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Toxicity of a secondary-treated sewage effluent to marine biota in Bass Strait, Australia: Development of action trigger values for a toxicity monitoring program

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Abstract

Melbourne Water's Eastern Treatment Plant (ETP) produces a secondary-treated sewage effluent which is chlorinated and discharged into Bass Strait at Boags Rocks, Victoria, Australia. Disappearance of the sensitive brown seaweed *Hormosira banksii* from rock platforms immediately adjacent to the shore-line discharge was identified in the early 1990s. Subsequently, Melbourne Water and CSIRO undertook an environmental impact assessment and review of land and marine effluent disposal options, which included ambient water quality monitoring, biological monitoring, bioaccumulation studies and toxicity testing of existing effluent to assess the nature and magnitude of the environmental effects. This paper presents data from the toxicity monitoring programs since 2001. Chronic toxicity testing using macroalgal germination and cell division (*H. banksii*), microalgal growth rate (*Nitzschia closterium*) and scallop larval development (*Chlamys asperrima*), confirmed that ammonia was the major cause of effluent toxicity. Results from this toxicity monitoring program were used to develop action trigger values for toxicity for each species, which were then used in a refined monitoring program in 2005–2007. An upgrade of the ETP is in progress to improve nitrification/denitrification in order to reduce ammonia concentrations and the toxicity of the effluent. Toxicity testing with a simulated upgraded effluent confirmed that ammonia concentrations and toxicity were reduced. Estimated "safe" dilutions of effluent, calculated using species sensitivity distributions, decreased from 1:140–300 for existing ETP effluent to 1:20 for nitrified effluent, further confirming that treatment improvements should reduce the impact on marine biota in the vicinity of the discharge.

Keywords: Sewage effluent; Toxicity testing; Ammonia; Monitoring program; Toxicity identification and evaluation (TIE)

1. Introduction

Direct toxicity assessment (DTA) or whole effluent toxicity (WET) testing is an integral part of the regulatory framework in many countries to assess and manage effluents, leachates and contaminated ambient waters in marine and freshwater environments. DTA provides a direct measure of toxicity and bioavailability of mixtures whose chemical composition may not be known, and can also serve as an early warning capability so that management actions can be implemented to minimise ecosystem impacts (De Vlaming et al., 2000). DTA provides one line of evidence, along with chemical, biological and bioaccumulation monitoring, to both predict impact and protect aquatic ecosystems.

DTA has been widely used for compliance monitoring of sewage effluents in the USA and Canada as part of a tiered approach (USEPA, 1995). Its use in Australia has been more sporadic, largely due to the small number of toxicity test protocols with local native species, particularly

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those applicable to marine discharges. The largest DTA program in Australia was undertaken by Sydney Water in the late 1990s, and focused on testing 17 sewage treatment plants discharging into the Hawkesbury–Nepean freshwater catchment (Bailey et al., 2000), however, few published studies of DTA applied to sewage effluents discharging into marine waters are available.

Discharge from sewage outfalls has the potential to cause environmental impacts to surrounding aquatic ecosystems. Melbourne Water's Eastern Treatment Plant (ETP), situated at Carrum, treats 42% of Melbourne's sewage (equivalent to 370 ML/day). The treatment plant uses a non-nitrifying activated sludge process based on physical and biological processes to produce a secondary-treated sewage effluent which is chlorinated and discharged into Bass Strait at Boags Rocks near Cape Schanck, 56 km south of the treatment plant. Following commissioning of the ETP in 1975, decreased abundance of brown macroalgae at the discharge site was noted within the first 12 months (Manning, 1979). Disappearance of the sensitive brown seaweed *Hormosira banksii* from rock platforms immediately adjacent to the shore-line discharge was also identified in the early 1990s (Brown et al., 1990). Subsequently, Melbourne Water and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) undertook an environmental impact assessment and review of land and marine effluent disposal options, which included extensive chemical monitoring of receiving water quality, biological monitoring, bioaccumulation studies, toxicity testing of the existing effluent, and oceanographic modelling studies to assess the nature and magnitude of the environmental effect (CSIRO, 1999).

Biological monitoring and bioaccumulation of contaminants in biota offshore and on intertidal rocky platforms at Boags Rocks was carried out in 1997–1998 (CSIRO, 1999). Of particular interest was the loss of the brown seaweeds *H. banksii* and *Durvillaea potatorum* and increased occurrence on rock platforms at the outfall site of opportunistic green macroalgae, invertebrates and a spionid worm. Offshore monitoring of the sea bed revealed a lower diversity of infauna within 660 m of the outfall and impacts on the offshore reef (about 600–800 m from and running parallel to the shore) out to about 1.4 km. Potential contamination of seafood through toxicant bioaccumulation was measured in abalone, parrot fish and cunjevoi collected at the discharge site. A suite of chemicals of concern (metals, toluene, phthalate esters and polychlorinated dibenzo-*p*-dioxins) were measured and it was found that concentrations of these contaminants in tissues of the three species were below Australian food standards (CSIRO, 1999). Biological monitoring has continued to assess changes in ecosystem structure, with particular emphasis on the abundance and distribution of macroalgal species.

It was not known whether the disappearance of sensitive brown macroalgae on adjacent rock platforms was associated with increased nutrient loads, decreased salinity due to the large volume of freshwater discharge, or to toxicants in the effluent. Initial studies therefore focused on toxicity testing of the effluent using locally relevant test species. Objectives of the toxicity assessment of ETP effluent were:

1. to assess the acute and chronic toxicity of the ETP effluent,
2. to identify the chemical contributions to effluent toxicity,
3. to establish a monitoring program to assess ETP toxicity using appropriate local toxicity tests and,
4. to assess the toxicity of improved (upgraded) effluent.

Studies focusing on the first two objectives are reported in detail in CSIRO (1999) and Hogan et al. (2005). Chronic toxicity to microalgal growth (*Nitzschia closterium*), macroalgal fertilisation, germination and cell division (*H. banksii*), scallop larval development (*Chlamys asperrima* aka *Mimachlamys asperrima*), acute toxicity to Microtox® (*Vibrio fischeri*) and survival of fish larvae (*Macquaria* sp.) were used to test the toxicity of ETP effluent on three occasions in 1997. ETP effluent was not acutely toxic to bacteria and fish larvae or to fertilisation of macroalgae. Chronic toxicity to microalgae, macroalgae and scallops was observed, with scallop larval development the most sensitive test. Because toxicity identification and evaluation (TIE) protocols had not yet been established for the scallop test, TIE was undertaken on ETP effluent using protocols recently developed with the microalga *N. closterium* (Hogan et al., 2005). Results indicated that ammonia in ETP effluent was the major toxicant to *N. closterium*, although a minor unidentified non-polar organic compound might also have been contributing to toxicity (Hogan et al., 2005). "Safe" dilutions of effluent to protect 95% of species with 50% confidence were calculated using species sensitivity distributions (SSDs) following the ANZECC/ARMCANZ (2000) approach. Required "safe" dilutions of effluent were estimated to be about 1:300 for effluent containing 30–40 mg total ammonia-N/L.

A review of land and marine effluent disposal options concluded that treatment improvements and increased reuse provided a compromise between cost, sustainability and environmental improvement (CSIRO, 1999). As a result, Melbourne Water implemented an extensive upgrade of its treatment plant to improve nitrification/denitrification for more efficient removal of ammonia from the effluent discharged at Boags Rocks. The process of nitrification/denitrification converts ammonium ion to nitrite and nitrate under aerobic conditions (nitrification), and nitrite to nitrogen gas (denitrification) under anaerobic conditions for removal of nitrogen compounds.

This paper describes the application of toxicity testing to the development of a monitoring program for Melbourne Water's ETP from 2001 to 2003 and 2005 to 2007. Three tests with local species were chosen for their environmental relevance to Boags Rocks and because standard test protocols with appropriate quality assurance procedures were available. The unicellular microalga, *N. closterium*, is a