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Reconciling yield stability with international fisheries agencies precautionary preferences: The role of non constant discount factors in age structured models☆

José María Da-Rocha[a,b], Javier García Cutrín[c], María-José Gutiérrez[d,*], Julia Touza[e]

[a] ITAM, Centro de Investigaciones Económicas. Av. Camino Santa Teresa 930, C.P. 10700 Mexico, D.F., Mexico
[b] Universidade de VIGO, EUEE-Escuela Universitaria de Estudios Empresariales, Calle Torrecedeira 105, 36208 Vigo, Spain
[c] Universidade de Vigo. Departamento de Matemáticas, C/ Leonardo da Vinci s/n, 36310 Vigo, Spain
[d] FAEII and MacLab, University of the Basque Country (UPV/EHU), Avd Lehendakari Aguirre 83, 48015 Bilbao, Spain
[e] York University, Environment Department, Heslington Road YO10 5DD, York, UK

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ABSTRACT

International fisheries agencies recommend exploitation paths that satisfy two features. First, for precautionary reasons exploitation paths should avoid high fishing mortality in those fisheries where the biomass is depleted to a degree that jeopardise the stock's capacity to produce the Maximum Sustainable Yield (MSY). Second, for economic and social reasons, captures should be as stable (smooth) as possible over time. In this article we show that a conflict between these two interests may occur when seeking for optimal exploitation paths using age structured bioeconomic approach. Our results show that this conflict be overtaken by using non constant discount factors that value future stocks considering their relative intertemporal scarcity.

1. Introduction

Fisheries agencies have a preference for stable exploitation paths with low annual intervariability on captures and that implement precautionary reductions of the fishing mortality in those fisheries where the biomass is below its Maximum Sustainable Yield (MSY). The objective of this article is to show that stable and non-overfishing exploitation paths can be the optimal response for age-structured fisheries that have to restore the stock to levels that produce MSY.

It is commonly accepted among practitioners that exploitation paths should be stable over time without showing drastic changes in fishery mortalities. Penas (2007) argues that plans that cause substantial decreases in fishing possibilities from one year to the next will meet with fierce opposition from fishers and stakeholders. Dichmont et al. (2010) point out that closing a fishery could be optimal only if vessels had a viable alternative and fishers can cover fixed costs, and regaining skilled fishers when a fishery reopen is possible. Thus, long-term plans that recommend closing fisheries or that involve drastic capture reductions in the short-term are not realistic, even if those restrictions result in greater benefits in the long-run. This issue is reflected, for instance, in the development of the European multi-annual plans of fish stocks that set maximum limits on year-on-year TAC variations of 15%, to provide stability in the fishery industry (Penas, 2007).

On the other hand, in real practice fisheries agencies boost the reduction rather than the increase of the fishing mortality when stock size is below that which produces MSY level. For instance the National Oceanic and Atmospheric Administration (NOAA) for tracking the

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* Corresponding author. Fax: +34 946017123.
E-mail addresses: jose.darocha@itam.mx, jmrocha@uvigo.es (J.M. Da-Rocha), mariajose.gutierrez@ehu.es (M.-J. Gutiérrez).

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status of US fish stocks penalises "overfishing" stocks, defined as those stocks whose fishing mortality is above the rate that produces MSY (NOAA, 2015).

In our analysis the exploitation trajectories are the solutions of a bioeconomic model in which a regulator maximizes the present value of the utility associated to the profits considering that the fish population is age-structured.

Age-structured population models have been the centrepiece of fisheries management for long time. From Baranov's seminal article (1918) to subsequent developments by Beverton and Holt (1957), Ricker (1975) or Shepherd (1982), there has been a vast amount of studies showing the advances of adopting age-structure approach. In real practice, the vast majority of contemporary stock assessments that attempt to reconstruct population biomass for marine species are based on age-structured models (Punt et al., 2013). In fact, age composition is the common population structure used in Virtual Population Analysis for fish stock assessment (Lassen and Medley, 2000).

During years many economists have considered that models with explicit age structure were very convenient for practical management problems but intractable from the analytical point of view when studying optimal harvesting decisions. This has changed recently and an increasing number of authors argue that age-structured models are more appropriated than biomass models to best reflect the complexity of fish stocks (Wilen, 1985; Getz et al., 1985; Townsend, 1986; Clark, 1990; Quinn and Deriso, 1999; Hilborn and Walters, 2001; Walters and Martell, 2004). Moreover, some studies show that optimal harvesting decisions when age-structured information is taken into account may be different to those found when optimization is based on conventional biomass variables (e.g. Tahvonen, 2009; Skonhoft et al., 2012).

The analysis of optimal harvesting based on age-structured models has shown that in many circumstances the optimal solution takes the form of pulse fishing (Hannesson, 1975; Clark, 1976, 1990; Tahvonen, 2009; Steinshamn, 2011; Da Rocha et al., 2012a, 2013). This means that optimal exploitation paths consist of periodic cycles of fishing followed by fallow periods to enable stocks to recover. Therefore, pulse fishing represents a type of solution far away from the stable trajectories usually advocated by practitioners and regulators.

Given our interests in stable exploitation trajectories which are intrinsically continuous (against pulse fishing trajectories which are non-continuous), our analysis integrates the findings of the economics literature that links the concavity of the objective function and the continuity of the optimal trajectory solutions (Scarf, 1959; Stokey et al., 1989). In fisheries economics this link between concavity and continuity is established by Dawid and Kopel (1997, 1999) for biomass models. For age-structured models, Da Rocha et al. (2012c) show numerically that pulses are not longer a viable optimal solution by maximizing the logarithm of the catches instead of just the catches. This result is reinforced in Da-Rocha et al. (2013) where it is shown analytically that the concavity properties of the management objective function are essential to remove optimal pulse fishing under imperfect selectivity. In the context of schooling fisheries, Tahvonen et al. (2013) also show that using nonlinear harvesting costs that guarantee the concavity of the manager's objective function generates smooth optimal paths toward the steady state. On the contrary, a linear harvesting cost implies pulse fishing instead of smooth continuous harvesting

This article continues with this research line of proposing concave functions to be maximized in the management problem as a way to guarantee stable exploitation paths. In particular, in our age-structured bioeconomic model managers maximize the present value of the utility associated to the profits of the fishery. In economics, a utility function is a formula that assigns a numerical score representing the satisfaction that an economic agent gets from consumption of a given basket of goods or services. In our context, the objective in the management problem is not to maximize net profits but the utility derived from those net profits. We consider a constant elasticity substitution (CES) utility function which is the most frequently used in intertemporal decision problems (Blanchard and Fischer, 1989) and which allow us here to represent the decisions over stability in profits when regulating commercial fisheries.

Even though the CES function has been extensively used in macro and micro economic analysis, it has hardly been used in fisheries economics. Some exceptions are Hoff (2004) and Quaas and Requate (2013) which apply a CES utility function in a static context to characterize the substitutability between the inputs of the production function of the Danish trawler fleet operating in the North Sea;, and between the consumption of different species of fish, respectively.. In our case, the CES utility function will be used to stress the substitutability between current and future harvesting in dynamic context. As far as we know, the CES utility function has not been used to represent the preferences of decision makers in charge of regulating commercial fisheries.

The CES utility function is also justified because it can be fully parameterized with the intertemporal elasticity of substitution (IES) in dynamic contexts. The IES is a positive parameter that expresses the degree of substitutability between current and future consumption (harvesting in our case). The closer to (farther from) zero the IES parameter is, the more substitute (complementary) current and future captures are. Decision makers that are more (less) willing to substitute between current and future harvests can be considered to have a lower (higher) desire for smooth exploitation paths.[1] Consequently, the IES parameter represents the level of importance attributed to stability (smooth paths) in decision making and can be interpreted as the smoothness parameter.

Moreover, the conventional approach of maximizing profits or yield used to evaluate recovery plans (Gröger et al., 2007; Da Rocha et al., 2010; Da Rocha and Gutiérrez, 2011; Simons et al., 2014), multispecies stocks (Punt et al., 2011; Da Rocha et al., 2012b; Gourguet et al., 2013) or new management policies (Quaas et al., 2013) can be seen as a particular case of the methodology proposed here with the maximization of a CES utility function. This is because when the smoothness parameter tends to infinity, the CES utility function represents a situation where the discounted fishery profits (or yield) are maximized. Also when the smoothness parameter equal one, the logarithm of the profits or yield is maximized (Da Rocha et al., 2012c).

Our results show that including concavity in the management decision problem with a utility function and keeping constant the discount factor generates a non desirable response in the short term. Our numerical analysis illustrates that if the fishery is in the steady state situation (MSY) and there is a shock that affects negatively the biomass, then the optimal exploitation decision consists of increasing the fishing mortality in the short term approaching smoothly to the MSY in the long term. This means that the precautionary principle is not followed, as this optimal response promotes the increase of the fishing mortality and the fishery can be considered as having overfishing. Moreover, our analysis shows that this effect over the short run exploitation not only disappears but can be reverted when the present value is calculated using adequate non constant discount factors.

[1] Following the economics terminology we use smoothness to refer to the level of variability in intertemporal paths. The lower the average of annual variability between captures in long-term management plans, the smoother we say the exploitation path is. Smoothness is also related with the term stability. In a broad sense, stability can be considered a synonymous of smoothness for intertemporal paths; although stability is a more precise mathematical concept applied to dynamic systems.

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