Ocean and Coastal Management 165 (2018) 80–98

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Predicting estuarine faunal assemblages using enduring environmental surrogates, with applications in systematic conservation planning

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ARTICLE INFO

Keywords:
Estuary
Systematic conservation planning
Abiotic surrogates
Faunal prediction
Fish
Benthic macroinvertebrates

ABSTRACT

Conservation planning in estuaries has lagged behind that in terrestrial and marine areas, despite these valuable ecosystems being among the most degraded. The core of any such approach is a reliable habitat classification and inventory of target biota. These data, and particularly the latter, are often lacking at the local-regional scales most relevant to estuarine management. This study presents a quantitative approach for predicting the likely fish and benthic invertebrate assemblages at any unsampled estuarine site using readily-obtainable and enduring biophysical attributes. We apply this scheme to an urbanised estuary and predict the above faunas throughout its entire nearshore zone. These data are then used to systematically design an exploratory spatially-efficient reserve that meets representation targets for numerous faunal conservation features, and test the ability of an existing, unsystematically-derived Marine Park to do the same.

Spatial patterns in the enduring biophysical attributes of local-scale habitats provided good to excellent surrogates for those in the fish and invertebrate faunas. All unsampled sites were then successfully assigned to their respective habitat and correlated fauna using biophysical measurements and a predictive decision tree. The resultant spatially-continuous 'faunal map' enabled quantification of 67 conservation features, from which reserves aimed at representing 10–30% of each feature were systematically derived. All reserves were highly efficient and almost always met representation targets, contrasting with the existing Marine Park which underrepresented 40–80% of features. Reserve designs were, however, spread throughout the system, highlighting the complexities in designing representative reserves for estuarine environments that capture their spatio-temporal diversity.

1. Introduction

Effective and holistic management of estuarine ecosystem health is difficult, reflecting the inherent complexity of these environments, the well-documented natural and human-induced stressors they commonly face, and demands from multiple and competing uses and users (e.g. Townend, 2002; McLusky and Elliott, 2004; Weinstein, 2007; Elliott and Whitfield, 2011). Conservation reserves have been used effectively to help manage competing requirements in common-pool resource environments such as these, with many examples documented in terrestrial and, over the last decade, marine areas (e.g. Margules and Pressey, 2000; Stewart et al., 2003; House et al., 2017). Yet, despite the widely acknowledged environmental, ecological and socio-economic importance of estuaries, estuarine conservation planning has typically lagged behind that of the above environments. This has been attributed to the challenges of strong physico-chemical gradients typically present in estuaries (e.g. Neely and Zajac, 2008), conflicts between preserving natural integrity vs growing economic gain (e.g. Gibbs et al., 2007) and the sometimes lower aesthetic appeal of these ecosystems (e.g. Edgar et al., 2000).

This situation is changing or has changed in some parts of the world. For example, the European Union (EU) has legislated various environmental directives, such as the Habitats Directive, which requires Member States to contribute to a network of Special Areas of Conservation by protecting or restoring sites, including those in estuaries, that are representative of regional ecological and community values (e.g. Apitz et al., 2006; Evans, 2006, 2012). The National Estuarine Research Reserve System, comprising 28 protected and comprehensively monitored estuaries throughout the United States, provides another good example of an integrated reserve network for conserving estuarine integrity at larger scales (e.g. Kennish, 2004; Mills et al., 2008). This contrasts markedly with the situation in Australia and

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https://doi.org/10.1016/j.ocecoaman.2018.08.007
Received 18 April 2018; Accepted 1 August 2018

more particularly Western Australia (WA), where although maintenance of estuarine health is supported by both legislation (e.g. the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and the State *Waterways Conservation Act 1976*) and government authority (e.g. Hallett et al., 2016a; b), there has to date been a highly lax approach to establishing representative reserve networks in these environments. There are only two Marine Parks in estuaries in the southern half of the State, neither of which contain sanctuary (no-take) zones (https://www.dpaw.wa.gov.au/management/marine/marine-parks-and-reserves; November 2017). While several estuaries lie within the newly-formed Great Kimberley Marine Park in northern WA and two are proposed to include sanctuary areas, further legislation is required to enforce this zoning (e.g. http://www.fish.wa.gov.au/Sustainability-and-Environment/Aquatic-Biodiversity/Marine-Protected-Areas/Pages/Recreational-fishing-in-North-Kimberley-Marine-Park.aspx; November 2017).

The core of any spatial planning approach for biodiversity conservation is a reliable classification of biophysical habitats and an inventory of their biota (e.g. Stevens and Connolly, 2004; Pittman et al., 2011; França et al., 2012a; Davis et al., 2017). Indeed, implementation of the EU Habitats Directive would not have been possible without the European Nature Information System (EUNIS), an extensive hierarchical scheme for classifying habitats and their biota ('biotopes'). Moreover, demonstrating that the links between biophysical habitats and their biota are both statistically-significant and repeatable is vital for (i) validating the ecological relevance of nominal habitat types and (ii) predicting the species likely to occur at any unsampled site using biophysical (surrogate) data, the latter of which is far easier and cheaper to obtain. Such predictive capability has many applications for ecosystem management, including rapid anticipation of species likely to be impacted by proposed developments, ready identification of priority conservation areas and ecosystem model development.

This study focuses, in part, on proposing an exploratory, spatially-efficient conservation reserve within a large iconic estuary in south-western Australia (the Swan-Canning Estuary) that meets biodiversity targets for both fish and benthic macroinvertebrate faunas. While a Marine Park already exists in this system, it was delineated unsystematically and focused mainly on waterbird habitats (Department of Conservation and Land Management, 1999). In contrast, the current study adopts a systematic approach using the conservation planning software Marxan (Ball et al., 2009), which has been widely employed in marine and terrestrial areas to identify 'optimal' reserve designs that meet representation targets for select conservation features and minimise cost.

When target conservation features include biota that cannot be readily mapped across the entire region of interest (e.g. mobile fauna), a common problem faced is the disparity between the full spatial coverage of the 'planning units' that provide the reserve building blocks, and the discrete (and often spatially-biased) biotic data collected only at select sites (e.g. Pressey, 2004; Sarkar et al., 2005; Malcolm et al., 2012). Limited capacity or poor choices in extrapolating the latter data over the former invariably lead to misrepresentative reserve solutions (e.g. Game and Grantham, 2008). The use of biophysical habitats as surrogates for faunal characteristics provides one way of circumventing this issue, particularly when habitat attributes can be readily obtained from spatially-continuous maps. Yet in many cases, and particularly at finer spatio-temporal scales, there is limited quantitative knowledge of how well these so-called 'coarse filter' environmental surrogates represent the biota of interest, and planners have to proceed on the basis of assumed relationships. While this may be the only option in data-poor situations, various studies have demonstrated the dangers of using such proxies in reserve planning when their capacity to well reflect shifts in target features has not been verified (e.g. Stevens and Connolly, 2004; Grantham et al., 2010; Januchowski-Hartley et al., 2011; Hermoso et al., 2013).

This study contributes one approach for overcoming the above issue. We firstly employ a series of local-scale nearshore habitats in the Swan-Canning Estuary, which were quantitatively classified by statistically identifying 'natural breaks' in a composite set of enduring environmental variables (Valesini et al., 2010). We then seek to establish a significant spatial match between these habitats and their fish assemblages. Such correlations have recently been well established for the benthic macroinvertebrate assemblages by Wildsmith et al. (2017). We then employ a predictive decision tree (Valesini et al., 2010) to extrapolate detailed faunal (fish and invertebrate) assemblage data to all unsampled nearshore areas based on the above readily-measurable habitat attributes. While the uses for this predictive framework are many and varied, the final study component focuses on one application, namely providing reliable data on key faunal conservation features to support the systematic design of an exploratory conservation reserve. The specific study objectives are as follows.

1. Determine whether the pattern of spatial differences among nearshore habitats in the Swan-Canning Estuary, as defined by their enduring environmental characteristics (sensu Valesini et al., 2010), is significantly correlated with that in their fish faunas, as has already been established for their benthic macroinvertebrate faunas by Wildsmith et al. (2017).
2. Given significant habitat-faunal matches above, produce a spatially-continuous map of the habitats and their associated faunas throughout the full nearshore zone of the estuary by employing the predictive decision tree approach of Valesini et al. (2010).
3. Use the above map to derive a suite of faunal conservation features for supporting the systematic design of a spatially-efficient and representative reserve system.
4. Compare the resultant reserve design with that of the existing Swan Estuary Marine Park, and ascertain the extent to which the latter meets the representation targets for the above conservation features.

2. Materials and methods

2.1. Study area

The Swan-Canning Estuary on the lower west coast of Australia (32.055°S, 115.735°E) experiences a temperate Mediterranean climate and mainly diurnal tides with a spring range of ~0.5 m. The estuary, which is ca 50 km long and 55 km^2, is a drowned river valley system that is permanently-open to the sea (Hodgkin and Hesp, 1998). It comprises a narrow entrance channel, a large central lagoonal basin, a smaller second basin and the tidal portions of the Swan and Canning rivers (Fig. 1). Much of the estuary is < 5 m deep with extensive shallow areas (~0.5 m deep) in the basins, but reaches ~20 m in parts of the upper channel. The estuary bisects Perth, the capital city of Western Australia, and its 121 000 km^2 catchment contains ~75% of the States' population (www.abs.gov.au, March 2018). The system is extensively modified (National Land and Water Resources Audit, 2002a; b) and contains a Class A Marine Reserve in the main basin (the Swan Estuary Marine Park; Fig. 1), which was established in 1990 and is managed for conservation, recreation, education and fishing (Department of Conservation and Land Management, 1999).

2.2. Examining habitat-faunal relationships and predicting faunal assemblages

The following steps were undertaken to test the match in spatial pattern between the nearshore habitats (≤2 m deep) and their fish faunas in the Swan-Canning Estuary, then predict the species