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A bio-economic management strategy evaluation for a multi-species, multi-fleet fishery facing a world of uncertainty

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ABSTRACT

A bio-economic analysis was conducted for two fisheries using a multi-species size-based meta-population model built using the BIOMAS modelling system. The model was built to represent the prawn fisheries of northern New South Wales, Australia and calibrated against 26 years of catch and effort data from this region. A number of alternative management strategies, including the use of more size selective gear and a cap on total effort, were evaluated for their impact on the sustainability of the fish stocks and the profitability of the fleets as well as their robustness to future biological, climatic and economic uncertainties. Although the differences in management strategies were blurred by the uncertainty incorporated into the model there were still some very interesting high-level insights to be gained from the analysis. The modelled prawn species appear to be much more robust to changes in management strategies and product prices than the fleet profits, suggesting the stocks are less vulnerability to such uncertainties than the fleets that harvest them. We also found larger differences in profitability from changes in product prices than from changes in management strategies, indicating that strategies to protect product prices may be of more importance to the profitability of the fisheries than changes to fishing gear or effort levels. Such results highlight the complexity of multi-species, multi-fleet fisheries and the importance of including all relevant species and fisheries in any management strategy evaluations. This complexity can however sometimes mask simple economic truths, such as the need for strategies to maintain the market price of locally caught seafood products under the increasing pressures of international competition.

1. Introduction

Determining the best strategy for managing a multi-species fishery is an extremely complex issue. Particularly when such an evaluation must be based not only on the sustainability of the fish stocks but also on the economic viability of the fishing fleets involved (Lam, 2012). This, however, is the legislated responsibility of most fisheries management agencies in the world (Schumann and Macinko, 2007; FAO (Food and Agriculture Organization), 2009; Simmonds et al., 2011; Bess, 2012; Nunan, 2013). Fortunately, tested modelling frameworks have been developed to allow such analyses to be undertaken. Management strategy evaluation (MSE) (Butterworth and Punt, 1999; Sainsbury et al., 2000) is one such decision framework that can be used for comparing the expected consequences of alternative management actions across a set of well-defined hypotheses about the future states of the system being modelled. This manuscript describes one such MSE analysis undertaken using the BIOMAS modelling system (Ives and Scandol, 2013) on a multi-species, multi-fleet prawn fishery located in the Clarence River region of New South Wales, Australia.

The Clarence River is the largest coastal river in south-eastern Australia with flow covering approximately 103 km^2 and catchment covering over 220,000 km^2 (McVerry, 1995). Numbers have fluctuated over the past decade but around 40 licensed trawl boats and 30 stow netting fishers have actively worked the Clarence River estuary, while around 60 licensed boats have trawled the ocean waters surrounding the Clarence River. Twenty-six years of catch history from these fleets was available for this study along with the outcomes of a considerable number of research studies into the life history, growth, behaviour and movement of prawns (Dall, 1957; Racek, 1959; Ruello, 1973a, 1975, 1977; Glaister, 1977; Young and Carpenter, 1977; Glaister, 1978b, 1983; Coles and Greenwood, 1983; Suthers, 1984; Montgomery, 1990; Courtney et al., 1995; Ochwada et al., 2009; Taylor and Ko, 2011; Ochwada-Doyle et al., 2012) including the selectivity of the various fishing gears (Broadhurst et al., 1998, 2004b; Macbeth et al., 2005a,b, 2006).

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The Clarence River trawl fleets are responsible for over half of the fisheries produce of northern NSW (McVerry, 1995), with over 40% of the NSW estuary prawn trawl boats and over 30% of the NSW ocean trawl boats operating in this region. The main target species for the estuary boats are the school prawn (*Metapenaeus macleayi*) and for the ocean trawls the eastern king prawn (*Melicertus plebejus*), although both prawns are caught in each fishery. A substantial quantity of by-product species, about half of the catch by weight, are also caught by the trawlers, with only the ocean trawl fleet being allowed to retain them. The two prawn species have been the subject of a number stock assessments (Lucas, 1974; Glaister et al., 1990; Gordon et al., 1995; Scandol, 2003; Ives and Scandol, 2007; Ives et al., 2009), however no previous research has included both species together in a multi-species, multiple-fleet model using environmentally driven population dynamics and economically driven fleet dynamics.

Commercial fishing for prawns in the Clarence River estuary and adjacent ocean waters is authorised pursuant to the *Fisheries Management Act 1994* and grouped into the NSW Ocean Prawn Trawl (OPT), Estuary Prawn Trawl (EPT) and Estuary General (EG) fisheries. These fisheries are managed primarily through input controls, including restrictions on the number of endorsements; restrictions on fishing gears, boat size and engine power; as well as temporal and spatial closures. These fisheries can therefore be regarded as state-regulated, limited access resource markets (Iudicello et al., 1999) with fishers entitled to take as many fish as they can, provided they adhere to regulations.

A number of bio-economic models relating multi-species fisheries have been developed in the past (Mendelssohn, 1980; Strobele, 1991; Tuck and Possingham, 1994; Holland et al., 2005; Greenville and Macaulay, 2006). However, many of these models are theoretical constructs designed to test economic theory. The bio-economic model presented here has been purpose built to evaluate actual management strategies in an existing fishery. A similar bio-economic analysis was conducted on the Texas shrimp fishery (Önal et al., 1991); however, this Texas model employed a much simpler biophysical model with a more complex economic model. In particular, Önal et al. (1991) included economic demand functions for the shrimp and sought the optimal management strategy in terms of changes to producer and consumer surplus.

The primary objective of this research project was to determine whether any of a number of alternative management strategies provided better outcomes than the current management regime in terms of stock sustainability and profitability, given the uncertainty associated with future prices of the main inputs and outputs of the industry. In contrast to the work of Önal et al. (1991) we did not attempt to find an optimal management strategy or to maximise profit for the fisheries involved but rather have sought to provide insight into whether any of the proposed management strategies can provide improved fishery profits without risking over-exploitation of the harvested species.

2. Methods

2.1. The bio-economic model

The bio-economic model developed for this study was based on a stage/size-structured metapopulation model for multiple species with fishing effort driven by catch-rates, profits and management regulations. The model was built using the BIOMAS modelling system (Ives and Scandol, 2013) with additional model components and equations as presented in Appendix A. The three species included in this model were the eastern king prawns, school prawns and a composite "seafood" product henceforth referred to as "by-product". Over 50 by-product species are also caught and retained by these fisheries, primarily in the ocean trawl, including various whiting (*Sillago* spp.), octopus (*Octopus* spp.), cuttlefish (*Sepia* spp.), squid (*Teuthida*), bugs (*Ibacus* spp.), flathead (*Platycephalus* spp.), and shark species (*Carcharhinus* spp.). To reduce the complexity of the modelling exercise a composite by-product species was modelled that was capable of producing a biomass with length distributions similar to the mix of by-product species but with other life history characteristics based on those of the dominant by-product species (Lande et al., 2003), the school whiting (*Sillago flindersi*), which makes up almost half of the by-product from the ocean trawl fishery. Three fishing fleets harvest these populations including Ocean Prawn Trawl (OPT), Estuary Prawn Trawl (EPT) and Estuary General (EG). Fishing behaviour in future years is based on a combination of past effort history, catch rates and the profitability of fishing activity (see Appendix B for more details). The model also incorporated environmental effects, such as river discharge and temperature, which have been identified as important to the movement and growth of the two prawn species (Ruello, 1973a, 1975, 1977; Glaister, 1978a; Glaister et al., 1987; Loneragan, 1999). In short, higher temperatures increase growth rates and river discharge events increase seaward migration and food available for growth (see Appendix A for more detail). As each of the fisheries operate in different areas of the Clarence River and surrounding ocean waters, any such environmental effects on prawn movement and growth can impact the economics of the ocean and estuary fisheries in different ways.

In economic modelling for fisheries it is common to ignore stochasticity and uncertainty in the biophysical components of the model, as most bio-economic models are used to provide general theoretical analysis (Routledge, 2001). As this study was concerned more with an evaluation of alternative real world management strategies, a more complex biophysical component was employed to include stochasticity in the form of recruitment variation, variability of river discharge levels and fluctuations in input and product prices. Additional uncertainty (or prior knowledge) was included in the form of Bayesian priors on the most important model parameters. The management strategies were then compared based on their performance under a large number of alternative parameter values and stochastically different scenarios.

2.2. Spatial structure of model

The model was designed to represent the Clarence River region and was defined by five compartments. The division of compartments was based primarily on the fisheries that harvest the populations in the Clarence River area, but can be represented as spatial areas (Fig. 1).

The first compartment shown in Fig. 1 is the non-fishing zone (C1) which consists of the areas of the Clarence River closed to commercial fishing and encompasses all areas upstream of Ulmarra (near Grafton). The second compartment is the estuary fishing grounds (C2), which consists of the areas of the Clarence River open to estuary prawn trawl and estuary general fishing. The third compartment is the ocean fishing grounds (C3), which consists of the ocean waters surrounding the mouth of the Clarence River between 29° and 30°S. This zone covers what is understood to be the extent of ocean movements of the school prawns that emigrate out of the Clarence River estuary (Glaister, 1978b). Accounting for these movements greatly strengthened the stock-recruitment relationship incorporated into the model for this species. Finally, compartments C4 and C5 encompass the oceanic zones to the south and north of C3 and are used to model the large coastal migration patterns of the eastern king prawns.

Like the school prawns the eastern king prawns emigrate out of the Clarence River estuary into ocean waters. However, eastern king prawns have a far greater spatial extent to their ocean