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The Role of Precaution in Stock Recovery Plans in a Fishery with Habitat Effect

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ABSTRACT

The precautionary principle has become a cornerstone of modern fisheries management and is recognised as being of particular importance to the rebuilding of depleted stocks and in cases where fishing activity poses a risk to habitat. Harvest control rules and marine reserves offer two means of controlling fishing mortality, and provide managers with mechanisms through which precaution can be exercised. We incorporate the two control mechanisms into a bioeconomic model in which fishing-induced habitat damage occurs. A parameterized model is used to assess alternative ways of exercising precaution in stock recovery plans in achieving stock rebuilding, while taking into consideration the economic and socio-economic objectives of fisheries management. Results strengthen the case for using marine reserves to rebuild depleted stocks, highlighting their role in providing a hedge against negative habitat-fishery feedbacks by directly protecting biomass and indirectly preventing a decline in the carrying capacity. Overall, we show that where a fishery is characterised by fishing-induced habitat damage, a stock rebuilding strategy that incorporates both harvest control rules and marine reserves will outperform a strategy that uses the two control mechanisms individually, across all performance indicators.

1. Introduction

The precautionary principle of natural resource management was first articulated in the United Nations' World Charter for Nature in 1982, and has since been integrated into many legally binding international treaties, as well as the legislation of numerous countries. In broad terms, the precautionary approach expresses a desire to prevent damage to the environment before it occurs and, if damage has previously occurred, not to postpone or avoid taking action due to scientific uncertainty. The precautionary principle in the context of fisheries management was first introduced in the FAO Code of Conduct for Responsible Fisheries (1995). In this context, the objective of the precautionary principle is to prevent resource and environmental degradation and to rebuild depleted fish stocks, while taking into consideration the economic and socio-economic requirements of fisheries (González-Laxe, 2005). The prevention of fish stock collapse, and so the avoidance of the economic and social costs that accompany stock collapse, therefore provide a strong incentive to apply the precautionary principle to fisheries management (Caddy and Agnew, 2004). The current depleted state of a large proportion of fisheries (FAO, 2016) means that understanding the outcome of applying the precautionary principle to fisheries rebuilding is highly relevant for many countries.

Stock recovery plans have been applied to fish stocks around the world with varying levels of success (Murawski, 2010). A stock recovery plan involves defining a rebuilding target, selecting a trajectory for stock recovery and choosing the mechanisms through which the target is achieved along the selected trajectory (Caddy and Agnew, 2004). The identification of the right mechanism to control fishing mortality is, therefore, central to the success of the rebuilding plan. Two mechanisms commonly used to control fishing mortality are harvest control rules and no-take marine reserves. Harvest control rules manage fishing mortality by directly setting limits on the amount of biomass that can be harvested in any given time period of the rebuilding trajectory (Agardy et al., 2011; Buxton et al., 2014; Punt, 2010). No-take marine reserves, on the other hand, control fishing mortality by protecting some proportion of the biomass from harvest (Lester et al., 2009). The challenges of designing and implementing harvest control rules, and the way in which the precautionary principle is integrated into the development of harvest control rules has been widely discussed in the literature (Cadrin and Pastoors, 2008; Hilborn et al., 2001; Kvamsdal et al., 2016; Punt, 2006). Moreover, no-take reserves have been shown to be a means of applying the precautionary approach in fisheries management, while mitigating factors such as scientific uncertainty, management error and habitat damage (Lauck et al., 1998; Mangel, 2000; Roberts et al., 2005).

The limitations of using the two control mechanisms individually to

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control fishing mortality in recovering a fishery are widely acknowledged in the literature. For example, implementing the precautionary approach though harvest control rules alone may fail to limit fishing mortality at a desired level, due to the lack of wider ecosystem considerations inherent in such rules (Cadrin and Pastoors, 2008). Further, management's limited capacity to frequently revise the rules may lead fishery managers to adopt a more precautious harvest control rule at the beginning of the rebuilding plan, which will heighten the trade-offs between competing fishery objectives, such as the maintenance of short-term harvest and the stock rebuilding period (Wetzel and Punt, 2016). Despite these limitations, there are few studies that look at implementation of the precautionary principle in stock recovery plans using the two mechanisms together. Exceptions are Little et al., 2011 and Yamazaki et al., 2015 who have studied the complementarity of harvest control rules and no-take marine reserves. In particular, the latter shows that the use of harvest control rules and no-take reserves together allows a fishery manager to design a rebuilding plan which can hasten the speed of stock recovery without reducing the profitability and annual harvest of the fishery.

The aim of this paper is to extend this literature by exploring how the precautionary principle should be implemented through the two control mechanisms both individually and in concert in a stock recovery plan where the fishery is subject to fishing-induced habitat degradation. Previous studies assume no relationship between fishing activity and habitat damage, thereby assuring the rebuilding of fish stocks in response to reduced fishing pressure. However, the collapse of a fishery is often characterised by both the depletion of fish stocks and the degradation of habitat, the latter of which may prevent stock rebuilding due to slow regeneration processes or irreversible habitat loss. The connection between fishing activity and habitat damage is the subject of increasing study and concern (Hiddink et al., 2011; Kahui et al., 2016; Shephard et al., 2010; Turner et al., 1999). Moreover, previous literature has examined habitat and marine reserve interactions under different regulatory regimes (Akpalu and Bitew, 2014; Akpalu and Bitew, 2011; Moeller and Neubert, 2012, 2015; Reithe et al., 2014; Upton and Sutinen, 2005). To the best of our knowledge, however, there has been no study to date of how marine reserves and harvest control rules may be used together in stock recovery plans where fishing-induced habitat damage is a feature of the fishery.

To this end, we develop a bioeconomic model of a fishery where the carrying capacity of the population biomass is impacted by fishing (i.e., habitat effect) and the regeneration of the habitat does not occur immediately but requires time. We consider alternative stock rebuilding strategies characterised by different levels of precaution exercised jointly or separately through the harvest control rule and marine reserve. The performance of alternative stock rebuilding strategies is assessed against three indicators which broadly correspond to the biological, economic and socio-economic objectives of fisheries management. Using the three performance indicators we identify and assess trade-offs between potentially conflicting fisheries objectives where different levels of precaution are exercised through harvest control rules and marine reserves. We further explore the possibility of maximising the economic and socio-economic indicators while meeting the constraint of a mandated time limit for stock rebuilding. Stock recovery plans generally aim to rebuild fish stocks within a prescribed time period (see, for example, the Magnuson-Stevens Fisheries Conservation and Management Act of the USA). However, the needs of fishers and other stakeholders to earn income and maintain employment in both the short- and long-term are also important considerations (Hilborn et al., 2001; Mardle and Pascoe, 2002). An understanding of how stock rebuilding plans may be designed to minimise the trade-offs between these competing objectives is, therefore, of high importance.

2. Methods

2.1. Biomass Dynamics

Specification of the biomass dynamics is based on previous studies (Conrad, 1999; Grafton et al., 2006; Hannesson, 1998; Sanchirico and Wilen, 2001; Yamazaki et al., 2015). The total population, x_t, consists of two subpopulations such that $x_t = x_t^H + x_t^R$, where x_t^H is the harvest population and x_t^R is the reserve population, and the subscription $t = 0,1,2, \ldots$ denotes the time index. The size of the reserve is defined as the proportion of the population carrying capacity that is not exposed to fishing and is determined by the parameter $s \in [0, 1]$.

The biomass dynamics of the two subpopulations are specified as:

$$x_{t+1}^H = x_t^H + G^H(x_t^H, K_t, s) + T(x_t^H, x_t^R, K_t, s) - h_t \tag{1}$$

$$x_{t+1}^R = x_t^R + G^R(x_t^R, K_t, s) - T(x_t^H, x_t^R, K_t, s) \tag{2}$$

where h_t is the total harvest at time t where harvest of the reserve population is prohibited. Each subpopulation has its own specific growth function, $G^H(\cdot)$ and $G^R(\cdot)$, and the annual growth of each population depends on the population biomass and carrying capacity[1] at time t, x_t^j and K_t, as well as the reserve size, s. The two subpopulations are linked by the transfer function $T(\cdot)$. The growth functions for the harvest and reserve populations are specified as:

$$G^H(x_t^H, K_t, s) = rx_t^H\left(1 - \frac{x_t^H}{(1-s)K_t}\right) \tag{3}$$

$$G^R(x_t^R, K_t, s) = rx_t^R\left(1 - \frac{x_t^R}{sK_t}\right) \tag{4}$$

where r is the intrinsic growth rate.[2] The transfer function takes the following form:

$$T(x_t^H, x_t^R, s) = m(1-s)\left(\frac{x_t^R}{s} - \frac{x_t^H}{(1-s)}\right) \tag{5}$$

where m is the transfer coefficient which measures the strength of the links between reserve and harvest subpopulations. We base our assumptions on population transfer on empirical evidence which suggests that fish migration is likely to be density-dependent and a function of reserve size (Abesamis and Russ, 2005; Goñi et al., 2010; Kramer and Chapman, 1999). The pre-multiplicative term, (1-s), ensures that the spillover between reserve and harvest populations becomes smaller with increased reserve size (Grafton et al., 2006; Hannesson, 1998; Kramer and Chapman, 1999).

2.2. Habitat Effect and Dynamic Carrying Capacity

Ecosystem externalities occur when the act of harvesting fish impacts the underlying processes that govern the ecological system (Ryan et al., 2014). Ecosystem externalities may include adverse impacts on the productivity of stocks through damage to the habitat (Janmaat, 2011). This paper incorporates the effect of fishing-induced habitat changes on fish biomass through the population carrying capacity. That is, the population carrying capacity increases when the habitat recovers and decreases when the habitat is damaged due to fishing. Following Upton and Sutinen (2005) and Udumyan et al. (2010), the dynamics of the population carrying capacity is specified as follows:

$$K_{t+1} = K_t + H(K_t) - D(E_t, K_t, s) \tag{6}$$

[1] As we assume two subpopulations of a single stock, the two subpopulations share the same population carrying capacity K_t.

[2] In the extreme case where $s = 0$ or $s = 1$, the carrying capacity of one subpopulation will become zero, so that the entire biomass will be either exposed or not exposed to harvesting.