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The importance of spatial scale for the conservation of tidal flat macrobenthos: An example from New South Wales, Australia

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A B S T R A C T

Planners of Marine Protected Areas (MPAs) commonly use maps of habitat types when choosing areas to conserve. This assumes that habitats are homogeneous, and therefore, that any area of habitat will represent the full spectrum of ecological diversity within that habitat. Here, we report that macrobenthic assemblages in tidal flat habitats were spatially heterogeneous in terms of beta diversity (taxonomic turnover), abundance, taxonomic richness and Shannon–Wiener H′ Diversity. Importantly, the patterns of heterogeneity were scale dependent for the three spatial scales we examined; plots (20 m), sites (100s of m) and estuaries (<30 km). The three estuaries in the study were compositionally similar as they shared the same dominant taxa, although one estuary had significantly more taxa and a higher abundance of macrobenthos. Assemblages within tidal flats differed at scales of 100s of m for all ecological measures. Most notably, beta diversity was highest at this scale. Assemblages were relatively more homogeneous at the 20-m scale. These findings highlight the value of examining more than one ecological measure and estimating magnitude of effects across a variety of scales. This work presents two important considerations for MPAs. First, although tidal flats in different estuaries are compositionally similar for dominant taxa, rarer taxa and high heterogeneity in abundance should influence the choice and number of tidal flats in MPAs. Second, strong compositional heterogeneity within individual tidal flats implies that conservation of whole habitat, rather than sections of a tidal flat, is essential if this habitat type is to be used to represent taxonomic diversity.

1. Introduction

The design of MPAs is an emerging science that utilizes experiences from the design of terrestrial conservation areas, but also requires new approaches that address the unique challenges of the marine environment (Pressey and Mc Neill, 1996). Historically, MPAs have been designed in an ad hoc or opportunistic fashion (Pressey, 1994; Avery, 2003). This is due in part to limited knowledge of the patterns of biological distributions from the marine environment (Boersma and Parrish, 1999; Stewart et al., 2003). Conservation efforts are also usually heavily compromised due to perceived socio-economic impacts by a range of stakeholders (Roberts and Hawkins, 2000). Consequently, conservation efforts may be

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inefficient, inadequate or even fail to achieve set goals for reserve systems (Pressey, 1995; Stewart et al., 2003). To avoid this, many MPAs are now mandated to be designed according to guidelines of comprehensiveness, adequateness and representativeness (CAR) (Burgman and Lindenmayer, 1998; Lubchenco et al., 2003). CAR reserve systems must contain multiple representative samples of all ecosystems, habitats and associated taxa within bioregions (ANZECC TFMPA, 1998). Bioregions in Australian marine waters are areas that delineate ecological characteristics distinct from other areas in Australia, and are usually at scales of 100–1000s of km (ANZECC TFMPA, 1999).

A precursor to establishing a CAR system of MPAs is mapping the different habitat types within each bioregion (Pressey and Ferrier, 1995; Jordan et al., 2005), which function as surrogates for ecological diversity (Ward et al., 1999; Stewart et al., 2003). During planning, these maps are used to choose habitat reserves. However, numerous critiques of MPA design state that an important limitation to this approach is a lack of systematically surveyed biological data (Ward et al., 1999; Avery, 2001; Banks and Skilleter, 2002; Ponder et al., 2002). In particular, there is limited information on the spatial scales at which faunal assemblages change in taxonomic composition within a habitat type. It is well established that taxa do turn over between assemblages along a distance or environmental gradient (Jablonski and Sepkoski, 1996), which is best described by the term beta diversity (Pielou, 1974; Clarke and Cranme, 1997; Gray, 2000). There are diverse applications for the concept of beta diversity (Gering and Crist, 2002; Ricotta et al., 2002; Koleff et al., 2003), but here it is used according to early definitions (Pielou, 1974) and a review by Gray (2000), where beta diversity can describe taxonomic turnover in assemblages at various spatial scales within a habitat. Beta diversity is an important ecological measure for the siting of Marine Protected Areas that aim to represent the full range of taxa in a region. Conservation planners need to consider beta diversity for two reasons; first, if beta diversity is low at the scale of bioregion, i.e. assemblages consistently contain the same taxa in all habitat locations, then any location has the potential to be a comprehensive and representative area for conservation. If, however, beta diversity is high at the scale of bioregion, then multiple habitat locations that encompass this beta diversity will be required to achieve comprehensiveness and representativeness. Second, at smaller scales, interpreting habitat as an indicator of biological homogeneity can be misleading as many taxa exhibit patchy distributions within what appears to be homogeneous habitat (Thrush, 1991; Stevens and Connolly, 2004). This assumption is rarely tested for conservation purposes despite habitat heterogeneity being documented in the scientific literature (Thrush, 1991; Hacking, 1998; Dittman, 2000; Curley et al., 2002; Stevens and Connolly, 2004; Rodrigues et al., 2006). Heterogeneity may be an important defining characteristic of many habitats (Holt et al., 2004; Tews et al., 2004), but it is rarely known what scales of habitat and associated heterogeneity are required to represent or adequately "maintain the status of" assemblages (Constable, 1999). Consequently, if a portion of habitat is protected and scales of beta diversity are greater than the reserve area, there is a risk that the goal of representing species and ecological heterogeneity in the reserve will not be achieved. If habitats are to be mapped as surrogates for ecological diversity, then spatial scales of ecological heterogeneity or the processes that drive habitat heterogeneity need to be known to ensure that the full range of taxa are adequately represented in reserves.

Estuarine tidal flats are one habitat used as a planning unit and surrogate for taxonomic diversity in Australian MPAs (NSW Marine Parks Authority, 2001). This habitat is an important transition zone, with ecological processes that functionally link terrestrial, freshwater and marine ecosystems (Wall et al., 2001; Gray, 2002). For example, tidal flats are a principal energy link between primary production and consumers such as birds and fish (Loneragan and Bunn, 1999; McLusky, 1999; Levin et al., 2001). Therefore, it is important to include tidal flats in a system of MPAs.

Despite considerable international research on the ecology of estuarine tidal flats (Thrush and Warwick, 1997; Constable, 1999), there have been relatively few Australian studies (Fairweather and Quinn, 1995). Existing studies report small and intermediate scale spatial patterns of assemblages or taxa in tidal flats (see reviews by Thrush (1991), Constable (1999) and Gray (2002)), but they are rarely presented in a context that can contribute to conservation planning. There are some notable exceptions, and in particular, Edgar et al. (2000) identified discrete biological assemblages associated with up to nine different morphological types of estuaries (e.g. barred estuaries, drowned river valleys, etc.), as well as considerable biological variation at smaller scales within each estuarine type. However, taxonomic turnover (beta diversity) between estuaries of the same morphological type was not determined.

The aims of this research were to determine which of three spatial scales (20 m, 100s of m and <30 km) of ecological heterogeneity are most important for conservation planning of tidal flat habitat on the South Coast of NSW. We measured beta diversity as well as three other ecological measures: abundance, taxonomic richness and Shannon Wiener Diversity (H′), to determine if different measures showed the same patterns. The results should be relevant to spatial conservation planning in MPAs by answering practical questions: (a) Does a single tidal flat provide a comprehensive and representative reflection of other tidal flats in the region? (b) Do we need to include whole tidal flats in reserves to represent all infaunal macrobenthos? (c) What further research is necessary in order to optimize the selection of tidal flats in MPAs?

2. Methods

2.1. *Study sites*

Three similar, permanently open, barred estuaries on the south coast of New South Wales (NSW), Australia were chosen as study sites (Fig. 1) within a larger temporal study (Winberg, in preparation). The first year of data was used for this study in order to describe spatial ecological heterogeneity. In each estuary, the first tidal flat upstream – within 1 km of the estuarine mouth – was sampled. One of the tidal flats, Currambene Creek (35° 01′ S, 150° 40′ E), was proposed as a Sanctuary Zone (no take zone) in the Jervis Bay Marine Park (JBMP). The two other estuaries were at Sussex Inlet (35° 10′