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Ubiquity of microplastics in coastal seafloor sediments

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ABSTRACT

Microplastic pollutants occur in marine environments globally, however estimates of seafloor concentrations are rare. Here we apply a novel method to quantify size-graded (0.038–4.0 mm diam.) concentrations of plastics in marine sediments from 42 coastal and estuarine sites spanning pollution gradients across south-eastern Australia. Acid digestion/density separation revealed 9552 individual microplastics from 2.84 l of sediment across all samples; equating to a regional average of 3.4 microplastics·ml^{-1} sediment. Microplastics occurred as filaments (84% of total) and particle forms (16% of total). Positive correlations between microplastic filaments and wave exposure, and microplastic particles with finer sediments, indicate hydrological/sediment-matrix properties are important for deposition/retention. Contrary to expectations, positive relationships were not evident between microplastics and other pollutants (heavy metals/sewage), nor were negative relationships with neighbouring reef biota detected. Rather, microplastics were ubiquitous across sampling sites. Positive associations with some faunal-elements (i.e. invertebrate species richness) nevertheless suggest high potential for microplastic ingestion.

1. Introduction

Marine environments comprise the ultimate destination for many pollutants including waste plastics, which are now recognised as a global environmental problem. While marine plastic pollution was first identified in the 1970s (Frias et al., 2016 and Carpenter and Smith, 1972), meaningful social and scientific concerns were not raised until the early 21st century (e.g. Moore et al., 2001; Frias et al., 2016). The increasing accumulation of plastics throughout the world's oceans is concurrent with its increased production and functionality, with ~250–300 million tonnes of plastic produced per year since 2006 (Castillo et al., 2016). Currently, plastics are the most abundant category of marine litter (Frias et al., 2016), found everywhere from the deep ocean basins to the Arctic (Costa and Barletta, 2015), with terrestrial run off comprising a primary source of marine plastic debris (Ng and Obbard, 2006).

Overall, the occurrence and distribution of marine plastic litter has been well documented (Andrady, 2011; Cole et al., 2011; Eriksen et al., 2014; Van Sebille et al., 2015), with the negative effects of plastic debris on the marine environment described extensively by both scientific and social communities (Costa and Barletta, 2015 and Claessens et al., 2011). While the largest pieces of plastic debris and their interaction with mega-fauna such as seabirds, turtles and cetaceans have historically received the most scientific and public attention, recent focus has expanded to include assessment of the prevalence and environmental effects of 'microplastics' (Clark et al., 2016) – plastic particles ≤ 5 mm diameter, as defined by NOAA (2016). Microplastics are commonly derived from the fragmentation of larger plastic particles over time (secondary plastic; Costa and Barletta, 2015), but can also be directly manufactured (primary plastic), as is the case with many cosmetic products such as "micro-beads" (Clark et al., 2016).

On a global scale, marine plastic particles are becoming smaller and more widespread, primarily due to fragmentation by physical abrasion and photo-degradation of existing plastics into smaller, more mobile fragments (Barnes et al., 2009). While the direct consumption of, and entanglement with, larger plastics by marine life is dramatically apparent, consumption of microplastics has also been demonstrated (Clark et al., 2016). Inspection of the gut contents of many marine species, including sea birds, pelagic fishes and estuarine crustaceans, reveal that microplastic ingestion is commonplace throughout marine ecosystems (Clark et al., 2016). In addition, biomagnification of these ingested microplastics can potentially impact higher trophic levels (Fossi et al., 2012).

While the potential harmful effects of marine microplastic pollution have recently received greater consideration, much of the attention has focused on the prevalence of microplastics in pelagic waters (Frias et al., 2016; Eriksen et al., 2014). Such studies have largely ignored denser plastics, which are deposited on, and accumulate in, the seafloor below (Frias et al., 2016). To gain an accurate assessment of plastic prevalence, seabed plastic accumulation must be considered during

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accounting. This is particularly important given that 70% of marine litter globally is projected to sink and remain in marine sediments (Frias et al., 2016). Despite the presumed prevalence of non-buoyant plastics in the marine ecosystem, plastic accumulation on the seafloor remains largely unquantified.

Here we apply a novel approach to determine concentrations, forms and sizes of plastics in subtidal marine sediments from 42 sites spanning urban population centres and environmental gradients across the south-eastern Australian coastline. We examine these patterns with respect to potential drivers, environmental variables including other pollutants, and benthic biodiversity. Specifically, we ask whether patterns of microplastic concentrations in seafloor sediments vary consistently with local human population density or other pollutants (such as heavy metals, sewage and run-off indicators), and also examine how benthic biodiversity correlates with plastic pollution – a critical first step in gauging possible negative impacts of increasing plastic pollution on sedentary marine species and ecosystems.

2. Methods

2.1. Field sampling of marine sediments for microplastics

With a focus on examining gradients in pollution, we sampled microplastics in shallow marine sediments adjacent to the major urban centres, and thus point sources of pollution, in south-eastern Australian states (Fig. 1). Within each state, sites were distributed across contrasting polluted and relatively pristine locations. Locations sampled comprised Sydney Harbour, Jervis Bay and Eden in NSW; from adjacent to the city of Melbourne towards The Heads in Port Phillip Bay, Victoria; Port Adelaide south along the Adelaide metropolitan coast in South Australia; and the Derwent Estuary south to the D'Entrecasteaux Channel, plus relatively pristine sites in eastern Tasmania. Each of the large capital cities has major ports and industry, and substantial known pollution (e.g. heavy metals). This includes historical 'legacy' industrial pollution as well as contemporary inputs of heavy metals, petrochemicals, organic enrichment and plastics from storm water runoff and effluent discharges from urbanised and agricultural sub-catchments (Johnston and Keough, 2002; Townsend and Seen, 2012; Stuart-Smith et al., 2017).

At each site, subtidal marine sediment was collected from depths of 5 to 13 m using a vessel-deployed Van Veen sediment grab (30 cm by 30 cm gape) during September to November 2015. The sample for microplastic extraction was then taken by 'coring' the retrieved sediment with a 70 ml sample tube pushed into the surface sediment layer to an effective maximum depth of 7 cm into the benthos. Samples were then frozen for storage and thawed prior to extraction of plastics as outlined below.

2.2. Microplastic extraction

Microplastics were extracted from sediment samples using a novel size-graded approach based on existing methods that have been validated by comparing a known number of microplastics implanted within samples with the eventual number of microplastics extracted from the sample (Claessens et al., 2013; Masura et al., 2015; Nuelle et al., 2014).

Biological material was excluded by digestion using Wet Peroxide Oxidation. This was achieved using 20 ml aqueous 0.05 M iron oxide [Fe(II)] solution and 20 ml 30% hydrogen peroxide mixed with the whole ~70 ml sediment sample within a 600 ml beaker. The sample sat for 5 min before heating to 75 °C on a magnetic stirring hotplate for 45 min, at which point all-biological material was visibly bleached. The digested sample was then poured and washed through a stack of stainless steel sieves with mesh sizes of 4 mm, 1 mm, 0.50 mm, 0.250 mm, 0.125 mm, 0.063 mm and 0.038 mm.

Following biological digestion, we used high-density NaI solution

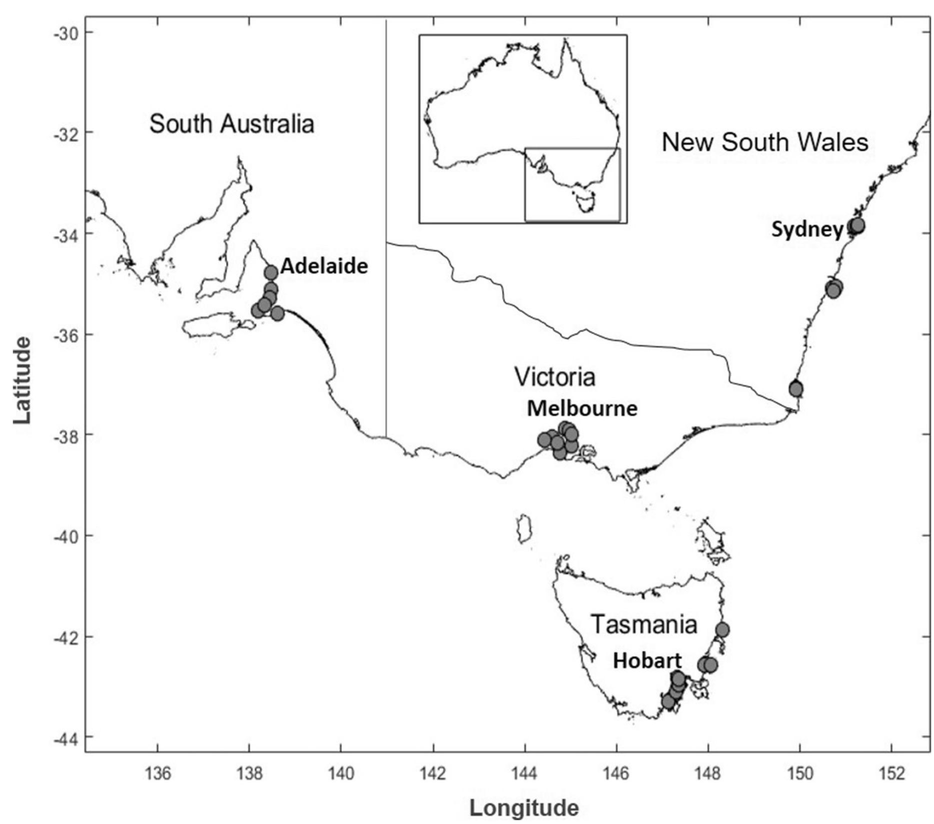

Fig. 1. Map of south-eastern Australia showing sites where marine sediments were sampled. Samples were obtained near human population centres (shown in bold) and at relatively pristine sites in New South Wales (n = 12 sites), South Australia (n = 6 sites), Victoria (n = 8 sites) and Tasmania (n = 16 sites).