Fisheries Research 187 (2017) 139–149

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

The performance and trade-offs of alternative harvest control rules to meet management goals for U.S. west coast flatfish stocks

Chantel R. Wetzel[a,b,*], André Punt[b]

[a] Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, United States
[b] School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195-5020, United States

ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form
22 November 2016
Accepted 23 November 2016
Handled by Prof. George A. Rose

Keywords:
Management strategy evaluation
Harvest control rules
Simulation
U.S. west coast

ABSTRACT

U.S. federal fisheries managers are mandated to obtain optimum yield while preventing overfishing. However, optimum yield is not well defined and the concept of maximum sustainable yield (MSY) has often been applied to provide an upper bound for the optimum yield value, but determining the MSY, identifying the relative biomass that produces MSY and the associated fishing rate required (F_{MSY}) is difficult. The Pacific Fishery Management Council, which manages groundfish stocks off the U.S. west coast, has employed proxy targets in lieu of species-specific estimates of MSY, B_{MSY}, and F_{MSY}. The proxy targets are life history specific, with flatfish stocks managed using a target B_{PROXY} of 0.25 of unfished biomass and a harvest control rule that applies an exploitation rate equal to a spawner-per-recruit harvest rate of $F_{0.30}$, with a linear reduction of catch to zero if the stock falls below 5% of unfished biomass (B_{LIMIT}). A management strategy evaluation was performed to explore the performance of the current harvest control rule applied to flatfish stocks to meet management goals, along with alternative harvest control rules that explore varying the values for $B_{PROXY,}$ B_{LIMIT}, and F_{SPR}. Each of the harvest control rules explored maintained stocks at or near B_{PROXY} when stock-recruit steepness was 0.85 or greater, with very low probabilities of reducing relative biomass below a minimum stock size threshold (set at 0.50 B_{PROXY} of each harvest control rule). The most aggressive harvest control rule, which applied a B_{PROXY} of 0.20 and a target harvest rate of $F_{0.25}$, led to fishing rates that exceeded the operating model F_{MSY} values for low steepness (0.75), reducing the stock below B_{PROXY} with catches exceeding MSY. Trade-offs exist among alternative harvest control rules where the more aggressive harvest control rules resulted in higher average catches, but with an increase in the average annual variation in catches and a decrease probability of the relative biomass being with 10% of the B_{PROXY}. The trade-offs among the performance metrics and alternative harvest control rules coupled with the risk to the resource across a range of life histories should be carefully considered by fishery managers when selecting a harvest control rule that will meet the goals of management.

1. Introduction

The concept of maximum sustainable yield (MSY) has a long history in fisheries management (Russell, 1931; Hjort et al., 1933; Graham, 1935). The theory behind sustainable yield within fishery science states that as stocks are fished down, a surplus yield, an amount beyond the replacement biomass, would be available for exploitation, and there exists a biomass that would produce MSY in long-term equilibrium (B_{MSY}) and a fishing rate that results in MSY (F_{MSY}). However, estimating MSY and B_{MSY} can be difficult (Punt et al., 2002; Magnusson and Hilborn, 2007). To accurately determine these values one must have an understanding of the density-dependent behavior of the population, manifesting through a spawner-recruit relationship. However, recruitment data are notoriously noisy, making it difficult to determine the shape of this relationship with any confidence. Hence, there has been much debate on the viability of achieving MSY and its use in fisheries management (e.g. Larkin, 1977; Sissenwine, 1978).

* Corresponding author at: Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, United States.
E-mail address: Chantel.Wetzel@noaa.gov (C.R. Wetzel).

http://dx.doi.org/10.1016/j.fishres.2016.11.019
0165-7836/Published by Elsevier B.V.

The challenge of estimating B_{MSY}, MSY, and F_{MSY} with confidence has led to the development of alternative approaches to define targets to achieve optimum yield, including proxy target biomasses and harvest rates in the place of stock-specific estimates of B_{MSY} and F_{MSY}. Proxy values based on general life history attributes for a marine species can be applied to determine target stock sizes that produce yields that are close to MSY (Clark, 1991, 2002; Hilborn, 2010), avoiding the uncertainty and challenge of determining the stock-recruit relationship for each stock. The Pacific Fishery Management Council (PFMC) manages a range of groundfish life history types along the U.S. west coast. It has employed the use of two types of proxies to manage groundfish stocks that are life history specific: 1) a B_{MSY} proxy defined in terms of biomass relative to the unfished level termed B_{PROXY}, and 2) an F_{MSY} proxy harvest rate based on spawning biomass-per-recruit termed F_{SPR} (PFMC, 2016).

The PFMC aims to maintain stocks at or near B_{PROXY}, and has adopted a threshold management strategy to achieve this aim. This strategy is in the form of a harvest control rule dictating that catch is a function of estimated biomass. Harvest control rules can be an effective management tool when they are defined appropriately based on the biology of the stock and management goals, providing explicit guidelines defining harvest based on stock biomass (Deroba and Bence, 2008; Punt et al., 2008, 2014c). The harvest control rule reduces the catch linearly when the relative stock biomass falls below B_{PROXY}, reducing catch to zero when the stock is at or below a lower limit (B_{LIMIT}).

Groundfish stocks along the U.S. west coast are highly diverse in life history and productivity, and the PFMC has accounted for these differences in the proxy targets and harvest rates, along with the associated harvest control rule. Flatfish species (e.g. petrale sole *Eopsetta jordani*, Dover sole *Microstomus pacificus*) are one of the more productive groundfish species groups off the U.S. west coast. Historically, the PFMC applied the same harvest control rule for rockfish and flatfish stocks within the groundfish Fishery Management Plan (although with life history specific proxy harvest rates, F_{SPR}) (PFMC, 2006). The Council amended the flatfish harvest control rule by updating the B_{PROXY}, B_{LIMIT}, and F_{SPR} values in 2009 to account for the more productive nature of flatfish stocks relative to rockfish species (PFMC, 2011). The harvest control rule was adjusted from the previous targets of $0.40SB_0$ for B_{PROXY}, $0.10SB_0$ for B_{LIMIT}, and a spawner-per-recruit harvest rate of $F_{0.40}$, termed the "40-10" harvest control rule, to updated values that linearly reduce catch when the stock falls below $0.25SB_0$ to zero if the stock falls below $0.05SB_0$ with a spawner-per-recurit harvest rate of $F_{0.30}$, termed the "25-5" harvest control rule.

The changes to the targets and harvest rate applied in the harvest control rule were based on the theoretical deterministic relationship between stock size and density-dependent recruitment compensation (also known as steepness) for U.S. west coast flatfish based on a meta-analysis (Myers et al., 1999) and previous research on threshold management strategies (Punt et al., 2008), with the goal to manage towards a stock size that would produce maximum yield (PFMC, 2009). This work uses management strategy evaluation (MSE) (Smith et al., 1999; Punt et al., 2014b) to evaluate the performance of the amended harvest control rule and the proxies for U.S. west coast flatfish stocks in a single stock context with limited exploration of alternative assumptions about productivity and recruitment. The MSE was developed based on discussions with industry stakeholders and advisory groups to the PFMC. Alternative harvest control rules were developed based on feedback and were explored to provide management and stakeholders with a suite of potential outcomes and trade-offs among approaches. The MSE performed here was generally parameterized based on petrale sole, a commercially important flatfish stock currently exploited off the U.S. west coast. However, since the flatfish harvest control rule is applicable to all assessed flatfish stocks, a range of life history parameter combinations designed to encompass other flatfish species was explored. This MSE aims to address the ability of each harvest control rule to maintain stocks at or near the target level, the potential risks of each approach, and the trade-offs between potential catches and target stock sizes.

2. Materials and methods

2.1. General approach

A flatfish life history based on petrale sole was simulated (Table 1). The MSE is based on an age- and sex-structured population dynamics model. In the simulations underlying the MSE, populations experienced fishing for 50 years prior to the first assessment and were sampled by two fisheries and a single survey, providing length- and age-composition data and an annual survey index of abundance, both with endogenous measures of uncertainty. The data were used to estimate stock size and hence future catch limits. Catch limits were determined using one of a suite of harvest control rules given the estimated relative stock biomass. The data generation, catch limit calculation, and updating of stock biomass was conducted in an iterative fashion for 75 years (termed the "management period") following the first assessment conducted in year 50. This period was selected because it was long enough to eliminate the impact of the historical fishing pattern, such that results would be driven solely by the harvest control rule.

Table 1
The biological parameter values for the base simulations.

Parameter	Female	Male	Standard Deviation	Distribution
Steepness, h	0.85		–	–
Natural mortality (M, year^{-1})	0.15	0.16	0.15	lognormal
Minimum length (cm) at age 2	16	16	2.5	normal
Maximum length (cm), L_∞, at age 40	54	43	2.5	normal
Growth coefficient (year^{-1}), k	0.134	0.202	0.15	lognormal
Body weight (kg), $w_l = aL^b$				
Growth coefficient, a	2.08e^{-6}	3.05e^{-6}	–	–
Growth exponent, b	3.47	3.36	–	–
Maturity slope (year^{-1})	−0.743		–	–
Length at 50% maturity (cm)	33		–	–
Recruitment variation, σ_R	0.40		–	–
Autocorrelation, ρ_R	0.0		–	–
Catchability Coefficient, Q	3		–	–
Survey CV, σ_S	0.20		–	–