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Using biofilm as a novel approach to assess stormwater treatment efficacy

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ABSTRACT

Contaminants associated with stormwater are among the leading causes of water quality impairment in urban streams. Multiple device treatment systems are commonly installed with the aim of reducing contaminant loads within stormwater discharge. However, the *in situ* performance of such systems remains poorly understood. We investigated the efficacy of an advanced stormwater treatment system by monitoring biofilm associated metals and biofilm bacterial community composition at multiple locations through the treatment system (which included rain gardens, grassy swales, a stormwater filter and a wetland) and in the receiving stream above and below the stormwater discharge. Changes in bacterial community composition were assessed by Automated Ribosomal Intergenic Spacer Analysis (ARISA) and concentrations of biofilm associated metals monitored by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). Significant differences in bacterial community composition were detected throughout the stormwater network. Bacterial communities gradually changed towards a community more similar to that within the receiving stream and the discharge of treated stormwater had little effect on the composition of bacterial communities in the receiving stream, suggesting the effective conditioning of water quality by the treatment system. Concentrations of some biofilm-associated metals declined following sequential treatment, for example copper (73% reduction), zinc (48% reduction) and lead (46% reduction). In contrast, levels of arsenic, cadmium, chromium and nickel were not reduced by the treatment system. We demonstrate that biofilm bacterial community composition is a sensitive indicator of environmental changes within freshwater ecosystems and an efficient indicator to monitor water quality in enclosed stormwater networks where traditional biological indicators are not available.

1. Introduction

In urban areas, rainwater flowing onto impervious surfaces may accumulate various contaminants, including suspended sediments, heavy metals, nutrients, hydrocarbons and organic chemicals (Burton and Pitt, 2002; Ward and Trimble, 2003) which can impact the ecological health of the receiving water bodies. Concern about the effects of urban

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runoff on freshwater ecosystems has led to implementation of Low Impact Development (LID) strategies (Barbosa et al., 2012; USEPA, 2000) including installation of retention ponds, wetlands, green roofs, rain gardens, grassed swales, infiltration trenches and sand filters. These technologies aim to enhance urban runoff management and reduce contaminant loads, often while simultaneously enhancing aesthetic aspects of urban development and creating wildlife habitats. Because of its complex composition, a multifaceted treatment-system approach combining several LID processes is generally desirable to reduce the cocktail of contaminants present in urban stormwater before discharge into rivers and streams (Wong et al., 2006). In such an approach, stormwater is directed through multiple treatment systems, each linked in sequence by an underground pipe network. However, while such multiple treatment systems continue to gain popularity, we know comparatively little regarding the extent to which each treatment system contributes to the remediation of contaminated stormwater (Ahiablame et al., 2012) or the overall efficiency of such an approach. This knowledge gap exists because (i) it remains impractical to quantify the concentration of the diverse range of contaminants typically present within urban stormwater and (ii) because traditional biological indicators of water quality [e.g., communities of fish and macroinvertebrates (Adams et al., 2005; Araújo et al., 2000; Rosenberg and Resh, 1993; Whitfield and Elliott, 2002)] are largely absent within enclosed stormwater pipe networks.

Recent studies have demonstrated the analysis of biofilm bacterial communities as a sensitive measure of ecosystem health in rivers and streams (Lear et al., 2009; Lear and Lewis, 2009). Unlike fish and macroinvertebrates, bacteria are ubiquitous (Lear et al., 2013), being detected in virtually all aquatic environments and remaining viable even within 'extreme' environments [i.e., from the clouds of the upper trophosphere (DeLeon-Rodriguez et al., 2012) to boiling hydrothermal vents at the bottom of our deepest oceans (German et al., 2010)] and they are highly responsive to changes in environmental parameters (Besemer et al., 2007; Lear et al., 2008a). Since bacterial communities embedded in biofilms are relatively sessile, their composition and structure can provide very useful information on their past and present surrounding environment.

In this study, we used Automated Ribosomal Intergenic Spacer Analysis (ARISA) to evaluate the composition of bacterial communities in microbial biofilm located within different sections of a stormwater treatment network and in the stream to which the stormwater network discharged. The analysis of bacterial community composition to assess environmental changes in aquatic ecosystems is novel, and this is the first example of such an approach being used to assess the efficacy of a stormwater treatment network. To further investigate the efficacy of stormwater treatment, we simultaneously monitored concentrations of various, potentially toxic, biofilm- and sediment-associated heavy metals including Cu, Zn and Pb at each sampling location.

The aim of this study was to assess the efficacy of a multiple device stormwater treatment system to reduce the biological impact of stormwater contaminants before discharge into a nearby stream. Our goals in this study were thus two-fold. First, we tested whether the biological impact of the stormwater varied throughout the treatment network. We would expect that greater changes in stormwater composition will cause greater changes in biofilm bacterial community composition. Therefore, differences in bacterial community composition were monitored upstream and downstream of every treatment device; concentrations of common stormwater contaminants (i.e., Cu, Pb, Zn) in the biofilm were measured in parallel. Second, we examined differences in biofilm bacterial community composition and concentrations of stormwater contaminants (in biofilm and sediment) both upstream and downstream of the stormwater outlet. If there was an effective treatment of the stormwater, we would expect to see no increase in stormwater contaminants in the stream water downstream of the stormwater outlet, and relatively little change in bacterial community composition.

2. Material and methods

2.1. Experiment outline

As part of a low impact development (LID), an integrated stormwater treatment system has been incorporated throughout the site of the Albany Travel Interchange, New Zealand (36°43′18 S, 174°42′45 E), which includes a bus station, open-air parking for over 500 cars, multiple access roads and other associated infrastructure. Enviropod™ catchpit filters that detain trash and debris (for more details refer to www.stormwater360.co.nz) are fitted to most stormwater drains throughout the complex. Surface water from the bus station and surrounding area is sequentially channelled from impermeable surfaces and through rain gardens and grassy swales to a commercial filter treatment system containing zeolite, perlite and activated carbon media to bind a range of metal and organic contaminants. Finally, the stormwater passes through a wetland before discharge into a nearby stream (Fig. 1).

Biofilm bacterial samples were taken at nine different locations along the treatment system (A to I, Fig. 1) on two sampling occasions (29.01.09 and 26.03.09). Stormwater pipes were accessed by manholes and three biofilm samples removed, each by swabbing an area of approximately 100 cm^2 at the bottom of the pipe using a fresh Speci-Sponge™ (Nasco, USA). Three additional samples were removed on the second sampling occasion, in a similar manner, and used to quantify concentrations of biofilm-associated metals within each site.

To assess the impact of the treated stormwater on the receiving stream, biofilm samples were removed from 11 sites, one in the stormwater outlet, five upstream of the outlet and five downstream of the outlet. Water from the stormwater outlet passes down a 5 m slope before joining the stream, such that the water collected at the outlet is not expected to be influenced by conditions in the receiving stream. Sampling sites in the stream were located at regular intervals (approximately 10 m apart) and samples taken on three occasions (30.01.09, 26.02.09 and 26.03.09). Six biofilm samples were taken from each of the 11 sites on each date, three were used for microbiological analysis and three for biofilm associated metal analysis. For each sample, a rock of approximately