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Optimal strategy for structured model of fishing problem

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Abstract

In this work we study a structured fishing model, basically displaying the two stages of the ages of a fish population, which are in our case juvenile, and adults. We associate to this model the maximization of the total discounted net revenues derived by the exploitation of the stock. The exploitation strategy of the optimal control problem is then developed and presented. ***To cite this article: M. Jerry, N. Raïssi, C. R. Biologies 328 (2005).***

Résumé

Stratégie optimale d'un problème de pêche basé sur un modèle structuré. Ce travail consiste en l'étude d'un modèle structuré mettant en évidence les différents stades d'âge du stock, en l'occurrence juvénile et adulte. Nous associons à ce modèle la maximisation du total escompté du revenu net généré par l'exploitation du stock. La stratégie d'exploitation du problème de contrôle optimal est recherché. ***Pour citer cet article : M. Jerry, N. Raïssi, C. R. Biologies 328 (2005).***

Keywords: Structural model; Global model; Fishing effort; Optimal strategy; Maximum principle; Recruitment

Mots-clés : Modèles structuraux ; Modèles globaux ; Effort de pêche ; Stratégie optimale ; Principe de maximum ; Recrutement

1. Introduction

The models used for resources assessment rarely take into account the total life cycle of an exploited marine population. Often, they only consider the individuals susceptible to exploitation, which constitute the so-called stock. The exploited stock does not contain in general larvas and old fish, because larvas and alevins are too small or absent in the potential fishing zones, and the old fish eventually leave the fishing zones, or become inaccessible to the fleet. But we notice that the fishers do not exclude the fishing of the juvenile, and that it is developing in an alarming way and without control even if there are strict measures

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that forbid this fishing, therefore to solve this problem, there must take in consideration this fishing with taking in account the juvenile stage in the system that describes the stock evolution.

In building a model of a resource it is necessary to define variables which adequately describe the state of the resource at any time. Such variables are called state variables. For renewable resources they often describe a 'standing stock', frequently the number of individuals in a population or the 'biomass' of the population. If the age structure, sex ratio, or other population characteristics are important, the model will require more than one state variable. In the literature, models representing the evolution of a stock exploited, are divided in two groups: global models [1–8] and structured models [9–13]; the first one presents the stock as a unique variable, whereas, the second distinguishes between several stages (classes of ages, of size...) of the stock and associates with each one of them a dynamical variable.

So, the global models give a general vision of the stock evolution. But, the responsible authorities of the fishing management may be interested in the impact of certain technical measures like for instance, the reduction of the mesh's fishing nets. The structured models are able to respond to this type of investigations. They permit a qualitative description of the system since they take into account both features: the fish size and the time mechanism of reproduction of the exploited stock.

The objective of this work is to find an optimal strategy of the fishing problem based on a structured model. The case of a dynamics following from a global model is a classic one, and the research of an optimal exploitation policy has been the object of several articles (see, for instance, Clark [1], Clark et al. [2], Jerry and Raïssi [14,15], Raïssi [16]). Section 2 is devoted to the formulation of the fishing problem. In Section 3, we apply the maximum principle to the resulting fishing problem. In Section 4 we present the optimal strategy exploitation.

2. Presentation of the fishing model

Our objective consists on the study of a structured model containing a stage of juvenile. In some previous studies, the recruiting stage is formulated either as a constant or as noise. The restrictive feature of this approach is that the stock – recruitment relationship does not appear. On the other hand, there exist stock – recruitment relationships in literature, for example, the model of Deriso [17], generalized by Schnute [18], Model depositories [19], etc. In this work we are inspired by the models used by Ricker [11,12], Beverton and Holt [9,10], and Touzeau [13] because they are synthetic and mathematically tractable. Even without data on the previous stages of the recruitment, these equations remain a useful tool for the assessment of the stocks [20].

More precisely, our dynamic model is a continuous time model with two states: the juvenile and the adult, where every stage is described by the evolution of its biomass X_0 and X_1, respectively.

$$\begin{cases} \dot{X}_0 = -\alpha X_0 - m_0 X_0 + F_1 X_1 - q_0 E_0 X_0 \\ \quad X_0(0) = X_0^0 \\ \dot{X}_1 = \alpha X_0 - m_1 X_1 - q_1 E_1 X_1 \\ \quad X_1(0) = X_1^0 \end{cases} \tag{2.1}$$

where E_i and q_i denote, respectively, the fishing effort and the catchability coefficient for every stage i. E_0 and E_1 are independent, because we consider that we have two fishing fleets which belong to the same decision maker, on the other hand each fleet fishing either juvenile or adults.

Remark 2.1. $X_0 = 0$ or $X_1 = 0$ corresponds to the extinction of the species, because if we have $X_0 = 0$, according to the first equation of the system (2.1), we will have $\dot{X}_0 = F_1 X_1 = 0$, but F_1 is a non-null constant, then $X_1 = 0$, in the other case, if we have $X_1 = 0$, according to the second equation of the system (2.1), we will have $\dot{X}_1 = \alpha X_0 = 0$, but α is a non-null constant, then $X_0 = 0$.

Each stage i of the stock suffers a mortality rate, due to fishing and natural disaster. The natural mortality incorporates diseases, perturbations generated by the environment and by other species outside the stock, in other words, all factors except the human exploitation and the interactions within the stock. We assume that this mortality is linear (constant rate m_i). The ageing is also supposed to be linear. On the other hand, the passage rate α from the juvenile class to the adult stage is supposed to be constant with respect to