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Environmental variability and phytoplankton dynamics in a South Australian inverse estuary

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ABSTRACT

Estuaries are widely viewed as hotspots of primary productivity. The Coorong in South Australia is an inverse estuary divided into two lagoons, extremely important to the associated riverine, lacustrine and marine environments and characterized by a steep, lateral salinity gradient. Here, we analyzed the abundance and distribution of primary producers over two years (August 2011–2013) and investigated the biogeochemical factors driving observed changes. The phytoplankton community was numerically dominated by chlorophytes in the North Lagoon with *Chlorohormidium* sp. and *Oocystis* sp. being the most abundant species. In the South Lagoon, diatoms dominated the community, with *Cylindrotheca closterium*, *Cyclotella* sp. and *Cocconeis* sp. being the most prevalent species. Finally, cryptophytes and dinoflagellates were found to be present throughout both lagoons but in comparatively much lower abundances. Salinity was the most important driver of phytoplankton communities and ranged from 0.15 to 72.13 PSU between August 2011 and August 2013. Chlorophytes were found to be most prolific in freshwater areas and abundances rapidly declined laterally along the Coorong. Beyond a salinity threshold of 28 PSU, extremely limited numbers of *Crucigenia* sp. and *Oocystis* sp. were observed, but abundance were seven to ten-fold lower than in less saline waters. The salinity of the North Lagoon was found to be directly controlled by the flow volume of the River Murray, however, no effect of river flow on the South Lagoon was evident. Our findings suggest that management plans for the Coorong need to be put into place which can regulate salinity regimes via river flow, even during periods of drought. This is highly important in order to maintain low enough salinities throughout the North Lagoon, ensuring a continued healthy ecosystem state.

1. Introduction

Estuaries are defined as bodies of water marking the interface between one or more rivers and the open ocean. They are generally influenced by tidal forcing and, in the case of inverse estuaries, often exhibit pronounced spatial salinity gradients (Corlis et al., 2003; Cyrus and Blaber, 1992). In addition to being of significant economic value, estuaries are highly productive ecosystems, acting as breeding grounds for birds or nurseries for marine, brackish and riverine/lacustrine fish species (Lamontage et al., 2004). Fueled by the influx of nutrients from the sea, rivers and terrigenous compounds, they also often constitute biological hotspots of primary productivity (Cloern, 1987; Millie et al., 2004).

In Australia, the Murray-Darling Basin (MDB) represents the largest river system and is shared by five states/territories. Ranked fifteenth in the world in terms of length (3780 km) and twentieth for area (covering 1,056,000 km^2), it drains an estimated 14% of the Australian landmass (Lintermans, 2007) and supplies approximately 2 million people with freshwater. Nearly 30,000 wetlands have been described in the MDB, most of these wetlands being recognized as important for feeding and breeding of waterbirds and native fish. In particular, the Coorong (South Australia) is recognized as a habitat of significant importance to endemic wildlife, including birds and fish (Fig. 1; Leterme et al., 2010; Nayar and Loo, 2009). It is characterized by strong salinity fluctuations which become extremely pronounced during recurring periods of drought (e.g., between 2004 and 2010) (Leterme et al., 2012; Zampatti et al., 2010). Persistent spatial salinity

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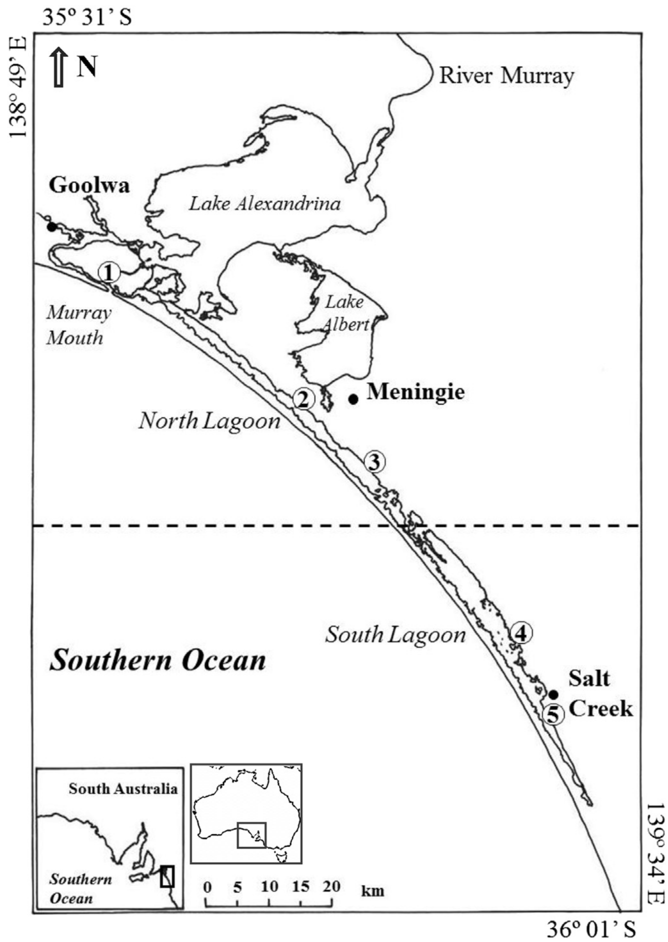

Fig. 1. Schematic map of the sampling sites (1–5) located along the Coorong, South Australia, between Goolwa and Salt Creek. The weather station recording the rainfall data is located at Meningie, approximately at the middle of the Coorong.

gradients, ranging from riverine conditions to hyper-saline conditions well in excess of 150 Practical Salinity Units (PSU) at the furthest point from the ocean during drought periods have previously been recorded (Leterme et al., 2010).

The Coorong is connected to the sea at the mouth of the River Murray which flows into Lake Alexandrina, which in turn is separated from the Coorong wetland by a series of barrages constructed in the late 1930s (Lintermans, 2007; Fig. 1). Recurring drought conditions throughout South Australia had prompted the construction of the barrages to retain water levels and to protect the Lower Lakes (Lake Alexandria and Lake Albert; Fig. 1) from seawater intrusion (Nayar and Loo, 2009). These barrages, however, also limit the influx of fresh water into the Coorong, further contributing to increasing salinity levels, especially during summer or drought periods. Therefore, the Coorong, like many temporarily open/closed estuaries, is largely unaffected by littoral tidal regimes during dry periods. Instead, the mixing of the water column and exchanges between deeper and shallow sections of the estuary are exclusively driven by wind stress and riverine/lacustrine influx (Thomas et al., 2005; Webster, 2007). In years during which drought conditions are not met, water is irregularly flushed through the barrages into the Coorong, further adding to the variability of salinity and other environmental parameters (Nayar and Loo, 2009).

In inverse estuaries, where annual evaporation exceeds fresh water input, strong spatial salinity gradients can be observed (Corlis et al., 2003). These gradients result in the formation of a range of micro-habitats, exhibiting distinct environmental conditions and unique biota composition (Turner et al., 1979). Due to their fundamental importance as the base of aquatic trophic webs and typical rapid response to environmental change, phytoplanktonic organisms are widely used as indicators of ecosystem health (Smol and Stoermer, 2010). Driven by seasonally changing environmental conditions, recurring multi-specific blooms of brackish dinoflagellates and centric diatoms have previously been characterized and studied extensively in estuaries (Orive et al., 1998; Smayda, 2008). Environmental changes can generate alterations in morphology, as well as shifts in abundance, distribution and biodiversity (Flöder et al., 2010; Leterme et al., 2010; Piehler et al., 2002). However, information is still lacking on the impact of salinity gradients on the dynamics of primary producer communities in inverse estuaries.

Monthly samples were collected over a two year sampling period (between August 2011 and August 2013) to investigate (i) temporal and spatial changes in the biochemical properties of the estuary and (ii) the effect fluctuations in these properties have on the abundance, diversity and distribution of the phytoplankton community along the Coorong wetland. This study was performed to establish the background knowledge on primary producers in the Coorong and how changes in environmental conditions affect them to provide a tool for future management of the estuary.

2. Materials and methods

2.1. The Coorong wetlands

The Coorong is an inverse estuary located 70 km south of Adelaide, South Australia (Fig. 1) and is recognized as a habitat of significant importance to native and migratory fish and bird species (Nayar and Loo, 2009). It stretches approximately 170 km in length along the coast between Goolwa and Salt Creek, but remains protected from the Southern Ocean by a barrier of established foredunes. Its only connection to the ocean is located where the Coorong, the River Murray and Encounter Bay/the Southern Ocean meet at the Murray Mouth and it is divided into two lagoons (North and South) at Parnka Point (Fig. 1).

2.2. Sampling design

Monthly samples were taken along the Coorong at five sites (Sites 1 to 5, Fig. 1) between August 2011 and August 2013. Three sites were located in the North Lagoon and two sites in the South Lagoon. In order to assess environmental variability and its effects on phytoplankton communities, a range of parameters were measured in the sub-surface waters at each site, in 70–100 cm of water.

2.2.1. Hydrological and physical parameters

Salinity (PSU), pH, and water temperature (°C) were measured using an AquaRead multi-parameter probe. The monthly river flow data (volume) of the Murray River were retrieved from WaterConnect (WaterConnect, 2014). The half-hourly wind speed data ($m\,s^{-1}$) were obtained from the Bureau of Meteorology weather station at Meningie (Fig. 1) to approximate wind stress following the formula for estimating boundary layer turbulence proposed by MacKenzie and Leggett (1991):

$$\varepsilon_W = 5.82.10^{-9} w^3/z$$

where w is the wind speed and z is the water depth.

2.2.2. Nutrients

Dissolved inorganic nutrient concentrations (i.e., silica [Si], ammonium [NH_3], orthophosphate [PO_4] and nitrate/nitrite