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Drought and flood effects on macrobenthic communities in the estuary of Australia's largest river system

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ABSTRACT

Estuaries are prone to drought and flood events, which can vary in frequency and intensity depending on water management and climate change. We investigated effects of two different drought and flow situations, including a four year long drought (referred to as Millennium drought) and a major flood event, on the macrobenthic community in the estuary and coastal lagoon of the Murray Mouth and Coorong, where freshwater inflows are strictly regulated. The analysis is based on ten years of annual monitoring of benthic communities and environmental conditions in sediment and water. The objectives were to identify changes in diversity, abundance, biomass and distribution, as well as community shifts and environmental drivers for the respective responses. The Millennium drought led to decreased taxonomic richness, abundance and biomass of macrobenthos as hypersaline conditions developed and water levels dropped. More taxa were found under very high salinities than predicted from the Remane diagram. When a flood event broke the Millennium drought, recovery took longer than from a shorter drought followed by small flows. A flow index was developed to assess the biological response subject to the duration of the preceding drought and flow volumes. The index showed higher taxonomic richness, abundance and biomass at intermediate and more continuous flow conditions. Abundance increased quickly after flows were restored, but the benthic community was initially composed of small bodied organisms and biomass increased only after several years once larger organisms became more abundant. Individual densities and constancy of distribution dropped during the drought for almost all macrobenthic taxa, but recoveries after the flood were taxon specific. Distinct benthic communities were detected over time before and after the drought and flood events, and spatially, as the benthic community in the hypersaline Coorong was split off with a salinity threshold of 64 identified by LINKTREE analysis. Salinity, low dissolved oxygen saturation and sediment properties accounted for further community splits in the estuarine Murray Mouth. This long term monitoring revealed ecological benefits of intermediate and continuous flow and that resilience of estuarine macrobenthos to drought and flood events was affected by flow history. The index can be applied to other flow regulated estuaries and inform environmental watering targets.

1. Introduction

Many estuaries around the world are subject to periodic droughts or flooding, which is further exacerbated by flow manipulation for water management or flood protection (Montagna et al., 2002a; Whitfield and Taylor, 2009; Neto et al., 2010). Ecological understanding of the effects of each of these stressors to estuarine ecosystems has grown, yet implications of various combinations or sequences of droughts, floods and flow manipulations are poorly known. As extreme climate events and

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increased climate variability are predicted to intensify in the future, the response and recovery of estuarine ecosystems to drought and floods is a growing management issue (Pollack et al., 2011; Wetz and Yoskowitz, 2013).

Benthic invertebrates in estuaries are relevant prey for higher trophic levels (Humphries and Potter, 1993; Meire et al., 1994; Zharikov and Skilleter, 2003), affect sediment properties and exchange processes (Savage et al., 2012; Kristensen et al., 2013) and are useful indicators of pollution or other environmental stressors (Essink and Beukema, 1986; Gaston et al., 1998; Wildsmith et al., 2011). Estuarine organisms are exposed to highly fluctuating environmental conditions from variable river flows and usually aligned along an estuarine gradient subject to their tolerance (Attrill and Rundle, 2002; Whitfield et al., 2012). The primary environmental variables affecting the structure and zonation of estuarine benthic communities are salinity and sediment properties (Ysebaert et al., 2003; Pollack et al., 2011; Mariano and Barros, 2015). Drought and flood events change salinities and sediment properties in estuaries and lagoons, and thus affect benthic communities and the functioning of estuarine ecosystems.

Droughts can lead to mouth closures of estuaries and lagoons, causing hypersalinity, loss of aquatic habitat and decline in benthic fauna (Pillay and Perissinotto, 2008; MacKay et al., 2010). Despite such deleterious effects, droughts can improve water quality in some estuaries by lowering nutrient load, yet effects on water quality and benthos can be more complex in intermittently closed and open estuaries (Dye, 2006; Hastie and Smith, 2006; Wetz and Yoskowitz, 2013). Connectivity to the sea and freshwater inflows are critical for macrobenthic dynamics of estuaries and lagoons (Geddes, 1987; Currie and Small, 2005; Joyce et al., 2005; Palmer et al., 2011).

Freshwater inflow can lead to higher benthic biomass and secondary production through nutrient loading, as long as low salinity, turbidity and hypoxia are not impacting on benthic fauna (Montagna and Kalke, 1992; Montagna et al., 2002b; Wetz and Yoskowitz, 2013). High freshwater discharge and floods are disturbance events and reduce benthic diversity and abundance, although different communities and habitats may respond differently (Kanandjembo et al., 2001; Cardoso et al., 2008; Pollack et al., 2011). Floods are usually episodic events and their effects may vary with intensity and duration, potentially leading to temporary displacement or even population declines of some estuarine and marine biota, followed by long recovery (Moverley et al., 1986; Matthews and Fairweather, 2004; Currie and Small, 2005).

Changes in abundance, biomass and diversity of benthic communities after flood and drought events can differ over spatial scales, across habitats and also taxa (Jones, 1990; Grilo et al., 2011). The response can also be affected by an accumulation of consecutive extreme events such as floods, heat waves and drought (Grilo et al., 2011). Furthermore, climatic changes are not occurring in isolation from other anthropogenic impacts such as eutrophication in estuaries and lagoons (Dolbeth et al., 2011) or river flow manipulation through artificial barriers (dams, flood gates and barrages). Such barriers can affect connectivity, nutrient and sediment discharge, and thus impact on biota through restrictions to movement and poor water quality (Smaal and Nienhuis, 1992; Ritter et al., 2008).

Long term studies of benthic communities have become more common through monitoring requirements to inform on management frameworks and habitat restoration measures (Borja et al., 2008; Rodrigues et al., 2012; Felix et al., 2013). Insight gained includes identification of different periods related to changes in human pressures or climate driven droughts and floods (Chainho et al., 2010). Also, the severity and accumulation of disturbance events, such as flood, drought and eutrophication, can affect recovery time and compromise resilience (Neto et al., 2010; Dolbeth et al., 2011).

The definition for estuaries was recently refined to account for differences between hemispheres and the particular types of estuaries found in arid climates of southern Africa and Australia, and under microtidal settings (Potter et al., 2010; Elliott and Whitfield, 2011). The Murray-Darling river system has a large catchment (1,061,469 km^2) across several states of Australia, more similar to river systems in the northern hemisphere. However, the estuary is located in the driest state of the continent and discharges into a microtidal bay of the southern ocean, similar to other estuaries in the southern hemisphere. Much of the riverine discharge of the Murray-Darling is constrained by a series of locks and barrages along the river (Leblanc et al., 2012), leading to closure of the mouth under low flow conditions which requires dredging to keep the mouth open (Shuttleworth et al., 2005; Webster, 2011). The Murray-Darling estuary is thus an example for extreme changes in estuaries following man made manipulation and water management, exacerbated by climatic extremes such as a recent Millennium drought (Leblanc et al., 2012), which have affected the ecological condition of the estuary and adjacent Coorong lagoon and Lower Lakes (Brookes et al., 2009; Kingsford et al., 2011). The onset of a La Niña weather pattern in 2010 led to floods in the catchment that resulted in the opening of barrages in late 2010, to let the flow peak pass through the system and restore estuarine connectivity after the Millennium drought.

The extreme conditions experienced in the Murray Mouth and Coorong with a prolonged drought period and reduced freshwater inflows from freshwater abstraction are similar to the St Lucia lake and estuary in South Africa, which is also defined as a choked coastal lagoon (Kjerfve, 1986; Webster, 2010) that experienced comparable deterioration of its ecological state (Lester and Fairweather, 2009; Whitfield and Taylor, 2009). The estuary of the Murray-Darling thus provides an important example for understanding consequences of different flow scenarios to support management of environmental water requirements (Adams, 2014).

As the Coorong, Lower Lakes and Murray Mouth are a Ramsar site as well as an Icon Site of The Living Murray program, concern over declining shorebird numbers and condition of the ecosystem led to the commencement of macrobenthic monitoring. Diversity, abundance, biomass and community structure were evaluated annually from 2004 to 2013. Here, data from these ten years of condition monitoring are used to assess the response of macrobenthos to drought and flood events. The aims of the analyses were to (a) describe changes in species diversity and distribution, (b) identify community shifts over space (estuary and lagoon) and time (drought and flood), and (c) explore environmental drivers for benthic community responses. The findings are discussed to explore whether the prolonged drought affected the ability of macrobenthic communities to recover after such events.

2. Material and methods

2.1. Study sites and times

The Murray Mouth and Coorong lagoons are located at the terminus of the Murray-Darling river system in South Australia (Fig. 1). The Murray Mouth consists of channels on either side of the river mouth opening to the Southern Ocean, and covers a distance of about 20 km. The Coorong is a narrow and shallow lagoon sheltered from the ocean by a long peninsula (>100 km in length), and only connected to the ocean through the Murray Mouth. The narrowest section at Parnka Point separates the Coorong into a North and South Lagoon (Fig. 1). Monitoring commenced in 2004 and eleven sites were selected based on their relevance as a foraging ground