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Contrasting effects of managed opening regimes on water quality in two intermittently closed and open coastal lakes

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ABSTRACT

Intermittently closed and open lakes and lagoons (ICOLLs) are shallow barrier lakes which are intermittently connected to the sea and experience saline intrusions. Many ICOLLs are mechanically opened to prevent flooding of surrounding agricultural and urban land and to flush water of poor quality. In this study, the effects of modified opening regimes (frequency and duration of barrier openings and closures) on water quality and phytoplankton in two New Zealand ICOLLs were investigated over a number of opening/closure cycles. Water quality in Lake Ellesmere (Te Waihora) responded weakly to both opening and closing events, indicating that sea–ICOLL exchange did not markedly improve water quality. Conversely, water quality in Waituna Lagoon responded rapidly to barrier openings; water level decreased to near sea level within days of opening and subsequent seawater exchange resulted in rapid decreases in nitrate and chlorophyll *a* concentrations. The closure of Waituna Lagoon resulted in rapid rise in water level and a pulse of nitrate and phosphorus in the water column and phytoplankton chlorophyll *a* concentrations increased with increasing closed-period duration. Based on data on the underwater light climate and nutrient dynamics, phytoplankton in Lake Ellesmere was probably light-limited, whereas phytoplankton in Waituna Lagoon was rarely light-limited, and appeared to be predominately P-limited. The marked differences in responses of Lake Ellesmere and Waituna Lagoon to barrier openings and closures reflected differences in ICOLL water levels and morphological characteristics, which dictated the degree of tidal flushing when the barriers were open. The inter-ICOLL differences observed in this study indicate that unless the effects of ICOLL openings/closures on phytoplankton and nutrient dynamics are understood, changes to ICOLL opening regimes may have unintended consequences for the water quality and ecology of these systems.

1. Introduction

The biology and biogeochemistry of estuaries with permanent openings to the sea have been investigated for nearly two centuries (McLusky and Elliott, 2004), yet far less research effort has been devoted to estuaries with intermittent connections to the ocean like those common to arid, semi-arid and sub-humid coastlines. Many of these estuaries (sometimes termed intermittently closed and open lakes and lagoons or ICOLLs; Roy et al., 2001), have been degraded by eutrophication and declining river inflows (Doody, 2001). ICOLLs are characterized as barrier estuaries with shallow embayments, moderate to low river inflows relative to volume, and high rates of long-shore and/or on-shore sediment transport (Ranasinghe et al., 1999; Kirk and Lauder, 2000; Roy et al., 2001; Haines et al., 2006). River inflow to ICOLLs is insufficient to maintain permanent openings resulting in the closure of seaward margins for months to years. During closed periods, freshwater inputs from rivers, groundwater and rainfall create brackish or freshwater lakes, with natural openings resulting either from rising lake levels overtopping and subsequently eroding barriers or through erosion by ocean waves (Stretch and Parkinson, 2006). Openings facilitate lake water outflow and tidal sea–ICOLL exchange until re-closure by sediment deposition into the openings.

Under natural conditions, alternating inundation and exposure of large areas of fringing wetland occurs as a result of the opening

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regime. In many ICOLLs, artificial opening regimes are employed to facilitate agriculture by maintaining low water levels (Gale et al., 2006; Haines et al., 2006). As a result, agricultural land has claimed the wetland margins of many ICOLLs (Kirk and Lauder, 2000; Haines et al., 2006). Such agricultural development around ICOLLs increases nutrient loading (Gerbeaux, 1993; Twomey and Thompson, 2001; Qu et al., 2003), leading to eutrophication, the loss or reduction of macrophyte beds, and the destabilization of lake bed sediments (Nienhuis, 1992; Gerbeaux, 1993; Qu et al., 2003). Artificially increasing the frequency and/or duration of barrier openings has been carried out in some ICOLLs to attempt to alleviate eutrophication by facilitating flushing and sea–ICOLL exchange (e.g. Suzuki et al., 1998; Roy et al., 2001). However, in some ICOLLs increasing the frequency of opening led to unintended ecological consequences such as nutrient enrichment (dos Santos et al., 2006), macrophyte die-offs, (dos Santos and Esteves, 2002) and increased chlorophyll *a* concentrations (Twomey and Thompson, 2001; Gobler et al., 2005). Therefore, while agricultural encroachment and intensification within the catchment encourages more frequent artificial ICOLL openings, the relationship between opening regimes and eutrophication may depend on multiple factors specific to each ICOLL. ICOLLs embody a variety of intrinsic values and ecosystems services and an understanding of how opening regimes affect these is important for ICOLL conservation, management and restoration.

In this study, we compared the timing and duration of barrier openings and closures of two New Zealand ICOLLs, Lake Ellesmere (Te Waihora) and Waituna Lagoon. While hydrological and water quality data are available for both, relationships between opening regimes, inflows, turbidity, nutrient levels and phytoplankton is rudimentary. We compared the degrees of flushing and sea–ICOLL exchange facilitated by openings and examined the effects of opening regimes on light and nutrient availability, factors that may limit phytoplankton and macrophyte growth. Finally, we compare the water quality responses of barrier openings/closures in our study with those from South America, Australia and the USA.

2. Materials and methods

2.1. Study sites

Lake Ellesmere and Waituna Lagoon occupy depressions between alluvial fans on the east and south coasts of New Zealand's South Island (Fig. 1; Table 1). These microtidal coasts (<2 m amplitude) are characterized by substantial long-shore drift associated with the north-flowing Canterbury and Southland Currents, moderate wave energy and high rates of gravel supply to the coast from rivers draining the Southern Alps and foothills (Kirk and Lauder, 2000). These conditions result in the rapid formation of coastal berms above the high tide level.

The current opening prescriptions at Lake Ellesmere and Waituna Lagoon are based on water surface elevations: Lake Ellesmere is opened when the water level near the barrier reaches 1.05 m above mean sea level (a.s.l.) (August–March), or 1.13 m a.s.l. (March–August), while Waituna Lagoon is opened when the water level reaches 1.69 m a.s.l. in the eastern arm of the lagoon (Table 1). Mean sea level at Waituna Lagoon was calculated as the mean water level during open periods excluding data from the first 7 days after opening the ICOLL (Schallenberg and Tyrrell, 2006). Waituna Lagoon was recently re-surveyed and the trigger level was revised to 2.008 m a.s.l. (C. Jenkins, Environment Southland, unpubl. data), a difference of +318 mm relative to the earlier trigger level estimate used in this study.

Lake Ellesmere and Waituna Lagoon are windswept polymictic ICOLLs in which temporary horizontal and vertical density stratification occur near barrier openings due to saline intrusions. Based on the trophic classification of Burns et al. (1999, 2000), Lake Ellesmere is hyper-eutrophic, while Waituna Lagoon is meso-eutrophic. Water quality in Lake Ellesmere has been monitored by the Canterbury environmental management authority (Environment Canterbury) monthly since 1992, while water quality in Waituna Lagoon has been monitored by Environment Southland monthly since 2001.

Prior to 1968, macrophyte beds consisting of *Ruppia megacarpa*, *Potamogeton pectinatus* and *Lepiliana bilocularis* were reported on the margins of Lake Ellesmere, where water clarity was noticeably greater than in the middle of the lake. The extent of macrophyte beds fluctuated until 1968, when they were nearly eliminated, coincident with a severe storm (Hughes et al., 1974; Gerbeaux, 1993). The macrophyte beds have not recovered since that time and now only isolated plants are found in some sheltered bays. Since the loss of substantial macrophyte beds 41 years ago, turbidity and phytoplankton biomass in Lake Ellesmere have remained high (Taylor, 1996), conditions which have been attributed to the loss of macrophyte beds and to increasing nutrient loading from the surrounding catchment (Gerbeaux, 1993; Taylor, 1996).

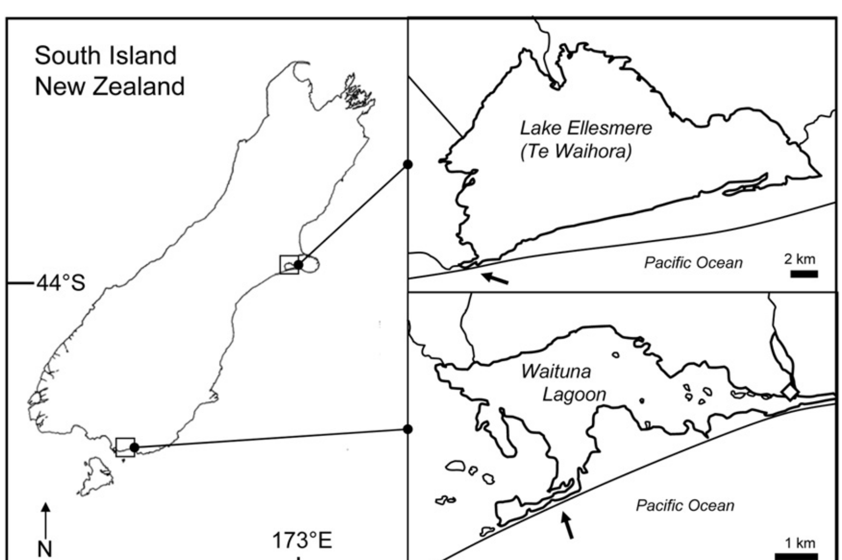

Fig. 1. Map showing locations of Waituna Lagoon and Lake Ellesmere. Arrows show current locations of barrier breaches.