Marine Pollution Bulletin 133 (2018) 209–217

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

An experimental assessment of impacts of pollution sources on sessile biota in a temperate urbanised estuary

Amelia E. Fowles[a], Graham J. Edgar[a], Nicole Hill[a], Rick D. Stuart-Smith[a], Jamie B. Kirkpatrick[b,*]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, Private Bag 49, Hobart, Tas 7001, Australia
[b] Discipline of Geography and Spatial Sciences, University of Tasmania, Private Bag 78, Hobart, Tas 7001, Australia

ARTICLE INFO

Keywords:
Biodiversity
Marina
Sewerage outfall
Fish farm
Stormwater discharge
Macroalgae

ABSTRACT

Populations of macro-algae and sessile invertebrates have precipitously declined in urbanised coastal waters in Australia since European occupation. Responses of healthy subtidal sessile assemblages to cumulative impacts and types of urban impacts were measured in one of the most polluted estuaries in Australia - the Derwent Estuary - by transplanting sessile communities established on pavers to locations adjacent to marinas, sewerage outfalls, fish farm cages, and stormwater discharges, each with associated controls. Reef communities translocated to sites adjacent to central urban pollution sources (within 5 km of Hobart) lost canopy-forming algae. Fish farms, marinas, and storm water drains were all characterised by higher filamentous algal cover than their controls. Marinas were associated with losses in canopy and foliose algae. Restoration of subtidal reef near highly urbanised areas is unlikely to be successful until current pollution levels are dramatically reduced.

1. Introduction

Estuaries with cities on their shores are more heavily disturbed than other coastal waters (Edgar et al., 2000), resulting in substantial biotic changes from the pre-urban condition (Folke et al., 2004). Ports, marinas, and aquaculture operations (Di Franco et al., 2011; Edgar et al., 2005; Singh and Turner, 2009), industrial effluents (Townsend and Seen, 2012), stormwater (Birch and Rochford, 2010; Birch and Taylor, 1999; Edgar and Barrett, 2000), and sewage (Arévalo et al., 2007; Díez et al., 2013) all affect benthic diversity and health (Airoldi and Beck, 2007) through changes to the physical and chemical qualities of estuarine waters. Thus, gradual losses of natural condition, declines in diversity of species, and loss of ecosystem resilience characterise urbanised estuaries (Edgar and Samson, 2004; Lotze et al., 2006; Stuart-Smith et al., 2015).

Estuarine subtidal rocky reef habitats are rich in sessile invertebrates and alga, which, in turn, support commercially important species, as well as providing other ecosystem services such as water filtration (Dayton, 1985; Morton and Gladstone, 2014). These reef systems are usually located in shallow near-shore areas, making them particularly susceptible to urban pollutants. Canopy-forming and other seaweeds are disappearing from some urban coasts (Airoldi and Beck, 2007; Connell et al., 2008; Díez et al., 2014). Canopy-forming species provide habitat, shelter and food for numerous other species in temperate coastal rocky habitats (Schmidt and Scheibling, 2007). At polluted locations, canopy algae are often replaced by structurally less complex species, many of which trap large amounts of sediment (Gorman and Connell, 2009). Once a shift to an alternative state has occurred, that state can persist even after the perturbations that caused the initial change have ceased (Perkol-Finkel and Airoldi, 2010).

Different types of urban pollution may have different impacts on macroalgal assemblages, depending on the nature, magnitude and duration of perturbation (Borja et al., 2010), and the reproduction, recruitment and growth characteristics of macroalgal species (Crowe et al., 2013). Sewage and finfish aquaculture increase nitrogen, organic matter, and suspended sediments, favouring rapid colonizers and thread-like or sheet like algae (Ajani et al., 2001; Eriksson and Johansson, 2005; Irving et al., 2009). An addition of nutrients may enhance species richness and macroalgal production in oligotrophic systems (Littler and Murray, 1975), whilst species richness may be reduced in more fertile waters (Hall et al., 2000).

Sediment affects the growth and reproduction of benthic organisms via physical scouring and smothering, favouring faster-growing species (Eriksson et al., 2002). Marinas are associated with a build-up of anti-fouling biocides and metals, such as copper and tributyltin (Johnston et al., 2011; Schiff et al., 2004). Toxins may act selectively upon targeted species, including adversely affecting non-targeted native biota (Katranitsas et al., 2003) and favouring more tolerant exotic species (Piola and Johnston, 2006, 2008). Urban stormwater drains increase chemical and metal pollution (Birch and Rochford, 2010), potentially

* Corresponding author.
E-mail address: J.Kirkpatrick@utas.edu.au (J.B. Kirkpatrick).

https://doi.org/10.1016/j.marpolbul.2018.05.040
Received 30 October 2017; Received in revised form 15 May 2018; Accepted 21 May 2018
0025-326X/

influencing natural colonization, as well as encouraging marine invaders (Ruiz et al., 1999).

Clearly, more work is needed to clarify the nature of relationships between levels of various types of urban pollution and the degradation or recovery of benthic communities (Díez et al., 2013; Pinedo et al., 2013).

To help fill this gap, we document the responses of sessile organisms on rocky reefs to four common anthropogenic sources of chemical stressors in estuaries: marinas, sewerage outfalls, fish farms, and stormwater drains. These sources of pollution were chosen because they are widespread in temperate urban estuaries, including the Derwent estuarine system studied. Non-chemical sources of pollution, including artificial light and noise, were not considered because they are unlikely to affect benthic macroalgae and sessile invertebrates to the same extent as chemical pollutants, while no large power plants or other major sources of thermal pollution are located within the estuary.

For each of the disturbance types we tested the hypothesis that proximity to disturbance caused changes in sessile assemblages and macrophyte functional groups when exposure and region were held equal. Furthermore, we tested the hypothesis that estuarine conditions close to the highly-urbanised Hobart central business district (CBD) promoted the development of sessile assemblages distinct from those on more distant reefs. To test these hypotheses, we transplanted standardised assemblages grown in a location not subject to high levels of pollutant stressors to paired reefs in close proximity, and at distance, from disturbance sources. We investigated consistencies in impact associated with individual stressors, while recognising that, because the distribution of pollutant stressors were only partly overlapping within the region studied, the relative importance of the different stressors could not be directly assessed.

2. Materials and methods

2.1. Study areas

Our study region consisted of two connected marine embayments on the south-eastern coast of Tasmania, Australia (Fig. 1): the Derwent Estuary, located adjacent to central Hobart and associated industry, and the D'Entrecasteaux Channel. The Derwent Estuary and the D'Entrecasteaux Channel are micro-tidal (0.8 m), with exposure to moderated oceanic swells, and wide entrances that promote efficient marine flushing (Whitehead et al., 2010). The less-polluted sections of these estuaries have high macroalgal biodiversity and productivity (Scott, 2012), and considerable urban development on their shores. Both are used for recreation, boating, fishing and marine transportation.

The Derwent Estuary is a drowned river valley that extends inland for 52 km with a total catchment area of 198 km^2 (Coughanowr, 1995). It is a salt-wedge estuary that is well mixed in the middle and lower regions, the locations of our study sites. Average water depths are 10–20 m with a maximum depth of 44 m. The mean flushing time is 15 days (Whitehead et al., 2010), which may help buffer against some impacts. Freshwater flows primarily discharge to sea along the eastern shore as a result of prevailing westerly winds (Butler, 2006). The industrial zone of Hobart is located adjacent to the middle estuary. Over 200,000 people live in suburbs adjacent to the Derwent (Coughanowr and Whitehead, 2013).

The nearby D'Entrecasteaux Channel (446 km^2 catchment area) is located between the mainland of Tasmania and Bruny Island, with a net flow of seawater from the D'Entrecasteaux Channel into the Derwent (Whitehead et al., 2010). Most of the waterway exceeds 10 m depth, reaching a maximum depth of 55 m. The estimated mean flushing time of the D'Entrecasteaux Channel waterway is 26 days (Herzfeld et al., 2008). Urban development occupies ~30% of the coastline in the lower section of the Derwent Estuary and the Channel, as opposed to 95% shoreline development within 5 km of the CBD.

The marine ecosystems of the estuaries have dramatically changed since the European invasion (Edgar and Samson, 2004). The distribution of sessile rocky reef communities indicates that elevated heavy metal concentrations have probably reduced occurrence of fleshy macroalgae, which have been replaced with filamentous algae and turf (Fowles, 2017). Navigational charts indicate that kelp communities presented a shipping hazard in the nineteenth century (British surveys 1861–1911) in locations where they are now absent. More recent sources of impact include marinas and a rapidly expanding aquaculture industry in the D'Entrecasteaux Channel (Oh et al., 2015).

2.2. Contaminants

Past industrial practices have resulted in heavy metal contamination of sediments and biota that is among the highest in the world (Whitehead et al., 2010). Despite reductions in metal outputs and a concomitant improvement of water quality, most sediments do not meet national sediment quality guidelines for arsenic, cadmium, copper, lead, mercury and zinc (ANZECC, 2000; Whitehead et al., 2010), with highly contaminated sediments extending 40 km down the estuary from the zinc works. This pollution remains an issue because metal contamination may be available to marine biota (Jones et al., 2013), especially after re-suspension. Contemporary sources of metal contaminants include urban stormwater run-off (Coughanowr and Whitehead, 2013), antifouling paint fragments (Singh and Turner, 2009), and wastes associated with shipping operations, port facilities and marinas.

Nutrient inputs are mostly contemporary and exhibit high spatial and temporal variability (Ross and Macleod, 2013), often making it difficult to partition nitrogen inputs between natural and anthropogenic sources. Salmon aquaculture operations located in the D'Entrecasteaux Channel contributed 1778 t of fish waste, primarily as ammonia, into the system in 2009 (Whitehead et al., 2010); however, fish production has increased markedly since that time. The other major point sources of nutrient pollution are sewage treatment plants. Elevated nutrient concentrations are largely retained within the estuarine system (Coughanowr and Whitehead, 2013).

2.3. Experimental design

One hundred and thirty-eight cement garden pavers (300 × 300 × 50 mm), each ~8 kg in mass, were deployed at Tinderbox (43.0320°S, 147.3376°W), a central and comparatively unimpacted and well-flushed rocky reef location within the system, at the head of the D'Entrecasteaux Channel (Fig. 1). Pavers were half covered with plastic to keep half of them free for a separate recruitment experiment (Fowles et al., 2018). They remained submerged at 3–4 m depth for 7 months, during which time a diverse community developed, which included mature fronds, representative of natural and "healthy" assemblages in this region. Paver assemblages were dominated by canopy-forming algae such as *Ecklonia radiata, Carpoglossum confluens* and *Macrocystis pyrifera,* with understorey species such as *Hemineura frondosa* and *Plocamium angustum* occurring in lower abundances.

To address our first hypothesis, four pairs of impact and control sites were placed near each of four pollution sources: marinas, stormwater discharges, sewage discharges and fish farms. Fully randomised interspersion of sites with pollution treatments was not possible because of the concentration of pollution sources other than fish farms near Hobart city. To address our second hypothesis, recipient sites were divided between "Hobart central" (< 5 km from the city port) and the 'greater Derwent region' (> 5 km). We commenced with the full set of 32 sites, however, storms dislodged and overturned some pavers during the year, resulting in 27 sites from which data were collected at the end of the experiment.

Four pavers, and their associated mature algal assemblage, were randomly distributed at each site. Pavers were transported in seawater-filled plastic bins, with transport time < 1 h. They were laid flat on