Ecological Economics 99 (2014) 110–120

Contents lists available at ScienceDirect

Ecological Economics

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

Analysis

Risk versus economic performance in a mixed fishery

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ARTICLE INFO

Article history:
Received 14 June 2013
Received in revised form 15 January 2014
Accepted 17 January 2014
Available online 8 February 2014

Keywords:
Bio-economic modelling
Uncertainty
Risk-performance trade-offs
Fishing strategy
Northern Prawn Fishery

ABSTRACT

Balancing bio-economic risks and high profit expectations is often a major concern in fisheries management. We examine this trade-off in the context of the Australian Northern Prawn Fishery (NPF). The fishery derives its revenue from different prawn species with different dynamics and recruitment processes. A multi-species bio-economic and stochastic model is used to examine the trade-offs between mean profitability of the fishery and its variance, under a range of economic scenarios, fishing capacities and distributions of fishing effort across the various sub-fisheries that comprise the NPF. Simulation results show that the current fishing strategy diversifying catch across sub-components of the fishery entails a compromise between expected performance and risk. Furthermore, given the current economic conditions, increases in fleet size would improve the expected economic performance of the fishery, but at the cost of increased variability of this performance.
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1. Introduction

Globally, many capture fisheries do not achieve their full economic potential and are subject to excess capacity (Munro, 2010). For some fisheries, this may be due to failure in regulating the race to fish. Other fisheries may be managed to achieve Maximum Sustainable Yield (MSY), rather than Maximum Economic Yield (MEY). In some cases, social considerations may dominate the management decision process leading to the approval of even higher levels of capacity. In other cases, differences between observed harvesting levels of individual species and the levels which would ensure MEY may be related to the fact that commercial fishers operate across a range of species, with varying ability to target these species separately, leading to difficulties in identifying optimal fishery-wide levels of fishing capacity and allocation of fishing effort. Moreover, revenues from fisheries may vary greatly from year to year owing to natural variation in fish stocks (Kasperski and Holland, 2013) that cannot be predicted with any reliability, leading to varying levels of economic risks for fishing operators (Sethi, 2010). While maximising economic yield is usually seen as a desirable objective for fisheries management, industry stakeholders usually also value stability over time. This may be due to risk aversion, but also to the need to maintain markets, avoid market saturation and guide investment decisions relating to non-malleable capital (Holland and Herrera, 2009). Successful fisheries management should therefore identify and cope with risk to minimize the effects of unpredictable variability (Sethi, 2010). Indeed, as expressed by Hilborn et al. (2001): "if we are to succeed at management – if we are to maintain stable fishing communities – we have to begin to manage risk". The process of dealing with risk in fisheries management involves the formulation of advice for fisheries managers in a way that conveys the possible consequences of uncertainty, but also handles the ways in which managers take uncertainty into account in making decisions (Francis and Shotton, 1997).

In multi-species fisheries, the different fish stocks contributing to the overall catch may present different levels of natural variability, such that the choice of fishing strategies can be associated with trade-offs between mean and variance of the fishery's economic yield. Portfolio theory focuses on the selection of assets (such as species) to create a bundle that provides the greatest expected economic performance (such as catch or annual income) at the least variation about the expected performance (Markowitz, 1952; Roy, 1952). Mean-variance analysis, which is consistent with portfolio theory, is particularly important in finance (Epstein, 1985). While portfolio effects have been studied for fisheries management (Sanchirico et al., 2008; Sethi, 2010), mean-variance analyses have not been explicitly applied in the context of allocating effort in a multi-species fishery.

This article focuses on a mean-variance analysis of inter-temporal profits of a fishery in which the set of target species have different levels of environmentally driven variability in recruitment. The study is based on a dynamic bio-economic modelling approach, in line with capital theory (Clark and Munro, 1975), where fish stocks are taken as natural capital assets and where net present value of profits plays a major role. The analysis is applied to the case of the

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0921-8009/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecolecon.2014.01.013

Northern Prawn Fishery (NPF) in Australia. The bio-economic model is used to explore the trade-offs between mean performance and risk associated with alternative managements, taking into account the distribution of fishing effort across its sub-components and different assumptions regarding changes in fuel and prawn prices. Simulation results show that the economic performance of the fishery could be improved by increasing the capacity of the fleet, but at the cost of increased inter-annual variability of this performance. The current allocation of fishing effort between the sub-components of the fishery achieves a compromise between performance and risk. With likely changes in economic conditions, maintaining current fishing capacity and effort allocation would achieve the highest economic yield, but for a similar level of performance this would come with higher risk than were a reduced fleet to focus more on the relatively stable tiger-prawn component of the fishery.

2. Material and Methods

2.1. Case Study: The Northern Prawn Fishery

The Northern Prawn Fishery (NPF), which is located off Australia's northern coast (Fig. 1), is a multi-species trawl fishery based on several tropical prawn species. It is one of Australia's most valuable federally managed commercial fisheries, and has regularly returned a positive profit (Rose and Kompas, 2004) since its establishment in the late 1960s. However, in recent years the fishery has experienced a decline in value as a result of the increased supply of aquaculture-farmed prawns to both domestic and international markets, strong Australian currency and increasing fuel prices (Punt et al., 2011).

The NPF is currently managed using input controls in the form of limited entry, gear restrictions, as well as time and spatial closures. Management of the fishery has been supported by the development and application of a full Management Strategy Evaluation (MSE) approach (Dichmont et al., 2006, 2008; Venables et al., 2009). Following several industry and government funded buy-back schemes, the NPF now comprises 52 vessels, which is believed to be the number required to achieve Maximum Economic Yield (MEY) in the fishery (Barwick, 2011). By comparison, more than 120 vessels operated in the fishery a decade ago, and over 300 vessels in the 1970s and 1980s.

The NPF operates over two 'seasons' spanning the period April to November with a mid-season closure of variable length from June to August. Seasonal closures are in place to protect small prawns (closure from December to March), as well as spawning individuals (mid-season closure) (AFMA and CSIRO, 2012). The fishery consists of two main sub-fisheries that are (to a large degree) spatially and temporally separate[1]. The banana prawn sub-fishery is a single-species fishery targeting the white banana prawn (*Penaeus merguiensis*), while the tiger prawn sub-fishery is a mixed species fishery targeting grooved and brown tiger prawns (*Penaeus semisulcatus* and *Penaeus esculentus*, respectively), as well as blue endeavour prawns (*Metapenaeus endeavouri*) which are caught as by-product (Woodhams et al., 2011). Two different fishing strategies can be identified within the tiger prawn sub-fishery, one associated with catching grooved tiger prawns (called the grooved tiger prawn fishing strategy) and the other associated with catching brown tiger prawns (called the brown tiger prawn fishing strategy).

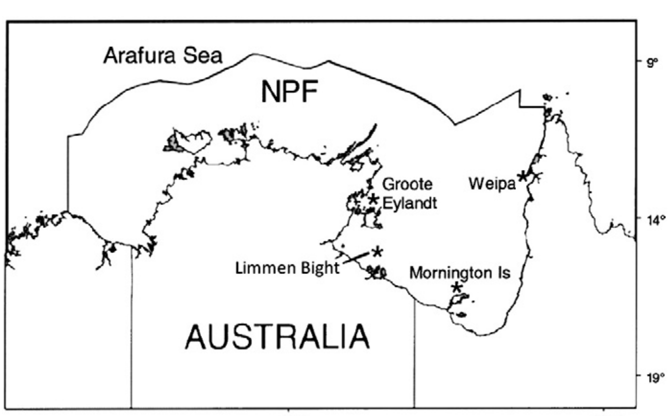

Fig. 1. Map of northern Australia showing the extent of the Northern Prawn Fishery (Milton, 2001).

White banana prawn stocks are strongly influenced by weather patterns, seasons of higher seasonal catches generally following higher than average rainfall during the preceding summer (Vance et al., 1985). The variability of white banana prawn stocks makes it difficult to set catch or effort limits in a way that protects spawning stocks but also allows operators to profit from years in which prawns are abundant (Buckworth et al., 2013). Tiger prawn stocks are more stable and predictable and these species are generally more dispersed relative to white banana prawns. Consequently, even though the same vessels are used in both sub-fisheries, the fishing gears and techniques differ. The banana prawn sub-fishery operates mostly during the first season. However, if banana prawns are still available in large enough numbers, some vessels will continue to target them during the second season. The fleet then switches during the second season to the tiger prawn sub-fishery, for which catches per unit effort are lower than for white banana prawns, but less variable.

2.2. Bio-Economic Model

To date, bio-economic analysis of the fishery has been largely focused on the more predictable component of the fishery, namely the tiger prawn sub-fishery (Dichmont et al., 2008, 2010; Punt et al., 2011). The bio-economic model developed here synthesizes, in a single model, previous modelling works by Dichmont et al. (2003, 2008) and Punt et al. (2010, 2011) on the NPF, and extends it by integrating the more variable banana prawn resource. The model is based on recent developments in mixed fisheries bio-economic modelling (Gourguet et al., 2013). Our model captures the major components and interactions that characterise the NPF, as described in Section 1 and detailed in Fig. 2.

Population dynamics of tiger and blue endeavour prawns are based on a multi-species weekly time-step, sex-structured population model with Ricker stock-recruitment relationship and environmental uncertainties. The population dynamics model allows for week-specificity in recruitment, spawning, availability and fishing mortality. However, white banana prawns are represented without explicit density-dependence mechanisms, due to highly variable recruitment and absence of a defined stock–recruitment relationship.

The bio-economic analysis is based on the sake of satisfying trade-offs between expectation and variability of profitability of the entire NPF. By profitability is meant net present value (NPV) of profits, in line with capital theory and optimal control approach (Clark and Munro, 1975). A mean-variance analysis is used to examine the trade-offs.

2.2.1. Tiger and Endeavour Prawns: Multi-Species, Stochastic and Dynamic Models

The population dynamics of grooved and brown tiger prawns (species $s = 1$ and 2, respectively) and blue endeavour prawns ($s = 3$) are based on a sex- and size-structured model relying on a

[1] A third sub-fishery exists in the Joseph Bonaparte Gulf in the far western part of the fishery based on red-leg banana prawns (*Fenneropenaeus indicus*). This sub-fishery is exploited by a relatively small number of vessels as it occurs at the same time as the (more valuable) tiger prawn sub-fishery, and is not included in the subsequent analysis.

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