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# Interactive responses of primary producers and grazers to pollution on temperate rocky reefs☆

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ABSTRACT

Macroalgal beds provide important habitat structure and support primary production for rocky reef communities, but are increasingly degraded as a result of human pressures. Various sources of pollution can have both direct and interactive effects on stressed ecosystems. In particular, interactions involving invertebrate grazers could potentially weaken or strengthen the overall impact of pollution on macroalgal beds. Using a paired impact-control experimental design, we tested the effects of multiple pollution sources (fish farms, marinas, sewerage, and stormwater) on translocated and locally established algal assemblages, while also considering the influence of invertebrate grazers. Marinas directly affected algal assemblages and also reduced densities of amphipods and other invertebrate mesograzers. Fish farms and sewerage outfalls tended to directly increase local establishment of foliose and leathery algae without any indication of changes in herbivory. Overall, pollution impacts on algae did not appear to be strongly mediated by changes in grazer abundance. Instead, mesograzer abundance was closely linked to availability of more complex algal forms, with populations likely to decline concurrently with loss of complex algal habitats. Macrograzers, such as sea urchins, showed no signs of a negative impact from any pollution source; hence, the influence of this group on algal dynamics is probably persistent and independent of moderate pollution levels, potentially adding to the direct impacts of pollution on algal beds in urbanised environments.



## 1. Introduction

Urban pollution profoundly influences ecological community structure in coastal areas (Airoldi and Beck, 2007), through both direct and indirect effects on assemblages (Underwood and Fairweather, 1989). This is particularly the case in human-dominated sheltered embayments and estuaries, which are subject to a variety of urban as well as natural environmental pressures (Edgar et al., 2000). Common sources of urban pollution (such as marinas, stormwater drains, sewerage outlets and finfish aquaculture) release heavy metal toxicants, organic toxicants, nutrients, and sediment into the water column that create impacts at multiple trophic levels (Johnston et al., 2011; Pratt et al., 1981; Russell and Connell, 2005; Soto and Norambuena, 2004). These pollutants can influence reef assemblages and alter food webs differently, potentially altering the importance of bottom–up versus top–down forcing, especially in naturally complex ecosystems (Duffy et al., 2015). Assessing the effects of common pollutants at multiple trophic levels is important for separating the effects of urban impacts and environmental and ecological drivers of biodiversity patterns.

Associated studies have indicated that algal communities respond selectively to different pollution sources (Fowles, 2017), but it is unknown whether observed impacts on algae from such *in*

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*situ* experiments have been associated directly with pollutant effects, or have been mediated through ecological interactions with herbivorous animals. Herbivory can be a very influential driver of algal community structure in marine systems (Franco et al., 2015; Poore et al., 2009).

Small grazing herbivorous invertebrates (mesograzers such as isopods, amphipods, and small gastropods) are extremely abundant and diverse in many temperate marine and estuarine systems, and have the capacity to suppress growth and modify ecosystem processes over large areas (Edgar and Moore, 1986; Poore et al., 2009). For example, amphipod grazing has been associated with declines in biomass of kelp (Graham, 2002) and seagrass beds (Whalen et al., 2013). Consumption of algae by these grazers varies between taxa and with algal traits (Poore et al., 2012). Overall grazing rates may potentially be enhanced by pollution, particularly if nutrient loadings fuel high production rates of favoured microalgal food (Cloern, 2001).

Macrobenthic herbivorous invertebrates (macrograzers) can also exert a strong influence on macroalgal communities. In temperate areas, this is perhaps best-known through cases of overgrazing of kelp beds by sea urchins (Ling et al., 2015), but the macrograzer community on rocky reefs also includes large gastropods, crustaceans and cryptic fishes (Edgar, 2008). Conflicting trends in pollution impacts on some sea urchin species between locations (Stuart-Smith et al., 2015) suggests that other ecological interactions, such as predation pressure, may have greater consequences on some key macrograzers than pollution. Thus, in situations where macrograzers are pollution tolerant, indirect influences of grazing pressure on macrograzers are likely to be relatively low.

In this study, we undertook a transplantation experiment of healthy natural algal assemblages to polluted and nearby 'control' locations in a temperate urban estuary. We quantified responses of translocated algal assemblages and local establishment of new algal assemblages in relation to the effects of pollution from fish farms, marinas, stormwater and sewerage outfalls, and to varying local meso- and macrograzer assemblages. We specifically sought to answer three questions:

1. How do common pollution sources influence grazers and algal groups?
2. Are meso- and macro-grazers differently influenced by pollution?
3. Are macroalgae indirectly affected by pollution types through the interactive influences of grazers?

## 2. Materials and methods

### 2.1. Study location

The study was undertaken in the Derwent Estuary and the D'Entrecasteaux Channel (Fig. 1), a conjoined estuarine system exposed to moderated oceanic swell with wide entrances that promote efficient marine flushing (Whitehead et al., 2010). The Derwent Estuary is a drowned river valley that extends inland for 52 km with a total catchment area of 198 km$^2$ (Coughanowr and Whitehead, 2013). It is a salt-wedge estuary that is well mixed in the middle and lower regions. Freshwater predominantly flows downstream along the eastern shore as a result of prevailing westerly winds. Approximately 212,000 people (around 40% of Tasmania's population) live around its shores. The land adjacent to the middle estuary supports large industries, including paper production, zinc smelting, fertilizer production and boat building (Coughanowr and Whitehead, 2013). The adjacent D'Entrecasteaux Channel is located between the mainland of Tasmania and Bruny Island. It is a 40-km long semi-enclosed water body with a net flow of seawater from the D'Entrecasteaux Channel into the mouth of the Derwent (Whitehead et al., 2010), and with a high concentration of fish farms (Oh et al., 2015). Both estuaries are fringed by extensive subtidal rocky reefs.

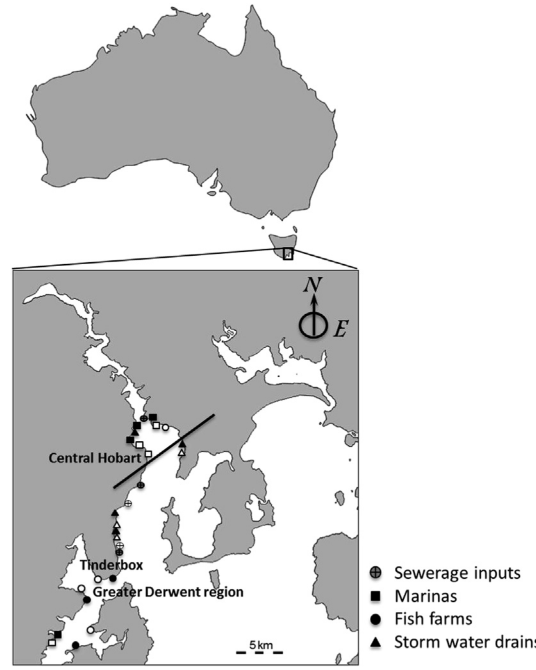


**Fig. 1.** Location of the 27 sites used to test the effects of different pollution sources and invertebrate grazers on algal assemblages. Solid line indicates sites within 5 km from the city centre. Solid symbols are the impact sites, open symbols are control sites.

We conducted a manipulative experiment on subtidal estuarine reefs, with impact sites located in close proximity to four types of pollution sources. The impact sites were compared to control sites that were located on rocky reefs at a distance of 1–3 km from impact sites. Marina sites were located <50 m from boat moorings inside marinas harbouring 200–400 recreational and commercial vessels. Fish farm sites were located <100 m from farm lease boundaries. Leases typically had 4-8 cages (20–30 m in diameter), which were periodically moved within the lease. Stormwater sites were located <20 m from the outlets of large concrete pipes (30–50 cm in diameter). Sewage sites were within 20 m of sewerage pipe outfalls.

### 2.2. Algal assemblages

Cement pavers were used to standardise the area and successional stage of macroalgal habitat (Fowles, 2017). Before the experiment was initiated, 128 large garden pavers (300 × 300 × 50 mm) were deployed at Tinderbox (−43.03°, 147.34°), a central and comparatively well-flushed and less impacted location near the mouth of the estuarine system (Fig. 1). Half of each paver was covered with plastic to prevent recruitment, to allow later assessment of pollution impacts on algae that established during the experiment. Pavers remained submerged at 3–4 m depth for seven months, during which time a diverse assemblage developed on the uncovered part of the paver, including perennial k-strategy species.

At the beginning of the experiment in March 2010, four replicate pavers and their associated macroalgal assemblages were transplanted to each of 32 sites. Sixteen of these sites were associated