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Harvesting induced fluctuations: Insights from a threshold management policy

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Abstract

In this work, it is shown that in a deterministic context, a threshold policy can induce cyclic behavior in an otherwise exploited stable population. These dynamics ensue as a result of the combination of the degree of harvesting pressure and more protective threshold densities. Virtual equilibrium in variable structure systems plays a determinant role in this dynamical outcome.
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1. Introduction

Harvesting has been a subject of theoretical studies in population as well as in community dynamics. It has been considered a factor of stabilization [5], destabilization [1], anomalous enhancement of mean population levels [11], induced fluctuations [6], and control of non-native predators [10].

In this context threshold management policies for exploited populations [8] have also been investigated so as to provide higher yields in a demographic and environmental stochastic setting [9,6]. Jonzén et al. [6] demonstrate that in a stochastic context, harvest per se may cause a population with damped internal dynamics to undergo quasi-cyclic fluctuations if the harvest fraction

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is time variant. A similar behavior comes about when an adaptive harvest strategy (e.g., a higher harvesting fraction when the population is increasing than when it is decreasing) or a threshold harvest strategy (a proportion of the population is captured above a threshold density) is applied.

It is pointed out then that the potential role of harvesting as an external noise factor keeping periodical fluctuations going should be treated in detail. Especially when in some exploited populations harvesting is the most important source of mortality and potentially an equally important source of variability.

In this work, it is shown that in a deterministic context, a threshold policy where two time invariant specific quotas are captured depending on whether the population is above or below a specified threshold level, can induce cyclic behavior in an otherwise stable population. These dynamics ensue not only as a result of the population dependent harvesting, but rather as a combination of the chosen threshold level and the capture quotas. Interestingly, this occurs when a more protective (i.e., higher) threshold is designed to control harvesting.

Since in general, threshold management policies creates two structures in the population models (different harvesting intensities), the analysis bears upon the concept of variable structure systems [12,13] and virtual equilibrium points [3,7].

As will be shown next, the latter plays a predominant role in the creation of the ultimate cyclic dynamics.

The outline of the work is as follows. In Section 2, the mathematical definition of the threshold strategy is laid out. In Section 3, the proposed strategy is applied to the Ricker model. In Section 4, a discussion of the dynamical results is made.

2. Mathematical definition of the threshold policy

A threshold policy (hereafter called TP) can be defined as the function $\phi(\tau)$:

$$\phi(\tau) = \begin{cases} \alpha & \text{if } \tau > 0 \\ \beta & \text{if } \tau > 0, \end{cases} \quad \alpha, \beta \text{ constants,} \tag{1}$$

where τ is the threshold density.

The proposed TP, ϕ, applied to a species x can be cast as

$$x(k+1) = F(x(k)) - \phi(\tau), \tag{2}$$

where $\phi(\tau)$ is given by (1) and

$$\tau = x(k) - x_{\text{th}}.$$

Or equivalently,

$$x(k+1) = \begin{cases} F(x(k)) - \alpha & \text{if } x > x_{\text{th}}, \\ F(x(k)) - \beta & \text{if } x > x_{\text{th}}. \end{cases}$$

$F(x(k))$ is the species growth rate, α, β are density independent quantities of harvesting, and x_{th} a threshold level. The intensity of the control action represents a post-reproductive constant harvest quota and depends on whether the populational level x is above or below x_{th}. Within this setting, this policy creates two systems with their own equilibrium points, separated by the threshold

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