Marine Environmental Research 129 (2017) 291–303

Contents lists available at ScienceDirect

Marine Environmental Research

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

Differences in rocky reef habitats related to human disturbances across a latitudinal gradient

Tim M. Glasby [a, *], Peter T. Gibson [a], Juan J. Cruz-Motta [b]

[a] New South Wales Department of Primary Industries, Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay, NSW, 2315 Australia
[b] Department of Marine Sciences, University of Puerto Rico-Mayagüez, PO Box 9000, Mayagüez, PR 00681-9000, Puerto Rico

ARTICLE INFO

Article history:
Received 16 December 2016
Received in revised form
20 June 2017
Accepted 22 June 2017
Available online 23 June 2017

Keywords:
Estuary
Urbanisation
Spatial scale
Intertidal
Subtidal
Nutrients
Temperate

ABSTRACT

This study tested for differences in the composition of intertidal and shallow subtidal rocky reef habitats subjected to a range of human pressures across ~1000 km of coastline in New South Wales, Australia over 5 years. Percentage covers of habitats were sampled using aerial photography and a large grain size (20 m^2 intertidal; 800 m^2 subtidal) in a nested hierarchical design. Results were consistent with anthropogenic impacts on habitat structure only around estuaries with the most heavily urbanised or agriculturally-intense catchments. The most convincing relationships documented here related to environmental variables such as SST, latitude, reef width and proximity to large estuaries irrespective of human disturbance levels. Moreover, there were suggestions that any influences of estuarine waters (be they anthropogenic or natural) on reef assemblages could potentially extend 10s of kilometres from major estuaries. In general, our results supported those of studies that utilised smaller grain sizes (greatest variability often at smallest spatial scales), but we found that variability over scales of 100s of km can be similar to or greater than variability over scales of 10s of metres.

1. Introduction

Urbanisation can cause profound changes to natural habitats, their associated species and ecological processes (Hobbs, 1993; Vitousek et al., 1997; Grimm et al., 2000; Faulkner, 2004; Garden et al., 2006), thereby producing a mosaic of distinct habitats (Bulleri and Chapman, 2010; Dafforn et al., 2015; Glasby and Connell, 1999; Hobbs et al., 2006; Pickett et al., 2001; Wiens, 1995). Unless our ability to manage anthropogenic disturbances improves markedly, there will almost certainly be increasing pressures on terrestrial and marine habitats. Urbanisation of low-lying coastal zones is increasing globally at a far greater rate than that of inland areas (Seto et al., 2011). In Australia, a further 1 million people are expected to reside in coastal areas by 2035 and in that country's most populous state (New South Wales), there was a 10% increase in residential population of coastal areas from 2001 to 2010 (SoE, 2011).

Estuarine and coastal habitats are subjected to a range of anthropogenic disturbances, including habitat destruction and modification, nutrient and contaminant inputs, introduced species and climatic change (Thompson et al., 2002; Airoldi and Beck, 2007; Diaz and Rosenberg, 2008; Wernberg et al., 2016). There is evidence for anthropogenic impacts to subtidal rocky reef habitats occurring over large spatial extents, related to over harvesting, sedimentation and nutrient inputs (e.g. Steneck et al., 2002; Airoldi and Beck, 2007; Benedetti-Cecchi et al., 2001; Connell et al., 2008; Gorman et al., 2009). In contrast, direct anthropogenic impacts to rocky intertidal habitats on exposed coastlines are typically more localised (Crowe et al., 2000), although there are some examples of large scale impacts associated with urbanization (e.g. Siegfried et al., 1994; Scherner et al., 2013; Worm et al., 1999).

Much of our knowledge of the effects of anthropogenic disturbances to rocky reef habitats, and indeed of the ecology of these habitats, is derived from studies that have utilised small sampling units (i.e. a small grain size; Wiens, 1989) (see Hawkins et al., 2016). Small grain sizes are not only practical to use, they enable the sampling of small and cryptic species. Many studies of rocky reef habitats that have been done over large spatial extents have typically used small grain sizes in a nested hierarchical design (e.g. Foster, 1990; Connolly and Roughgarden, 1998; Underwood et al., 1991, 2008; Bryson et al., 2014; Connell and Irving, 2008; Cruz-Motta et al., 2010). Although there is increasing evidence that the results of small-scale studies can be used to understand and

* Corresponding author.
E-mail address: tim.glasby@dpi.nsw.gov.au (T.M. Glasby).

http://dx.doi.org/10.1016/j.marenvres.2017.06.014
0141-1136/

interpret patterns at larger spatial scales (Fraschetti et al., 2005; Irving et al., 2004; Wootton, 2001), this knowledge is primarily gleaned from the aggregation of small grain sizes rather than specific knowledge about moderate–large grain sizes. Many have argued that studies that utilise larger grain sizes and spatial extents are needed to complement traditional smaller scale studies and provide a better understanding of the impacts of large scale disturbances (Wiens, 1989; Levin, 1992; Fraschetti et al., 2005; Mac Nally and Quinn, 1998; Thompson et al., 2002; Underwood et al., 2008) at the spatial scales at which many management actions are implemented.

The present study was designed to test for large scale anthropogenic impacts to intertidal and shallow subtidal habitat-forming species (primarily algae, but also some invertebrates such as solitary ascidians) on wave-exposed rocky reefs in New South Wales (NSW), Australia. Sampling encompassed most of the NSW coastline (~1000 km) and included locations subjected to a wide range of anthropogenic disturbances. Sampling was repeated over multiple years to test for temporal consistency in patterns and will be replicated in the future to test hypotheses about temporal changes in assemblages related to urbanisation and climate change. The primary hypotheses being tested in this phase of the project were that increasing anthropogenic disturbance would correlate with (i) a reduction in the cover of canopy-forming algae and an increase in turf-forming or filamentous algae (in response to increased sedimentation and nutrients; Airoldi and Beck, 2007), (ii) an increase in subtidal, urchin-grazed barren reef (due to urchin predators being harvested; Ling et al., 2009), (iii) a reduction in intertidal species such as *Pyura stolonifera* (solitary ascidian) and small algae due to bait collection (Fairweather, 1991) and trampling (Keough and Quinn, 1998), respectively, and (iv) an increase in temporal variability of rocky reef assemblages (Chapman et al., 1995). Anthropogenic disturbance was estimated using a variety of measures relating to human population, nutrient inputs and catchment development. Simultaneously, we tested for associations between the composition of habitat-forming species on intertidal and subtidal rocky reefs and environmental variables relating to temperature, shoreline complexity, the size of rocky reefs and latitude.

Our study focussed on processes that occur over large spatial and temporal scales and on habitat-forming species that typically occur in large patches. We therefore used a sampling technique that could encompass large grain sizes (20 m^2 intertidal or 1600 m^2 subtidal), could be replicated over a large spatial extent within a short period of time (to minimise temporal confounding), and provided a permanent record to assist with examining future changes in assemblages. This was achieved using low altitude, high resolution aerial photography from a helicopter which also enables wave-exposed intertidal assemblages to be photographed when not obscured by waves (Glasby et al., 2015). Here we describe the results of the initial five-year sampling program which provides a different perspective on these well-studied temperate rocky reef assemblages.

2. Materials and methods

2.1. Sampling design

Habitat-forming organisms were sampled on intertidal and shallow subtidal rocky reefs in NSW, from Merimbula (36° 54′ S, 149° 56′ E) in the south to Hastings Point (28° 21′ S, 153° 34′ E) (Fig. 1). The yearly average SST (sea surface temperature) at these locations ranged from 16 °C (Merimbula) to 23 °C (Hastings Point). All sampling was done in spring (September–November) from 2009 to 2013. A pilot study indicated that there was little temporal variability in the habitats sampled over an 8-week period in spring (Glasby unpubl. data).

Sampling locations were stratified by 'regions' which related to biogeographical provinces defined according to distributions of intertidal species (Bennett and Pope, 1953). The boundaries between biogeographical provinces are not distinct (and indeed there are differing opinions about the number of provinces in NSW; Knox, 1963; Womersley, 1981), so we allowed for a ~60 km gap between regions (Fig. 1). The three rocky reef habitats sampled were mid intertidal (dominated by barnacles, encrusting algae and turf-forming algae), low intertidal (dominated by macroalgae) (Underwood, 1981) and shallow (~1–8 m below low tide) subtidal, dominated by macroalgae, algal-turfs and urchin-grazed barrens (Underwood et al., 1991). Locations were selected haphazardly from a range of reefs that were wave-exposed, had a minimum area of 2000 m^2 (intertidal) or 15 000 m^2 (subtidal), and were moderately flat or gently sloping (~10°–25°, see Lathlean et al., 2015 for details of some mid intertidal sites).

The specific locations sampled each year differed slightly among habitats (Supplementary Material, Appendix Table 1). Low shore intertidal habitats were sampled at a maximum of 21 locations (ranging from 20 to 145 km apart) per year. At each location, two sites (separated by 1.5–5 km) were sampled in 6 haphazardly-positioned replicate quadrats (4 × 5 m), each separated by 20–50 m. Mid shore intertidal sampling used a similar design, except that a maximum of 15 locations was sampled (in 2009) and a minimum of 8 locations in other years. Subtidal habitats were generally not sampled within sites, only at the larger scale of locations (ranging from 10 to 100 km apart). At each subtidal location, species were sampled within 5 haphazardly-positioned replicate quadrats (40 × 40 m), each separated by 50–100 m.

Some of the sites sampled were either aquatic reserves or multi-use marine parks. As such they were afforded some level of protection from collection of species, but not from boat anchoring (see online Supplementary Material, Appendix Table 1). This factor was not analysed formally given the different types of protection and the different number of years of protection for different sites. Any protected sites that were identified as being different in analyses have been highlighted in the Results. Of the intertidal sites sampled, only three (Long Reef, Cape Banks and Burrewarra Point), within three separate locations, had restrictions on the taking of animals and algae. Nine subtidal locations were zoned 'no take' (i.e. removal of fish or vegetation prohibited), of which five had been protected for less than four years prior to the initiation of this project.

2.2. Sampling methods

Photographs of rocky reefs were taken from a helicopter using a Nikon D3 (full frame sensor, 12 megapixel, 50 mm lens) on sunny days when there was low swell (<1.5 m) and wind speed of <15 kts. The camera was mounted vertically and operated by a passenger, enabling photos to be taken when there were no breaking waves obscuring the reefs. Images of intertidal habitats were taken at low tide from an altitude of 40 m and had a resolution of 0.7 cm. Shallow subtidal images (3 cm resolution) were taken during mid–high tide from an altitude of 185 m to encompass a larger area and maximise light penetration and hence clarity of subtidal features. Photography has long been used for sampling rocky reef assemblages, but has the obvious limitation of excluding cryptic species (Littler and Littler, 1985). When combined with field validation, low-altitude aerial photography can be used effectively to sample habitat-forming species on rocky reefs (e.g. Andrew and O'Neill, 2000; Littler and Littler, 1987; Vadas and Manzer, 1971).

Percentage covers of biota, 'bare rock' or sand were sampled in photographs using the software package Coral Point Count (Kohler