et al., 2009, Yimin et al., 2013). At MSY, catches are maximised at levels where stocks can regenerate. However, the sustainability of this monospecific strategy is disputed (Larkin, 1977). Instead of MSY, many resource economists advocate the use of maximum economic yield (MEY) targets, at which profits are maximised (Dichmont et al., 2010). Although it depends on the discount rate, the sensitivity of costs and revenues to biomass and harvest, and the marginal growth of the biomass, harvesting at MEY may favour higher biomass levels than MSY, for instance in the case of zero discounting (Grafton et al., 2007, Clark, 2010). Adopting the MEY management strategy may lead to a win-win outcome under frictionless conditions even when the discount rate is much higher than the intrinsic growth rate of fish (see Grafton et al., 2010, 2007), and when onshore sectors (retailing, fishing processing) are incorporated (Grafton et al., 2012). MEY was chosen as a reference point for Australian fisheries. However, the extent to which MEY management can be adapted to climate change and more globally to the ecosystem approach remains an open question.

The aim of this paper is to explore fishery management in the face of the ecological-economic effects of global warming and in particular to evaluate the bioeconomic merits of MEY policies for operationalising ecosystem-based management of fisheries confronted with climate change. In order to do so, we analyse the case of the French Guiana shrimp fishery (FGSF), a challenging task since, despite major reductions in fishing effort and harvest levels over the past two decades, the shrimp stock continues to decrease, which suggests that other factors may have a stronger influence on that fishery. Accordingly, the dynamic bioeconomic model developed in this paper considers that the shrimp stock's growth function depends on sea surface temperature (SST), as suggested in Sanz et al. (2017).

The natural growth and harvest functions of the bioeconomic model of the FGSF are estimated using catch and effort time series collected by Ifremer (French Research Institute for Exploitation of the Sea) over the period 1993–2009. We then compare the bioeconomic performance of three management strategies under two distinct IPCC (Intergovernmental Panel on Climate Change) climate scenarios (RCP 2.6 and RCP 8.5) for the period 2010–2050. These strategies include maintaining the Status Quo in fishing effort, the Closure of the fishery and a third strategy relating to (dynamic or discounted) MEY through the optimisation of the net present value derived from fishing.

The paper is organised as follows: Section 2 describes the FGSF in greater detail, notably concerning its institutional context. Section 3 presents the bioeconomic model, its calibration, and the climate scenarios as well as the three distinct management strategies. Section 4 focuses on the results of the simulations over the period 2010–2050, Section 5 discusses the results, and Section 6 presents some concluding remarks and prospects.

2. The French Guiana Shrimp Fishery

After being the most highly traded fishery product for decades on a global scale, shrimp nowadays still ranks second in terms of value. Shrimp is mainly produced in developing countries, and much of this production enters international trade (FAO, 2016). For French Guiana, the shrimp fishery constitutes a major source of value: it represents the third largest export sector (25% of the total volume) (Garandeau, 2006). The FGSF targets two species, brown and pink shrimp (*Farfantepenaeus subtilis* and *Farfantepenaeus brasiliensis*). Fishing activities in the FGSF started in the late 1960s with US and Japanese fleets, which gradually became French between 1970 and 1990. Since 1992, the fleet has been made up solely of French trawlers targeting shrimp on the continental shelf.

From 1992 to 1999, shrimp stock assessments of shrimps were performed by a working group within the institutional and international framework of the FAO's Western Central Atlantic Fishery Commission (WECAFC). Since 1999, stock assessments to provide management advice have been carried out by Ifremer. The method used for assessments carried out on a monthly basis is the “Virtual Population Analysis” (VPA) which enables recruitment and abundance as well as spawning stock biomass and fishing mortality to be determined.

Management rules were gradually adopted for the FGSF, starting with the creation of the Exclusive Economic Zone in 1977. In 1983, a Total Allowable Catch (TAC) system was implemented for both brown and pink shrimp, in particular to comply with European legislation. This TAC is calculated on the basis of MSY by combining a Schaefer production model and size structure statistics. Initially set at 4108 tonnes, including 108 tonnes allocated to neighbouring countries (Suriname, Trinidad, Barbados), it remained unchanged until 2011. Moreover, in 1991, a licensing system aimed at limiting the number of trawlers was introduced for both species. Licences are managed by the French Ministry of Agriculture and Fisheries and are issued free of charge. The TAC is set by the European Union. In terms of regulations, there also certain spatial restrictions: in order to limit the impact of trawling on juvenile shrimp and avoid conflicts with the small-scale coastal fishery, trawling is forbidden in coastal waters less than 30 m deep. This rule is more restrictive than the spatial limitation applied to trawlers in European waters.

Despite these different regulations and management rules, the FGSF has faced many difficulties for the past two decades. Shrimp stock has decreased since 1993, while the economic dynamics of the fishery has been characterised by a reduction in fleet size, with fishing activities currently concentrated among a small number of profitable vessels (around 10). Other difficulties include the fact that the TAC has never been fully reached. Similarly, the licensing system also has not been useful since the number of active shrimp trawlers is smaller than the number of available licences. The high variability of stock recruitment (Béné and Doyen, 2000), globalisation of the shrimp market (which has led to a 50% decrease in real prices since 1997), and long-term increases in fuel prices worldwide, as well as the 2007 financial crisis, partly explain the economic problems of the fishery. However, the decline of the shrimp stock despite the significant reduction in fishing effort and harvest levels for two decades suggests that other factors may have a stronger influence on the FGSF. Among those drivers, Sanz et al. (2017) focus on environmental factors, and show that sea surface temperature (SST), together with river flow rates and El Niño and La Niña phenomena, affect the quality of offshore waters and thus the productivity of the local marine ecosystem. The French Guiana marine fishing area might indeed be affected by changes in SST since the latter significantly increased between 1970 and 2004 along the Guianese coast. The difference between the average values of these two periods is estimated at 0.65 °C, with an accentuation of this phenomenon since 1995 (Bernard, 2006).

Consequently, this paper investigates the ecological and economic effects of ocean warming on the FSFG. To achieve this, a dynamic bioeconomic model, in which shrimp's growth function depends on SST is calibrated. The empirical quantification of the model combines