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Analysis

Fishery externalities and biodiversity: Trade-offs between the viability of shrimp trawling and the conservation of Frigatebirds in French Guiana

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ABSTRACT

Sustainable management of natural resources, and in particular fisheries, must take into account several conflicting objectives. This is the case in the French Guiana shrimp fishery for which profitability objectives imply a reduction in the fishing activity. On the one hand, this fishery has negative externalities on marine biodiversity due to discards. On the other hand, this fishery has positive externalities on the economy of the local community and interestingly enough on a protected seabird species in the area (the Frigatebird that feeds on discards). In this paper, we examine the viability of that system considering two sustainability objectives: an economic objective in terms of the profitability of the fishing activity, and a conservation objective in terms of the Frigatebird population. For that purpose, we have developed a dynamic model of that bioeconomic system and study here the trade-offs between the two conflicting objectives. It provides a means to quantify the necessary give and takes involving the economic and ecological objectives that would ensure a viable management solution. Our study confirms the relevance of the viability approach to address natural resource management issues, which should lead to the development of new tools for the arbitration of conflicting sustainability objectives. In particular, such tools could be used as a quantitative basis for cost–benefit analysis taking into account environmental externalities.

1. Introduction

Fishery activities generate externalities on biodiversity. On the one hand, there are numerous negative externalities linked to fishery discards in terms of bycatch species and loss of marine biodiversity. Indeed, eliminating discards is currently a major political objective (CEC, 2007). On the other hand, one potential positive externality of these discards is that they may play a fundamental role in marine bird feeding (Furness, 2003). According to Furness (1999), reducing fishery discards may dramatically reduce some seabird populations. This is also the case when discards are reduced due to an adjustment of fishing activities related to the economic context. For example, the prior level of fishing activity of the French Guiana shrimp fishery is no longer economically viable given the present prices, costs, and amount of subsidies. The recent reduction in that fishing activity has resulted in a high rate of Frigatebird chick mortality and has triggered a conflict between the ecological objective of the Frigatebird conservation program off the Caribbean coast of French Guiana and the economic objective of the fishery. Managing fishery activities in a sustainable way must thus take into account conflicting objectives that would ensure economic viability while preserving marine and bird biodiversity.

In ecological economics, it is now recognized that multicriteria modeling, and especially the viability approach (Aubin, 1991), are well-suited to address sustainability issues (De Lara and Doyen, 2008). The aim of the viability approach is to study the consistency between a dynamic model and a set of constraints. It involves defining the conditions such that the constraints are satisfied at all times. In particular, thanks to the viability approach, it is possible to characterize the dynamics of a bio-economic system in terms of its capacity to achieve, in the long-run, sustainability objectives represented by ecological and economic constraints. Béné et al. (2001), Doyen and Béné (2003) and Eisenack et al. (2006) have used the viability approach to investigate natural resource management issues. Cury et al. (2005) have argued that the application of the viability approach is relevant for an ecosystem management of fisheries. Indeed, the viability of fisheries has recently been studied by Doyen et al. (2007), Martinet et al. (2007) and Chapel et al. (2008), among others. In particular, Béné and Doyen (2000) study the viability of the French Guianese shrimp fishery in terms of economic issues alone, without accounting for environmental externalities.

Viability studies usually account for constraints with given levels. It may result in problems with no viable solutions. Martinet and Doyen (2007, appendix A.1.5) introduced the idea that relaxing some constraints would be one way to overcome from such non-viable solutions. It may also be necessary to conciliate ecological and economic requirements for particular ecological economic states to

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be viable. In this study, we follow this lead to investigate a way to account for potential interactions between constraint levels, using the French Guiana case-study. It is a means to provide much needed information about trade-offs between sustainability objectives. In the example of the shrimp fishery and Frigatebirds, it allows us to describe the trade-offs between ensuring the viability of the shrimp trawling and maintaining the bird population which feeds on fishery discards.

To this end, we have developed a dynamic bioeconomic model of a fishery that generates discards which are a source of food for a bird population. We account for two sustainability objectives (represented by constraints): an economic constraint on the profitability of the fishing activity and a conservation constraint of the bird population. We examine how these sustainability objectives are compatible one with respect to the other, and if there are trade-offs between both viability constraint levels. In other words, we are dealing with how to cope with two seemingly different objectives at the same time, and more specifically with the give and take in the level of constraints that must be worked out to be able to reach these objectives.

The paper is organized as follows. In Section 2, we present a model based on the Guianese shrimp fishery. In Section 3, we address the co-viability issue of achieving at the same time economic and ecological objectives in a dynamic way. In Section 4, we extend this viability analysis by describing the trade-offs between economic and biological objectives. We also define the economic conditions that are necessary (including the minimum amount of subsidies) if the Guianese fishing activity is to be viable while maintaining a targeted Frigatebird population level. In Section 5, we discuss how this approach fits into the literature on biodiversity conservation. In Section 6, we conclude on the potential use of the viability approach as a tool that provides a well-grounded basis for arbitration between conflicting sustainability objectives. Parameter values and mathematical proof are provided in the appendix.

2. Model of a fishery interacting with a seabird population

2.1. The French Guiana case study

The shrimp fishery in French Guiana is composed of trawlers fishing for shrimp on the continental shelf. Two main species are involved: *Farfantepeneus subtilis* and *F. brasiliensis*. Only *F. subtilis* was accounted for. It is the species caught the most often and, since the eighties, it has been thoroughly investigated by Ifremer (the French institute of research for the exploitation of the sea) providing solid knowledge of the population and exploitation dynamics. From a historical point of view, the economic dynamics of the fishery have been characterized by a decrease in the fishing activity for profitability purposes. In turn, the amount of catch has dramatically decreased, and actually it is about half the Maximum Sustainable Yield (MSY). This decrease in fishing activity has meant a decrease in discard.

The Frigatebird *Fregata magnificens* population in French Guiana is the most important colony of this seabird species from northern Brazil to Venezuela. The colony is located in a natural reserve on “Le Grand Connetable”, a small island which makes survey easy. They are exceptional birds, because of their low reproduction rate, their long period of parental care (the longest of any bird), and their long life spent (more than 30 years) (Weimerskirch at al., 2003). Before the development of the shrimp fishery (and associated discards), the Frigatebird population was stable, with about 180 nesting couples managing to raise their chick. Since it is not possible here to represent the Frigatebird population in a dynamic way in our case (sufficient long-run data is not yet available to assess the dynamics), the number of breeding bird couples serves as a proxy for the Frigatebird population.

Calixto-Albarran and Osorno (2000) have found a correlation between the variety of fish in the diet of Frigatebird population on Isla Isabel (off the Pacific coast of Mexico) and species discarded by prawn-fishing trawlers in the area, thereby assuming an opportunistic feeding during nesting period. Based on personal field observation that found 120 Frigatebirds feeding on the discard of a sole shrimp trawler, the same correlation is assumed to hold for the Guianese population. A strong correlation has been also observed between chick mortality during breeding and periods of reduced fishing activity (and associated decreasing discards) within the area of bird foraging (unpublished data). Until recently, the decrease in discard had no impact on the Frigatebird population, but the ongoing decline of the fishery and the associated observed mortality of chicks now jeopardize the conservation program. In the 2007 economic context, some of the 639 surveyed couples were not able to feed their chick. Understanding the interactions between economic dynamics and the conservation objectives is therefore necessary. For that purpose, we have developed a bioeconomic model of the fishery.

2.2. The bioeconomic model

We consider a single stock fishery, characterized every year t by the biomass B_t of the resource stock (shrimp in our case study). The dynamics of the bio-economic system is controlled by the fishing effort E_t, following Clark (1985). The global harvest is defined by $H_t = qB_tE_t$, where the constant parameter q represents the catchability of the resource. Using a discrete time version of the “logistic model” to represent the growth function of the shrimp stock, the dynamics of the resource stock is given by

$$B_{t+1} = B_t + R(B_t) - H_t = B_t + rB_t\left(1 - \frac{B_t}{B_{\text{sup}}}\right) - qB_tE_t \tag{1}$$

where B_{sup} is the carrying capacity of the ecosystem, and r the natural growth rate of the resource stock ($r<1$).

The fishery is characterized by profit given as

$$\pi_t = (p+\tau)H_t - cE_t = (p+\tau)qB_tE_t - cE_t \tag{2}$$

where p is an exogenous resource price, τ is a production subsidy and c is the per effort unit cost.

This fishery generates discards of bycatch species. These discards depend on the fishing effort E_t. A part of these discards is used by seabirds to feed themselves and to feed newborns during the breeding season (Frigatebirds in our case study). We define the quantity of discards available for birds as $D_t = dE_t$, where d is a discard constant, i.e., the quantity of discarded biomass that birds can eat per unit of fishing effort. An important point is that the discards are made up of bycatch species (fish, squid, starfish, crabs, jellyfish), hence not proportional to the catches of the targeted species (to the shrimp biomass) but to the fishing effort (the overall number of trawler's haul).

We are interested in the number of Frigatebird couples that make a nest and find enough food to raise the chick until it can leave the nest.[1] We assume the following relationship between discards and Frigatebird nests

$$F_t = sD_t + F_0 \tag{3}$$

where F_0 is the number of Frigatebird couples that raised a chick successfully before fishing began in the area and there was no discard. s is a constant parameter describing the effect of the new food source provided by discards.

2.3. The viability constraints

In the present analysis, we will focus on two viability constraints.

On the one hand, the economic viability of the shrimp fishery depends on its profit that has to be positive, i.e., $\pi_t \geq 0$.

[1] Using breeding units as a proxy for the population size is usual when the ecological dynamics is unknown. See, for example, Montgomery et al. (1999).