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Research paper

The economic value of fisheries harvest supported by saltmarsh and mangrove productivity in two Australian estuaries

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ABSTRACT

Broad-scale links between productivity of estuarine habitats (such as saltmarsh and mangrove) and the exploited species that rely on them have often been used to build a case for habitat conservation and repair. Stable isotope composition can provide a temporally and spatially integrated measure of trophic connectivity with which to quantify habitat-fishery linkages, allowing primary producers that comprise these habitats to be linked with harvested biomass with relatively few assumptions. We present a novel model that applies this approach to estimate the economic value of fisheries harvest derived from dominant estuarine habitats, in two eastern Australian estuaries. Estimated values of fisheries harvest supported by habitats within the model regions ranged from ~AUD100,000 y^{-1} to ~AUD7,200,000 y^{-1}. Saltmarsh in the Clarence River had by far the greatest economic value per-unit-area, with an average estimated Total Economic Output (from fisheries harvest) of AUD25,741 $ha^{-1}\,y^{-1}$, whereas mangrove was estimated to be AUD5,297 $ha^{-1}\,y^{-1}$. Average Total Economic Output in the Hunter River was AUD2,579 $ha^{-1}\,y^{-1}$ and AUD316 $ha^{-1}\,y^{-1}$ for saltmarsh and mangrove habitats respectively. Estuarine habitats are key ecological indicators of fisheries productivity, and the framework presented here will be broadly useful in estimating the potential economic impacts associated with changes in these indicators.

1. Introduction

Estuaries represent the interface between land and sea, and while these ecosystems provide a highly productive environment, they can also be subject to substantial anthropogenic modification (such as habitat loss). Many exploited species rely on the various resources available in estuarine systems for one or more life-history stages (Abrantes et al., 2015), such as favorable physico-chemical conditions conducive to optimal juvenile growth, structural habitats that provide a refuge from predation, and productive trophic resources (Beck et al., 2001). Consequently, habitat loss and concomitant effects on these resources can adversely affect ecosystem services such as fisheries production, either through effects on mortality and growth of early life-history stages, or through impacts on the productivity of exploited size-classes that rely on food webs supported by vascular primary producers. Any decline in ecosystem services has an economic cost, but estimating this cost ultimately relies on quantifying the monetary value of the services and linking back to the habitats that support them (Barbier et al., 2011).

The valuation of ecosystem services is increasingly being employed to support an economic case for habitat conservation and repair. Such valuation also supports national environmental accounting (e.g. the System of Environmental-Economic Accounting [SEEA], Bureau of Meteorology, 2013), where expenditures for protection or costs of degradation of environmental assets (such as fish habitat) are quantified relative to production gains or losses (Food and Agriculture Organization of the United Nations, 2004). Valuation of ecosystem services derived from fish habitat is essential for considering environmental assets in monetary terms, but examples of this are rare as it requires a quantitative measure of the linkages between estuarine habitats, the fish stocks they support, and the value of those fish stocks (i.e. quantifying habitat-fishery linkages). Such valuations are usually system-specific (Grabowski et al., 2012), and even a small subset of the available literature demonstrates that there is substantial variation in such estimates across species, systems and habitats, and across different valuation approaches. For example, Watson et al. (1993) estimated potential economic values of AUD72–AUD11,084 $ha^{-1}\,y^{-1}$ (here and after, all values are converted to 2015 dollars) from prawn harvest derived from the standing stock of juveniles in seagrass in northern Australia; whereas Blandon and zu Ermgassen (2014a) used a similar

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approach across multiple species in south-eastern Australia, and estimated the benefits of seagrass to commercial fisheries production was around AUD31,650 ha^{-1} y^{-1} (Blandon and zu Ermgassen, 2014b). Chong (2007) estimated the net fisheries contribution of mangrove forest (across multiple species) in Malaysia amounted to about USD967 ha^{-1} y^{-1}, and Bell (1997) calculated that coastal saltmarsh in the Gulf of Mexico supported recreational fisheries up to a value of USD36,902 ha^{-1} y^{-1} (converted from value-per-acre). This variation highlights a need to further refine estimation of economic values across multiple habitats and estuarine ecosystems. Although many methods exist to achieve this, using trophic relationships as a basis for these linkages may represent an efficient method that can be applied in a similar fashion across multiple systems.

Both physical and biological connectivity mediate the transfer of resources from productive intertidal estuarine habitats (such as mangrove and saltmarsh) to adjacent sub-tidal habitats. Mangrove habitats are inundated relatively frequently, and although recent work has questioned the extent to which fish directly interact with these habitats (Sheaves, 2017), there is evidence of broader exchange of mangrove-derived productivity and other areas in the estuary (Bouillon et al., 2008). In southern Australian estuaries, high elevation of saltmarsh habitats mean there are lower rates of inundation during which larger nekton can directly access the marsh surface (Becker and Taylor, 2017; Connolly et al., 1997). However, the movement of carbon synthesized on the marsh surface, either through the transport of particulate material (e.g. Abrantes and Sheaves, 2009; Melville and Connolly, 2005) or the movement of primary consumers and other nekton (e.g. Guest and Connolly, 2004, albeit over small scales), has been shown to link saltmarsh productivity with adjacent areas. Consequently, the transport of carbon from intertidal habitats can provide an important trophic resource for animals in other parts of the estuary (Abrantes et al., 2015).

While there is a long history of research that deals with the trophic linkages between various primary producers and exploited species in estuaries (e.g. Dittel et al., 2006; Hadwen et al., 2007; Loneragan et al., 1997; Selleslagh et al., 2015), these studies are rarely extended to estimate the actual fisheries impact of these primary producers. Modelling source contributions from stable isotope composition is ideal for establishing the trophic resources underpinning fisheries productivity. Stable isotopes can provide a temporally and spatially integrated measure of this contribution in fish of harvestable size that can be directly linked to the harvested biomass with relatively few assumptions. This manuscript provides two case studies that demonstrate a novel model to establish habitat-fishery linkages and derive associated economic value using trophic relationships established through stable isotopes.

2. Materials and methods

2.1. Description of the study systems

The Hunter River estuary (−32.90, 151.78) is a mature wave-dominated barrier estuary and important fishery on the mid-north coast of New South Wales, Australia (Fig. 1), particularly for crustacean species. Wave dominated barrier estuaries are often characterized by high coverage of mangrove and saltmarsh habitat, and generally support high productivity of important commercial species such as *Metapenaeus macleayi* (School Prawn; the species supporting the highest prawn harvest by biomass in New South Wales), *Mugil cephalus* (Sea Mullet; the species supporting the highest fish harvest by biomass in New South Wales), *Girella tricuspidata* (Luderick) and *Scylla serrata* (Mud Crab, Pease, 1999; Saintilan, 2004). The Clarence River estuary (−29.43, 153.37) is the largest estuarine system in New South Wales, and supports the state's largest estuarine fishery similarly dominated by harvest of School Prawn and Sea Mullet. Overall, the catchment is a mix of forested and agricultural land use, and areas adjacent to the lower watershed are dominated by agriculture and aquaculture. The Clarence River estuary shares similar geomorphological attributes and a similar species assemblage to the Hunter River estuary. In both estuaries, a model region was specified that dealt with the areas between the mouth of the estuary and ~20 km from the mouth, since this is where much of the commercial harvest takes place (Fig. 1).

2.2. Overview of framework

A summary of the biology of exploited species examined in this study is provided in Table 1; all species investigated were estuarine-dependent or -resident, and primarily harvested within estuarine systems. We used the contributions of saltmarsh and mangrove plants to the biomass of these exploited species as modelled from stable isotope composition (Tables 2 and 3; and see Supplementary information) for the Hunter and Clarence Rivers, to apportion the commercial harvest biomass that was derived from these habitats. We then applied a simple market value at first-point-of-sale to establish the Gross Value of Production, as well as an economic multiplier (calculated from the economic data presented in Voyer et al., 2016) to convert the Gross Value of Production to Total Economic Output (described below). Simulations were conducted within a Monte-Carlo Analysis of Uncertainty (MCAoU) framework, and model parameters were thus provided as distributions where possible (see Tables 2 and 3). While this framework represents the union of a simple set of relationships to link habitats with species harvested in an estuary and the value of that harvest, it is important to highlight there are two main assumptions associated with the approach: 1) that modelling of stable isotopes effectively describes trophic relationships; and 2) that the fishery and market price data are accurate. The effects of these assumptions on model estimates are elaborated in the Discussion.

2.3. Parameterisation and modelling

Stable isotope data for dominant primary producers in the estuary (see Supplementary information) was used to derive average source contributions for commercially sized individuals in the Hunter and Clarence River, and errors around these contributions (Tables 2 and 3). Economic value was derived using the formula:

$$GVP_{s,p} = C_{s,p} \cdot H_s \cdot M_s \cdot P_s$$

where $GVP_{s,p}$ is the Gross Value of Production (AUD y^{-1}) of species s derived from primary producer p within the model region (the lower estuary; Fig. 1), $C_{s,p}$ is the proportional contribution of primary producer p for species s derived from stable isotope measurements and associated modelling, H_s is the annual harvest of species s (kg y^{-1}), M_s is the market value for species s (AUD kg^{-1}), and P_s is the spatial partitioning coefficient for species s (see below). Collectively $H_s \cdot M_s$ represent the total GVP for species s in the entire estuary (GVP_s, AUD y^{-1}), $C_{s,p}$ apportions that GVP among primary producers in the estuary, and P_s further refines GVP to account for the relevant section of the estuary. Commercial catch data was extracted from the NSW DPI Commercial Catch and Effort Reporting System (see http://www.dpi.nsw.gov.au/fishing/commercial/catch-effort), and annual harvest (mean and variance, Tables 2 and 3) was estimated on the basis of catch reporting for each estuary for the 10 years between 2005/06 and 2014/15. This period included a range of both wet years (2008–13) and dry years (2005–08, and 2013–15). The panel of species modelled (Table 1) represented approximately 85% of the commercial harvest biomass in these estuaries. Market price was estimated from CPI-corrected (consumer price index) Sydney Fish Market values across the same time period (extracted from records compiled in the NSW DPI Resource Assessment System).

Estuarine catch in New South Wales is reported by fishers at the estuary level only. Although the bulk of species biomass often tends to