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Loss of native rocky reef biodiversity in Australian metropolitan embayments

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ABSTRACT

Urbanisation of the coastal zone represents a key threat to marine biodiversity, including rocky reef communities which often possess disproportionate ecological, recreational and commercial importance. The nature and magnitude of local urban impacts on reef biodiversity near three Australian capital cities were quantified using visual census methods. The most impacted reefs in urbanised embayments were consistently characterised by smaller, faster growing species, reduced fish biomass and richness, and reduced mobile invertebrate abundance and richness. Reef faunal distribution varied significantly with heavy metals, local population density, and proximity to city ports, while native fish and invertebrate communities were most depauperate in locations where invasive species were abundant. Our study adds impetus for improved urban planning and pollution management practises, while also highlighting the potential for skilled volunteers to improve the tracking of changes in marine biodiversity values and the effectiveness of management intervention.

1. Introduction

Of numerous contemporary threats to global marine biodiversity, pollution and disturbance associated with coastal urbanisation are consistently regarded amongst the most serious and widespread (Suchanek, 1994; Gray, 1997; Vitousek et al., 1997; Nystrom et al., 2000; Shahidul Islam and Tanaka, 2004; Halpern et al., 2008). In a global assessment of threats based on a quantitative expert interview approach, Halpern et al. (2007) listed coastal development, point source organic pollution and direct human impacts amongst the eight greatest threats to biodiversity across all marine ecosystems. Only increasing sea temperature and fishing-related impacts were considered to be more pervasive in global oceans. In line with this, Crain et al. (2009) stressed the need to better understand the cumulative impacts on our coastal ecosystems through community-level field studies. Such studies can provide the only means to quantify overall net effects on marine ecosystems without making assumptions regarding the nature of interactions, and are needed to inform and complement controlled experiments designed to explore mechanistic links.

Field studies of community-level impacts of urbanisation on sub-tidal marine fauna have mostly focussed on soft sediment habitats (Reish, 1955; Heck, 1976; Inglis and Kross, 2000; Claudet and Fraschetti, 2010), or on sessile components of hard substrates (Johnston and Roberts, 2009). Sub-tidal rocky reef communities make up a substantial component of faunal biomass in coastal areas, and are often of greater recreational and commercial importance than soft sediment communities, typically containing high densities of large-bodied fishes and mobile invertebrates (Edgar, 1990; Taylor, 1998; Cowles et al., 2009). Relatively little is known about the community-level impacts of urbanisation on mobile fauna associated with rocky reefs, including the extent to which such values are compromised under multiple, interacting threats.

Common local responses to organic and inorganic pollution observed in soft-sediment and sessile faunal communities are shifts in the abundance distribution of species towards an increasingly uneven community dominated by few species (Johnston and Roberts, 2009), and corresponding changes in the relative proportions of species with different tolerances to disturbances, feeding

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modes or life-history characteristics (Reish, 1955; Heck, 1976; Pearson and Rosenberg, 1978; Warwick, 1986; Schaaf et al., 1987; Claudet and Fraschetti, 2010; Edgar et al., 2010). Few studies have assessed pollution impacts on marine fishes at the community level, but from those included in the meta-analysis of McKinley and Johnston (2010), positive responses in overall abundance and species richness to organic enrichment were the only relatively consistent trends identified. The clearest message apparent from previous research is that community-level responses to urbanisation may be complex and unpredictable, affected by varying tolerances of different species to numerous contaminants and sources of disturbance. Ecological interactions and indirect effects of urbanisation through habitat degradation will further contribute to variable outcomes at this level of organisation.

The major goal of our study was to document the distributions of fishes and mobile invertebrates on rocky reefs throughout three major urban embayments in south-eastern Australia in order to understand how they vary spatially with the distribution of urban impact types. Our study focused on the three state capitals: Sydney (New South Wales), Melbourne (Victoria) and Hobart (Tasmania). These cities have major ports and industry, and substantial known heavy metal pollution as a legacy from historical industrial pollution and through contemporary inputs such as storm water runoff and discharges from urbanised sub-catchments (Birch, 2000; Johnston and Keough, 2002; Townsend and Seen, 2012). All contain areas of fringing rocky reef with temperate faunas (although Sydney also receives seasonal recruitment of tropical species) and a mix of algal dominated habitat and bare rock/urchin barrens. Invasive species are also known to be common in these cities, mostly introduced as a result of intense shipping activity, so we also considered the pressures associated with invasive species alongside urban impacts.

Although much has been assumed from broader biogeographic trends, surprisingly little is known of the distribution of rocky reef biodiversity associated with these cities; prior to this study, no systematic study of rocky reef biodiversity had ever been undertaken across Sydney Harbour, despite being the location of the first European settlement in Australia and the site of its largest city. Our approach involved training and engaging committed local recreational SCUBA divers in each of the cities through the global Reef Life Survey program (RLS; www.reeflifesurvey.com) to enable a comprehensive coverage of collection of data, as well as establishing a cost-effective mechanism for ongoing monitoring at these cities using standardised methods through the future.

We tested the hypotheses that: (a) the community structure of fishes and mobile invertebrates recorded at shallow reef sites by RLS divers is generally related to the distribution of a number of urban impacts, including heavy metal contamination, surrounding human population density, the proximity to sewage outfalls, proximity to the city port, and the distribution of invasive species; and (b) spatial patterns in impacts are consistent among different taxonomic groups, impact types and the three cities examined, despite biogeographic differences in species composition and physical characteristics. We then assessed trends in important univariate community metrics to better understand the nature of impacts, specifically in relation to expectations from previous research associated with loss of species, reduced productivity, and compositional differences related to life-history strategies.

2. Methods

2.1. Ecological data

Underwater visual census methods were used to estimate densities of fishes and mobile macroinvertebrates at sub-tidal reef sites distributed throughout Port Phillip Bay (Melbourne), Sydney Harbour (Sydney) and the Derwent Estuary (Hobart). Surveys were undertaken using standard RLS methods, which involve separate surveys of fishes and mobile macroinvertebrates along 50 m transect lines. Detailed descriptions of methods are provided in Edgar and Stuart-Smith (2014) and an online methods manual (Reef Life Survey, 2013). Multiple 50 m transect lines were set at each site, each along a depth contour. The fish surveys involved a pair of divers swimming either side of the transect line, while recording on waterproof paper the abundance and size of all fishes sighted within 5 m of the line. Abundances of fishes in large schools were estimated by counting a subset and estimating the percentage of the total school that the subset comprised.

Mobile macroinvertebrates (echinoderms, large gastropods and large crustaceans >2.5 cm length) and cryptic fishes, closely associated with the bottom and often missed on larger-scale fish censuses, were surveyed in 1 m wide blocks on either side of the same transect lines used for fish counts. Divers undertook this component immediately following completion of the fish survey. The algal canopy was brushed aside where necessary to search all exposed surfaces of the substratum within the block, with counts made for each species sighted. Only data on native species were included as response variables in analyses, with invasive species recorded, but excluded from data used in response variables.

Data on fish abundance and size were used to estimate the biomass of each species on transects. Species-specific length–weight relationships provided in Fishbase (www.fishbase.org) were applied, with relationships from congeners (and occasionally family) used if not available for particular species. Additional Fishbase relationships were used to convert total length to fork length as necessary. The bias in divers' perception of fish size underwater was corrected using relationships presented in Edgar et al. (2004). Fish biomass estimates, in grams per 500 m^2 transect, were log (x + 100 g) transformed for all analyses (although raw data in kg are presented in plots). The estimates can be regarded as relative, suitable only for comparisons with data collected using the same methods, rather than providing absolute estimates of biomass.

Data were analysed from 35 sites in Port Phillip Bay, 27 in Sydney Harbour and 37 in the Derwent Estuary (Hobart) (Fig. 1). Surveys were undertaken between November and May (>70% between December and February) over three summer periods from 2008 to 2011. An average of two 50 m transects surveyed at each site was analysed, after transects deeper than 10 m were excluded. Data used were means among transects within sites (overall mean depth was 4.3 m), averaging out any depth-associated variation, which is relatively small for the depth range and regions covered in this study. Little reef habitat exists deeper than 10 m in the three embayments other than near the Sydney Heads.

Thirty-six RLS divers participated in data collection; all with training to a scientific standard in survey methods, as evidenced by comparison with data from scientists who accompanied divers on the same transect blocks on previous surveys. Previous assessment of data quality from trained RLS volunteers found the differences to data produced by professional biologists non-significant and also trivial (<1%) when compared to variation attributable to depth (over a greater range than in this study), site and region (Edgar and Stuart-Smith, 2009).

2.2. Urban impact and environmental variables

A range of local urban impact and pollution data were obtained and aligned with the ecological survey sites where fish and invertebrate data were collected. These included local heavy metal pollution, invasive species densities, proximity to sewage treatment plant outfalls, and local human population densities.