Marine Pollution Bulletin 133 (2018) 233–239

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Stable isotopes demonstrate the effectiveness of a tidally-staged sewage release system

Hayley L. Kaminski[a,b,*], Brian Fry[a], Jan Warnken[a,b], Kylie A. Pitt[a,b]

[a] Australian Rivers Institute – Coasts and Estuaries, Griffith University, QLD 4222, Australia
[b] Griffith School of Environment and Science, Gold Coast Campus, Griffith University, QLD 4222, Australia

ARTICLE INFO

Keywords:
Nitrogen
Wastewater
Rocky shore
Algae
Limpets
Barnacles

ABSTRACT

Nutrient loading from sewage wastewater discharge contributes to the eutrophication of coastal waters. Wastewater from the Gold Coast, Australia is discharged into the Gold Coast Seaway (GCS) for 13.5 h d^{-1} primarily on the ebbing tide to disperse wastewater seawards. Nitrogen stable isotopes were used to assess how effectively the tidally staged release system dispersed wastewater out of the GCS and identified pathways by which sewage-N was incorporated into food webs. Turf algae, limpets and barnacles were sampled at the GCS, at two coastal sites and at the mouth of a control estuary that lacked point-source discharge. In the GCS $\delta^{15}N$ values of algae and limpets returned to coastal baseline levels within 250 m of the diffusers. In contrast, $\delta^{15}N$ of filter-feeding barnacles did not significantly vary indicating wastewater-N does not dominate the pelagic food web. Nitrogen stable isotopes clearly demonstrated that the tidally-staged wastewater release system effectively disperses wastewater offshore.

1. Introduction

The release of anthropogenic wastewater is a major nutrient loading process for nitrogen (N) and phosphorus in coastal systems. Primary productivity in marine ecosystems is often limited by the availability of N (Dugdale and Goering, 1967; Gartner et al., 2002). Therefore, the discharge of wastewater can increase the overall availability of N and stimulate primary production, which can induce eutrophication (Vitousek and Howarth, 1991; Castro and Freitas, 2011). Although tertiary treatment technologies have considerably reduced the amount of N being discharged, upgrades of many existing treatment systems are often limited due to technical, resource or economic constraints (Schmidt et al., 2003). To maintain the quality and amenity of coastal waters, the location and timing of wastewater discharge should be optimized to maximize dilution and efficiently disperse wastewater away from shore.

Tracing the distribution of a wastewater plume in coastal waters can be challenging. Direct measurement of dissolved nutrient concentrations is the most common method to track wastewater plumes in marine environments (Gartner et al., 2002; Smith, 2003). Nutrient concentrations, however, often fluctuate depending on hydrodynamic and weather conditions and extensive spatial and temporal sampling is required to adequately characterize nutrient loads (Johnes, 2007). Even intense spatio-temporal sampling, however, can still underestimate nutrient loads in catchments with dynamic hydrology (Cassidy and Jordan, 2011).

An alternative approach to tracing the distribution of wastewater is to analyse stable N isotopes in biota (e.g. Tucker et al., 1999; Costanzo et al., 2001; Parnell, 2001; Pitt et al., 2009). Sewage effluent is often enriched in ^{15}N because ^{14}N reacts faster than ^{15}N during the naturally occurring processes of nitrification and denitrification (Kendall et al., 2008). Nitrification converts NH_4^+ (ammonium) to NO_3^- (nitrate) leaving the residual ammonium pool enriched in ^{15}N (Peterson and Fry, 1987; Kendall et al., 2008). During the denitrification process, nitrate reacts anaerobically to N_2 gas leaving the residual nitrate enriched in ^{15}N (Kreitler, 1975; Peterson and Fry, 1987; Kendall et al., 2008). Both residual NH_4^+ and residual NO_3^- are discharged in wastewater and can lead to high $\delta^{15}N$ values in nutrients, plants and food web consumers impacted by wastewater nutrients (McClelland et al., 1997).

Once discharged, sewage-derived nitrogen is assimilated by primary producers such as phytoplankton or benthic algae. The isotopic values in the primary producers are transferred to higher trophic levels with some enrichment (usually 2–4‰) in ^{15}N for each trophic level due to trophic fractionation (Minagawa and Wada, 1984). The consistency of fractionation across trophic levels allows wastewater to be traced through different components of the food web (Kendall et al., 2008). The turnover rate of N within organisms mostly depends upon the growth rate and lifespan of the organism (Piola et al., 2006). Turf algae

* Corresponding author.
E-mail address: hayley.kaminski@griffithuni.edu.au (H.L. Kaminski).

https://doi.org/10.1016/j.marpolbul.2018.05.020
Received 25 November 2017; Received in revised form 7 May 2018; Accepted 11 May 2018

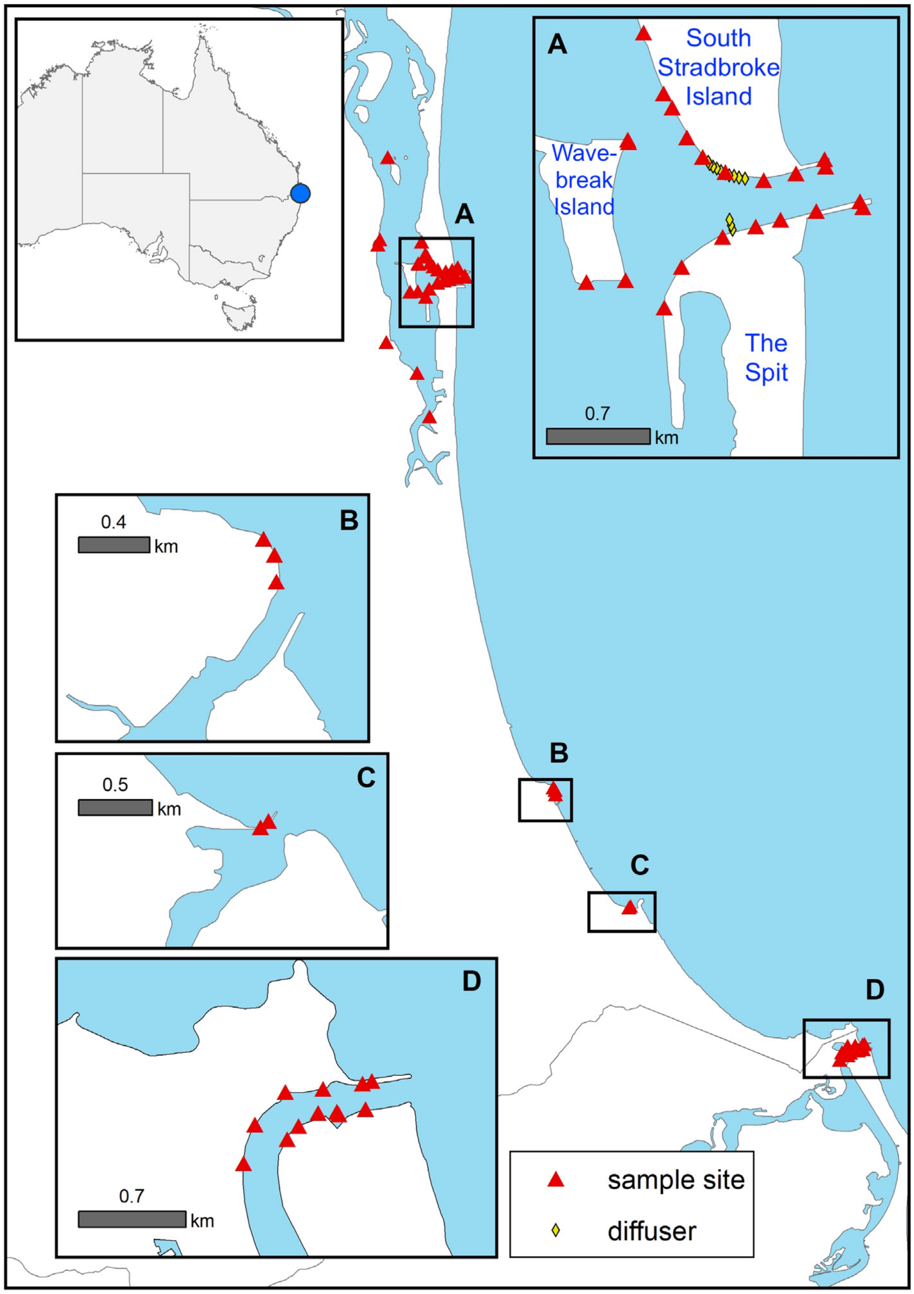

Fig. 1. Sampling locations in south-east Queensland, Australia. A = Gold Coast Seaway (GCS) and surrounding Broadwater. B = Burleigh. C = Currumbin. D = Tweed River.

and macroalgae typically have rapid growth rates, especially in the spring and summer seasons, therefore nutrients are assimilated into their tissues over days to weeks (Gartner et al., 2002; Risk et al., 2009). Slow growing gastropods have a much longer N turnover time; from 7 weeks to 12 months in larger individuals (McIntyre and Flecker, 2006). Temporal variation in the distribution of the wastewater plume can thus be determined by sampling biota with different turnover times of N (Gartner et al., 2002; van de Merwe et al., 2016). Assessing the N isotopic values of select biota, therefore, is an effective way of tracing the geographic distribution of wastewater plumes over short and long time periods (Gorman et al., 2017).

The Gold Coast Seaway (GCS), in southeast Queensland, Australia, is a stabilized tidal inlet connecting the Broadwater estuary to the Pacific Ocean (Fig. 1). The treated effluent from the four major treatment plants in the Gold Coast region (population = 582,215) (Australian Bureau of Statistics, 2017) is discharged into the Seaway using a uniquely designed tidally-staged release system. Each day, 113Ml of wastewater is released, primarily on an ebbing tide to prevent the re-entry of wastewater into the Broadwater (Stuart et al., 2009). The release commences 10 min after high tide and ceases 50 min after predicted low tide, resulting in wastewater being released for 13.5 h per day (Stuart et al., 2009). Wastewater is discharged from 13 diffuser pipes (9 along the north wall and 4 along the south wall) located in the inner part of the GCS (Rasch et al., 2007) (Fig. 1). Diffusers on the southern wall of the GCS collectively release 48Ml of effluent per day from the two oldest wastewater treatment plants (WWTP), which have been upgraded to include biological denitrification (Rasch et al., 2007; Higgins, 2009). The northern wall diffusers release approximately 65Ml of wastewater from the largest WWTP on the Gold Coast, and, a smaller WWTP designed to produce recycled water for urban reuse (Allconnex Water, 2009; Higgins, 2009).

Hydrodynamic models and in situ measurements of water quality