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Harvest control rules for a sustainable orange roughy fishery

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ABSTRACT

Some of the best described examples of unsustainable deep-sea fisheries have been for the orange roughy, *Hoplostethus atlanticus*. Nevertheless, fisheries for orange roughy around New Zealand have persisted for more than 30 years, and some stocks that were overfished and substantially depleted now appear to be recovering. Scientific advice on the status of New Zealand orange roughy stocks has historically used population models fitted to various observational data, but this approach has proved problematic, largely due to uncertainty in recruitment, to the extent that from 2008 these models were replaced by a simple harvest control rule (HCR). The catches taken under this HCR were a fixed proportion of the weight of the mature stock, estimated principally from acoustic surveys. We test the performance of the current HCR, and some alternative HCRs, using a simulation model. The model simulates long-term single-species orange roughy stock dynamics, stock monitoring surveys, and management decisions. We allow for uncertainty in model parameters, but focus on the effects of changes in mean recruitment and recruitment variability, because the latter have been considered the primary source of uncertainty in future stock status. Results show that the current HCR is likely to lead to a sustainable fishery. Nevertheless, there are alternative HCRs that could out-perform the existing HCR. With a reliable series of biomass estimates from acoustic surveys, good knowledge of biological parameters (natural mortality in particular), some revision of a HCR to control catch, and spatial management to control habitat damage, it appears that an orange roughy fishery might achieve best-practice sustainability and environmental standards.

1. Introduction

The expansion of the fishing industry into the deep sea was relatively recent, and followed the decline of shallow-water fisheries and the advent of new technology (Morato et al., 2006; Norse et al., 2012; Watson and Morato, 2013). Many deep-sea fisheries have proven to be short-lived, however, and commercial deep-sea fisheries have a worldwide, and often deserved, reputation for being unsustainable (Roberts, 2002; Morato et al., 2006; Norse et al., 2012). This led researchers to call for a stop to deep-sea fishing, and a focus instead on rebuilding and sustainably fishing more resilient and productive coastal species (Norse et al., 2012). The plea to stop deep-sea fishing was echoed by non-governmental organisations and lobby groups worldwide (e.g., Greenpeace, WWF, Deep Sea Conservation Coalition). Despite these opinions, it seems likely that many deep-sea fisheries will persist. In December 2013, the European Parliament rejected a proposal to ban deep-sea trawling in EU waters, and in New Zealand, for example, deep-sea fisheries continue to be a mainstay of the commercial fishing industry (Ministry for Primary Industries, 2013).

Some of the best described examples of unsustainable fisheries have been for the orange roughy, *Hoplostethus atlanticus*, and as a result this species is commonly cited as one of the worst possible purchasing choices for ethical seafood consumers (Roheim, 2009). Nevertheless, a few fisheries for orange roughy have persisted, and some around New Zealand continue after 35 years of fishing (Ministry for Primary Industries, 2013). In addition, the orange roughy stock (population) on the Challenger Plateau (New Zealand) was depleted and then closed to fishing, but surveys show biomass has been rebuilding in the area and it now supports low levels of fishing again (Ministry for Primary Industries, 2013).

The reasons for the collapse of many orange roughy fisheries have already been discussed (Boyer et al., 2001; Bax et al., 2005; Francis and Clark, 2005; Foley et al., 2011; Clark and Dunn, 2012), but briefly it has been because orange roughy (i) are a valuable product in premium international markets, providing incentive for fishing, (ii) form large and predictable aggregations that can be easily found and rapidly depleted by industrial-scale trawlers operating in the deep-sea, (iii) are long-lived and unproductive, meaning sustainable catches are relatively small and recovery from overfishing is slow, and (iv) have proven difficult and

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expensive to study scientifically, such that scientific data and advice are often sparse or acutely uncertain, and consequently science can be a marginal contributor to fishery management.

In this study, we consider how the remaining or rebuilding orange roughy stocks might be managed to support sustainable fisheries. We use a case study of the fishery on the east and south Chatham Rise, New Zealand, but our analyses could, in principle, be applied to any orange roughy stock, or other species having similar population dynamics. The Chatham Rise orange roughy fishery started in the late 1970s, and has proven to be the largest in the world (Clark, 2001; Norse et al., 2012; Ministry for Primary Industries, 2013). Chatham Rise is a relatively large and highly productive area of continental shelf; as such, the east and south Chatham Rise orange roughy stock may be rather special in having been able to support a long-term fishery. Historically, the status and sustainable yield of the stock was scientifically assessed using demographic population (stock assessment) models fitted to various observational data (Sissenwine and Mace, 2007). Stock assessment model results led total allowable commercial catch limits (TACCs) to be reduced in the mid-1990s, to levels estimated to be sustainable and to allow the stock to rebuild. However, over the following decade the expected biomass rebuild was not apparent in scientific observations, nor in fishery performance (Sissenwine and Mace, 2007). The biomass rebuild was predicted by stock assessment models assuming deterministic recruitment, and it was therefore suspected that recruitment had not been deterministic, but a period of reduced recruitment had started at about the time that the fishery started (Ministry for Primary Industries, 2013). In 2008, the credibility of the stock assessment model was questioned to such an extent that it was discarded, and in its place an assessment-model-free stock evaluation was completed (Dunn et al., 2008; Ministry for Primary Industries, 2013). Stock assessment models, although still used to provide scientific advice for some New Zealand orange roughy stocks, continue to be problematic, as they do not always explain observed data well, and are not easily applied where observational data are sparse (Clark and Dunn, 2012; Ministry for Primary Industries, 2013).

In the absence of predictions of sustainable yield from a stock assessment model, the TACCs for the east and south Chatham Rise were set using a relatively simple harvest control rule (HCR) (Ministry for Primary Industries, 2013). In essence, the HCR sets the TACC to be a small proportion of the current estimated stock size. The first step in this process is to obtain an estimate of the current size of the spawning stock, primarily from an acoustic survey of the spawning aggregation ('plume') that occurs in early July on flat areas of the northeast Chatham Rise, in an area known as the 'Spawning Box'. Technological advances make acoustic surveys currently the most credible method for estimating orange roughy biomass (Branch, 2001; Hordyk et al., 2011; O'Driscoll et al., 2012; Macaulay et al., 2013). The survey of the Spawning Box plume covers the historical main spawning aggregation, but orange roughy are also known to spawn simultaneously elsewhere within the stock boundaries. This additional spawning biomass has been surveyed less frequently, and the available estimates are added to the Spawning Box plume estimate to give total spawning biomass. It is known that not all mature orange roughy spawn every year, so the total spawning biomass is then scaled up, using a fixed ratio, to give the total mature biomass. Subsequent fishery management decisions about the size of the TACC are made using the estimate of total mature biomass. The simple HCR sets the TACC equal to the total mature biomass multiplied by the estimate of natural mortality (M). This is a constant fishing mortality rate (F) HCR, where the TACC is equal to $F \times$ current mature biomass, and $F=M$. Setting F equal to M has been suggested as a surrogate for fishing at the rate that produces maximum sustainable yield (F_{MSY}; Mace, 1994; Quinn and Deriso, 1999; Gabriel and Mace, 1999; Deroba and Bence, 2008). However, simulation studies have suggested M may be better viewed as an upper bound for F_{MSY} rather than a surrogate, and setting F equal to M may not be sustainable for some stocks (Quinn and Deriso, 1999).

To determine whether the $F=M$ HCR should result in a long-term sustainable fishery for orange roughy, we test this HCR in a simulation model of the east and south Chatham Rise stock. The model simulates the population dynamics, acoustic surveys, and the HCR decisions and resulting fishery catches. Many simulations are conducted, using different model parameter settings, thereby evaluating the HCR across a wide range of uncertainties about stock status and dynamics, which includes changing levels of mean recruitment. The latter was included because of the pronounced uncertainty in orange roughy recruitment. We then use the simulation model to evaluate alternative HCRs, to see if any of these might do better than $F=M$. We evaluate the performance of the HCRs using simple measures, such as the level of fishery yield, stability in yield over time, and the risk of stock biomass being depleted below reference levels. Our performance measures were set without stakeholder consultation, and therefore our study is best described as an evaluation of an empirical management procedure, rather than a management strategy evaluation (Rademeyer et al., 2007).

2. Materials and methods

2.1. Overview of the simulation model

Each HCR was tested with 1000 model simulations. The simulations were completed using a simple age-structured stock model (Beverton and Holt, 1957). The model was age structured with ages 1–120, with the final age including all fish at that age and older (a plus group), with a single sex, assumed to reside within a single homogenous area. Age was incremented at the start of the year, and recruitment entered at age 1. The fishery was assumed to take the catch at the mid-point of the year. The model was single species, with no species interactions.

Some demographic parameters were assumed to be constant across all simulations. The constant parameters described the initial size of the unfished stock (B_0), maturity at age, spawning at age, vulnerability to the fishery at age, and the fish growth rate (weight at age). We thereby assumed that productivity was determined primarily by recruitment levels, not by growth rate or maturity or proportion spawning at age, and that the fishery exploitation pattern (fish vulnerability at age) was constant.

The demographic parameters that varied with each simulation run were M, which determined mean productivity, the pattern of annual recruitment variability, the shape of the relationship between spawning stock size and subsequent recruitment, a scaling factor to allow for the proportion of mature fish that were not spawning (SR), and the level to which the stock was depleted when the HCR started. The simulations were specified such that the HCR started 30 years after the start of the fishery, consistent with the HCR starting in 2008. In each simulation run, the un-fished stock was simulated for 120 years, then a constant fishing mortality was applied over 30 years to reduce the biomass to the selected level of depletion by the start of the HCR period. This meant that this fishing mortality during the first 30 years varied for each simulation depending on the selected level of depletion and the pattern of recruitment. After this, a period under the HCR was simulated for a further 200 years. Recruitment had stochastic variability around a mean recruitment level (R_0). Simulations either assumed a constant R_0 throughout, or that R_0 halved, or doubled, for the HCR simulation period. This persistent change in R_0 is analogous to assuming a regime shift occurred, where the carrying capacity (B_0) of the environment halved or doubled. The change in R_0 took place in the first year of the HCR simulation period, so the influence of this change on