Fisheries Research 183 (2016) 549–558

Contents lists available at ScienceDirect

Fisheries Research

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

Using bioeconomic modeling to improve a harvest strategy for a quota-based lobster fishery

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A R T I C L E I N F O

Article history:
Received 14 October 2015
Accepted 6 May 2016
Handled by George A. Rose
Available online 9 June 2016

Keywords:
Harvest control rule
Bioeconomic modeling
Limit reference point
Net present value
Lobster fishery management

A B S T R A C T

In Australian fisheries, explicit harvest control rules are increasingly applied to achieve bioeconomic objectives. Enhancing economic return, an objective valued by both regional communities and the fishing industry, can often be achieved by increasing stock abundance, consequently supporting the second principal management objective of sustainability. A harvest strategy proposed by the fishing industry for the Southern Zone rock lobster fishery in South Australia implemented in 2011 was based on a table that, given CPUE from the preceding season, specified the following year's catch quota (total allowable commercial catch, TACC). A guiding principle in constructing the 2011 harvest control rule was to target a constant exploitation rate. Here we report on bioeconomic modeling undertaken to evaluate and improve this harvest strategy. A length-based stock assessment model was extended to forward project biological and economic time series to evaluate candidate harvest strategies. Key performance indicators were the 10-year projected discounted profit, biomass, egg production and catch stability. These simulations imply that the 2011 harvest strategy required only moderate change: (1) current or moderately lower levels of exploitation are economically optimal; (2) narrower CPUE band widths for the TACC-vs-CPUE decision rule table enhance yearly catch stability; and (3) for depressed levels of stock abundance, exploitation rates were set to decrease linearly down to a lower limit reference point of CPUE below which the fishery is closed. A final harvest strategy incorporating these features was adopted in 2014 for yearly quota setting.

1. Introduction

In Australian fisheries, two principles increasingly guide fishery management: (1) to implement decision rules that unambiguously determine the yearly catch quota, wherein one or several data-based performance indicators are fed into a harvest control rule (HCR), and (2) to designate net economic return (profitability) as an explicit objective, along with resource sustainability. In this paper, we summarize the model-supported improvement of a harvest strategy guided by these two principles.

A formal harvest strategy (PIRSA Fisheries and Aquaculture, 2013) was first implemented for the Southern Zone of the South Australian southern rock lobster (*Jasus edwardsii*) fishery (SZRLF) in 2011 (PIRSA Fisheries and Aquaculture, 2013). The HCR in this strategy, initially proposed by representatives of the Southern Zone fishing industry, is a table used to set yearly total allowable commercial catch (TACC) given the previous year's CPUE. In this table (Table 1), higher catch rates stipulate higher catch quotas, giving an approximately constant exploitation rate. The TACC level chosen for each CPUE band in this HCR determines the effective exploitation rate. Fishers chose TACCs in this table based on a target range of fishing effort, 1.4–1.6 million pot lifts per year.

The 2011 harvest strategy implemented in the SZRLF had five components (see Section A6 of Appendix A for full technical details): (1) the HCR table specifying the TACC to be set given yearly commercial CPUE from the previous season (Table 1), (2) a one-jump-only rule that restricts TACC increases (but not decreases) to one row in the table each year, (3) a further restriction on TACC increases to years when the pre-recruit index (PRI) exceeded a threshold set at the average historical PRI, (4) a limit reference point

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http://dx.doi.org/10.1016/j.fishres.2016.05.005
0165-7836/

Table 1
The TACC-vs-CPUE table in the 2011 SZRLF harvest strategy (PIRSA Fisheries and Aquaculture, 2013). Given CPUE from any fishing season, the next season's TACC is set by the level shown for each CPUE band. For CPUE below 0.5 kg potlift^{-1}, an LRP procedure comes into effect specifying 50%, 40% and 30% exploitation rates in the first, second and third years that the CPUE is below 0.5 kg potlift^{-1}.

CPUE band (kg potlift^{-1})	TACC (t)
0.5–0.6	950
0.6–0.8	950
0.8–1	1250
1–1.2	1400
>1.2	1600

(LRP) procedure, which specifies the management response when stock abundance declines to levels below a selected (upper LRP) CPUE, and (5) above an upper threshold level of CPUE, a cap on the TACC of 1600 t.

The performance of four broadly-defined policies for managing the SZRLF have been compared (McGarvey et al., 2015). These included minimum and maximum size limits, constant quota, and a dynamic quota set yearly to achieve a fixed exploitation rate. The last policy was the best performing, leading to higher profitability, higher average catch, and higher egg production, but lesser yearly catch stability. All strategies evaluated here are variations on the dynamic constant exploitation rate policy, but are based on a harvest control rule with discrete bands of TACC rather than a continuous linear relationship between biomass and TACC.

Here, we evaluate the 2011 lobster fishery harvest strategy and explore the performance of potential improvements to this strategy considered by a Harvest Strategy Working Group. The Working Group was appointed by the Department of Fisheries and Aquaculture (PIRSA, South Australian state government) to review the 2011 SZRLF harvest strategy and to advise the Rock Lobster Management Advisory Committee on potential improvements. It included six fishermen, a fishery manager, an independent scientist, a stock assessment biologist, a fishery modeler and the industry peak body executive officer. We describe the model evaluation process for several components of the harvest strategy that, in two stages, led to the adoption of an improved harvest strategy in 2014.

2. Material and methods

The five components of the 2011 SZRLF harvest strategy (PIRSA Fisheries and Aquaculture, 2013) are included in a bioeconomic projection model (Punt et al., 2011; McGarvey et al., 2015), developed by extending a length-based maximum likelihood stock assessment estimator for the fishery (Punt and Kennedy, 1997; McGarvey et al., 2010). Details of the projection model as applied in this harvest strategy simulation are given in Appendix A.

The 2011 HCR for setting TACC given the previous season's CPUE is shown in Table 1. This table and the five harvest strategy components outlined above were programmed into the projection model. For each harvest strategy evaluated, 100 replicated 10-year projections were run. The projection model algorithm made the following assumptions:

a) Monthly projected CPUE values were lognormally distributed (Appendix Sections A4 and A5) about the model predicted mean to reflect fisher behavior and other yearly sources of error or variation that can cause CPUE to differ from a true index of biomass. The standard deviations (of respectively 0.20, 0.10, 0.08, 0.18, 0.13, 0.15, 0.29, and 0.32 on the log-scale for the eight monthly fishing season time steps) were calculated from the residuals of the fit of the population model to the historical CPUE data.
b) Errors in the estimates of yearly biomass needed to apply the 2011 multi-year declining exploitation rate rule when CPUE declines below the upper limit reference point of 0.5, were generated assuming lognormally distributed error (Appendix Section A6), with a standard deviation on the log-scale for biomass of 0.29. This value of standard deviation is the result of assuming a coefficient of variation for the estimate of biomass of 30% (arithmetic scale), which roughly matches the estimate of between-assessment variation obtained by Ralston et al. (2011).
c) PRI is a yearly measure of the catch rate of undersize lobsters (those below the legal minimum size of 98.5 mm carapace length) reported in logbooks. Like CPUE, PRI was simulated under the assumption of lognormal measurement error (Appendix Sections A4 and A5). The PRI catchability was based on the model-predicted undersize catch numbers per pot lift given historical PRI data over the five highest-catch (summer) months of each fishing season. The standard deviations of the logarithms of PRI for the months of November to March were respectively 0.15, 0.12, 0.16, 0.19, and 0.25.
d) Future yearly recruitment was sampled randomly with replacement from the set of historical estimates for 1993–2010.

Measures of each strategy's performance included year-to-year catch stability (Appendix Eq. (A.2)), yearly average egg production (Appendix Eq. (A.11)), and average yearly catch, based on the 10-year projections. The economic performance of each strategy was quantified using cumulative future economic yield (yearly profit, as harvest revenues less fishing costs), discounted and summed over the 10 projection years (Clark, 1976) to give net present value (NPV, Appendix Eq. (A.4)). For the first two model projection years, the TACC was fixed at the level of 1250 t that had previously been set for 2012 and 2013 when the Harvest Strategy Working Group was convened. The projected CPUE and PRI from the 2013 fishing season was then used as simulation input to the HCR for setting the 2014 TACC, with that process repeating yearly up through the final projection year of 2021.

2.1. Possible modifications to the harvest strategy

Three possible types of modifications to the 2011 harvest strategy were evaluated, both separately and in combination:

(1) Assignment of TACC's into CPUE bands using a range of target exploitation rates (Table 2, Supplementary Tables S1–S8). Seven target levels of exploitation rate (of H = 55%, 50%, 45%, 40%, 35%, 30% and 25%) were selected for evaluation as the basis of calculating TACC's for each CPUE band of the HCR table. These target levels of exploitation rate were used to assign TACCs in the 'normal' CPUE range above the upper LRP and below the TACC cap, which is the range of CPUE levels where the fishery has operated. The TACC for each CPUE band was computed by multiplying a biomass that is representative of the band (the midpoint) by the target H. This biomass was obtained from a regression of the yearly biomass on CPUE ($B_y = 662.16 + 2155.6 \times CPUE_y$). An alternative strategy of gradually decreasing exploitation rate from 50% to 40% to ease the short-term impact of reductions in exploitation rate was also evaluated.
(2) Reducing the CPUE table band widths from 0.2 to 0.1 CPUE units. Also evaluated was a combination (referred to as "band width = comb") using the narrower band width of 0.1 for all except the 1–1.2 band (Table 2, Supplementary Tables S9–S11).
(3) Replacing the LRP procedure by linearly declining exploitation rates (Table 2, Supplementary Tables S12 and S13). A weak feature of the 2011 harvest strategy was the LRP procedure that applies when CPUE declines to levels that signal unsustainably low stock abundance. Below a designated upper LRP