



# Assessing temporal and spatial trends in estuarine nutrient dynamics using a multi-species stable isotope approach



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## ABSTRACT

Coastal urbanisation can alter estuarine nutrient dynamics through the input of point-source and diffuse pollutants, and nutrient concentrations can be highly influenced by seasonal and episodic rainfall and river flow. Understanding of both the spatial and temporal variability of nutrient dynamics is therefore critical to managing these estuaries. This can be achieved by periodically analysing the stable isotopes a range of aquatic taxa with variable nutrient turnover rates, mobility and distribution within the estuary. In two subtropical urban estuaries with different land use patterns, we analysed the carbon and nitrogen stable isotopes of phytoplankton, shrimp, prawns and fish at various proximities to pollution sources in dry and wet seasons. The fast nutrient turnover rates and ubiquity of phytoplankton in the estuary resulted in stable isotopes varying over fine-scale spatial scales, particularly in relation to proximity to point-source pollution. The slower nutrient turnover rates and localised habitat use of prawns, resulted in stable isotopes varying over larger spatial (between pollution sources) and temporal (seasonal) scales. The much slower nutrient turnover rates and high mobility throughout the estuary of fish resulted in stable isotopes varying over very large-scale spatial scales (between estuaries). These results illustrate a wide range of spatial and temporal changes to estuarine nutrient dynamics in subtropical urban estuaries in relation to rainfall conditions and nutrient inputs. This research also highlights the application of stable isotopes in assessing estuarine trophodynamics, and provides direction on the types of organisms that should be used to assess different spatial and temporal trends.

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## 1. Introduction

Globally, estuaries are the foci of coastal urbanisation, which can disrupt the nutrient dynamics and ecology of these systems through direct habitat destruction, changes to hydrological flow (e.g. construction of dams), and input of both point-source and non-point-source pollutants (Cloern and Jassby, 2012; Lee et al., 2006). In particular, estuaries often receive significant nutrients from sewage treatment plants, storm water and industrial point sources, as well as more diffuse sources associated with urban and agricultural land uses (Lee and Olsen, 1985; Nixon et al., 1986; Vizzini et al., 2005). In excess, nutrients can have significant ecological impact in receiving environments, including facilitating phytoplankton blooms, eutrophication and hypoxia (Armon and Starosvetsky, 2015; Garnier et al., 2010; Romero et al., 2013).

In addition, distinct wet and dry periods in the subtropics and tropics can seasonally influence the trophodynamics of estuaries. Specifically, rainfall and river discharge can influence the relative contribution and availability of auto- and allochthonous production in estuaries (Cloern and Jassby, 2010). Understanding the spatial and temporal variability of nutrient dynamics is therefore critical, as well as challenging, to the management of estuaries, particularly in regions where rainfall and river flow are seasonal.

Stable isotope analyses, particularly for carbon and nitrogen, are useful tools for tracing the input and assimilation of nutrients in estuaries. Different sources of natural and anthropogenic nutrients have distinct elemental and isotopic composition. This, combined with relatively consistent fractionation between trophic levels ( $\sim 1\%$  for  $\delta^{13}\text{C}$  and  $\sim 3\text{--}4\%$  for  $\delta^{15}\text{N}$ ), mean that stable isotopes can be used to trace nutrients through food webs (Connolly et al., 2009; Fry, 2006), and identify the sources of nutrient inputs in estuaries (Connolly et al., 2013; Schlacher et al., 2007).

The different nutrient assimilation rates of organisms in an estuary allow investigations into trophodynamics over varying

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temporal scales. Phytoplankton assimilate nitrogen and carbon much more quickly per unit of biomass than do their consumers (Fry, 2006), therefore presenting a temporally responsive indicator for fluctuations in nutrient inputs. The stable isotopes of higher trophic level organisms, such as crustaceans and fish, represent the nutrients that are being assimilated from their prey (Fertig et al., 2010; Vizzini et al., 2005), and can provide a better time-integrated response to input of anthropogenic nutrients. Fish take up to several months to turnover their  $\delta^{13}\text{C}$  (Weidel et al., 2011), while prawns, having smaller body size, are expected to turnover  $\delta^{13}\text{C}$  within much shorter time frames. Prawns may therefore reflect changes in nutrient dynamics over shorter time frames (e.g. between seasons), whereas fish may provide a more temporally stable indication of the nutrient status of the system.

The mobility and distribution of different organisms allow investigations into estuarine trophodynamics at different spatial scales. Fish can be found over large salinity gradients, and are often highly mobile throughout an estuary (Schlacher et al., 2005). Their stable isotope signatures are therefore likely to represent a large spatial area. In contrast, prawns are generally less mobile and their stable isotope values will be more representative of the localised environment in which they are found. For example, juvenile penaeids are generally confined to the mangrove-lined creeks that run into main estuaries, for protection and nutrition during this early stage of their life-cycle (Meager et al., 2003). Further, although individual prawn species can be limited to particular salinity ranges, a variety of species sharing similar biology and ecology can be found along the entire range of estuarine habitats throughout the year. In subtropical estuaries, some prawn and shrimp species inhabit brackish and freshwater environments (e.g. the caridean *Macrobrachium* spp.) and others are restricted to higher salinities near the mouth (e.g. penaeids).

A multi-species approach encompassing seasonal wet and dry conditions may therefore provide the spatial-temporal resolution required for stable isotope values to accurately reflect the trophodynamics of subtropical estuaries. This approach should be especially useful in estuaries impacted by anthropogenic influences such as urbanisation, where additional nutrient sources may further complicate trophodynamics. This study investigated the stable isotope values of a suite of aquatic organisms with varying nutrient turnover rates, mobility and distribution to understand the influence of anthropogenic nutrient inputs on the trophodynamics of urban subtropical estuaries over different spatial and temporal scales. Phytoplankton, with very fast turnover rates and ubiquitous distribution throughout the estuary, may provide information at very fine temporal and spatial scales (within estuaries). Prawns, with moderate turnover rates and localised home ranges, may describe seasonal changes and broader scale spatial (i.e. between estuaries). And fish, with slow turnover rates and high mobility, may describe more time-integrated large-scale spatial differences. We demonstrate that this multi-species, spatio-temporal approach presents a comprehensive assessment of estuarine trophodynamics, and provides a framework for future investigations into trophodynamics in subtropical urban estuaries.

## 2. Methods

### 2.1. Study site

All sampling was conducted within the tidal limits of the Logan and Albert Rivers, southeast Queensland (Fig. 1). The Logan River discharges into southern Moreton Bay and is joined by the Albert River ~10 km upstream of the mouth.

The Logan and Albert catchments cover 3076 and 786 km<sup>2</sup>, respectively (EHMP, 2013), and land use in the upper catchments is

dominated by forests and grazing pastures with intermittent cropping (Fig. 2). In the estuarine regions of the catchments, where this study focuses, there is considerably more urban land use, with some agriculture (mainly sugarcane) and a number of prawn aquaculture facilities located near the mouth. The banks are lined by varying widths of mangrove forests dominated by *Avicennia marina* and *Aegiceras corniculatum*. There is no seagrass in the system due to the generally high turbidity. The lower reaches of the Logan estuary (downstream of the confluence) support commercial and recreational finfish and crustacean (mud crab, penaeid prawns) fisheries.

Using ArcGIS 10.1 (ESRI Inc, U.S.A.) and data compiled from the Queensland Land Use Mapping Project (DSITIA, 2013), the percent area of urbanisation was calculated to be 363 km<sup>2</sup> for the Logan catchment (12% of total catchment area), which was nearly six times larger than in the Albert (61 km<sup>2</sup>, 8% of total catchment area). There are two major sewage treatment plants (STPs) in these systems: the Loganholme STP that discharges into the Logan River approximately 6 km upstream of the confluence and the Beenleigh STP that discharges into the Albert River 3.5 km upstream of the confluence. The Loganholme STP discharges on average 50 ML of treated effluent into the Logan River each day (Jul 2010–Jun 2011), nearly four times the amount of effluent discharged into the Albert River by the Beenleigh STP (13 ML/day). Even if this is adjusted for the differences in mean river discharge volume (920 and 540 ML/day for the Logan and Albert rivers, respectively), the concentration of treated effluent in the Logan River is generally >2 times higher than in the Albert River.

There were 11 collection sites within the Logan and Albert Rivers (Fig. 1). These sites corresponded to the sites regularly monitored for water quality parameters (e.g. temperature, turbidity, salinity, DO, pH, nitrogen, phosphorous, chlorophyll *a*) by the Ecosystem Health Monitoring Program (EHMP), a regional scheme that assesses the health of southeast Queensland waterways (EHMP, 2013), and included sites directly adjacent to sewage treatment plants at Loganholme (site 205) and Beenleigh (site 1703). Since the first EHMP report cards (2001), the Albert and Logan estuaries have scored D (poor) or F (fail), generally due to high turbidity, high nutrients (N and P) and low dissolved oxygen (DO). Over the study period, total N concentrations in the tidal reaches of the Logan and Albert Rivers ranged from 0.5–2.8 mg/L and 0.2–1.8 mg/L, respectively (EHMP, 2013), and were generally above the Queensland Water Quality Guidelines upper value for estuaries of 0.45 mg/L (DEHP, 2009).

Juvenile penaeid prawns were also collected from five tidal creeks that flowed into the main estuary through natural (mangrove) and anthropogenic (aquaculture and urban) land use areas (Fig. 1).

### 2.2. Sample collection

Phytoplankton, shrimp (*Macrobrachium australiense*) and fish (bony bream, *Nematalosa erebi*) were collected from the main estuary sampling sites during the dry (May and September 2011) and wet (February 2012) seasons. Phytoplankton was collected from each site by towing a plankton net (mesh size: 53  $\mu\text{m}$ , diameter: 30 cm, length: 85 cm) for 10 min at the surface. *M. australiense* and *N. erebi* were euthanised in an ice slurry immediately after collection and then frozen until processing for analysis.

In July 2011 and March 2012, juvenile penaeid prawns (*Metapenaeus* spp. and *Fenneropenaeus merguensis*, <3 mm carapace length) were collected from creeks in urban, aquaculture and natural mangrove areas of the Logan River (Fig. 1) using a beam trawl (0.5 m  $\times$  1 m) towed behind a boat, and light traps. Beam trawl runs began just upstream of the mouth of the creeks and were pulled upstream for 2–5 min against a falling tide. Light traps were placed

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