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Changes in the water quality characteristics during a macroalgal bloom in a coastal lagoon

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ABSTRACT

The shift from seagrass to macroalgae, particularly the "boom and bust" cycle of the ephemeral Chlorophyta in estuarine environments has occurred worldwide, most likely as a result of anthropogenic nutrient loading. Contrary to popular view, these algal blooms are not harmful to humans, although they are perceived as unsightly and negatively affect aquatic leisure activities. Macroalgal blooms mostly occur in spring and summer when rainfall prior to and during this time is low and temperatures are high. Water quality data have been collected before and during an algal bloom at Avoca lagoon on the Central Coast of NSW, Australia, to identify changes in water quality associated with a bloom. Water dissolved oxygen declined significantly whereas turbidity and available phosphate increased significantly during the bloom. The changes could be detected only using intensive spatial and temporal replication. Identifying water quality changes during a bloom is a crucial first step for understanding the conditions under which extensive growth of algae occur and has important implications for prediction and management of the blooms in coastal lagoons.

1. Introduction

In estuaries, the shift from seagrass-dominated to macroalgae-dominated systems is a world-wide trend caused by eutrophication (Kemp et al., 1983; Lowthion et al., 1985; Duarte, 1995; Short et al., 1995; Short and Wyllie-Echeverria, 1996; Valiela et al., 1997; Raffaelli et al., 1998) Higher nutrient loads benefit opportunistic benthic algae and drift algae over seagrasses because, unlike seagrasses and other perennial macrophytes, soft-tissued filamentous algae are capable of quick uptake of nutrients and subsequent rapid increase in biomass, which leads to their domination in eutrophic systems (Pederson and Borum, 1997; Valiela et al., 1997; Nelson et al., 2008). High density algal mats can then shade seagrasses and bring in hypoxic conditions through respiratory processes at night. The combination of these can therefore lead to seagrass decline (Duarte, 1995: Pederson and Borum, 1997; McGlathery, 2001); invertebrate and fish kills (Raffaelli et al., 1989); benthic fauna mortality (Rosenberg, 1985) and other detrimental changes in community composition (Ahern et al., 1995; Norkko and Bonsdorff, 1996; Cummins et al., 2004).

Opportunistic algae tend to undergo 'boom and bust' cycles by rapidly increasing their biomass in favourable conditions and dying off when nutrient resources are exhausted. When algae are in decline, they produce rapidly decomposing organic material (Pederson and Borum, 1997), which accumulates in the sediments (Sfriso et al., 1987). These nutrient loads can have significant influence on the water quality of shallow lakes, but nutrient fluxes (benthic regeneration of sediment nutrients) for different types of estuaries are generally poorly understood. What is known, however, is the relative importance of sediment nutrients in contributing to algal blooms. For example, the sediments up to 20 cm depth in Gippsland Lakes (Victoria, Australia) hold very large stores of nitrogen and phosphorus relative to the nutrients in the catchment load. In fact, they are greater than 70 times the annual loads of catchment dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) (Longmore and Roberts, 2006).

Although macroalgal blooms are a world-wide phenomenon, there is no general consensus on what are the main factors causing the blooms. Macroalgal blooms occur during spring and summer when solar global exposure is higher (BOM, 2012). Nutrient loads, water residence times and availability of fringing vegetation are commonly considered important (Valiela et al., 1997), but no trigger values for nutrients have been identified. The conditions conducive to blooms are likely to be met in South-Eastern Australia, where

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light is not limited during spring and summer and input of nitrogen can lead to excessive growth of opportunistic algae. Interestingly, most of the bloom-forming species of macroalgae are common in the estuaries world-wide, although the types of water bodies and degree of eutrophication may differ substantially. For example, species such as *Enteromorpha (Ulva) intestinalis*, *Ulva lactuca*, *Chaetomorpha linum* were major contributors to macroalgal blooms in North American (Valiela et al., 1997), European (Scanlan et al., 2007; Canal-Vergés et al., 2014), and Australian (Cummins et al., 2004) estuaries. The common characteristic of these algae is their ability to take advantage of available nutrients by rapid uptake followed by rapid increase in biomass and spread throughout an estuary.

Avoca lagoon is known to experience irregular blooms (i.e. not every year), during which macroalgae cover most of the lake surface and become a problem from both environmental and economic perspectives. Although the blooms appear to occur during the warmer part of the year, the frequency and dynamics have not been documented so far. Yet their occurrence causes concern among the stakeholders, because they negatively affect recreational activities and, specifically, prevent people from swimming and boating on the lagoon. The strong smell from decomposing algae at the time of bloom decline creates additional cause of concern for the locals and a strong deterrent for visitors.

Spatial and temporal dynamics of a typical bloom in Avoca lagoon have been described by O'Neill et al. (2013). Blooms normally start in spring and decline by early summer. In 2012, isolated patches of macroalgae first appeared at the edges of the lagoon in late September (early spring) and had covered large shallow areas of the lagoon by December (early summer). The current study was done in parallel with mapping and modelling the blooms (O'Neill et al., 2013) with the aim of collecting detailed water quality measurements at a range of sites within the lagoon before, during and after the bloom to identify water quality conditions associated with massive growth of algae. In addition, we aimed to compare our measurements of water quality with those taken by the local council to determine the optimal sampling regime that allows early detection of water quality changes leading to a bloom.

2. Methods

2.1. Study area

Avoca Lake, classified as an Intermittently Closed and Open Lagoon Lake (ICOLL) is located about 90 km north of Sydney. The catchment to Avoca lagoon is within the Gosford City Council Local Government area and covers approximately 11.6 km^2, while the surface area of the lagoon is approximately 0.63 km^2. Much of the upper catchment is rural land, predominantly farmland or undeveloped forest. The lower slopes in the vicinity of the lagoon contain significant urban development. The lake is roughly star-shaped, consisting of four irregular arms and has a considerable area of wetlands around its perimeter (Fig. 1). The main tributary to the lagoon is Saltwater Creek which enters the lagoon on the western side and drains an area of 6.7 km^2, almost 60% of the catchment. Other tributaries all have catchment areas of less than 1 km^2 and enter the lagoon via the other arms.

The bed level of the lagoon generally varies from 0.0 m to 1.5 m AHD although there are dredge holes down to −4.0 AHD. The outlet to the ocean through Avoca Beach is generally closed by the beach berm, and water levels inside the lagoon are not usually influenced by ocean tides. The berm can be breached naturally during high sea surge events and also opened artificially providing a free connection between the lagoon and the ocean. The artificial opening of the entrance is based on water level data at the lagoon monitoring station and is utilised as a flood mitigation measure for surrounding residences. During the spring-summer bloom of 2012 the entrance to the ocean remained closed. An average estimate of around 1.5 m AHD for the lagoon level has been made, based on the available data (GCC, 2010).

Fig. 1. Avoca Lagoon showing our water quality sampling sites (small circles) and Gosford City Council Water Monitoring Site (large circle).

2.2. Water quality measurements

Water quality (temperature - °C, dissolved oxygen – mg/L and % saturation, pH, salinity – expressed according to the practical salinity scale, turbidity - NTU, conductivity - mS/cm, dissolved nitrate (NO_3-N) and orthophosphate (PO_4-P) – mg/L) was monitored at 10-20 sites throughout the lagoon, (Fig. 1) at least twice weekly since early spring. Sampling sites were initially haphazardly selected at various distances from the shoreline and at different water depths around the lagoon (Fig. 1), in order to represent the overall water quality of the lagoon. When first signs of the bloom became apparent, and during the development and collapse of the bloom, the sites were haphazardly selected from the sites where macroalgae growth was established. All measurements were taken in the middle of the water column. Physico-chemical variables (temperature, DO, pH, salinity, turbidity and conductivity) were measured using YeoKal water quality monitoring unit, and then 1 L sample of water was collected from each site to test for NO_3-N and PO_4-P using a La Motte colorimeter. NO_3-N was measured using cadmium reduction method and PO_4-P by ascorbic acid reduction.

Each of the variables were analysed by month in a single factor ANOVA (using IBM SPSS v22 software). Prior to ANOVA, Levene's was used to test for homogeneity of variances. If transformation did not help data was run as was. If significant monthly effects were found Tukey multiple comparisons were undertaken to determine specific patterns of differences.

Our water quality data have been compared with the water quality data obtained by Gosford City Council, who have the responsibility for managing Avoca Lagoon and other coastal lagoons within their local governmental area. Within Avoca Lagoon, there is a single sampling site that is located is at the end of a jetty in 0.5–1.5 m water depth (marked by a large circle in Fig. 1). A range of variables, water depth, salinity, pH, dissolved oxygen, total N, ammonia, oxidised N, soluble phosphorus, total phosphorus, turbidity, chlorophyll-a, faecal coliform bacteria and zooplankton were measured by the Council once a month at that site. The comparisons between the two data sets were made by summarising the water quality data obtained by Gosford City Council and describing its key trends.