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Preliminary evaluation of the costs and benefits of prawn stocking to enhance recreational fisheries in recruitment limited estuaries

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ABSTRACT

Hatchery-based fisheries enhancement involves supplementing natural recruitment through releases of cultured individuals to increase the productivity of wild harvest fisheries. The responsible approach to marine stock enhancement recommends economic assessment of enhancement endeavours be undertaken, but such assessments are difficult for recreational fisheries and consequently examples of such analyses are rare. This paper describes a bioeconomic assessment of hatchery releases to enhance a recreational Eastern King Prawn fishery in a recruitment limited coastal lake. Sensitivity analysis on the model indicated that parameters estimating growth and economic impact were the most important drivers of the model. A full Monte-Carlo Analysis of Uncertainty indicated that a scenario releasing 3,000,000 Eastern King Prawn postlarvae is most likely to yield over 5000 kg of harvest. Cost-Benefit results indicated that such a scenario would most likely generate AUD5.48 benefit for every AUD1.00 invested in releasing Eastern King Prawn. Achieving a benefit of less than AUD2.37 was extremely unlikely. This study indicates a favorable assessment of the potential economic benefits derived from a release of 3,000,000 Eastern King Prawns into Wallagoot Lake. Also, the simple approach presented provides a framework which may be useful for assessing other recreational fishery enhancement projects. Bioeconomic modelling is an important tool for understanding the potential benefits and risks of enhancement or sea ranching projects.

1. Introduction

Hatchery-based fisheries enhancement involves the supplementation of natural recruitment through the release of hatchery produced seed to increase the productivity of wild harvest fisheries at local or broad scales (e.g. Smith et al., 2012; Svåsand, 1998; Taylor et al., 2009). This can encompass a suite of different approaches, the primary approaches being 1) stock enhancement, which aims to both supplement harvest and contribute to the spawning stock feeding a population over time; and 2) sea ranching, which involves put, grow, and take operations, with enhancement of natural spawning stocks by hatchery-produced seed of lesser importance (Loneragan et al., 2013). The application of hatchery-based fisheries enhancement to marine and estuarine systems has greatly increased over the last 3 decades, with a key focus on developmental and ongoing research to underpin informed and adaptive management of such programs (Blankenship and Leber, 1995; Lorenzen et al., 2010; Taylor et al., 2005).

Most of these modern projects follow a framework of principles, which were first outlined in Blankenship and Leber (1995) and then updated in Lorenzen et al. (2010). A key element of the original and updated responsible approach involves the social and economic evaluation of fisheries enhancements. Quantitative assessment of social and economic impacts is not only an important means of assessing the performance of an enhancement program, it is also crucial to the adaptive management framework aimed at preventing large investments in ill-conceived enhancement programs (Lorenzen et al., 2010). This is exemplified in the analysis of Hilborn (1998), which highlights that a large number of commercial enhancements are not evaluated in economic terms, and the majority of those that were evaluated were economic failures. Despite the recommendations outlined above, economic evaluation of fisheries enhancements is still relatively uncommon, particularly in marine or estuarine systems.

In a broad sense, the majority of economic evaluations to date address enhancements aimed at improving commercial productivity. Examples which evaluate enhancement of recreational fisheries

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in marine or estuarine environments are relatively scarce, however, there are a few examples. Rutledge et al. (1990) conducted an evaluation of costs and benefits for an impoundment stocking program with Barramundi (*Lates calcarifer*), an iconic sportfish found in northern Australia. This estimated that each dollar invested in stocking generated an economic impact of $31. This study drew on the principles established for evaluating stocking of another important sportfish (Red Drum, *Sciaenops ocellatus*) in the estuarine and marine waters of Texas, USA (Rutledge, 1989), which estimated an economic impact of between $103–$1031 for each dollar invested. Palmer and Snowball (2009) conducted a study to establish the economic viability of a proposed Dusky Kob (*Argyrosomus japonicus*) stock enhancement program using the willingness-to-pay method, and found that under contingent valuation the benefits of stocking this sportfish far outweighed the cost. It is important to note that most published evaluations of "sportfish" stocking programs have derived favorable findings in terms of economic impact relative to costs, and these impacts are often an order of magnitude greater than the costs. However, there appears to be a paucity of "unfavorable" evaluations for recreational fisheries in the published literature, which may reflect either the widespread and significant benefits or impacts that can be generated from enhancement programs aimed at recreational fisheries, or potentially an unwillingness to publish unfavorable evaluations.

The enhancement of commercially exploited prawn (or shrimp) fisheries is well established (summarised in Bell et al., 2005), with several large-scale releases undertaken, mostly across Asia. Enhancement of recreational prawn fisheries is a relatively recent concept (Ochwada-Doyle et al., 2011, 2010; Ochwada et al., 2009), but examples of such enhancement endeavours are increasing (e.g. Broadley, 2014; Loneragan et al., 2013; Taylor, 2010). The most work in this area has involved Eastern King Prawn, which is an important recreational prawn species (Reid and Montgomery, 2005), and is now stocked into recruitment limited lakes in south-eastern Australia (Ochwada-Doyle et al., 2011).

Eastern King Prawn adults spawn off northern NSW and southern Queensland (Montgomery et al., 2007), and eggs and larvae are transported southward in the Eastern Australian Current over a period of weeks, while they develop and metamorphose. As the larvae reach the postlarval stage, they recruit into estuarine nursery habitats and remain there for the duration of their juvenile phase. Under normal conditions, this may last for 1–7 months (a portion of the population may over-winter in the estuary), before adolescent prawns migrate out of the estuary into the coastal zone, where they begin to mature and then commence their northward migration for spawning. This life-cycle contains two points that underpin enhancement of the species. Firstly, many of the shallow coastal lakes in south eastern Australia remain closed to the ocean for extended periods of time (Taylor et al., 2005) as a result of deposition of sand across the mouth from coastal wave energy, and minimal outflowing current. This creates a situation where the estuary is completely recruitment limited for this ocean spawning species. Secondly, a closed estuary mouth essentially traps stocked recruits within the estuary, where they can rapidly grow to a harvestable size without emigrating. These shallow coastal lakes are highly accessible to recreational dip-net fishers, making the species highly susceptible to recreational harvest.

As mentioned above, Eastern King Prawn are the subject of an ongoing marine stocking program in New South Wales, Australia, aimed at enhancing recreational fisheries. This study presents an assessment of the costs and benefits associated with enhancement (sea ranching) of this species in a normally-closed estuary (Wallagoot Lake).

2. Methods

2.1. Model overview

A single cohort, vector-based stochastic model was developed that links population dynamics with potential fishery outcomes, and then uses these estimates to establish economic impact of the stocking scenario. The model is thus divided into three components: 1) the population model; 2) the fishery model; and 3) economic model. The model primarily uses parameters that are commonly available from the literature or species stock assessments, and draws on some established approaches for evaluating the economic impact of stocking on recreational fisheries from the published literature.

2.2. Population model

Growth of stocked Eastern King Prawn (L_t) is modelled using the Somers (1988) growth model, which is a modification of the von Bertalanffy growth function appropriate for species that have seasonal growth (e.g. Western School Prawn, Broadley, 2014):

$$L_t = L_\infty \left(1 - e^{-k(t-t_0)-S(t)+S(t_0)}\right)$$

where

$$S(t) = \frac{C \times k}{2\pi} \times \sin(2\pi(t - t_s)) \quad \text{and} \quad S(t_0) = \frac{C \times k}{2\pi} \times \sin(2\pi(t_0 - t_s))$$

L_∞ is the asymptotic length, k is the rate of approach to L_∞, t_0 is the theoretical age at which L=0, C modulates the magnitude of growth according to the seasonal pattern, and t_s is the time between t = 0 and the time at which the first oscillation occurs. The model was fitted to a composite data set of known size-at-age data for Eastern King Prawn released and recaptured from Wallagoot Lake, using a non-linear least squares fit in MATLAB (Mathworks, Natick, MA, USA). All references to length refer to carapace length (CL).

Weight was estimated for each length increment using:

$$W_t = aL_t{}^b$$

where W_t reflect weight at time t, and a and b are the weight coefficient and exponent respectively. Using these relationships, the model produces three master vectors of time, length, and weight, from the period since hatching to the conclusion of the model period (t_{max}), and then extracts sub-vectors for the period between the age of prawns at stocking (t_{stock}) and the age at the conclusion of the model period (t_{max}).

Estimates of natural mortality obtained from empirical data are not readily available for small prawns. Loneragan et al. (2003), however, provides a length-based relationship which scales natural mortality with prawn size, of the form:

$$M_t = \alpha e^{-\beta L_t}$$

where L_t is the carapace length at time t, and α and β are constants which describe how natural mortality scales with animal size. Density-dependent mortality is a key consideration when undertaking stock enhancement or sea ranching. Loneragan et al. (2003) work on Brown Tiger Prawn *Penaeus esculentus* derived density dependent mortality rates from the stock-recruitment relationship for the species, and uses this to scale the population numbers of the enhanced stock. This approach is not appropriate for this study, as the stocked estuary is a closed population subject to complete recruitment limitation. When some level of natural recruitment does occur, the various environmental factors contributing to recruitment variability generally lead to the decoupling of recruitment magnitude from spawning stock size. Alternatively, the effects of density-dependent mortality can be estimated from empirical relationships. Ochwada-Doyle et al. (2012) created a