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Review

TBT contamination of remote marine environments: Ship groundings and ice-breakers as sources of organotins in the Great Barrier Reef and Antarctica

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ABSTRACT

Remote marine environments such as many parts of the Great Barrier Reef (GBR) and the Antarctic are often assumed to be among the most pristine natural habitats. While distance protects them from many sources of pollution, recent studies have revealed extremely high concentrations of organotins in areas associated with shipping activities. Sediments at sites of ship groundings on the GBR have been found to contain up to 340,000 μg Sn kg^{-1}. Very high concentrations (up to 2290 μg Sn kg^{-1}) have been detected in nearshore Antarctic sediments adjacent to channels cut through sea ice by ice-breaking vessels. In both cases, the bulk of the contamination is associated with flakes of antifouling paint abraded from vessel hulls, resulting in patchy but locally intense contamination of sediments. These particulates are likely to continue releasing organotins, rendering grounding sites and ice-breaking routes point-sources of contamination of surrounding environments. While the areas exposed to biologically-harmful concentrations of leached chemicals are likely to be limited in extent (1000–10,000 m^2), deposition of antifouling paints constitutes a persistent ecological risk in otherwise pristine marine environments of high conservation value. The risk of contamination of GBR and Antarctic sediments by organotins needs to be considered against an important alternative risk: that less effective antifouling of ships hulls may increase the frequency of successful invasions by non-indigenous species. Additional options to minimise ecological risk include accident prevention and reducing organotin contamination from grounding sites through removal or treatment of contaminated sediments, as has been done at some sites in the GBR.

1. Introduction

1.1. The Great Barrier Reef and Antarctica

The Great Barrier Reef (GBR) and Antarctic waters represent two of the most iconic and pristine marine habitats on Earth. The unique animals and plants, which live in these divergent habitats are well protected by national and international laws and treaties. However, despite the controls that are in place to protect these fragile ecosystems, ship groundings on reefs of the GBR (Haynes and Loong, 2002) and abrasion of antifouling paints from ice-strengthened ships in Antarctica (Negri et al., 2004) have resulted in extreme, localised concentrations of contamination of marine sediments by the highly toxic organotin antifoulant TBT.

1.2. GBR: habitats, marine life and management

The GBR is the world's largest coral reef system, extending for 2600 km along the coastline of tropical Queensland, Australia. Coral communities can be found fringing the mainland, surrounding many of the 900 islands and are largely responsible for the structure of 3000 platform and patch reefs, which range in size from less than 1 ha to lager than 10,000 ha (UNEP, 1997). The GBR is renowned for its immense biological diversity, providing habitat for over 1500 fish and 400 coral species, along with threatened marine mammals such as dugongs, whales and dolphins. Corals are the key functional group of the GBR, providing habitat for thousands of other organisms. The GBR Marine Park Act of 1975 established the GBR Marine Park and its management agency, the Great Barrier Reef Marine Park Authority. In recognition of the outstanding natural values of the GBR, it was listed as a World Heritage Area in 1981 (UNEP, 1997).

1.3. GBR: pollution

The reefs of the GBR World Heritage Area (GBRWHA) are rarely exposed to significant concentrations of organic contaminants. Only trace levels of pesticides such as diuron, atrazine, DDT, dieldrin and lindane have been detected in nearshore sediments of the GBRWHA (Haynes et al., 2000). The most extensive contamination

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issue is likely to result from nutrient and sediment inputs from adjoining catchments (Fabricius, 2005). Little industrial or urban waste is discharged into the GBR lagoon and corals of the GBR are relatively unimpacted compared with coral reefs in many other parts of the world (Wilkinson, 2004).

There are 6000 shipping movements (ships greater than 50 m in length) annually along the two main shipping routes within the GBRWHA (AMSA, 2001). Over 40% of these large ships are bulk carriers with hulls protected by antifouling paints containing TBT. In addition, there are an estimated 1500 tourist vessels and 25,000 fishing and commercial vessels operating within the GBR marine park (AMSA, 2001). Between 1985 and 2000 a reported 27 ship groundings and 14 collisions occurred within the GBRWHA (AMSA, 2001). The majority of groundings were on coral reefs. Despite the large number of ship groundings, contamination of reef sediment by antifoulants such as TBT remained unreported (AMSA, 2001) until the grounding of a Panamanian bulk carrier on Heath Reef in 1999 (Haynes and Loong, 2002).

1.4. Antarctica: habitats, marine life and management

Antarctica is the most remote and least populated continent. Coastal water temperatures are generally just below 0 °C, only varying by 2–4 °C throughout the year, and sea ice extends hundreds of kilometres offshore each winter, doubling the effective area of the continent. Despite this extreme environment, waters of the Southern Ocean are abundant with sea life, including well described and complex benthic invertebrate and algal communities in nearshore habitats (Dayton and Oliver, 1977; Wu and Brueggeman, 2007). Nearshore the seafloor varies from steep rocky scree slopes, often damaged and scoured by pack ice, to more stable flats of mud, sand and sponge spicule mats (Clarke, 1996). Dominant biota include fish, sponges, ascidians, soft corals, anemones, echinoderms and microalgae (Fig. 1D) and the cold water conditions dictate slow growth rates and often large sizes in marine biota (Knox, 2006). Most of the continent, islands and waters south of 60°S are subject to the Antarctic Treaty, which has been signed by 44 countries (ATS, 2007). Signatory States follow the Madrid Protocol (ATS, 2007), which provides a framework for minimising anthropogenic impacts and states "activities in the Antarctic Treaty area shall be planned and conducted so as to limit adverse impacts on the Antarctic environment and dependent and associated ecosystems".

1.5. Antarctica: pollution

The Antarctic marine environment is considered largely pristine, but some sites such as Winter Quarters Bay, adjacent to McMurdo Station, are recognised as highly contaminated (Lenihan et al., 1990; Kennicutt, 2003; Negri et al., 2006). This contamination by metals, polyaromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) is always highly localised near research stations and is mostly due to historical spills, the dumping of waste and combustion products from ships, vehicles and generators (Lenihan et al., 1990). Modern environmental practices have eliminated the majority of significant local contamination sources. The most substantial and diffuse source of organic contamination in the Antarctic environment this century is likely be atmospheric delivery of volatile organics from warmer climates (Tanabe et al., 1983). Current-borne contamination and migration of contaminated biota into Antarctic waters are also possible. Shipping within the Southern Ocean is increasing and includes visits by international fishing fleets as well as highly regulated visits by research vessels and tourist craft. There have been several well documented shipping accidents close to the Antarctic shore. In one of the most serious accidents, the Argentine navy transport vessel *Bahia Paraiso* ran aground on rocks, near Palmer Station in 1989. Around 600,000 L of diesel was spilt, killing shallow water invertebrates and algae (Kennicutt et al., 1991). The first reported accident involving a tourist ship occurred early in 2007, when the *Norwegian Coastal Voyage* (*NCV*) *Nordkapp* struck rocks near Deception Island on the Antarctic Peninsula (Williams, 2007). A small amount of fuel was spilt but, like in all previous Antarctic grounding reports, no mention was made of possible contamination by antifouling paints. In fact, until recently there has been no consideration that organotins, such as TBT, may contaminate Antarctic sediments (Negri et al., 2004) and biota (Magi et al., 2004).

2. Contamination of GBR reefs and Antarctic sediments by organotins

2.1. Contamination of GBR coral reefs by organotins

TBT was first detected in coral reef sediments of the GBR following the 6 h grounding of the 151 m cargo ship, *New Reach* on Heath Reef, north of Port Douglass in 1999 (Haynes and Loong, 2002). In fact there were no previous reports of organotin contamination associated with ship groundings anywhere. Extraordinary concentrations of up to 340,000 μg Sn kg^{-1} dry weight (dw) were detected in sediments from the site where the ship had gouged a large trench-like scar in the reef [Table 1 (Haynes and Loong, 2002)]. There were no reports of oil spills from this grounding and the ship was able to re-float under its own steam with the incoming tide. A second cargo ship, the 184 m cargo ship *Bunga Teratai Satu* ran aground on Sudbury Reef off Cairns the following year (Fig. 1A). Despite numerous attempts to refloat the vessel using its own engines, the ship remained grounded for 13 days, when it was towed off the reef by tugs (Marshall et al., 2002). Again, a large scar (70 m × 90 m) was formed in the reef by the hull of the ship, completely destroying approximately 1500 m^2 of reef (Fig. 2) (Marshall et al., 2002). Calcareous sediments and reef rocks were contaminated (often visibly) with red paint scraped or abraded from the hull of the ship. Following this incident, sediment was sampled and analysed for butyltins (TBT, DBT and MBT) as well as other likely antifouling ingredients such as Cu and Zn along four transects radiating outwards from the reef (Haynes et al., 2002). Within the scar, sediment TBT concentrations were reported to be as high as 160,000 μg Sn kg^{-1} dw [summarised in Table 1 (Negri et al., 2002)]. These concentrations varied greatly, depending on the amount of abraded paint in each sample. Lower concentrations of the less toxic breakdown products DBT and MBT were also detected, along with very high concentrations of Cu and Zn. TBT concentrations were recorded as high as 17,000 μg Sn kg^{-1} dw close to the reef scar (5 m) and remained higher than 1000 μg Sn kg^{-1} dw 50 m from the scar along one transect (Haynes et al., 2002). TBT was still detected 250 m from the scar but not in sediments collected at a distance of 1000 m. During efforts to refloat the vessel under its own power, large plumes of contaminated sediments were generated, spreading TBT over approximately a hectare of seabed.

The maximum concentration of 340,000 μg Sn kg^{-1} dw detected in the Heath Reef scar (Haynes and Loong, 2002) was undoubtedly due to the presence of freshly abraded paint coated on and crushed into sediments as described above. This concentration is extremely high compared with all other reports of TBT contamination. For instance, one of the highest concentrations of TBT detected in contaminated sediments from European marinas and ports was 17,500 μg Sn kg^{-1} dw (Ritsema et al., 1998). Concentrations of TBT in the sediments of most contaminated ports are generally an order of magnitude less than those adjacent to the grounding scars. For example, the sediments from the Cairns Port in tropical North Queensland contained up to 1275 μg Sn kg^{-1} dw [summarised in Table 1 (Haynes and Loong, 2002)] and very high sediment