ECOLOGICAL CHANGES IN LAKE ILLAWARRA FOLLOWING COMPLETION OF ENTRANCE WORKS IN 2007

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Prior to 2007 Lake Illawarra was frequently closed to the sea. The lake system received high nutrient and sediment loads from the catchment with little means to decrease these levels once resident within the lake. Water levels within the lake also fluctuated greatly, controlling the extent and distribution of local flora species. In July 2007 the Lake Illawarra Authority (LIA) completed works on training the entrance of the lake to create a permanent opening to the sea. The work has resulted in regular tidal flushing, improvements in water clarity and stabilisation in both lake levels and water quality parameters. Increased tidal exchange has also resulted in significant ecological changes throughout the lake including redistribution of seagrass and saltmarsh. Numerous aquatic animal species have also been found to return or appear for the first time in the lake, including a variety of prawn species, sharks, and even a seal.

The LIA now faces a new chapter in lake protection and rehabilitation. The open entrance now not only allows the free exchange of lake and ocean waters but also allows a passage for migrating organisms. Mangroves which were previously isolated and limited in extent in the lake are now flourishing along the inner mudflats of the entrance channel. The establishment and spread of such saltwater tolerant species poses competition to the saltmarsh species already growing along the lake foreshores. Aquatic pest species, including *Caulerpa taxifolia* and the European Green Crab, now have greater potential to enter the lake and compete with existing native species.

This paper evaluates data and observations demonstrating changes in Lake Illawarra since the permanent opening of the entrance and suggests likely long term effects of some of these changes. The work offers a clear insight of key management issues for others contemplating the construction of permanent entrance works.

Introduction

Lake Illawarra is a coastal lagoon located on the east coast of Australia on the NSW South Coast. The lake is characterised by a shallow bed with an average depth of 1.9m which provides an ideal habitat for seagrass and saltmarsh on the gently sloping foreshores. With an area of 35km^2 the lake has a variety of environments from rocky foreshores and muddy flats to sandy dunes. The lake has a rich ecology with a diverse range of both aquatic and terrestrial fauna inhabiting the lake and its foreshores (Chafer 1997). A number of protected endangered ecological communities have been identified within the foreshores of the lake, emphasising the significance of the environmental values of the lake. Some listed endangered communities include coastal saltmarsh, swamp oak flood plain forest and littoral rainforest. Numerous protected faunal species such as the Black-necked Stork (*Ephippiorhynchus asiaticus*), Pied Oystercatcher (*Haematopus longirostris*), Eastern Bentwing Bat (*Miniopterus schreibersii oceanensis*) and Spotted-tailed Quoll (*Dasyurus maculatus*), and flora species such as Eel Grass (*Zostera capricorni*), Large Fruit Tassel (*Ruppia megacarpa*) and Spiked Rice-flower (*Pimelea spicata*), are also known to inhabit the lake and its foreshores (NPWS 2010).

Now almost completely surrounded by urban and industrial land use, Lake Illawarra has been subject to increasing human influence since European settlement began 180 years ago. Development of the surrounding catchment threatened the ecology of the lake as sediment input loads were accelerated, vegetation cleared, large amounts of rubbish dumped along the foreshores and stormwater discharges containing high levels of nutrients and other chemicals flowed into the lake (Morrison and West 2004). By the 1980s the lake was experiencing a high frequency of algal blooms, thick foreshore sludge and excessive build ups of decaying seagrass and other organic matter. To add to this the entrance of the lake was often closed with a formidable sand berm forming across the entrance limiting the ability of the lake to flush with incoming seawater. With a closed entrance the lake was subject to drought and flood periods dependant of changing weather conditions. During drought periods lake levels significantly dropped up to 0.4m less than average lake levels. This resulted in the exposure of seagrass beds, a die back in saltmarsh communities and an increase in foul odours as a result of excessive decaying matter (White 2003). During flood periods high levels of rain resulted in increased lake levels with one of the biggest floods occurring in 1991 with the lake level reaching 1.9mAHD. These flood periods threatened local residential properties and resulted in the drowning of shoreline vegetative communities. During the intermittent phases of the lake commercial fishing records also noted a decrease in many species within the lake, especially in those species that utilised the lake as a breeding ground.

The Lake Illawarra Authority Entrance Works

In 1988 in response to the declining condition of the lake along with increased social and political pressure, the Lake Illawarra Authority (LIA) was formed by the NSW Government. In line with the objectives of the *Lake Illawarra Authority Act 1987,* the LIA has worked for over 20 years to improve the foreshores of the lake and its environs. As part of these works the LIA undertook numerous foreshore rehabilitation projects as well as algal harvesting, bank stabilisation and the construction of numerous gross pollutant traps and artificial wetlands around the lake.

Whilst these works significantly improved many aspects of the lake environment, the lake still contained high levels of nutrients and sediments from the sources continually flowing in from the catchment. In order to further improve the quality of the lake, as well as work to protect it from an increasing catchment population, the LIA needed to ensure continual flushing of the lake was possible. In 2000 Stage 1 works began to design and construct a training wall on the southern side of the lake entrance which would enable the entrance to the lake to be continuously open (PBP 2005). As part of these works approximately 100,000m3 of sand were pumped from the channel and used to form a tombolo with Windang Island. In 2002 however, droughts combined with unfavourable tidal conditions resulted in the deposition of large amounts of sand in the lakes entrance, closing the entrance channel.

In 2003 work began investigating the construction of a northern training wall in order to prevent the reclosing of the entrance channel (Lawson and Treloar 2004). In June 2006 construction began on Stage 2 of the entrance works resulting in the completion of a northern training wall and an extension of the existing southern wall. In April 2007 as flood levels reached above 0.8mAHD the entrance was reopened and additional material from throughout the channel was dredged and used to renourish nearby Perkins Beach (LIA 2008).

Outcomes of the Entrance Works

Since the completion of Stage 2 of the entrance works in 2007 the entrance has remained open and stable. Within the channel sand movement is dynamic, however a defined channel has remained allowing navigation of various marine vessels in and out of the lake. Monitoring of the entrance channel area still continues with aerial photographs which are taken quarterly.

With a continuous open entrance, extreme water levels within the lake have no longer been experienced and so far minimal effects of flood or drought have been detected. Studies have now been undertaken using tidal gauging to determine the tidal range and hydraulic flushing of the lake. MHL (2009) found that within the eastern side of the lake a tidal variation of 0.25m AHD occurred compared to the 1.8m AHD variation which occurred on exposed coastal sites. On the western side of the lake a tidal variation of 0.15m was found to occur. Through this study it was also identified that tidal forces had the greatest impact on changing water quality suggesting that tidal movements through the entrance provided flushing to the sites monitored within the lake.

These physical changes in the hydrodynamic properties of the lake in turn resulted in a shift in the biological and water quality characteristics of the lake, many of which are still shifting and adjusting as the period of marine exposure continues.

Changes to the Water Quality of the Lake

With the opening of the entrance, as expected the most prominent change in water quality characteristics was an increase and stabilisation in the levels of salinity. Now dominated by tidal influence and marine waters the salinity is now found to occur around 35ppt at fixed probes on both the eastern (Cudgeree Bay) and western (Koonawarra Bay) shores of the lake (Figure 1).

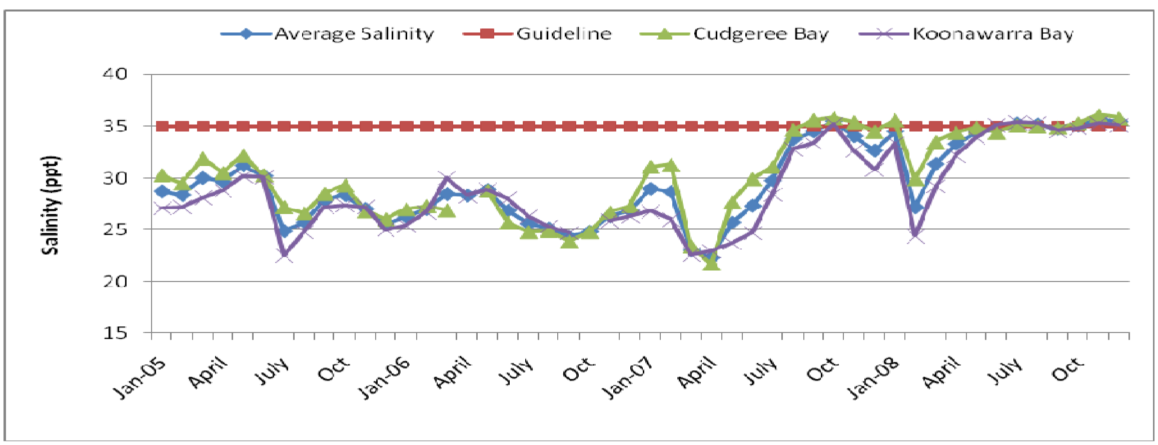

Figure 1. Salinity averages Lake Illawarra, 2005 to 2008.

Acidity (pH) demonstrated a similar response to the changing conditions and has been found to stabilise throughout 2008 (Figure 2). Also of note is the change in pH values on the eastern and western sides of the lake to a unified value of approximately pH 8. This suggests that generally within the lake continual tidal exchange within the entrance plays a greater role in controlling pH than freshwater inflows.

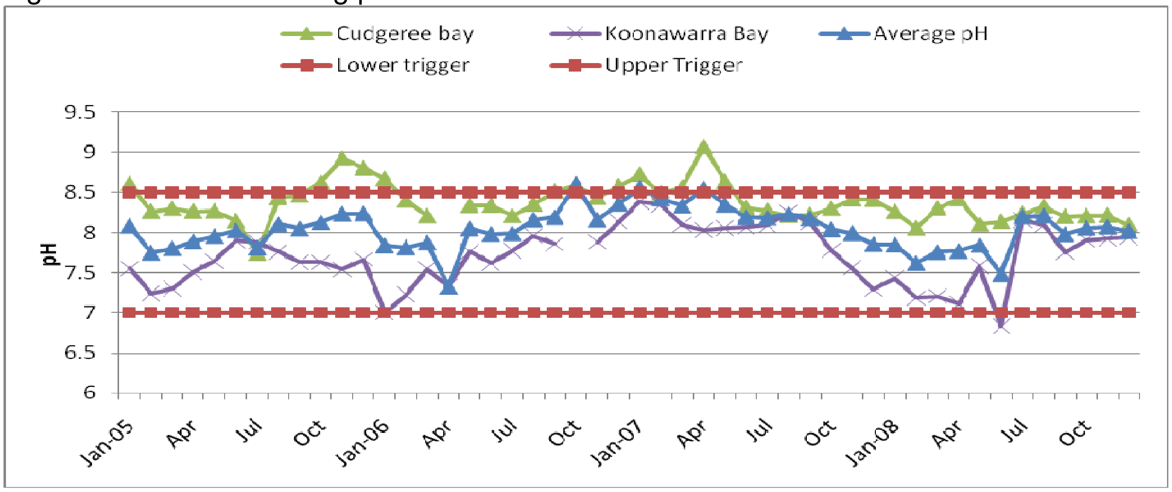

Figure 2. pH averages in Lake Illawarra, 2005 to 2008.

Nutrient parameters such as total phosphorus (TP), filterable reactive phosphorus (FRP) and total nitrogen (TN) were also found to decrease in variability and level (Figure 3). Turbidity demonstrated a less clear response in relation to the openning of the lake largely due to a peak reading which was taken at Kanahooka in April 2008. This peak echos through each of the nutrient data sets and is correlated to a high rainfall event which occured in this month. This suggests that whilst the entrance opening has improved general water quality paramenters within the lake, high rainfall events can still result in temporary declines in water quality. Depending on the paramenter these increased levels only last for a short period of a month of so.

These changes in the chemical and physical water quality paramenters of the lake have and will continue to result in changes in the biological features of the lake. The lake system has now shifted from one periodically dominated by freshwater inflows to a marine system, with catchment inflows found to only impact on the water quality during high rainfall events. The decreasing fluctuation of parameters also creates a more stable environment promoting the growth of certain species. Stabilisation of lake levels has also reduced stress on aquatic species in some areas such as seagrass and saltmarsh which has in turn provided stable habitats for a number of faunal species.

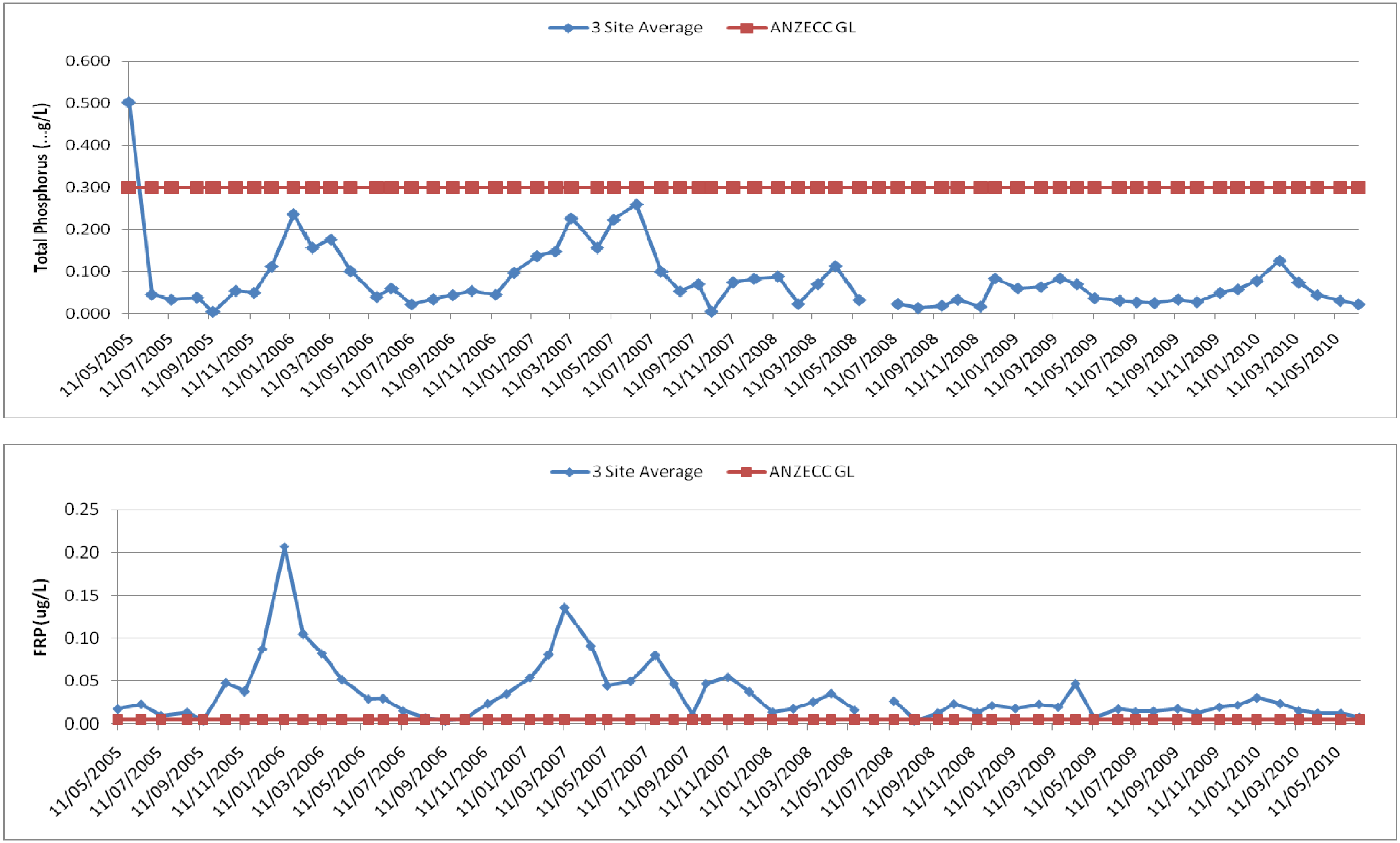

Figure 3. Total Phosphorus (TP) and Filterable Reactive Phosphorus (FRP) averages, Lake Illawarra 2005-2010.

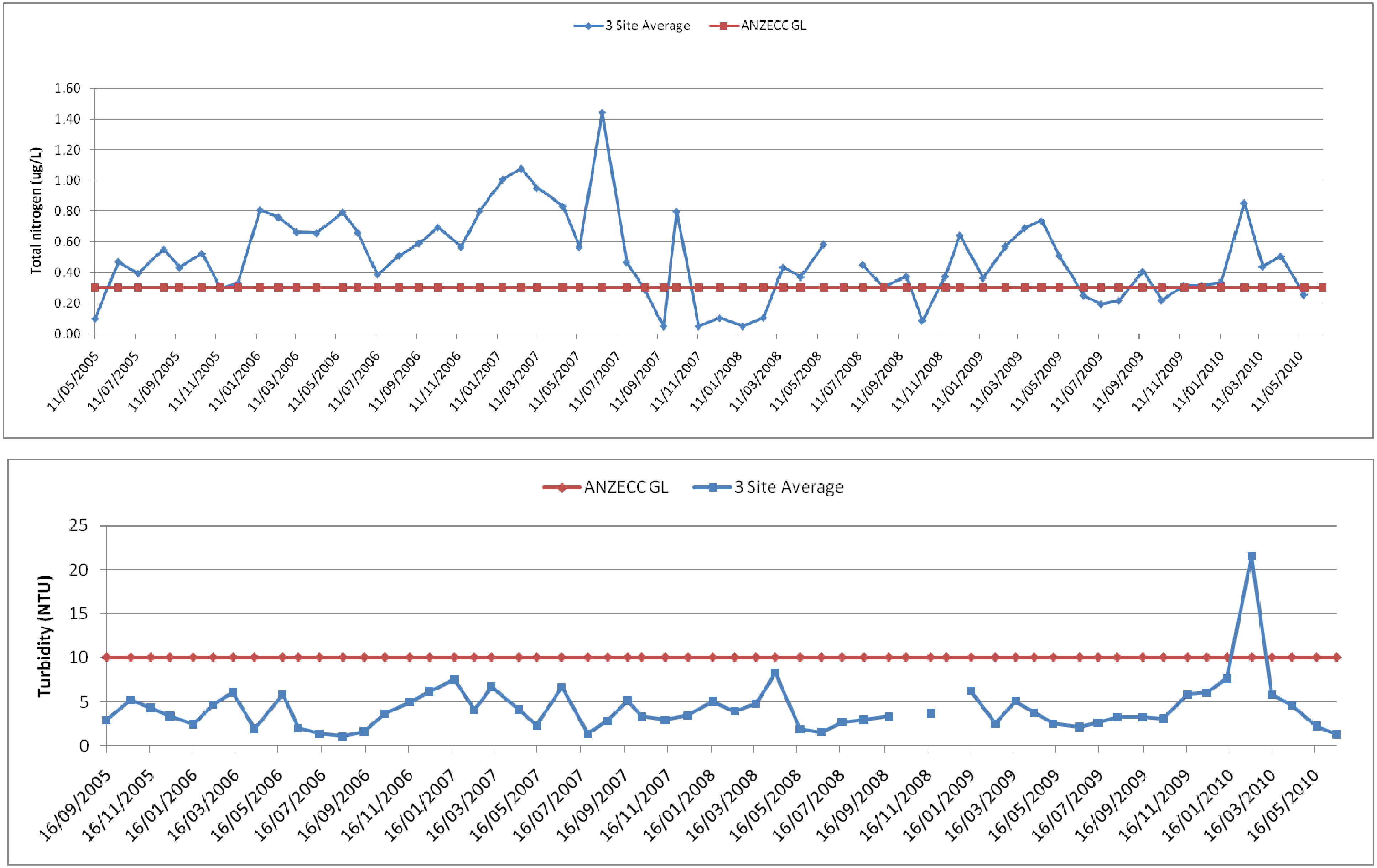

Figure 4. Total Nitrogen and turbidity averages, Lake Illawarra 2005-2010.

Biological Changes

Seagrass beds provide a dynamic ecosystem for a number of aquatic fauna and play an important role in both reproduction and as a nursery area for juvenile fauna. Distribution of seagrass is naturally influenced by light penetration, depth, salinity, nutrient status, bed stability and wave energy (Roy et. al. 2001). In Lake Illawarra seagrass beds are dominated by the fast growing species *Zostera capricorni* and *Ruppia megacarpa* (Ganassin and Gibbs 2008) resulting in dynamic changes in seagrass distribution within the lake as beds response to seasonal changes as well as changed to the physical and chemical properties of the lake (White 2003). Whilst comparable mapping data is limited prior to the opening of the lake, data sets from 2000, 2007, 2008 and 2009 demonstrate an increase in seagrass area in the first two years after the entrance works (Figure 5).

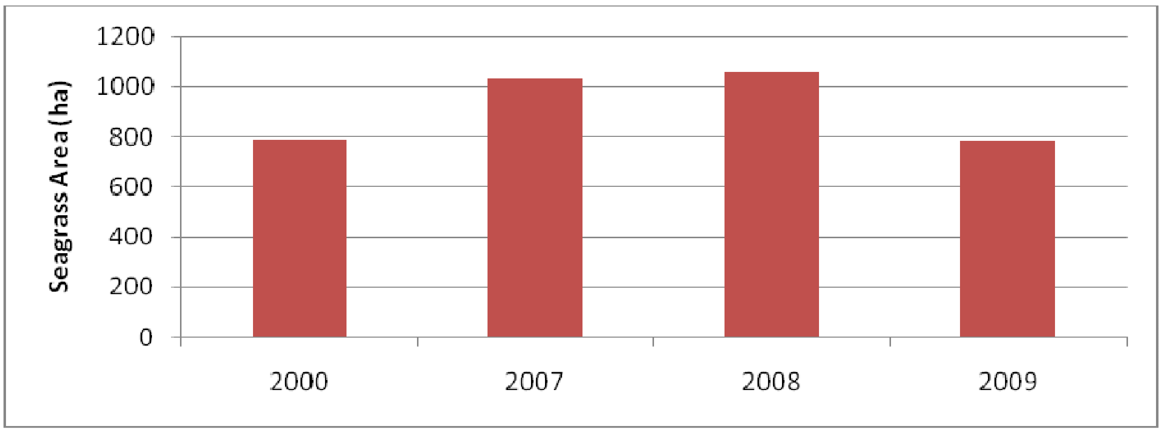

Figure 5. Change in seagrass area over time, Lake Illawarra (WBM 2000, Gray 2007, 2008,2009).

In 2009 seagrass areas were found to return to levels similar to 2000 even though lake levels have now stabilised. As these beds area a dynamic system and have been found to fluctuate yearly 2010 seagrass data will allow comparison to see if reduced seagrass area is a continuing trend potentially linked to changes in the lake environment or if 2009 was just a once off event cause but temporary unfavourable conditions such as climatic variations.

Lake Illawarra has saltmarsh inhabiting much of its foreshore area. These flora communities are strongly dependant on a number of environmental factors such as elevation, tide and salinity (Laegdsgaard 2006). The intermittent nature of the lakes entrance prior to completion of the entrance works resulted in constant fluctuations in all three of these parameters and so saltmarsh communities were limited in their ability to establish long term in many places. Since the completion of the entrance works, stabilised conditions have allowed the saltmarsh communities to extend into areas which were previously unsustainable due to the changing conditions. Open mudflat areas which experience high tidal variations are now demonstrating colonisation with species such as *Suaeda australis* and *Sarcocornia quinqueflora.* The LIA has now established a saltmarsh mapping regime in order to map these and other saltmarsh areas around the lake and to allow comparison in future years to determine the ability for these areas to form stabilised saltmarsh communities.

These new conditions within Lake Illawarra have also provided new competition for saltmarsh as mangrove communities within the entrance area are now booming in population. In 1999 mangroves were planted in the back channel area to allow foreshore stabilisation and create additional habitat for local fauna (LIA 2000). The plants however were not successful and many did not survive. The idea of using mangroves was forgotten and the few surviving plants slowly established however producing offspring throughout the following years appears to have not been successful. Today there is now a thriving population in this back channel area with 2 distinct generations in mangrove growth. A small number of fully established trees exist scattered along the shores which are estimated by height to be remaining from the original planning attempts and then hundreds of smaller mangroves are found among these established trees which are estimated to be less than 3 years old based on their height. This suggests that since the time of the lakes opening, conditions within the back channel area are now optimal for the progression of mangroves and new mangrove plants are quickly establishing and spreading.

Whilst the flourishing population of mangroves in the backchannel area may now be providing new mangrove habitat within the lake it is coming at a clear cost to saltmarsh habitat in this area as a definition is formed between areas of saltmarsh and mangroves. These two vegetative communities have a limited ability to coexist in an area and based on the change in conditions to a more saline tidal environment mangrove populations are most likely to prevail (Mitchell and Adam 1989). What is not known is the full extent to which mangroves will spread within Lake Illawarra.

In addition to changes to vegetation, recent changes in the distribution and abundance of faunal populations in Lake Illawarra has also been noted. Numerous anecdotal reports have been made by commercial and recreational fisherman about the return of a species of prawn which has not been identified in the lake in well over 40 years - the greasyback prawn (*Metapenaeus bennettae).* Another prawn species which utilizes both ocean and estuarine environments as part of its life cycle, the Eastern King Prawn (*Penaeus plebejus*) has been reported in record catches over the 2008-2009 summer.

Commercial catch data collected over the last 8 years has shown that the principle finfish harvested within the lake have been sea mullet, luderick, dusky flathead, silver biddy and bream, with 36% of the catch comprising sea mullet (DI&I NSW 2009). Sufficient data is not yet able to determine changes in the distribution and abundance of fish species in Lake Illawarra since 2007 however it is predicted that with the lake open to the ocean an increase in primarily marine fish species may occur. Future monitoring of commercial catches will allow changes in species composition to be determined.

The new entrance has already been found to attract interesting new faunal species to the Lake Illawarra such as sharks. In 2009 a Dusky Whaler Shark (*Carcharhinus obscurus)* attacked a man within the entrance channel and in 2010 a juvenile Great White Shark was found to inhabit the waters of the lake for a few days (*Carcharodon carcharias)*. These are the only species which have been spotted to date. However with the entrance now fully open to the sea numerous other shark species may now also periodically enter and exit the lake following schools of fish. A seal has also been found to now inhabit the lake and has been observed numerous times within the past year.

Other Potential Changes

In addition to the physical, chemical and biological changes which have already been identified, numerous other potential changes may still occur as a result of the training of the Lake Illawarra entrance. The movement of sand in and out of the entrance channel is still relatively unknown as extreme flood events have not yet occurred since the opening of the channel. It is predicted through the use of models that flood levels will result in the scouring of the entrance channel, though with the numerous complexities involved the actual effect on the entrance channel will not be known until a large flood event is experienced (Cardno 2010). Continual movement of sand through the entrance channel may also result in changes to the delta drop off area into the lake. Here we are currently seeing an extension of the sand delta as marine sands are now covering and overtopping the existing lake bed raising the height of the delta. Continuation of this process may result in the further extension of the delta into the lake and result in changes in flow dynamics in this area.

The response of Lake Illawarra to sea level rise has changed with the opening of the entrance. With an open entrance the lake is now more susceptible to rising of 0.4m by 2050 as outlined in the *DECC Floodplain Risk Management Guideline* (2007). The potential changes associated with sea level rise include shifts in tidal range and tidal prisms. These will impact on the risk of foreshore erosion and promote the growth of some vegetative communities (such as mangroves) but negatively impact on other vegetation within and surrounding the lake. The localised impacts of storm surges and other extreme weather events associated with climate change are also likely to be more severe due to the open entrance.

Potential changes are also expected in the micro communities of the lake such as diatoms, dinoflagellates and green algae. These species often result in algal blooms within the lake and depending on the distribution and abundance of species present can cause toxic blooms which can impact on other species within the lake. Changes in water quality characteristics such as the salinity range, will result in a change in species present which may result in changes in the occurrence and extent of algal blooms (McMinn 1991).

Whilst some changes in aquatic fauna have been identified, as the changed lake conditions caused by the open entrance persist many more are sure to come. With the increasing dominance of tidal marine conditions in most of the lake, marine species are expected to enter and increasingly dominate the system.

New Threats

Along with native marine species, there is also several marine pest species occurring on the NSW South Coast which are now able to enter the lake more easily. The most immediate threat is the invasive marine algae *Caulerpa taxifolia.* This species is fast growing has the potential to alter marine habitats and compete with existing protected seagrass species (DI&I NSW 2010). This species is easily transported through fragmentation and transportation of even only small pieces and has been identified in estuaries only a few hundred kilometres away from Lake Illawarra.

The European Shore Crab (*Carcinus maenas*) has been found to be slowly spreading northward along the NSW South Coast from Twofold Bay to Batemans Bay apparently through natural dispersal. This crab both feeds on and competes with native crabs and shellfish and has the potential to impact on both fisheries and aquaculture (DI&I NSW 2010). Similarly the New Zealand Screw Shell (*Maoricolpus roseus*) has spread along the NSW Coast and has even reached Sydney Harbour (CSIRO 2000). This species breeds prolifically and produces a hard screw shell which is impenetrable to predators. The shells smother the seabed to the detriment to other seabed organisms.

The Japanese Goby (*Tridentiger trigonocephalus*) is an introduced fish species which already occurs in nearby Port Kembla Harbour (DI&I 2010). This species is similar in appearance to native fish occurring in the area and so can be easily mistaken. The risk of these pest species arriving in Lake Illawarra has increased not only through the opening of the entrance but also through increased boating traffic from other estuaries. Boats now entering Lake Illawarra from the ocean may inadvertently transport pest species in to the lake.

Discussion

As Lake Illawarra is at the primary stages of ecological change in response to the opening of the entrance, it provides a unique opportunity to monitor and measure the environmental and ecological changes which are occurring and will continue to occur as a result of the entrance works. The difficulty however lies in determining if these changes are ultimately for the better or for the worse of the health of the system. Coastal lakes are naturally defined at a state of infilling however lakes such as Lake Illawarra have become so disturbed by anthropogenic forces that this process of infilling not only occurs at an accelerated rate but is also combined with high nutrient and pollution inflows along with foreshore disturbance. These pressures, along with growing human population demands, drive managers to look for alternate means of restoring and rehabilitating the lake whilst attempting to meet community demands and expectations. Whilst foreshores have been restored and habitats improved, in coastal lakes such Lake Illawarra the system continues to work as a sink accumulating excessive nutrients and pollutants from the catchment with minimal means to remove these materials from the system. The opening of the entrance to Lake Illawarra has provided some relief in allowing more regular flushing with seawater. Whilst tidal flushing is not a complete solution it significantly reduces the effects of some of the key stresses on the lake and provides more favourable conditions to many of the natural flora and fauna within the lake.

The challenge which is presented now to the LIA is how to manage these multiple changes and mitigate some of the more negative impacts as a result of the open entrance. Flood Plan Risk Management Studies have already been undertaken to identify flood risks and mitigation measures which can be undertaken to limit these risks (Cardno 2010). This study also incorporated sea level rise scenarios as directed in the *DECC Floodplain Risk Management Guideline.* The LIA is also undertaking a number of monitoring programs such as water quality and water level testing, vegetation mapping, entrance sand movement monitoring through aerial photography and bird surveys. In addition to this the LIA is working to integrate information with other Authorities along with developing new research projects with the University of Wollongong. A research plan has been developed by the LIA to guide research topics but also to allow the addition of new topics as issues within the lake are addressed. This research plan provides research targets to the LIA to ensure that the management decisions of the LIA are backed up by sound scientific research. Through this research it is hoped that over time the changes in the lake can be tracked and monitored providing valuable information for other Authorities contemplating entrance training as a means of coastal lake rehabilitation.

Conclusion

The creation of an open entrance channel in Lake Illawarra has resulted in significant improvements in tidal flows leading to improvements in key water quality parameters and increased recreational amenity for lake users and adjacent residents. However as a result of the entrance works this significant estuarine lake has shifted to a predominantly marine system. Changes in the ecology of the lake in response to this shift are already apparent and will continue. In this process, some species and communities will prosper while others will decline.

As managers of this changing estuarine system, the Lake Illawarra Authority are now implementing monitoring and research programs to better understand the changes taking place. By integrating this knowledge with further targeted on-ground works and with the ongoing support of the community, the LIA aims to achieve a continual and ongoing improvement in the health of Lake Illawarra.

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