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Analysis

Managing interacting species in unassessed fisheries

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ABSTRACT

This paper addresses the management of multispecies fisheries, and suggests the use of restricted fishing policies as an interesting option for unassessed fisheries (as is the case within developing countries). Specifically, we consider a predator–prey system under two potential management policies: an unrestricted regime where agents can compete to harvest from both species, and a second one where they are allowed to harvest only predators. The performance of both policies is compared from an ecological and an economic point of view. For a sufficiently large number of agents (or for strong biological interaction parameters) the assumed restricted fishing policy yields both higher long run stock levels and profits. Thus, this contribution suggests that such a policy, while requiring weaker monitoring/governance than instruments based on outputs (such as quotas or taxes), would meet environmental and economic objectives. Finally, several features of the analysis are discussed, including targeting prey instead of predator and the issue of compliance.

1. Introduction

Since the works of Gordon (1954) or Clark (1985), a vast literature has focused on the issues raised by the regulation of fisheries. Most contributions on the analysis of regulatory issues considered species in isolation and suggested mostly market-based approaches like taxes or (transferable) quotas.[1] These approaches have been shown to benefit data-rich fisheries within developed countries (Costello et al., 2008). However, they require strong governance and monitoring, which makes them more difficult to implement for unassessed fisheries in developing countries. Since unmonitored fisheries seem to be more threatened than assessed ones while accounting for over eighty percent of global catch (Costello et al., 2012), the analysis of more broadly appropriate policies has practical significance. Recent contributions have raised the idea of designing new management policies that account for species interactions or diversity. Still, there are few analyses of regulatory tools in situations characterized by economic competition (strategic externalities) and biological interactions. The present paper aims to contribute to this line of research. We will analyze a competitive situation in which two interdependent fish species are harvested, and we will assess the performance of a restricted management policy where agents are allowed to harvest only one species.

The literature on fisheries economics has adopted two main perspectives. First focuses on the analysis of either the socially optimal management policies (Agar and Sutinen, 2004; Hannesson, 1983; Strobele and Wacker, 1995; Tu and Wilman, 1992) or the open access bio-economic equilibrium (see Flaaten, 1988 for a theoretical and an empirical contribution). This type of contribution provides insights on the design of economic instruments in order to achieve socially optimal outcomes. Taxes and transferable quotas are usually suggested on the ground of economic efficiency, even though biological interactions are rarely accounted for in multispecies situations (Asche et al., 2007; Costa Duarte, 1992; Ussif and Sumaila, 2004). A growing number of contributions stress the importance of acknowledging species interactions or diversity in designing sustainable management policies (Akpalu, 2009; Akpalu and Bitew, 2011; Brown et al., 2005; Sterner, 2007); some of them suggest the use of instruments requiring weaker governance and monitoring than market based approaches. Examples of such instruments are the introduction of marine protected areas or marine reserves (Boncoeur et al., 2002; Schnier, 2005; White et al., 2008), or conservation policies where certain species are harvested on the basis of non use values (Hoekstra and van den Bergh, 2005). They are now often supported because they account for the specific interactions existing between species. Moreover, they seem to constitute more appropriate tools for unassessed fisheries.

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[1] Contributions on multispecies fisheries such as May et al. (1979), Quirk and Smith (1970) or Anderson (1975) focused on the difference between open-access harvesting and socially optimal harvesting.

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A second part of the literature focuses on game-theoretic models of fisheries in order to analyze the impact of strategic externalities on the sustainability of the species (see Clark, 1990, or Kaitala and Lindroos, 2007 for a good review). These models often consider the case of a single species only (Levhari and Mirman, 1980; Plourde and Yeung, 1989). A few contributions consider that agents might exploit several stocks simultaneously, and that these stocks might be biologically dependent. Some of these are Fischer and Mirman (1992, 1996) and Hannesson (1997), who analyze a two-country, two-species model and characterize the optimal non-cooperative consumption policies, or Kronbak and Lindroos (2011) who characterize the number of exploiters that may be sustained in a non-cooperative equilibrium without driving one stock to extinction. A recent literature has provided game-theoretic treatments of marine protected areas (Busch, 2008; Sanchirico and Wilen, 2001) and highlighted their potential as environmental conservation tools. Since the focus of these contributions is the impact of strategic externalities on the commons problem, regulatory issues are usually not accounted for explicitly.

The aim of this paper is to analyze the problem of regulating an area subject to weak governance and/or monitoring, characterized by biological and strategic interdependencies, and to examine the effectiveness (from the point of view of both environmental and economic objectives) of a simple instrument based on a restricted fishing policy (where the harvest of one species is forbidden).

More specifically, we consider a group of fishermen competing for the harvest of two interacting species, for which biological dependence is characterized as a predator–prey relationship. Two management regimes are available: one where fishermen can exploit the stocks of both species,[2] and the second where they can harvest the predator species only. Two main results are shown. First, the restricted fishing policy yields higher long-run stock levels for both species as long as the number of agents (or the value of the biological interaction parameters) is sufficiently large. Second, when this policy is superior from an environmental point of view it actually yields higher profits from fishing. Thus, it would be more palatable to politically powerful fishermen since it will be in their best interest to adopt it. This might contribute to ease its enforcement. These results imply that a simple policy based on restricted fishing would enable one to satisfy two extremely important but often opposite criteria: environmental conservation and economic acceptability. Moreover, this policy would be relatively simple to implement for data-poor fisheries as it would require no information about the agents' characteristics and the biological parameters. This is in contrast with taxes or input quotas, where the information gap that exists between the fishery manager and the fishermen, or weak governance and monitoring, would make their use more challenging (Costello et al., 2012).

Such restriction policies are sometimes implemented in practice, but usually fishing activity of one species is restricted in order to promote its environmental conservation and without explicit consideration of interactions with other species. Our results suggest that this might not be effective when the evolution of this species depends on another one. For biologically dependent fish species the right one must be targeted by the restriction. Moreover, when the policy is designed appropriately, this study provides additional support based on economic arguments. There are cases where this policy is actually economically profitable.

The rest of the paper is organized as follows. The model is introduced and described in Section 2. Section 3 analyzes the unrestricted management regime, and that of the restricted fishing policy is provided in Section 4. The comparison of both policies is provided in Section 5. Section 6 concludes.

[2] We thus consider a situation of targeted fishing where agents can exert specific efforts for each fish species.

2. The Model

Consider a situation with $N \geq 2$ agents, each of whom can harvest from two fish species. Let $x(t)$ be the stock of the prey and $y(t)$ denote the stock of the predators species at time t. Both fish stocks increase over time according to their respective growth function and decrease because of harvesting.

We consider a predator–prey relationship where the prey population density is resource-limited and each predator's functional response is linear (Hotelling, 1959). We use the standard extension of the basic Lotka–Volterra equations, in which the population of the prey species (which intrinsic growth rate is given by $\alpha \geq 0$) does not grow unbounded and exponentially in the absence of predators, but is limited by competition for food (Berryman, 1992; Holt, 1977). This cap on the size of the prey population (where $0 \leq \alpha \leq 1$ will denote the resource-limited parameter[3]) also limits the predator population (parameters $0 \leq \beta \leq 1$ and $0 \leq s \leq 1$ model the food conversion rate and the share of prey consumed per unit of time, respectively), which in turn may prevent them from hunting the prey to extinction and then starving.[4] The growth rate of the predator population decreases at a natural mortality rate, ξ, and according to its harvest level.

Finally, we assume a (widely used) harvest function *a la Schaefer*, which is characterized by a catch per unit of effort proportional to the abundance of fish species. We further assume a unique catchability coefficient, θ, but we assume that fishermen may choose different effort levels for the two species, $E^j(t)$ $(j = x,y)$ in order to allow for the option to harvest from species selectively. The capture rate of species j is denoted $\theta E^j(t)$.

The evolution of both species is then characterized by the following equations:

$$\dot{x}(t) = x(t)\left[\alpha - ax(t) - sy(t) - \sum_{i}^{N} \theta E_i^x(t)\right] \tag{1}$$

$$\dot{y}(t) = y(t)\left[s\beta x(t) - \xi - \sum_{i}^{N} \theta E_i^y(t)\right]. \tag{2}$$

Beyond the biological interaction between both species, the above evolution rules capture the existing strategic interaction between agents. In the following sections we will analyze two management regimes: one in which agents can harvest from the two species, the other where they can harvest from only one of the two species (specifically, the predators).

3. An Unrestricted Common-pool Resource Game

In this section, agents can harvest from both species. In order to focus on the issues driven by biological interactions, we consider a situation where agents can exert specific fishing efforts for each species, and where the commercial prices of both species are the same.[5]

[3] Observe that the resource-limited parameter is equivalent to the standard carrying capacity approach with $a = \frac{\alpha}{K}$. An enrichment of the ecosystem, a higher carrying capacity K, is equivalent with a lower crowding effect a. In the absence of predators, the maximum stock level is $x_{max} = \frac{\alpha}{2a}$.

[4] This is the simplest *functional response* which does not allow for predator satiation but allows us to characterize one important aspect of the prey–predator relationship. We refer the reader to Yodzis (1994) for a discussion on other types of functional responses. Using a logistic growth function for predators too might have been more realistic, but this would greatly increase the technical complexity of the analysis without adding further qualitative insights.

[5] We will discuss in Section 6 how all results extend when prices, catchability coefficients and effort costs differ for both species.