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Enhancing the performance of marine reserves in estuaries: Just add water

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ABSTRACT

Nature reserves are created to conserve biodiversity and restore populations of harvested species, but it is not clear whether this strategy is successful in all ecosystems. Reserves are gazetted in estuaries to offset impacts from burgeoning human populations, however, coastal conservation cannot be optimized because their effectiveness is rarely evaluated. We surveyed 220 sites in 22 estuaries in the Moreton Bay Marine Park, Queensland, Australia, including all six current estuarine marine reserves within the park. Fishes were surveyed using one hour deployments of baited remote underwater video stations twice at each site over consecutive days. We show that although the estuarine reserves in Moreton Bay contain a significantly different fish community, they fail to enhance the abundance of harvested fish species. We posit that performance is limited because reserves protect unique spatial features, or conserve narrow estuaries with weak connections to mangrove habitats and the open sea. Consequently, reserves as currently positioned protect only a subset of potential environmental conditions present for fish within the region, and potentially support residual estuarine habitats (i.e. expansive intertidal flats or shallow creeks) which are not particularly significant to either fish or fishers. We argue that reserve effectiveness can be improved by conserving deeper estuaries, with diverse habitats for fish and strong connections to the open sea. Without incorporating these critical spatial considerations into estuarine reserve design, estuarine reserves are doomed to fail.

1. Introduction

"It is not when truth is dirty, but when it is shallow, that the lover of knowledge is reluctant to step into its waters."

Friedrich Nietzsche.

Nature reserves have been created globally to conserve biodiversity, supplement populations of harvested species, and maintain ecosystem functioning (Wood et al., 2008; Boonzaier and Pauly, 2016). Today, the capacity for reserves to increase the abundance of harvested species within their boundaries is well established (Mosqueira et al., 2000; Brashares et al., 2001; Allan et al., 2005). Strategically placed and well-enforced reserves in some marine (e.g. Edgar et al., 2014), freshwater (e.g. Humphries and Winemiller, 2009) and terrestrial (e.g. Joppa et al., 2008) ecosystems can increase the abundance and biomass of harvested species within their boundaries, and drive trophic cascades that alter the ecological condition and functioning of entire ecosystems (e.g. Ripple and Beschta, 2007).

In coastal settings, reserves are often considered the primary tool for conserving biodiversity and species, but their effectiveness has rarely been evaluated in some seascapes (Ban et al., 2014; Schlacher et al., 2015; Olds et al., 2016). This is particularly the case for estuaries, which are surprisingly underrepresented in the spatial conservation literature relative to coral and rocky reefs (see Winberg and Davis, 2014). Estuaries are significantly impacted by the effects of growing coastal cities and populations (e.g. harvesting, habitat loss and degradation) (Barbier et al., 2011). Consequently, estuarine conservation is now considered a management priority (Winberg and Davis, 2014). However, because estuarine reserve effectiveness is rarely reported on, we lack the empirical data that is required to optimize conservation outcomes (Sala et al., 2002; Huijbers et al., 2015).

Reserves usually carry costs for fisheries, mining and other economic activities (Halpern et al., 2013; Klein et al., 2013; Stigner et al., 2016). Attempts at reducing such costs can lead to reserves being placed in *residual* locations, meaning that impacts on industries are lessened, but that conservation outcomes are also poor (Pressey and Bottrill, 2008). Residual reserves might be common in estuaries when massive pressures from fishing and land development relegate reserves to locations that are isolated, shallow, with low habitat diversity and of

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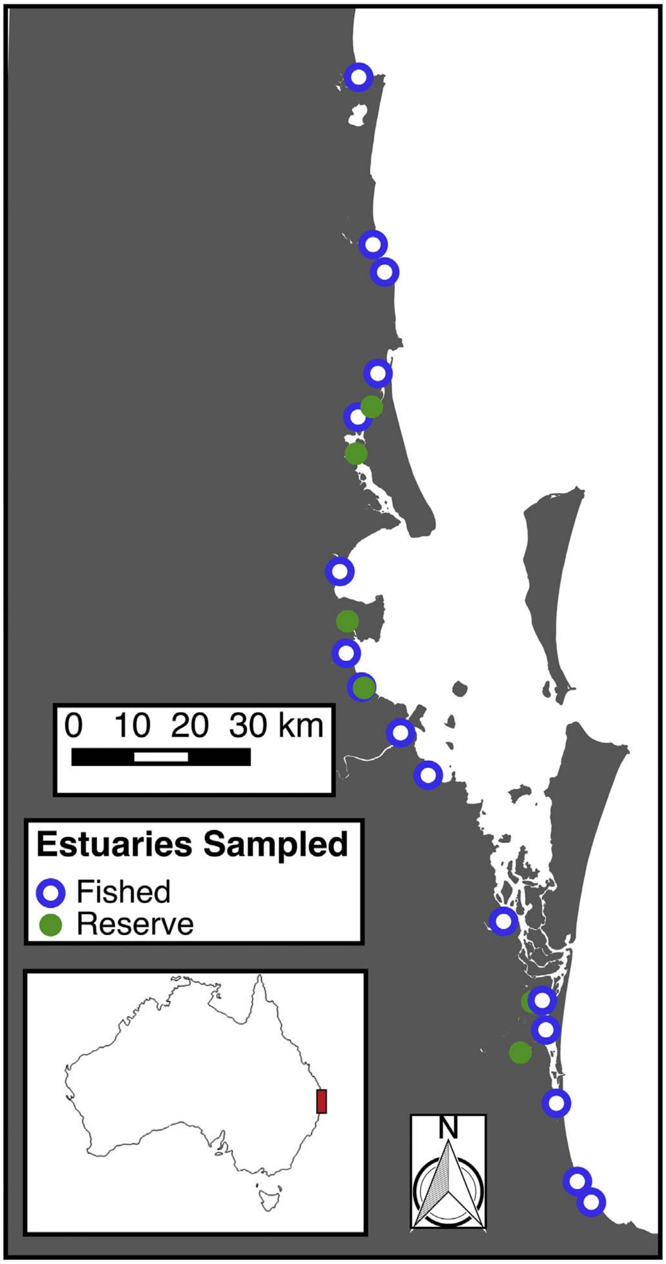

Fig. 1. Map showing the position of estuaries sampled in southeast Queensland, Australia, and their status as fished or reserve estuaries.

lower value to humans (see Devillers et al., 2015).

In this paper we evaluate the effectiveness of a network of six estuarine reserves in the Moreton Bay Marine Park (MBMP) in eastern Australia by testing whether reserves differ from fished reserves in terms of fish community structure and the abundance of harvested fishes. We then determine whether reserves contain a subset of the broader estuarine habitats in the region, and identify spatial attributes of estuaries that influence reserve effectiveness. Protection from fishing is expected to increase the abundance of harvested species inside reserves, and we hypothesise that reserve effectiveness will differ with variation in the spatial properties of estuarine seascapes.

2. Material and methods

2.1. Study design

The marine park was established in 1993 with one reserve in estuaries. In 2008, five additional reserves were added in estuaries as part of an expansion of reserves: we surveyed all six of these estuarine reserves (Fig. 1). All reserves that we sampled are fully no-take marine reserves (i.e. no extractive industries allowed) and are policed by three government agencies. Current reserves are selected primarily on the basis of conserving a minimum of 10% of each of the 16 recognized habitat types within the bay (e.g. sandy channels, mangrove, intertidal flats) within reserves, along with a suite of eight additional biophysical and four socio-economic guiding principles (Queensland Government, 2007). All estuaries are permanently open to the ocean. Pilot surveys of the estuarine reserves indicated that some were characterized by a distinct sub-set of habitat features, such as very large mangrove stands, wide intertidal mudflats, and shallow tidal channels. As a consequence, there are no fished and reserve locations available that could be paired as strict controls for habitat features. Thus, we sampled the full spectrum of estuarine habitats across the region, encompassing 16 fished estuaries in addition to the six reserves (Fig. 1). This design resulted in us sampling all estuarine systems wider than 100 m in high tide width in the region. Therefore, we sampled all estuaries that are likely large enough to potentially support an estuarine reserve.

Estuaries were surveyed in random order between June and August 2015. Fishes were surveyed at ten sites in each of the 22 estuaries twice over two consecutive days. Because salinity is a primary determinant of fish distributions in estuaries, we standardised for salinity by evenly spreading the ten sites from the estuary mouth upstream to where salinity had decreased to 30 psu (based on 10 years salinity data for each estuary; HWMP, 2016). The key harvested species in estuaries within this region (especially bream *Acanthopagrus australis*, moses perch *Lutjanus russelli*, mullet *Mugil cephalus*, and species of whiting *Sillago* spp. and flathead *Platycephalus* spp.; Webley et al., 2015) occur primarily within the lower estuary as they either spawn in these areas, or require linkages to the ocean for spawning migrations (e.g. Pollock, 1982; Davis et al., 2015). Consequently, the distribution of our sites along primarily marine salinities encompasses the majority of these species' ranges within estuaries in the region. Reserves always extend from the estuary mouth to a reserve-specific distance upstream that was always further than our 30 psu upper sampling limits. All sites were located over unvegetated muddy or sandy bottoms, in water depths between 1.5 and 2 m and within 30 m of adjacent mangroves to control for seascape scale effects (for example, see Martin et al., 2015).

2.2. Fish surveys

We used one hour deployments of baited remote underwater video stations (BRUVS) to survey fish communities at each site. BRUVS were constructed of a 3 kg weight and a 20 mm PVC pipe to attach baits at a fixed distance of 50 cm from a GoPro camera recording in high definition. Baits consisted of ~500 g pilchards *Sardinops sagax* placed into a 20 × 30 cm mesh bag with 0.5 cm^2 openings. A 20 × 20 cm visibility calibration disk was placed 1 m from the camera and used to quantify visibility. The disk had three vertical stripes (6.6 cm wide) of white, grey and black paint. When analysing footage, observers noted which stripes were seen and this was used to index visibility (i.e. white only = low visibility, white and grey = moderate, white, grey and black = high): we found that the composition of fish assemblages did not differ significantly between classes of visibility (permutational multivariate analysis of variance; $p > 0.15$) and hence visibility was not included in further analyses. Each video was analysed by counting the maximum number of individuals of each fish species that was visible between the camera and the above-described visibility disk (i.e. *MaxN*). Given the distance between sites (> 250 m) we considered it unlikely that the same individual was sampled at more than one site on the same day.

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