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Distinct responses of bacterial communities to agricultural and urban impacts in temperate southern African estuaries

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A B S T R A C T

Worldwide, estuaries are regarded as amongst the most ecologically threatened ecosystems and are increasingly being impacted by urban development, agricultural activities and reduced freshwater inflow. In this study, we examined the influence of different human activities on the diversity and structure of bacterial communities in the water column and sediment in three distinct, temperate permanently open estuarine systems within the same geographic region of southern Africa. The Kariega system is freshwater-deprived and is considered to be relatively pristine; the Kowie estuary is marine-dominated and impacted by urban development, while the Sundays system is fresh-water dominated and impacted by agricultural activity in its catchment. The bacterial communities in all three systems comprise predominantly heterotrophic species belonging to the Bacteroidetes and Proteobacteria phyla with little overlap between bacterioplankton and benthic bacterial communities at the species level. There was overlap between the operational taxonomic units (OTUs) of the Kowie and Kariega, both marine-influenced estuaries. However, lower species richness in the Kowie, likely reflects the impact of human settlements along the estuary. The dominant OTUs in the Sundays River system were distinct from those of the Kariega and Kowie estuaries with an overall decrease in species richness and evenness. This study provides an important snapshot into the microbial population structures of permanently open temperate estuarine systems and the influence of anthropogenic impacts on bacterial diversity and community structure.

1. Introduction

Estuaries are regarded as among the most productive and ecologically threatened ecosystems. Human activities including freshwater abstraction, nutrient loading and the over-exploitation of natural resources have contributed to the degradation of the ecological integrity of these systems (Kennish, 2002). The development of effective management systems for the conservation and sustainable use of estuaries is dependent on a fundamental understanding of ecosystem functioning and being able to predict the response of different biological components of estuarine ecosystems to increased human activity and climate change. The intrinsically dynamic nature of estuaries results in highly heterogeneous habitats that support high levels of biodiversity (Kirchman et al., 2005; Telesh and Khlebovich, 2010; Fortunato et al., 2012). Microorganisms, comprising mainly prokaryotes, are extremely abundant and diverse in aquatic ecosystems and play a major role in regulating key biogeochemical processes, including the carbon and nitrogen cycles (Kirchman, 2008). These highly diverse microbial communities display a wide range of specialised metabolisms and are sensitive to shifts in environmental conditions, resulting in the persistence and/or predominance of selected species (Hallin et al., 2009; Brown et al., 2012). Although numerous studies have assessed the microbial populations in ocean water and sediments (for example, Pommier et al., 2007; Schattenhofer et al., 2009; Zinger et al., 2011; Friedline et al., 2012; Hunt et al., 2013), freshwater and estuarine ecosystems have largely been neglected despite their economic and ecological importance (Zinger et al., 2012). The best-studied are urbanized estuarine systems that occur in the northern hemisphere (Bouvier and del Giorgio, 2002; Kirchman et al., 2005; Feng et al., 2009; Webster et al., 2010; Campbell and Kirchman, 2013). However, aside from a few

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reports (Matcher et al., 2011; Jeffries et al., 2016) little is known about the microbial ecology of temperate estuarine systems in the southern hemisphere.

The past two decades has seen an increase in urban, agricultural and rural development along the southern African coastline, particularly in the vicinity of the mouth of estuaries (Turpie et al., 2002; Mead et al., 2013). As a result, many estuaries are increasingly becoming the repository of human, domestic, agricultural and industrial waste (Orr et al., 2008; Carrasco et al., 2013; Moloney et al., 2013) and population growth has contributed to increased freshwater abstraction resulting in reduced inflow into these systems. Reduced freshwater inflow into southern African estuaries have been associated with a decrease in primary and secondary production rates within these systems, reduction in recruitment and a shift in the range distribution of both invertebrates and vertebrates (Froneman, 2000; Carrasco et al., 2013). The predicted decreased rainfall in southern African river catchments as a result of climate change (Faramarzi et al., 2013) will likely exacerbate these impacts (James et al., 2013; Wetz and Yoskowitz, 2013) and increase the vulnerability of communities that rely on the services provided by these systems in the region (Mead et al., 2013).

In this study, we examine the influence of human activities on the microbial diversity and community structures of three contrasting temperate permanently open estuaries within the same geographic region of southern Africa. The three systems differ with respect to the land-use practices within the catchment areas, magnitude of freshwater inflow and urban development. Two of the estuaries selected for study are regarded as freshwater-deprived: the Kariega is considered to be relatively pristine (Froneman, 2000), while the Kowie system is impacted by agricultural activity in its catchment and human settlement in the estuary (Moloney et al., 2013). By contrast, the Sundays Estuary is river-dominated, with a catchment that is heavily impacted by agriculture resulting in a high nutrient load in the estuary (Scharler and Baird, 2003). This study aims to compare and contrast the response of microbial communities to urbanization and agricultural activity and the hydrological dynamics of temperate estuaries.

2. Materials and methods

2.1. Site selection

Kariega Estuary: Situated ~120 km east of Port Elizabeth (33° 40′ 32″S; 26° 40′ 34″ E) on the south-eastern coastline of South Africa (Fig. 1). The Kariega Estuary is permanently open and is regarded as a homogenous oligotrophic marine system due to the low freshwater input resulting from sporadic rainfall, small catchment area ($\approx$680 km^2) the presence of several impoundments (three major dams and numerous small farm weirs) along the Kariega River and high evaporative losses (Froneman, 2000). Hypersaline conditions (salinity > 40) may predominate in the upper reaches of the system during the summer or during periods of drought. Water depth varies from 1.10 (upper reaches) to 3.96 m (mouth), depending on the tidal state. The catchment area of the Kariega River is relatively pristine and comprises mainly of Valley Bushveld.

Kowie Estuary: This estuary (33°36″S, 26°54″E) flows through the coastal town of Port Alfred (Fig. 1). Whilst the Kowie River's upper catchment area is comprised mainly of Valley Bushveld, this area has been extensively cleared for commercial agriculture which focuses on the production of beef cattle and pineapples (Cowley and Daniel, 2001). The estuary comprises a narrow channel 10–15 m in width and 1–6 m in depth and is mainly used as a harbour for small commercial fishing boats, recreational boats and yachts, and subsistence fishing also occurs in the estuary. The

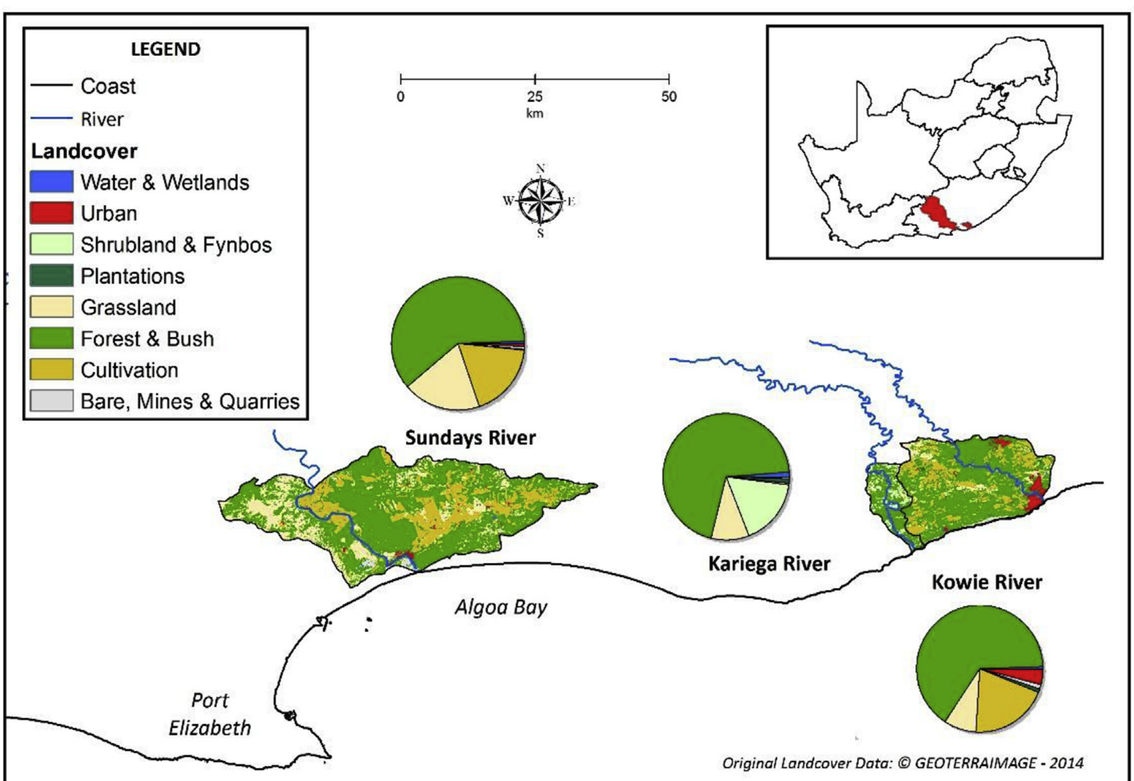

Fig. 1. Geographic location of the Kowie, Kariega and Sundays River estuaries along the south-eastern coastline of South Africa with the respective land-usage adjacent to each estuary as provided in the 2013–2014 South African National Land-Cover Dataset.