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Fish Community Survey of the 'Riverside' Lake, April 2007

Summary Report & Overview for Crighton Properties Pty Ltd

Executive Summary

The fish community of the Riverside lake (previously Myall Quays) was surveyed in April 2007 as part of a series of biological studies to record the aquatic ecological development of the lake. Seine netting and gill netting captured numbers of both individual fish and fish species that were well in excess of previous surveys. Substantially larger-bodied fish and some fisheries species were caught including yellow-fin bream, striped mullet, sand mullet and silver biddies. The distribution patterns and occurrence of aquatic plants in the lake were similar to those recorded in 2002.

Increased biological diversity and abundance of the fish community show that the Riverside lake is continuing its development towards the ecological condition of the surrounding Myall River estuary and supports casual observations of recreational fishing in the lake. Habitat conditions, water quality and the food web are continuing to develop, supporting fish recruitment and productivity. Fish recruitment and growth in the lake are contributing to biological values in the estuary as a whole and this should increase as ecological processes mature further.

It is recommended that previous recommendations for enhancing the amount and quality of aquatic habitats remain relevant and should be pursued in the design of any extension of the existing lake system, particularly with respect to increasing the extent, complexity and quality of near-shore habitats for fish, invertebrates and birds. It is also important to continue development and maintenance of runoff management systems to sustain high and stable water-quality values. Completion of the planned circular enlargement of the lake would increase tidal ventilation and reduce water-quality variability as well as improving the availability of habitats and food for aquatic and water-associated plants and animals. Additionally, some consideration could be given to augmenting the existing lake (where possible) with additional submerged structure such as sunken logs, rock mounds and artificial reefs to enhance the amount and quality of aquatic habitat.

These development initiatives will ensure the Riverside lake system continues to contribute increasingly to environmental assets of the Tea Gardens area.

Introduction

The third survey in an ongoing series of biological studies in the Riverside lake was completed by The Ecology Lab in April 2007. Previous surveys by the Australian Museum, including water quality, plants, macroinvertebrates and fish, were completed in 1998 (Appendix 1) and 2002 (Appendix 2) (Australian Museum 2002). The broad objective of these surveys is to monitor aquatic ecological and fisheries conditions in the lake and to record its ecological development from a constructed drainage basin to a functional component of the Myall River ecosystem. The general conclusion from the earlier surveys was that ecological conditions in the lake were still maturing, with an aquatic diversity of plants and animals that had not yet approached that of the surrounding waters of the Myall River estuary and with a salinity regime that varied substantially following rainfall runoff.

Ecological principles and options for the Riverside development were considered in a background paper (Harris 2002) (Appendix 3), which noted that the lake's dynamic ecology is driven by tidal and saline regimes together with rainfall runoff events. The paper listed options for ecological management and described ways in which aquatic habitat values could be enhanced, as well as reviewing fish population-dynamics processes that control the fish community.

Fish community analysis was chosen to represent the ecological condition of the lake for the current study because of the role of fish as indicators of the condition of the food web, water quality and other habitat conditions in aquatic systems (MDBC 2004; Harris 1995).

Methods

Fish were surveyed by a fieldwork team from The Ecology Lab on 26 and 27 April 2007 (Appendix 4). Aquatic plant distribution at sampling sites was also noted. Sampling sites in the lake are shown in a map (Appendix 5).

Seine netting

Seine netting was conducted along the shoreline at 8 locations (Appendix 1). GPS coordinates for sampling locations at given in Table 1. The seine used measured 25 m long x 2 m deep, with a mesh size of 5mm. The net was run out from the shore in a U-shape using a boat and then hauled up on to the bank. Fish were collected in the cod end and placed in a tub with water, in order to minimise handling and stress. Identification, measurements and enumeration were done and all native fish were then released. Those species not readily recognisable were preserved in formalin and returned to the laboratory for identification checks.

Gill netting

This technique was used to capture fish in deeper areas of the water body. Nets were made of a rectangular panel measuring 30m (50mm mesh x 0.25mm diameter) x 1.8m deep. Four gill nets were deployed along the middle of the lake with GPS points taken at the start and end of each panel. GPS coordinates for gill-net sampling locations are given in Table 2 and shown in Appendix 5. Gill nets were placed either perpendicular or horizontal to the shore. Deployment times were 90 minutes, with times deployed listed in Table 2. Captured fish were identified to species, measured and released. Those fish species not readily identifiable in the field were preserved in 10% formalin and checked in the laboratory.

Aquatic plants

Aquatic plants and algae were identified at fish sampling sites using a visual assessment of percentage cover.

Table 1 . Field sampling locations and time of each seine net shot. Datum: WGS84 - Zone 56H.

Sample	Easting	Northing	Date	Time
SEINE 1	420583	6155610	26/04/07	13:15
SEINE 2	420571	6386708	26/04/07	13:45
SEINE 3	420978	6386366	26/04/07	14:50
SEINE 4	421001	6386403	26/04/07	15:15
SEINE 5	420599	6386606	27/04/07	8:40
SEINE 6	420793	6386419	27/04/07	9:10
SEINE 7	420969	6386597	27/04/07	9:40
SEINE 8	420678	6386536	27/04/07	10:15

Table 2. Field sampling locations, depths and time for the start and end of each gill net set. Datum: WGS84 - Zone 56H.

	Start				
Sample	Date	Time	Easting	Northing	Depth (m)
GILL 1	26/04/07	12:55	420973	6386428	3.4
GILL 2	26/04/07	13:05	420829	6386389	3.5
GILL 3	27/04/07	8:15	420586	6386780	2.1
GILL 4	27/04/07	8:18	420642	6386597	3.1
	End				
Sample	Time		Easting	Northing	Depth (m)
GILL 1	14:25		420970	6386399	3.3
GILL 2	14:35		420814	6386373	3.4
GILL 3	9:45		420563	6386763	3
GILL 4	9:48		420629	6386572	3.5

Results

In fish samples there was a total of 11 or 12 species of finfish (the two flathead gudgeon species were not positively identified), listed in Table 3, and the palaemonid estuary shrimp. A total of 840 fish was caught. The catch was dominated by flathead gudgeons, striped ('sea') mullet, exquisite sand gobies, Pacific blue-eyes and silver biddies, with the other species in smaller numbers. Only one alien species (i.e. originating outside Australia) was recorded, the eastern gambusia, only four individuals were caught.

While small-bodied and juvenile fish dominated the catch, some larger fish were either caught or observed. They included striped mullet up to 420mm, sand mullet to 290mm and yellow-fin bream to 329mm.

Table 3. Fish species collected in combined netting samples from Riverside lake, 26-27 April 2007.

Species	Common name
Gambusia holbrooki	Eastern gambusia
Psuedomugil signifer	Pacific blue-eye
Mugil cephalus	Striped (or 'sea') mullet
Myxus elongatus	Sand mullet
Acanthopagrus australis	Yellow-finned Bream
Gerres subfasciatus	Silver Biddy
*Philypnodon grandiceps/*sp.	Flathead gudgeon/Dwarf flathead gudgeon
Psueudogobius sp.	Blue spot goby
Afurcagobius tamarensis	Tamar River goby
Amoya bifrenatus	Bridled goby
Favonigobius exquisitus	Exquisite sand goby

Aquatic plants that were identified included green algae *Cladophora* sp., *Spirogyra* sp. and *Rhizoclonium* sp.; unidentified filamentous Blue-Green/Red algae; the seagrasses *Zostera capricorni* and *Ruppia polycarpa;* the hornwort *Ceratophyllum demersu;* the emergent saltmarsh *Sarcocornia quinqueflora;* and emergent macrophytes including *Juncus* sp., *Triglochin striata and Phragmites australis.*

Conclusions

It is difficult to make direct comparisons of the fish communities represented in the three surveys, as the seasonality, amount of effort and sampling methods varied among the surveys. The current survey sampled less intensively than earlier ones. Nevertheless, previous samples of the Riverside lake's fish community in 1998 and 2002 recorded fewer species – nine in 1998 and seven in 2002 - compared to the 11 or 12 species captured in the current survey.

A much greater size range of fish is also present in 2007, up to 420mm, whereas all fish caught in the 2002 survey were less than 50mm long. And 304 individual fish were collected in the more-extensive sampling in 2002, compared with 840 caught in the current survey's sampling. Fishes that were collected in the current survey but not present in 2002 samples included sand mullet, yellowfin bream, the Tamar River goby, exquisite sand goby, bridled goby and silver biddy. The silver biddy and three gobies were recorded in the lake in 1998. A single common jollytail, *Galaxias maculatus,* was found in 2002 but none were detected in 2007 samples.

The distribution patterns and occurrence of aquatic plants in the lake were not examined in detail in the current survey, but the species listed were similar to those recorded in 2002.

The increased biological diversity and abundance of the fish community shows that the Riverside lake is continuing its development towards the ecological condition of the surrounding Myall River estuary. This result supports casual observations of increasing levels of recreational fishing activity in the lake. Habitat conditions, water quality and the food web are continuing to develop, supporting improved fish recruitment and productivity. Fish recruitment and growth in the lake are contributing to biological values in the estuary as a whole and this should increase as ecological processes mature further.

Recommendations

Previous recommendations (Harris 2002) (Appendix 3) for enhancing the amount and quality of aquatic habitats remain relevant and should be pursued, particularly with respect to increasing the extent, complexity and quality of near-shore habitats for fish, invertebrates and birds. These recommendations for optimising the quality of aquatic habitats, which are incorporated in current proposals to extend the lake area, include:

- Influencing the water-quality regime to increase habitat diversity and stability.
- Continuing effective management of the series of runoff-treatment ponds.
- Increasing variability of depth profiles by introducing physical structures such as submerged logs, rockwork or other artificial reefs
- Experimentally introducing indigenous submerged and emergent aquatic plants and planting littoral trees, shrubs and grasses and
- Introducing shoreline complexity in newly created waterway areas.

It is important to continue development and maintenance of runoff management systems to sustain high and stable water-quality values, especially through the system of treatment ponds.

Completion of the planned circular enlargement of the lake and incorporation of these recommendations would increase tidal ventilation and reduce water-quality variability as well as improving the availability of habitats and food for aquatic and water-associated plants and animals.

These development initiatives will ensure the Riverside lake system continues to contribute increasingly to environmental assets of the Tea Gardens area.

References

Australian Museum (2002). *Biological Study of Myall Quays Lake.* Report No. 2002009 for Crighton Properties Pty Ltd by Australian Museum Business Services, Sydney, September 2002.

Harris, J.H. (1995) . The use of fish in ecological assessments. *Australian Journal of Ecology,* **20** (1), 65-80.

Harris J.H. (2002). *Ecological Principles and Development Options for the Myall Quays Waterway.* Harris Research Pty Ltd Report to Crighton Developments Pty Ltd, August 2002.

MDBC (2004). *Sustainable Rivers Audit Program Report.* Murray-Darling Basin Commission, Canberra. November 2004.

Appendix 1.

Biological Study of Myall Quays Lake

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Summary

This study evaluated the health of the Myall Quays Lake by comparing the water quality with the ANZECC guidelines and by investigating the flora and fauna found in the lake. AMBS specifically looked at fishes, macro-invertebrate epifauna, seagrass and algal communities in the lake. Community structure was compared to water quality data, to evaluate whether salinity and nutrient levels influence the distribution of species in the lake.

Myall Quays Lake (32 30.40'S, 152 09.11'E) is contained within the Myall Quays development which is located near Tea Gardens, north of Newcastle. It was constructed as a detention basin to serve the needs of the adjoining residential development. The lake is approximately 4.8 hectares in surface area and varies in depth up to 4m. It has five freshwater inlets and is also tidal on certain spring tides (ie. ≥1.6m) through an established drain located in the easternmost corner of the lake.

The ecosystem within the lake is only two years old and communities within it may still be maturing. Currently, a total of eleven plants, nine fishes and one confirmed macro-invertebrate species are found in the lake, with a relatively uniform band of vegetation found in the shallow margin of the lake. The species are predominantly marine/estuarine species, although a few freshwater/brackish species are also found. As the lake was not horizontally stratified, the distribution of species and communities did not appear to be influenced by salinity and nutrient levels. Based on oxygen and the nutrient levels (total phosphorus and nitrogen) Myall Quays Lake has good surface water quality, with conditions within the guidelines recommended for lakes and reservoirs by ANZECC (1992).

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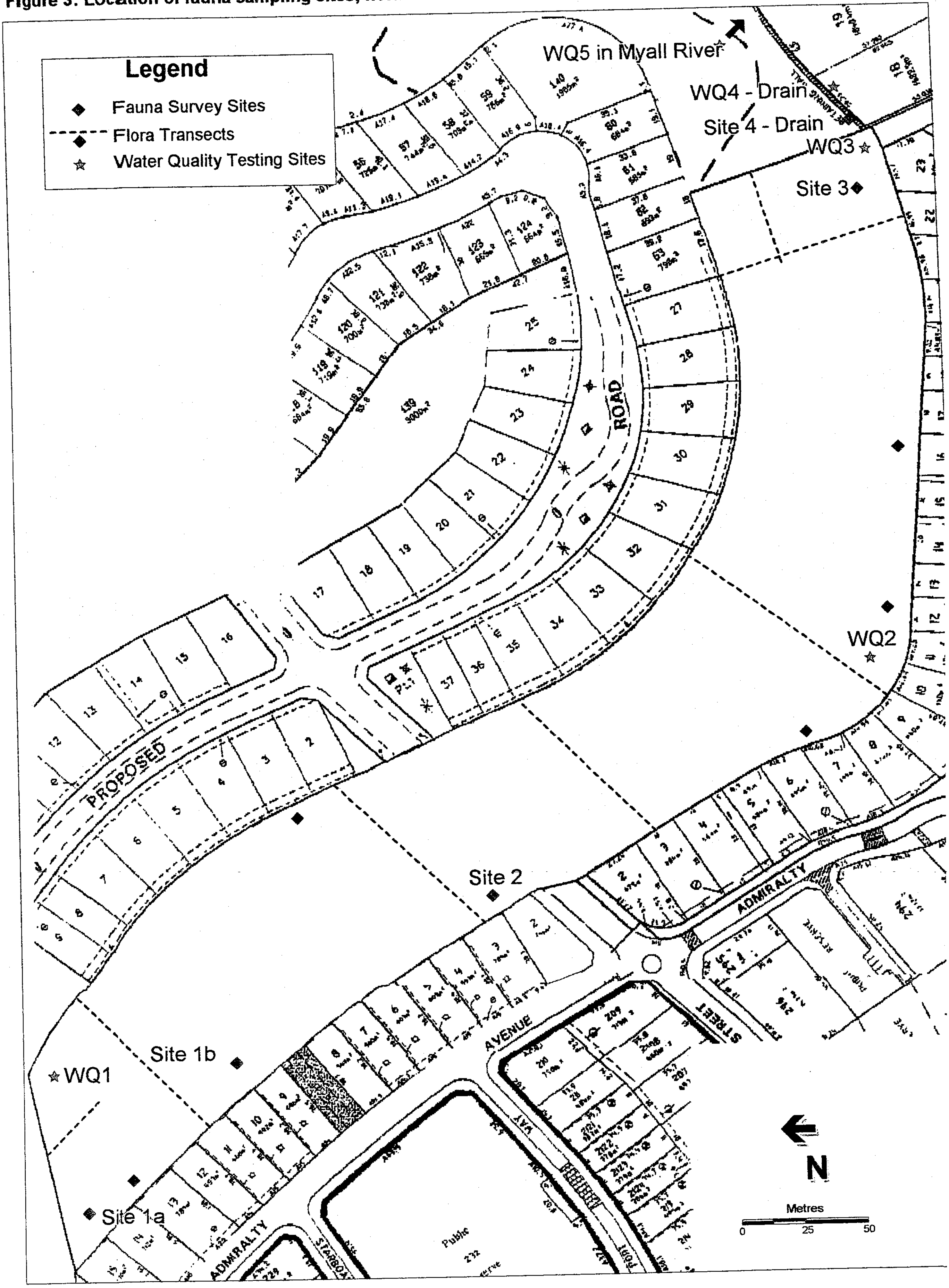
Figure 3: Location of fauna sampling sites, flora transects and water quality testing sites



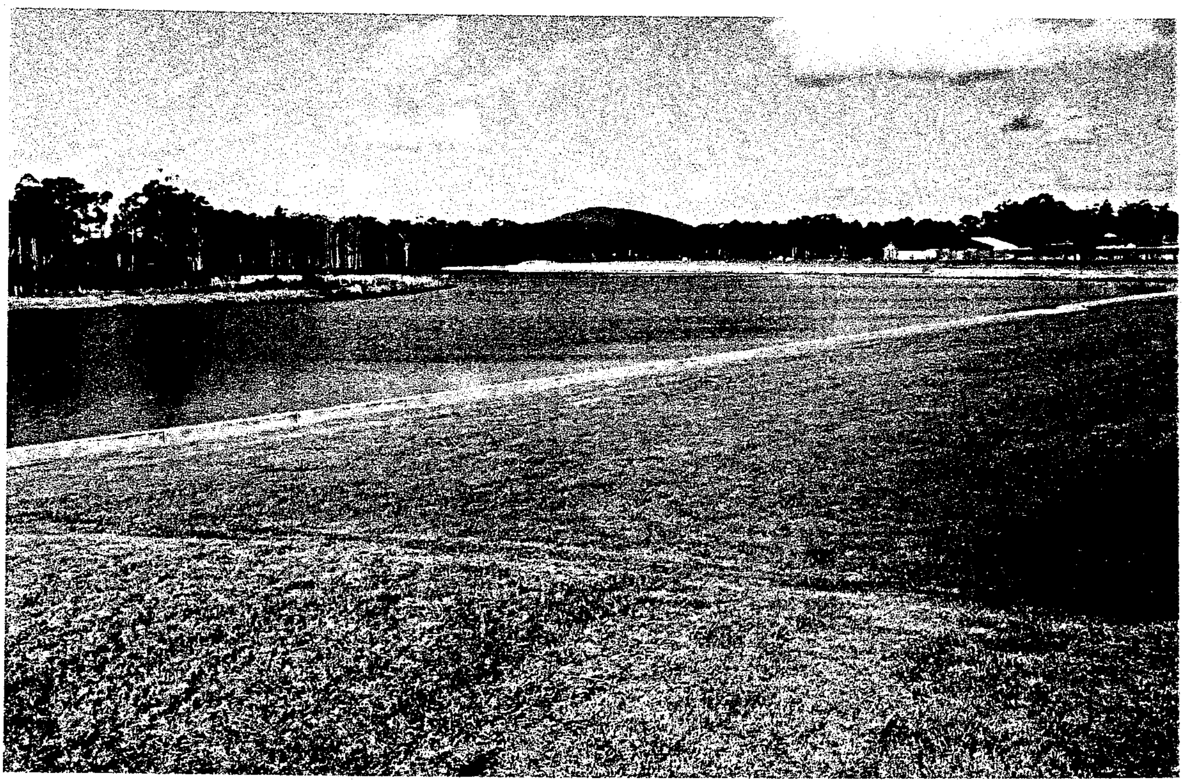
Biological Study of Myall Quays Lake

1. Introduction

Australian Museum Business Services (AMBS) was requested by Crighton Properties to undertake a biological survey of Myall Quays Lake (32 30.40'S, 152 09.11'E) The lake is contained within the Myall Quays development which is located near Tea Gardens, north of Newcastle. Myall Quays Lake was constructed as a detention basin to serve the needs of the adjoining residential development and has the capacity to detain 17,000 m^{-3} of stormwater (Figure 1). The lake is approximately 4.8 hectares in surface area and varies in depth up to 4m, with shallow edges (1:9 slope for 15-20m) sloping (1:4) into deeper water. It has five freshwater inlets and is also tidal on certain spring tides (ie. ≥1.6m) through an established drain located in the easternmost corner of the lake.

AMBS evaluated the health of the lake was evaluated by comparing the water quality with the ANZECC guidelines and by investigating the flora and fauna found in the lake. AMBS will specifically look at fishes, macro-invertebrate epifauna, seagrass and algal communities in the lake were specifically surveyed, their abundance estimated from various areas of the lake, including near the northwestern freshwater inlet and the eastern tidal mouth (drain) of the lake. Community structure is compared to water quality data, to evaluate whether salinity and nutrient levels influence the distribution of species in the lake.

Figure 1: Myall Quays Lake



2. Methods

2.1 Review of Available Water Quality Data

Hunter Water has been taking regular water samples from the lake at varying intervals from 3-10 months since February 1996. The Australian Museum assessed these data to determine the lake's nutrient status and its horizontal stratification. Horizontal stratification of the lake would influence the sampling design used during the fieldwork component of the project. As only single water samples were taken at each site, no data were available to determine the vertical stratification of the lake or the variation between replicate water samples.

Sampling times for water samples were compared to tide and rainfall data, as both factors should influence, at least, the salinity values. Tidal heights are taken from the tide tables for Australia, East Coast - Newcastle, for the years 1996 and 1997. At high tides of 1.6m and greater, there is an inflow of saline water from the lower Myall River into the lake (R. Wraight, pers. comm. 23/1/98). The rainfall figures are daily amounts in mm taken at the Myall Quays development site.

2.2 Field Work

Field work was conducted on 22 January 1998 by three members of the AMBS team, aided by personnel from Myall Quays Estate. Fish and macroinvertebrate epifauna were collected using seine nets (0.5cm mesh) at three sites within the lake and from the drain (Figure 2) leading into the lake from the wetlands adjoining the Myall River (Figure 3). Sites in the lake were located at either end of the lake and in the middle, so that variation in community structure could be determined.

Figure 2: Myall Quays Lake showing mouth of drain leading into the lake from the wetlands

The sampling site locations are:

Site 1a: Northwestern end of lake - bulrushes and algae growing near edge;

Site 1b: Northwest from office - 25m northwest from stormwater drainage inlet in front of freshwater lake;

Site 2: In front of Office;

Site 3: Eastern end of lake near drain entrance; and

Site 4: In drain.

In deeper areas of the lake a 25m long beach seine was used in conjunction with a rowboat; the seine was overweighted so it pulled along the bottom in deeper water. Both a 5m seine and small Japanese seine were used in shallower areas. The various fish collections retained were qualitative rather than quantitative. The majority of the mullet were returned to the lake and the largest specimens of mullet escaped by jumping over the seine. Larger numbers of the smaller species were retained because precise field identification is not possible for these. Fishes were identified primarily using Kuiter (1993) and McDowall (1996), and both sources were used for information on biology and distribution.

Observations on the extent, pattern of cover and species composition of aquatic angiosperms and macroalgae were made by the use of transects normal to the shoreline to determine the composition and distribution of plant communities (Figure 3). The transects extended until the limit of vegetation was reached. Observations were made by snorkelling and whilst wading. The abundance of the vegetation and their distribution patterns were recorded according to the abundance/sociability scale described in Table 1 (King and Barclay 1986). Sainty and Jacobs (1981), Moore (1986) and Womersley (1984, 1987) were the primary sources for identification of and information on the aquatic plants.

From these observations, a vegetation map was drawn up showing the distribution and abundance of the vegetation using the key outlined in Table 1. Specimens collected were identified by Australian Museum scientists.

Table 1: Abundance/sociability scale from King and Barclay (1986)

Abundance	Sociability		
	a Individual strands or clumps	b Patches	c Beds of relatively even distribution
1 Sparse growth (< 15%)	5%	10%	15%
2 Moderate growth (15-50%)	15%	25%	35%
3 Abundant growth (> 50%)	-	60%	65%

3. Results

3.1 Water Quality

The water quality data were limited to single samples taken at five sites over a period from January 1996 to November 1997. As no replicates were taken or samples from different depth (readings taken from within 1m of the surface), AMBS was unable to assess variability in readings at each site or whether the lake was vertically stratified. Vertical stratification, especially saline or dissolved oxygen levels, can significantly affect the composition and distribution of flora and fauna communities.

3.1.1 Salinity

After construction of the lake in January 1996, it was filled by stormwater following heavy rain during the first week. During the month of January 1996 the tide reached 1.8-2.0 m on 11 days. The salinity of Myall Quays Lake gradually increased from approximately 3.5ppt (February 1996) to 16.1-22.8ppt in January 1997. The salinity fluctuated from 7-12ppt between November 1997 and January 1998 (Figure 4). Water samples taken during the present survey indicated that the salinity of the lake was between 10-12ppt (Table 2), with the northwestern portion of the lake slightly lower than the middle and eastern portions of the lake. Water samples taken by Hunter Water show that there is little horizontal stratification within the lake, with minor variations in salinity between sites 1-3 at anyone point in time. However, in January 1997 the southern corner in the middle of the lake had a salinity of 22.8ppt, in contrast to 16.1-16.5ppt at either end of the lake, and only 11.9ppt in the drain.

Variations in salinity within the lake may occur as a result of:

- Freshwater influxes;
- Runoff;
- tidal influx;
- groundwater input; and,
- vertical stratification of salt and fresh water after heavy rainfall.

As the lake is fed by stormwater and saline river water during high tides (>1.6m), it may be expected that the salinity of the lake would fluctuate during the month depending on the amount of rainfall and the number of tidal flows into the lake. However, care needs to be taken when comparing the water quality data with tide and rainfall data because of the time lag between rainfall and freshwater influx, and the timing of water testing compared to tidal influx.

Figure 4: Salinity of Myall Quays Lake 1996-1997

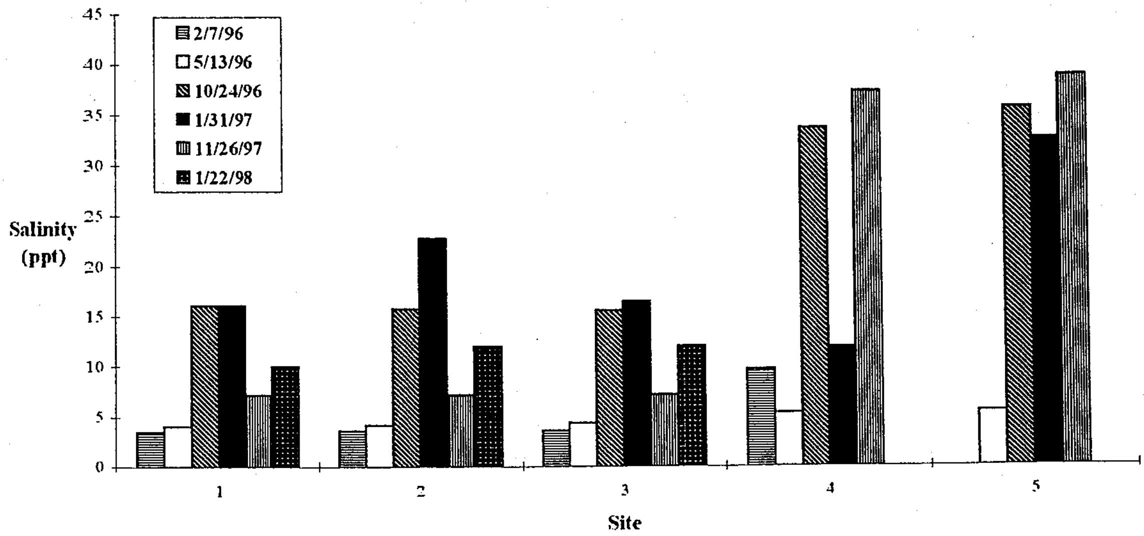
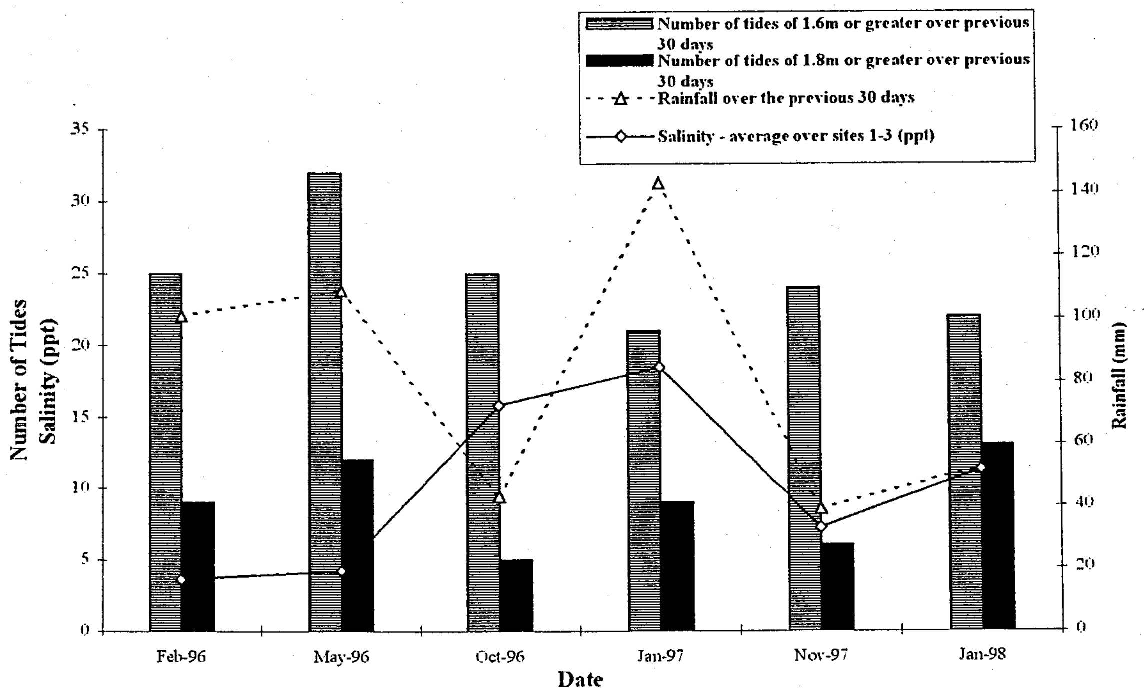


Table 2: Salinity reading recorded during January 1998

Site	Salinity (ppt)
1	10
2	12
3	12

When all three variables (salinity, tide and rainfall) are plotted (Figure 5), it can be seen that for the three samples of 1996, rainfall and salinity were highly correlated. When rainfall was high (100 or more mm in the preceding 30 days), salinity was low (less than 5ppt) and when rainfall was low (less than 50 mm in the preceding month) salinity was high (15+ppt). However, in January 1997, 143mm rain preceded a salinity of 15+ppt, and in November 1997, 39mm of rain preceded salinity of 7ppt. The addition of tidal information neither accounts for the breakdown of the rainfall/salinity relationship in 1997, nor improves the predictability of the model. Whether examining the number of tides 1.6m or greater in the preceding month, 1.8m or greater in the month, or the number of tides 1.6m or greater in the preceding week, the tides are not correlated with salinity variations.

Figure 5: Salinity, rainfall and high tide variations in Myall Quays Lake

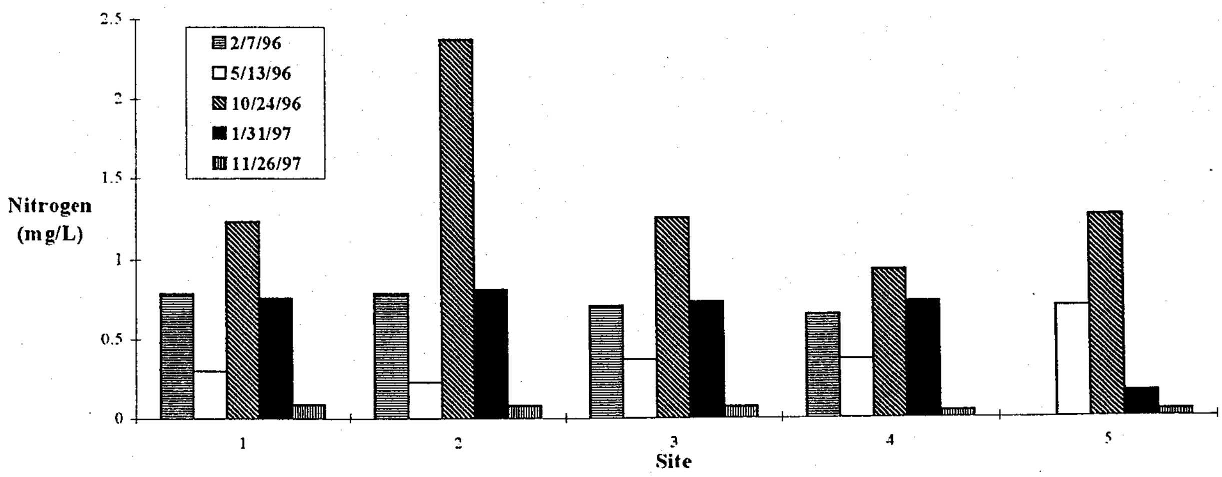


It is not clear from the tide and rainfall data what is causing the variation in salinity in the lake and drain in 1997. In January 1997 the salinity in the drain was 11.9ppt, about 25% lower than anywhere else in the lake and only about 1/3 of the salinity in the Myall River (Figure 4). Yet 21 tidal cycles in the previous 30 days had been 1.6 m or higher, and 9 of these had been 1.8 m or higher. In May 1996, the salinity in Myall River was only 5.5 ppt, compared with other river values in excess of 30 ppt. In January 1997 rainfall was more than 30% higher without significantly affecting river salinity. Thus, it is clear that salinity variations cannot be explained by simple variation in rainfall and tidal heights and that the lake and drain are part of a complex hydrological system that is influenced by other factors such as groundwater and vertical stratification.

3.1.2 Nutrients

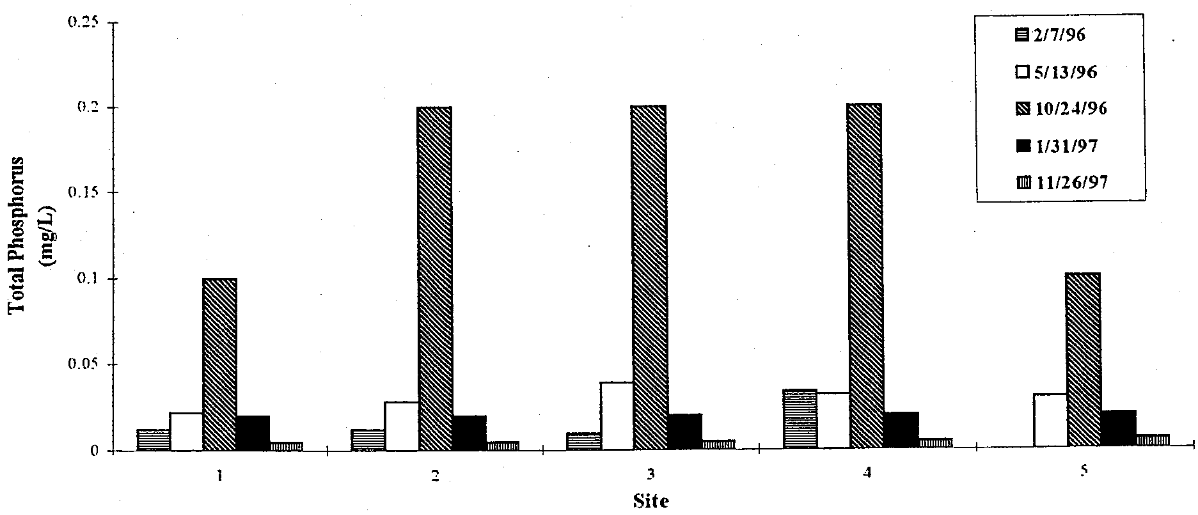
As for salinity, the nutrient levels (nitrogen and phosphorus) increased in the lake during 1996, with levels peaking in October 1996 (Figure 6 and Figure 7). During 1997, both total nitrogen and total phosphorus levels decreased in the lake. The variations in nitrogen and phosphorus levels are not correlated with rainfall, and may be a natural evolution of the lake as it matures. The low levels in 1997, particularly in November, match those in the Myall River. However, the phosphate values for November 1997 are for ortho-phosphate only and are not comparable to the total phosphate values given in all previous measurements. Total phosphate also includes the amount of condensed phosphates and organically bound phosphates as well as ortho-phosphate.

Figure 6: Total nitrogen in Myall Quays Lake 1996-1997



NB. February 1996 - January 1997 sum of Total Oxidised Nitrogen and Total Kjeldahl Nitrogen, November 1997 sum of Total Oxidised Nitrogen and Free Ammonia (no data available on Organic Nitrogen)

Figure 7: Total phosphorus in Myall Quays Lake 1996-1997

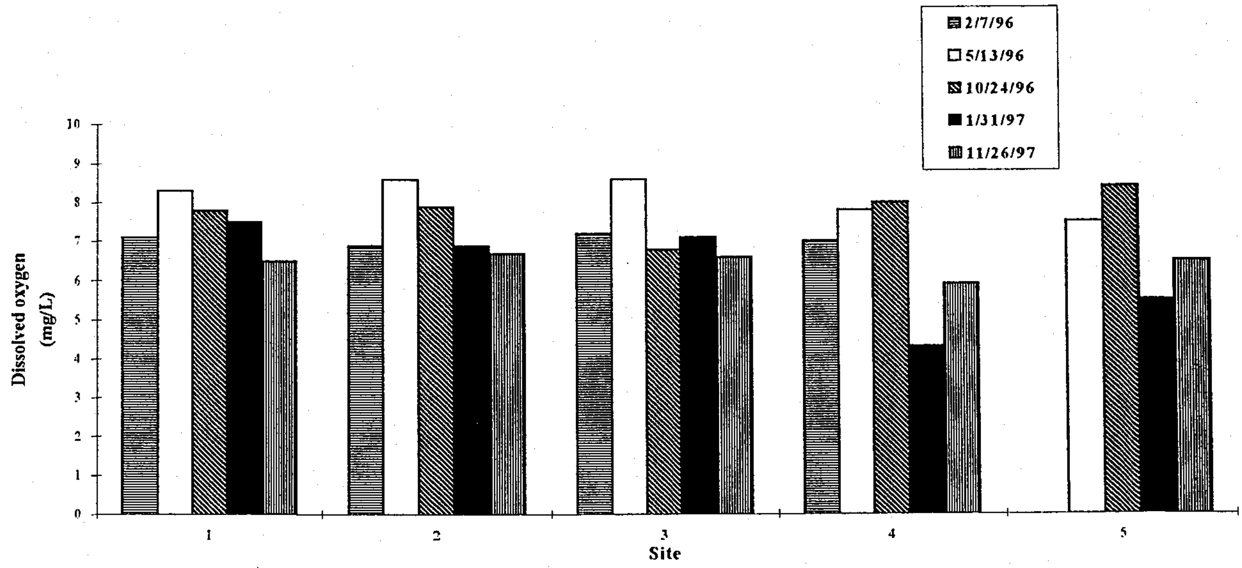


NB. February 1996 - January 1997 Total Phosphorus measured, November 1997 Ortho-Phosphate measured (no data available on condensed phosphates and organically bound phosphates)

3.1.3 Dissolved Oxygen

Dissolved oxygen levels, although increasing initially (from February 1996 to May 1996), have declined gradually but slightly over time (Figure 8). The variation in the drain has been greater, more closely approximating the variation in the Myall River. The amount of dissolved oxygen is inversely proportional to water temperature, with colder water able to hold more oxygen. Therefore, percent oxygen saturation is often calculated. Lake levels have varied between 80-96% saturation, while the Myall River has fluctuated between 76-100% saturation. Due to the limitations of the available water quality data, it is unknown whether the lake is vertical stratificatied in terms of dissolved oxygen levels.

Figure 8: Dissolved oxygen levels in Myall Quays Lake 1996-1997



3.2 Flora

3.2.1 Flora Species Present in Myall Quays Lake

The aquatic angiosperms and macroalgae recorded in Myall Quays Lake are:

Seagrass

Ruppia polycarpa (Sea Tassel)

Grows in coastal lakes and lagoons at similar or lower salinities than seawater. *Ruppia polycarpa* is the second most dominant species in Myall Quays Lake.

Aquatic angiosperms

Triglochin striata (Streaked Arrow Grass)

Grows in tidal and freshwater swamps. Found growing in shallow areas around the lake.

Elatine gratioloides (Waterwort)

Usually found in or on the margins of stationary or slowly flowing freshwater to about 40 cm. Isolated patches were found growing in the northwestern portion of the lake.

Juncus spp. (Rushes)

Most species of *Juncus*. occur in periodically damp areas but vary greatly in their tolerance to the intervening dry periods. Some species (eg. *J. acutus* and *J. usitatus*) prefer areas with damp subsurface moisture, while other species are able to survive permanent or periodic inundation (eg. *J. aridicola*, *J. prismatocarpus*).

The species found around Myall Quays Lake is most likely *J. krausii* (grows in saline or brackish conditions) or the commonly occurring freshwater species *J. acutus* or *J. usitatus*. However, specimens were not collected for identification as the species was growing around the lake rather than in the lake.

Other

Isolate plants of two unidentified aquatic angiosperms were observed growing in the northwestern/middle section of the lake.

Macroalgae

Charophytes (Stoneworts)

Lamprothamnium papulosum

Dominant vegetation in Myall Quays Lake. Studies have shown that *L. papulosum* has an optimal salinity range between 24-28 ppt, with a minimum salinity tolerance around 8 ppt. However, *L. papulosum* is able to withstand salinities up to and including 104ppt, although it does not grow satisfactorily in salinities over 60ppt (Womersley 1984). *Lamprothamnium papulosum* is reported to be a food source for water fowl (Delroy 1974 cited in Womersley 1984).

Nitella subtilissima

Usually found in still or flowing freshwater. Occasionally found in brackish water. Only one other record of its occurrence in NSW.

Chlorophyta (Green Algae)

Cladophora sp.

Member of the Chlorophyta which grow in freshwater and saline conditions. Usually found attached to rocks, hard substrates, plants and algae in eutrophic and alkaline streams and lakes.

Rhizoclonium sp.

Member of the Chlorophyta which is often found entangled with other filamentous algae in slow flowing water. Generally found in alkaline and/or saline streams and common in estuarine areas.

Spirogyra sp.

Member of the Chlorophyta which is found floating or attached in flowing or still freshwater.

Phaeophyta (Brown Algae)

Family Chordariaceae

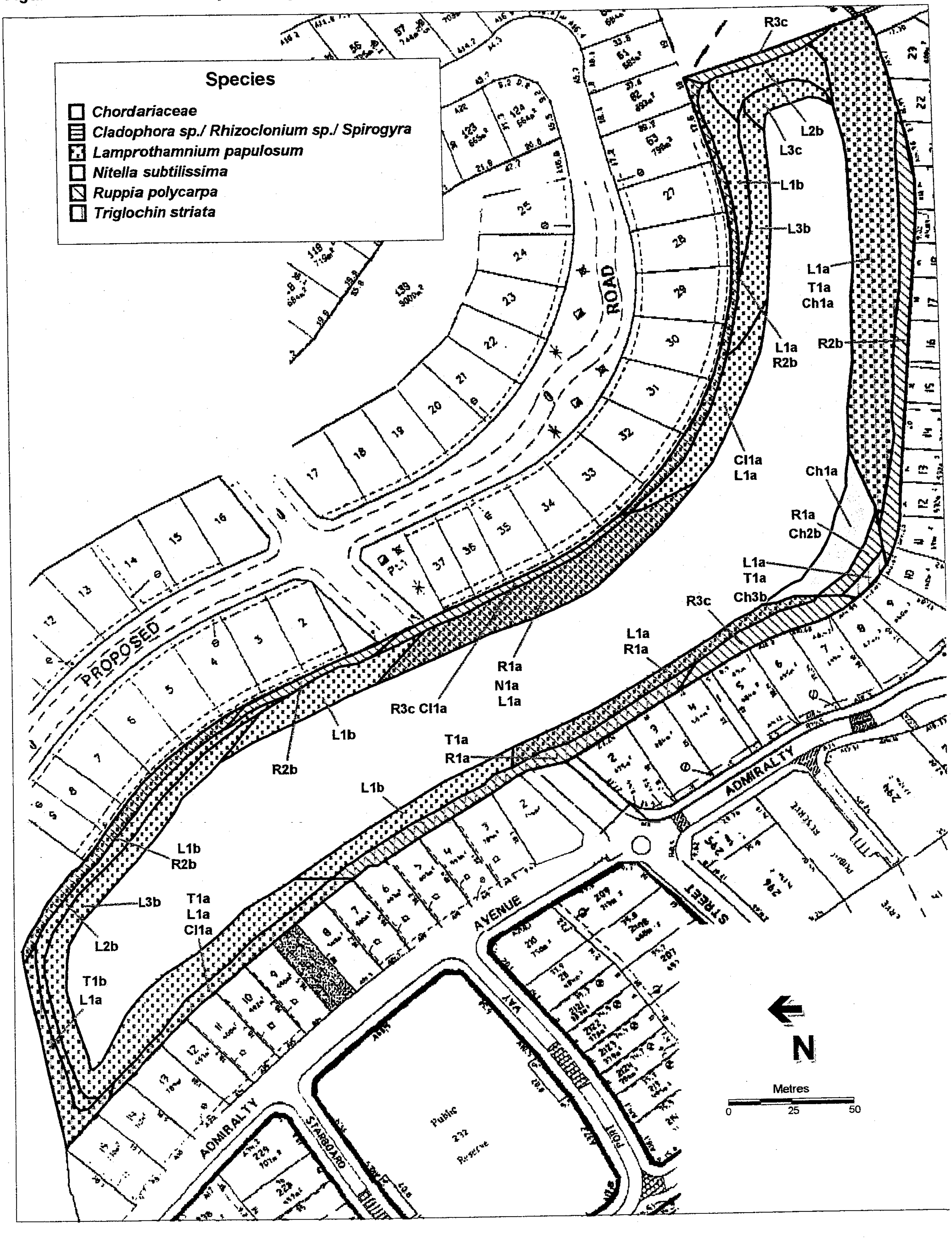
Members of this family are usually common in the lower intertidal and upper sublittoral and are also usually seasonal (in summer) in the occurrence of the macrosporophytes (macroscopic form of alga).

3.2.2 Distribution

The distribution of these aquatic angiosperms and macroalgae is presented in Figure 9, with a relatively uniform band of vegetation (approximately 20-25m in width) found around the margin of the lake. The vegetation of Myall Quays Lake was dominated by *Lamprothamnium papulosum* (a stonewort). In the deeper water (approximately 4m to 25m from the shore), *L. papulosum* was usually the only species present, with large clumps (up to approximately 50-75cm diameter and 50cm high) covering the bottom sediment. *Ruppia polycarpa* was dominant in shallow areas of the lake (less than 0.5m), where smaller clumps of *L. papulosum* were also found. These two species comprised approximately 80-90% of the total plant biomass of the lake. A brown alga of the family Chordariaceae was also abundant in the middle portion of the lake, where it formed a dense, free floating blanket over the bottom sediment. This patch was located near a stormwater outlet. Only isolated individuals of the other dominant species were found growing amongst the brown alga.

Several other species were also recorded, but they were usually found in isolated patches. In the northwestern portion of the lake, the number of species present appeared to be greater (including *Elatine gratioloides* and two unidentified aquatic angiosperms) than in the middle (southern) and eastern areas. However, further studies would be needed to verify this.

Figure 9: Distribution of aquatic vegetation in Myall Quays Lake



3.3 Fauna

3.3.1 Fauna Species Present in Myall Quays Lake

Fish and macroinvertebrates recorded in Myall Quays Lake are:

Fish

Family Poeciliidae

Gambusia holbrooki (Mosquito Fish)

Mosquito fish is an exotic species, introduced into Australia from the USA in the 1920s. It is widespread and abundant throughout NSW, SA and Victoria in both inland and coastal drainages, and coastal Queensland. Mosquito fish tolerates a wide range of salinities, from pure freshwater to full marine salinities. It is most abundant in warm and gently flowing or still waters, mostly around margins and along the edges of aquatic vegetation beds. This species feeds on a wide range of both terrestrial and aquatic organisms ie. it is an adaptable generalist predator, that may be a threat to other small fish species into whose habitat it has been introduced or spread. Recently it has been implicated in the reduction of green and golden bell frog distribution, presumably by feeding on the tadpoles.

Family Pseudomugilidae

Pseudomugil signifer (Southern Blue-eye)

Southern blue-eye is widespread throughout eastern drainages, from northern Queensland to Narooma, NSW (South-East Drainage). It is abundant in fresh or brackish coastal waters, but does not penetrate far inland.

Family Gerreidae

Gerres subfasciatus (Common Silver Belly)

Common silver belly is found in the northern half of Australia, south to Wollongong on the east coast. It occurs in estuaries and harbours out to fairly deep water along the shore.

Family Mugilidae

Mugil cephalus (Sea Mullet)

Sea mullet occurs along the entire Australian coast in estuaries; large schools migrate along ocean beaches. It spawns offshore and small schools of juveniles enter rivers, as do adults occasionally. The species can survive more than one year in freshwater. It is an important commercial species.

Family Gobiidae

Favonigobius exquisitus (Exquisite Sand Goby)

Exquisite sand goby occurs in NSW coastal bays and sandy estuaries, sometimes in seagrass.

Gobiopterus semivestitus (Glass Goby)

Glass goby occurs from southern Queensland to SA, in quiet coastal estuaries. It enters freshwater and is usually found in small to large schools.

Mugilogobius paludis (Mangrove Goby)

Mangrove goby is known from southern Queensland to SA. Its intertidal in mangroves and also enters lower reaches of freshwater streams.

Pseudogobius sp. (Blue-Spot Goby)

An undescribed species, but is not uncommon. It is found from southern Queensland to Victoria and occurs in coastal estuaries, usually in muddy upper reaches with rocks or seagrasses.

Philypnodon sp. (Dwarf Flathead Gudgeon)

Dwarf flathead gudgeon is another undescribed species, occurring in coastal streams of southern Queensland, NSW, Victoria and SA. It is found in brackish waters in estuaries, to altitudes of a few hundred metres and is common in coastal northern areas of range. This species prefers relatively calm waters and lives over mud or rocks, or in weedy areas.

Family Anguillidae

Anguilla reinhardtii (Long Finned Freshwater Eel)

Long finned freshwater eel occurs from Cape York to Tasmania, in all coastal rivers, streams and lakes, as well as in brackish waters. It migrates out to sea to breed after up to ten years in freshwater and is commercially important. Previously it was observed by Myall Quays staff, but it was not collected in January 1998.

Macroinvertebrates

Crustacea: Infraorder Caridea

Family Palaemonidae

These shrimps are commonly found in estuaries and feed on algae and detritus. The commonest species of estuary shrimps do not exceed 45 mm in length and are of no commercial importance.

Crustacea: Infraorder Brachyura

Family Portunidae

Portunus pelagicus (Blue Swimmer Crab)

Blue swimmer crab is found Australia-wide, in bays and estuaries as well as offshore. A large crab of commercial importance. Previously it was observed by Myall Quays staff, but was not collected in January 1998.

3.3.2 Distribution

The number of fish/macroinvertebrates captured is presented in Table 3. The fauna of Myall Quays Lake was dominated in numbers by *Favonigobius exquisitus* (Exquisite sand goby) and *Pseudomugil signifer* (Southern blue-eye). *Mugil cephalus* (Sea mullet) was the largest fish recorded in Myall Quays Lake, and dominant in biomass. No accurate count of numbers of this species was obtained, as most of the mullet were released. Several other fish species were also recorded with *Gobiopterus semivestitus* (Glass goby) the next most common species (based on numbers caught). Only one species of macroinvertebrates, an estuary shrimp of the family Palaemonidae, was caught during the sampling period.

Table 3: Fish numbers from Myall Quays Estate, Tea Gardens

Species		Site					Total
		1a	1b	2	3	4	
FISHES							
Gambusia holbrooki	Mosquito fish	-	-	6	-	16	**22**
Pseudomugil signifer	Southern blue-eye	132	26	1	40	75	**274**
Gerres subfasciatus	Common silver belly	-	-	-	6	-	**6**
Mugil cephalus	Sea mullet	-	2	11	3	2	**18**
Favonigobius exquisitus	Exquisite sand goby	32	52	19	174	-	**277**
Gobiopterus semivestitus	Glass goby	79	12	-	60	2	**153**
Mugilogobius paludis	Mangrove goby	-	-	-	-	1	**1**
***Pseudogobius* sp.**	Blue spot goby	5	9	1	10	-	**25**
***Philypnodon* sp.**	Dwarf flathead gudgeon	18	32	-	13	-	**63**
MACROINVERTEBRATES							
Palaemonidae		4	-	-	-	14	**18**
	Total	**270**	**133**	**38**	**306**	**110**	**839**

Most of the fish species appear to occur in all parts of the lake. The exception seems to be the mosquito fish *Gambusia*, with largest numbers in the drain and few in the lake proper. The same is also true of the estuary shrimp, with most in the drain and low numbers only in the northwest corner of the lake. The two rarest fishes, the Mangrove goby and Common silver belly, were both found only in the drain or eastern end of the lake near the drain entrance. All other fish species were taken in at least 3 of the 4 lake sites, but four fish species, including the commonest Exquisite sand goby, were absent from the drain.

4. Discussion

4.1 Water Quality

Indicative concentrations (preferred upper limits) of total nitrogen and phosphate for lakes and reservoirs (as recommended by ANZECC 1992) are shown in Table 4. They were not able to recommend a single set of nitrogen and phosphorus concentrations, as this would require a site-specific study. However, these ranges provide an indication of levels at or above which problems (such as phytoplankton blooms) have been known to occur (depending on a range of other factors eg. temperature, turbidity).

Table 4: Indicative concentration range of total nitrogen and phosphate for lakes and reservoirs (as recommended by ANZECC 1992)

Nutrient	Indicative Concentration Range
Total Phosphorus	5-50μg/L (0.005-.05mg/L)
Total Nitrogen	100-500μg/L (0.1-0.5mg/L)

With the exception of October 1996, total phosphorus in Myall Quays Lake has always been 0.04mg/L or less. All of the January 1997 values were less than 0.02mg/L (the November 1997 values were for ortho-phosphate and are not comparable).

With the exception of October 1996, where total nitrogen values of 1-2+mg/L were attained, all measurements of total nitrogen within the lake have been only slightly over or under the recommended value of 0.5mg/L. From the peak of October 1996 the nitrogen values have been steadily decreasing, with the values of November 1997 exceptionally low at >0.1mg/L. These values are indicative of very good water quality.

The figures given above are for freshwater; Australian estuarine studies are very limited and ANZECC (1992) recommended figures for estuarine waters, based on one study in Western Australia, are not presented in either total nitrogen or total phosphate and thus are not comparable to our data. Variation in nutrient levels within the lake may be a result of runoff from the catchment, either wastewater discharge or diffuse runoff. They may also be a result of metabolic decomposition, which may be seasonal resulting in a timelag in nutrient levels within the lake. In terms of potential algal blooms, one of the important factors is the ratio of total nitrogen/total phosphorus. With both nutrients being below the maximum recommended values, algal blooms should not be a problem if the present range of values are maintained.

The ANZECC (1992) guidelines also recommended that dissolved oxygen levels normally should not be permitted to fall below 6mg/L or 80-90% saturation. None of Myall Quays Lake surface (top 1m) values ever fell below these recommended minima. However, it is not known whether dissolved oxygen levels at the bottom of the lake comply with ANZECC guidelines. Dissolved oxygen varies significantly during a 24 hour period, depending on temperature, salinity, and biological activity (ie. whether the aquatic plants are photosynthesising during the day and producing oxygen or respiring at night and using oxygen). Therefore, oxygen levels should be determined over at least one circadian cycle. Water samples should also be taken at more than one depth including from near the bottom to determine if the lake is vertically stratified. Dissolved oxygen levels in bottom waters may be significantly different (lower) that surface waters due bacterial decomposition of organic matter. This can result in the death of organisms which are unable to escape from the zone of oxygen depletion (Scanes and Scanes 1995). Reduction in dissolved oxygen concentrations in water can also reduce the physiological efficiency of fishes and non-airbreathing invertebrates, with levels below 5mg/L stressful to many species (Koehn and O'Connor 1990). During both sampling times in 1997, oxygen saturation in the drain was less than 80% and in January 1997 the oxygen was only 4.3 mg/L, thus placing the fishes in the drain under stress. One feature of fishes is their ability which to move to higher quality water in times of stress, and they may have moved into the lake during January 1997.

Overall, on the basis of both oxygen levels and the nutrient levels of total phosphorus and nitrogen as recommended in the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, 1992), Myall Quays Lake has good surface water quality.

4.2 Flora

The vegetation of Myall Quays Lake was dominated by the Charophyte *L. papulosum*. The seagrass, *Ruppia polycarpa*, was also prominent in shallow areas of the lake. These two species made up 80-90% of the plant biomass of the lake. Charophyte beds are ecologically important as they have a high biomass, accumulate large concentrations of nutrients and have a large surface area which is readily colonised by micro-organisms which can support a large invertebrate population (Moore 1986). The large clumps of *L. papulosum* would most likely provide shelter and food for fishes.

Aquatic macrophytes usually grow best in lakes and rivers in areas of fine sediment and low current velocity (Wright and McDonnell 1986). These condition are met in Myall Quays Lakes, where the sediment is composed of fine sand and there is frequently little or no water flow. Macrophyte and algal growth in Myall Quays Lake is thought to be primarily limited by turbidity, with only *Lamprothamnium papulosum* found growing in the deeper, turbid waters of the lake. In the deepest areas of the lake no vegetation was found growing.

Charophytes, such as *L. papulosum* and *Nitella subtilissima,* usually prefer calcium rich waters which are low in phosphate, with phosphate levels above 20µg/L often inhibiting their growth (Moore 1986). Water quality testing of Myall Quays Lake has shown that total phosphate levels vary. However, total phosphate levels in January 1997 were less than 20µg/L (total phosphate was not recorded in November 1997). Thus the current physical environment within the lake appears to be suitable for Charophyte growth. A permanent increase in nutrient levels could affect the growth of Charophytes and result in a change in the vegetation communities found in the lake.

Highly fluctuating salinity levels may limit the survival of some aquatic plants. Many species, although able to withstand saline conditions, are unable to cope with rapidly fluctuating salinities. If the level of salinity change seen in the lake between January and November 1997 (from 23 to 7 ppt at site 2) occurred over a short period, some species probably would not survive.

4.3 Fauna

A total of nine species of fishes and one shrimp species were collected. The two dominant fish species in the lake in terms of numbers are the exquisite sand goby, *Favonigobius exquisitus,* and the southern blue eye, *Pseudomugil signifer.* The sea mullet, *Mugil cephalus,* is by far the largest in terms of biomass, making up all the large fish in the lake. Based on our sampling, the school of fish that comes to feed on the bread every day consists entirely of sea mullet.

All of the nine fish species are tolerant to relatively wide salinity ranges. However, if the salinity continue to vary over a wide range, the number of additional species to colonise the lake may be limited. Many species cannot tolerate such a wide range of salinities, particularly if the changes occur over a short period of time. It may be that these fluctuating salinities are a natural feature of this lake, due to its function as a stormwater reservoir, and therefore there will never be a rich fauna of resident fishes and macroinvertebrates.

4.4 Ecology of Myall Quays Lake

As the lake is only two years old, the communities within the lake are probably still maturing and may change in composition, abundance and distribution over time. Although the lake is currently dominated by the plants *Lamprothamnium papulosum* and *Nitella subtilissima,* and the fishes *Mugil cephalus, Favonigobius exquisitus,* and *Pseudomugil signifer*, the dominant species present could significantly change if nutrient concentrations or salinity were to change dramatically. Currently the species present in the lake are adapted to a changing physical environment, with fluctuations in salinity, nutrients and dissolved oxygen occurring as a complex result of freshwater influxes (stormwater), tidal flows, and other causes.

If nutrient levels within the lake increased significantly, this could also significantly affect the vegetation community currently found in the lake. Growth of the dominant species, *L. papulosum*, may be affected by high phosphate levels, which could result in decline of the species. Other species such as cyanobacteria and *Cladophora* sp. prefer high nutrient conditions, and if conditions changed in the lake such that nutrient levels increased, this may result in excessive growth of such species. Although not all species are toxic, excessive growth may affect other species by smothering or shading. The positioning of the brown alga currently found in the lake (family Chordariaceae), near a stormwater outlet suggests that biomass of this alga may increase in high nutrient conditions. An increase in cyanobacteria in the lake may result in blooms when suitable conditions (high temperature, stable water column, nutrients) occur. Cyanobacteria blooms are known to be toxic. Thus, although the species composition of the lake may not change due to increasing nutrient levels, the dominant species may. Changes in the vegetation community of the lake would affect faunal species that rely on the plants for food and shelter.

Presently the lower Myall River and wetlands serve as the main source for species found in the lake. The species composition of the lake may be expected to increase as the community becomes more complex with age. New plants may also be introduced into the lake by animals such as birds, while many freshwater invertebrates have aerial adult stages. There is a reasonable likelihood of achieving a healthy ecosystem with good water quality if a natural source of species is present. Many artificial lakes require considerable management, including the monitoring of water quality, to ensure that they do not become eutrophic (promoting the incidence of toxic cyanobacteria blooms) or deficient in dissolved oxygen.

The drain allows Myall River water to flow back into the lake during the highest tides of each month, benefiting water quality. During previous heavy rain in March 1997, the mullet population was washed out of the lake into the river. The present mullet, some of which exceed 20 cm length, are presumably juveniles that entered after that flood and have grown to their present size in the intervening year. Thus the lake can act as a supplementary growing area for populations of Myall River species.

4.5 Conclusion

The ecosystem within the lake is only two years old and communities within it are probably still maturing and may change in composition, abundance and distribution over time. Currently, a total of eleven plants (excluding *Juncus* sp.), nine fishes and one confirmed macroinvertebrate species are found in the lake, with a relatively uniform band of vegetation found in the shallow margin of the lake. The species are predominantly marine/estuarine species, although a few freshwater/brackish species (eg. *Nitella* sp., *Triglochin striata, Elatine gratioloides*) are also found. As the lake was not horizontally stratified, the distribution of species and communities did not appear to be influenced by salinity and nutrient levels. Based on oxygen and the nutrient levels (total phosphorus and nitrogen) Myall Quays Lake has good surface water quality, with conditions within the guidelines recommended for lakes and reservoirs by ANZECC (1992).

5. References

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Appendix 2.

Biological Study of Myall Quays Lake

Crighton Properties Pty Ltd

Draft Report

2002009

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Project Team

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Executive Summary

AMBS carried out an ecological survey of the Myall Quays Lake to assess the aquatic habitats present and determine changes to the assemblages since the baseline survey in 1998. An evaluation of the health of the lake was carried out by comparing historical water quality parameters with those recommended in the ANZECC Guidelines with relevance to the seagrass, macroalgae, fish and macroinvertebrates present.

Myall Quays Lake is contained within the Myall Quays development which is located near Tea Gardens, north of New Castle. It was constructed as a detention basin to serve the needs of adjoining residential development.

Generally the ecological assemblages within the lake can still be considered to be maturing. The lake appears to be influenced more strongly by rainfall events than tidal inundation and as a result the salinity concentration within the large are variable. It can be concluded that the variable water parameters are influencing the species able to inhabit the lake and conditions are more favourable to those able to with stand extreme fluctuations in salinity levels. While some water quality parameters such as dissolved oxygen and faecal coliforms are not within the recommended guidelines further monitoring is required to determine the effects of these variations.

During the study seven species of fish were collected. The lake appears to be supporting a small number of resident fishes that are probably present year round and breed within the lake. These fishes include the flathead gudgeon, dwarf flathead gudgeon, blue-spot goby and southern blue-eye.

The aquatic flora of the lake is maturing and has become more widespread throughout the lake. Four species of aquatic plants (excluding riparian plants) were present in the lake during this survey, the dominant seagrass *Ruppia polycarpa* and three macroalagae; *Lamprothamnion papulosum*, *Chara spp* and *Ulvaria oxysperm*.

Contents

1 Introduction

Australian Museum Business Services (AMBS Consulting) carried out a baseline biological survey of the Myall Quays Lake for Crighton Properties in 1998. This survey of the ecological assemblages of the lake was conducted in September 2002 to determine changes to the lake environment that may have occurred since the baseline study. The Myall Quays Lake is located within the Myall Quays development near Tea Gardens, north of Newcastle. The lake was constructed as a detention basin to serve the needs of the surrounding residential development.

The scope of the study was an ecological survey of the lake to assess the current habitats present and determine changes to the assemblages since the previous survey. An evaluation of the health of the lake was carried out by comparing historical water quality parameters with those recommended in the ANZECC Guidelines.

2 Project objectives

This study aimed to;

- Survey the existing fish, seagrass, macrophyte, macroalgae and macroinvertebrates present in the Lakes;
- Compare current ecological assemblages with those present during the baseline survey;
- Map current lake vegetation;
- Analyse historical water quality data with relation to rainfall and tidal influence;
- Discuss water quality parameters with relevance to community assemblages and
- Provide advice for future lake management decisions.

3 Background Information

The baseline survey was conducted in 1998 when the lake was two years old and the communities within it were maturing. Previously 11 plants, nine fishes and one macroinvertebrate species were collected from the lake. The species were predominantly marine/estuarine species. The distribution of the species did not appear to be influenced by water quality parameters. The water quality of the lake was within the recommended ANZECC Guidelines.

4 Methodology

4.1 Review of Available Water Quality Data

Hunter Water Laboratories have collected water quality parameters from the lake since 1996 and the most recent available data was sampled in April 2002. AMBS reviewed and analysed the data collected since the previous report (02.04.98-11.4.02) and compared the results with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC Guidelines) and the previous water quality analyses. As only single water quality samples were taken at each site, no data was available to determine the vertical stratification of the lake or variation between replicate water samples.

Rainfall data for the lake was provided by Crighton Properties and was compared with the water quality results to determine any existing relationship between the two. Tidal information was sourced from the Department of Defence Australian National Tide Tables for Newcastle and was compared with the water quality results to determine any existing relationship between the two.

4.2 Site Locations

Sampling was undertaken at the sites previously surveyed. A map of the locations is included in Appendix A and site photographs are included in Appendix B;
Site 1a: North western end of lake
Site 1b: North western from the office
Site 2: In front of the office
Site 3: Eastern end of the lake near the drain entrance
Site 4: Near the drain

4.3 Seagrass and Macroalgae

4.3.1 Field

AMBS staff mapped five previously surveyed representative transects in the lake to determine the extent, pattern of cover and species composition of the seagrass, macrophyte and macroalgae communities. The abundance and distribution patterns of the vegetation were determined using the abundance/sociability scale (King and Barclay 1987) below, used previously to allow comparisons to be carried out. The plants were identified in the field and some macroalgae samples were transported to experts at the Royal Botanical Gardens for confirmation.

Table 1. Seagrass Abundance and Sociability Scale (based on King and Barclay 1986)

		Sociability	
Abundance	A	B	C
	Individuals	Patches	Beds relatively even distribution
1			
Sparse Growth (<15%)	A1	B1	C1
2			
Moderate Growth (15-50%)	A2	B2	C2
3			
Abundant Growth (>50%)	A3	B3	C3

4.3.2 Mapping

The seagrass beds were mapped using MapInfo.

4.4 Fishes

4.4.1 Field

AMBS staff used a variety of techniques to sample fish from the five sites. Based on habitat characteristics of the sites the techniques used included electrofishing, a 10m seine, Japanese seine and a fine mesh seine. These techniques are described below;

- **Electrofishing** was undertaken using a Model 12-A POW Smith Root Backpack
- **A 10 metre seine** was operated by two people walking towards the shore from about 1m depth, each holding a pole at either end of the net. This net was also operated using a row boat which allowed a greater water depth to be sampled.
- **A Japanese seine** is a small one-person collecting device which consists of two poles separated by a fine-meshed scooped net. The operator can effectively collect small fishes from stream banks and many areas that larger seines are ineffective.
- **A Fine mesh seine** is a two-person mesh net of about 2-3m in length and about 1m in height. This seine has very fine mesh and is therefore useful for collecting small fishes which may escape through the mesh of larger seines.

The fishes that were collected were identified in the field where possible and returned to the water. Any specimens unable to be identified in the field were preserved in 10% formalin and returned to the laboratory for identification. The fishes were transferred from 10% formalin to 70% alcohol after about one week.

4.4.2 Laboratory

Fishes collected that were less than 5cm could not be accurately identification in the field to species level. These were returned to the museum for identification under microscopes.

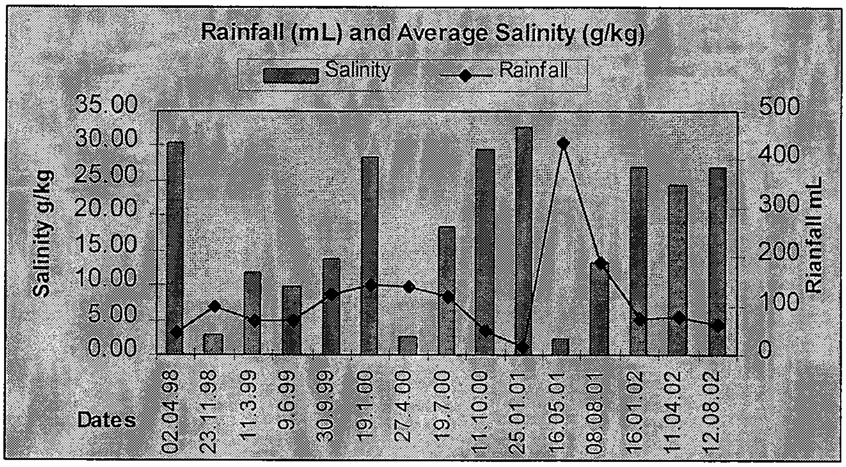
5 Results

5.1 Water Quality

5.1.1 Salinity

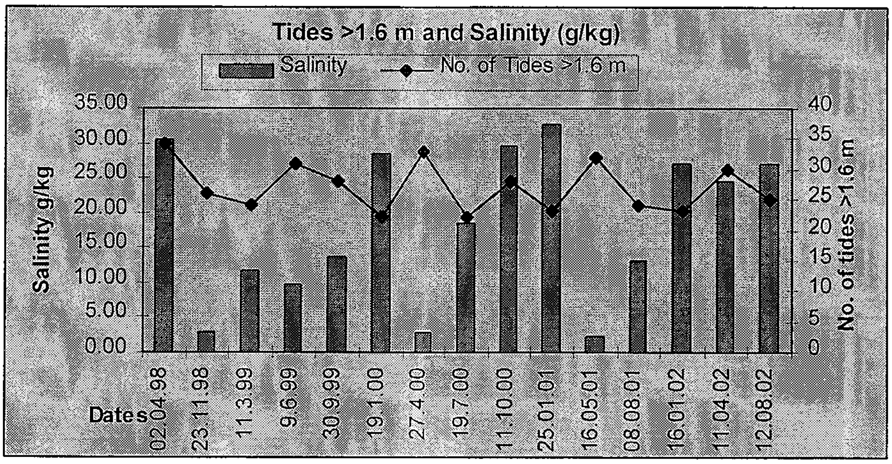
The average salinity in the lake ranged from 2.22 to 32.81. On average salinity levels have remained similar to the previous survey, however, fluctuations and periods of low salinity have increasingly occurred.
The salinity data was compared with rainfall totals for the month preceding the sampling to determine whether rainfall was influencing salinity levels in the lake. The lowest level of salinity occurred in 2001 following a period of high rainfall and the most saline sample was collected following a month of low rainfall. There would appear from the data to be a relationship between rainfall and salinity levels.

Figure 1 Salinity and Average Rainfall



The salinity data was compared with tidal influence by calculating salinity levels with the number of tides > than or equal to 1.6 metres in the month preceding the sampling event. There did not appear to be a relationship between the number of high tides and levels of salinity in the lake.

Figure 2 Tidal Influence and Salinity

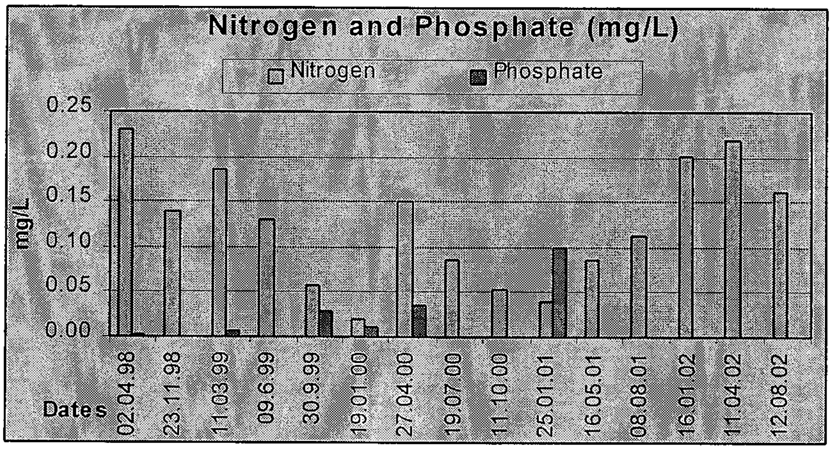


5.1.2 Nutrients

Nutrients in the environment are composed of phosphorus (P) and nitrogen (N). Levels of phosphorus and nitrogen in a water column are useful measures of the potential for nuisance plants to grow. Since the baseline survey phosphorus was measured as mg/L and the most bioavailable form of phosphorus, orthosphosphate was not analysed. Phosphate levels cannot be compared to the ANZECC Guidelines as the samples were filtered and do not include orthophosphate. Similarly, the oxidised nitrogen mg/L was measured without kjeldahl nitrogen so comparisons with the ANZECC Guidelines cannot be made.

General indications of trends relating to nutrient levels have been calculated using oxidised nitrogen, ammonia, and nitrates and phosphate (levels below .005 were considered as zero for nitrates and .01 for phosphate). On average levels of phosphate were low. The nitrogen levels on average reduced during 2000 but began increasing in 2001.

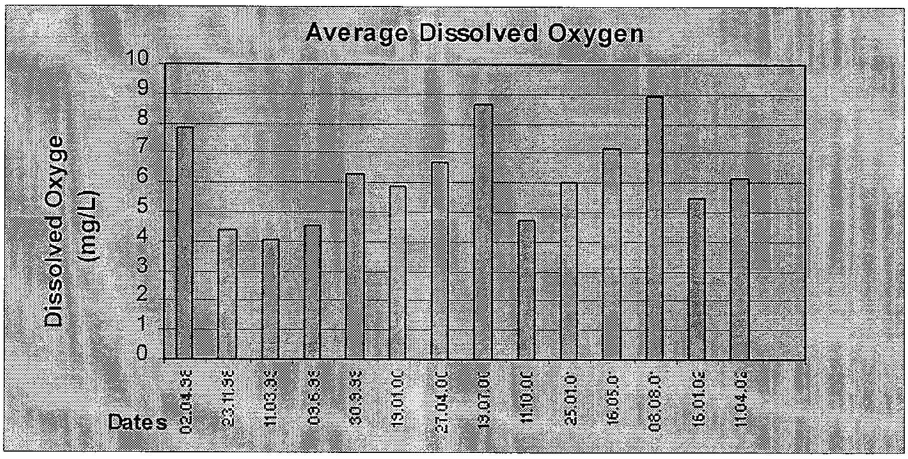
Figure 3 Average Nutrient Levels



5.1.3 Dissolved Oxygen

Average dissolved oxygen levels in the lake ranged from 4.4 -8.92 mg/L during the sampling period. The ANZECC Guidelines have set a default trigger range of 80-110% saturation levels for slightly disturbed estuarine environments. Levels of 6 mg/L and above will fall within the recommended guidelines. On average during half of the sampling events DO levels fell below the recommended guidelines. During the baseline survey all samples of DO fell within the recommended guidelines.

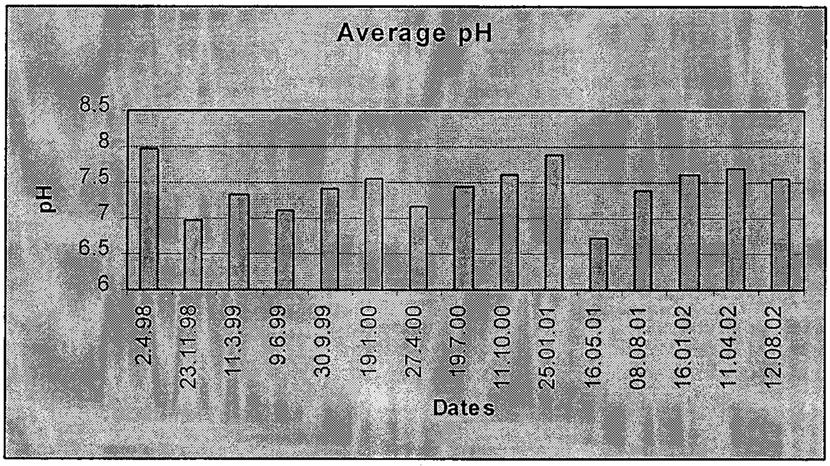
Figure 4 Average Dissolved Oxygen



5.1.4 pH

pH is the measure of the acidity or alkalinity of water on a scale of 0 (extremely acidic) to 7 neutral to 14 (extremely alkaline). The pH of natural fresh waters range from 6.5-8.0 and marine waters are commonly closer to 8.2. The average pH in the lake ranged from 6.72 -7.98, and values remained fairly consistent over the sampling period. On average the pH values of the lake were within the recommended guidelines for pH levels in estuarine environments.

Figure 5 Average pH Levels



5.1.5 Faecal Coliforms

Based on the ANZECC Guidelines for recreational water quality for primary contact the median bacterial content of fresh or marine waters should not exceed 150 faecal coliform organisms/100mL and 1000 organisms for secondary contact. Generally the levels were within the recommended guidelines but during five sampling events the faecal coliforms exceeded levels considered safe for primary contact such as swimming (Figure 6). It appears that the spikes in faecal coliform levels in the lake followed periods of rainfall. On average the lake did not exceed the recommended guidelines. Site 2 most commonly had the highest levels of coliforms. (Figure 7)

Figure 6 Faecal Coliforms

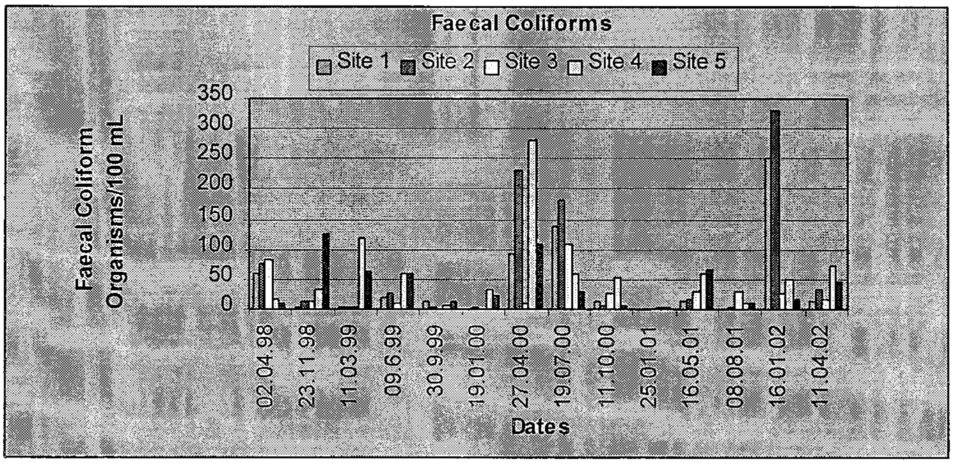
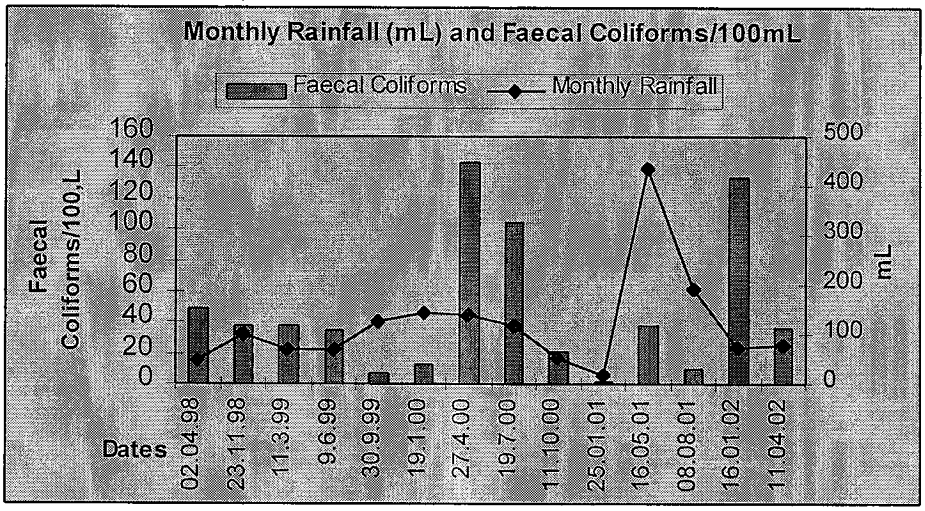


Figure 7 Monthly Rainfall and Faecal Coliforms



5.2 Seagrass and Macroalgae

The following aquatic flora were present in the lake:

5.2.1 Seagrass

Ruppia polycarpia (Sea Tassel)
Commonly grows in coastal lakes and lagoons at similar or lower salinities than seawater. *Ruppia polycarpa* is the most dominant species in Myall Quays Lake.

5.2.2 Aquatic Angiosperms

Triglochlin striata (Streaked Arrow Grass)
This is a useful stabilising species growing in tidal and freshwater swamps (Sainty & Jacobs, 1994). *Triglochlin striata* was found growing around the banks of the lake particularly in the north western end of the lake.

Family Caryophyllaceae
Paronychia brasiliana
Polycarpon tetraphyllum (Four leaved Allseed)
These plants were considered riparian and will not be discussed. *P. tetraphyllum* is a native to Europe.

Juncus spp. (Rushes)
These rushes surround the lake along the shoreline. They were not identified further as they were not growing in the lake.

5.2.3 Macroalgae

Chlorophyta (Green Alagae)
Ulvaria oxysperma

No information regarding this species could be sourced from the Royal Botanic Gardens. *U. oxysperma* was present in the shallows along the north western shoreline of the lake.

Charophytes (Stoneworts)
Chara spp
Is a native algae is found in lakes or slow moving water where calcium levels are high. *Chara* spp is present from the middle of the lake to the eastern end.

Lamprothamnion papulosum (Foxtail stonewort)
This stonewort is commonly associated with saline lakes in Australia in conditions ranging from relatively fresh to brine salt water salinities. This species is noted for its tolerance to salt water. *L. papulosum* was present only in the north western end of the lake in the shallows.

5.2.4 Distribution

A map of the distribution of the aquatic flora is presented in Appendix C. The vegetation of Myall Quays Lake was dominated by the seagrass *Ruppia polycarpa* in beds that included the charophytes; *Lamprothamnion papulosum* in the west and *Chara* spp in the middle and eastern ends of the lake. The beds were almost continuous across most of the lake thinning to the lake edges towards the eastern end of the lake. At the western end *Ulvaria oxysperma* was present in a shallow band around the lakes edge. The *L. papulosum* at the western end of the lake was present as sparse individual plants in the *R. polycarpa* bed extending to 25 metres from shore. The rest of the lake was dominated by *Chara* spp and *R. polycarpa* that formed beds covering the width of the lake. The seagrass beds were generally continuous ranging in densities from individual plants to very thick beds. Towards the eastern end of the lake the beds gradually became closer to shore. These eastern beds were dominated by gradually thinning *R. polycarpa.*

5.3 Fishes and Invertebrates

Fishes were collected at each of the five sites (1a, 1b, 2, 5 and 6). No fishes were returned to the water as all fishes were less than 5 cm and could not be accurately identified in the field to species level. The techniques carried out included electrofishing (no fishes caught), 10m seine (few gudgeons caught), Japanese seine (few gudgeons and gobies caught) and a fine mesh seine (most fishes were collected using this net). A small school of mullet (family Mugilidae) was seen, but not collected at site 6. All specimens are registered in the Australian Museum Fish Collection, under the station numbers, I. 41538 - I. 41542
Seven species of fishes representing six families were recorded from the lake. A total of 304 fishes were collected. The dominant fish species in the lake in terms of numbers collected was the blue-spot goby *Pseudogobius* sp., with 203 specimens collected (approx. two-thirds of all fish collected). The blue-spot goby was present at all sites. The next most dominant fish species in terms of numbers collected were the dwarf flathead gudgeon *Philypnodon* sp. (39 specimens from 4 sites), southern blue-eye *Pseudomugil signifer* (30 specimens from 3 sites) and flathead gudgeon *Philypnodon grandiceps* (24 specimens from 4 sites). The two other fish species

collected (Mosquitofish *Gambusia holbrooki* and Common jollytail *Galaxias maculatus*) were represented by 4 or less specimens and were only present at one site each.
The following fishes were collected from the lake;

Family Galaxiidae (Galaxiids)
Galaxias maculatus (Common jollytail)
Site 2: 1 specimen 33mm standard length
The common jollytail is very common in the coastal drainages of mainland south-eastern Australia (southern Qld to Adelaide, SA), Tasmania and southern WA (Denmark to Esperance). It is also known from Lord Howe Island, the Chatham Island, New Zealand, Argentina, Chile and the Falkland Islands. It is found in a variety of habitats, but most commonly occurs in still or gently flowing water of streams, rivers and lakes at low elevations. It has a high salinity tolerance and can live in fresh or seawater. This species is an important component of whitebait fisheries throughout the Southern Hemisphere. Adults typically migrate downstream into estuaries during high spring tides in autumn to spawn on fringing vegetation.

Family Poeciliidae (Livebearers)
Gambusia holbrooki (Mosquito Fish)
Site 6: 4 specimens: size range 19-22mm standard length
The mosquito fish is an exotic species, introduced into Australia from the USA in the 1920's. It is widespread and abundant throughout NSW, SA and Vic. in both inland and coastal drainages, and coastal Qld. It is also known from parts of WA. Mosquito fish tolerate a wide range of salinities from pure fresh water to full marine salinities. It is most abundant in warm and gently flowing or still waters, mainly around margins and along the edges of aquatic vegetation beds. It feeds on a wide array of both terrestrial and aquatic organisms. It is an adaptable generalist predator that may be a threat to other small fish species into whose habitat it has been introduced or spread. It has also been implicated in the reduction of green and golden bell frogs, presumably by feeding on the tadpoles.

Family Pseudomugilidae (Blue eyes)
Pseudomugil signifer (Southern Blue eye)
Site 2: 7 specimens: size range 12-25mm standard length
Site 5: 2 specimens: size range 24mm standard length (both specimens)
Site 6: 21 specimens: size range 12-17mm standard length
The southern blue-eye is widespread throughout eastern drainages, from Cooktown (northern Qld) southwards to Narooma, NSW. It is abundant in fresh or brackish coastal waters, but does not penetrate far inland and is usually found within 15-20km of the sea. It has been found in water temperatures of 15-28°C and pH values of 5.5-7.8.

Family Mugilidae (Mullets)
Mugil cephalus (Sea Mullet)
Site 2: 4 specimens: size range 19-28mm standard length
Sea mullet occur worldwide in tropical and temperate seas. It occurs along the entire Australian mainland coastline and northern Tasmania. It is primarily a coastal marine fish but frequently enters the lower reaches of large rivers. Large schools migrate along ocean beaches, leaving the estuaries to spawn offshore. Small schools of

juveniles enter rivers, as do adults occasionally. The species can survive for more than one year in freshwater. It is an important commercial species.

Family Gobiidae (Gobies)
Pseudogobius sp. (Blue spot goby)
Site 1a: 47 specimens: size range 9-22mm standard length
Site 1b: 31 specimens: size range 13-19mm standard length
Site 2: 58 specimens: size range 12-28mm standard length
Site 5: 28 specimens: size range 16-28mm standard length
Site 6: 39 specimens: size range 13-37mm standard length
Although this species is undescribed it is not uncommon. It is distributed from Bundaberg (southern Qld) southwards to the Victoria/SA border and is also in northern Tasmania. It occurs in coastal estuaries, coastal lagoons and swamps near the sea and usually inhabits aquatic vegetation over sand or mud.

Family Eleotrididae (Gudgeons)
Philypnodon grandiceps (Flathead gudgeon)
Site 1b: 2 specimens: size range 22-33mm standard length
Site 2: 3 specimens: size range 17-48mm standard length
Site 5: 11 specimens: size range 21-40mm standard length
Site 6: 8 specimens: size range 18-31mm standard length
The flathead gudgeon is widespread and common in the Southeast Coast Drainage Division between the Burdekin R. (Qld) and the Murray River mouth (SA), extending inland throughout the Murray Darling system. It is also found at Kangaroo Island (SA) and occasionally on Tasmania's northern coast. Adults feed on small fishes, crustaceans, insects and tadpoles. It attains a maximum size of 12cm and commonly occurs to 8cm.

Philypnodon sp. (Dwarf flathead gudgeon)
Site 1b: 5 specimens: size range 14-23mm standard length
Site 2: 4 specimens: size range 20-30mm standard length
Site 5: 24 specimens: size range 14-27mm standard length
Site 6: 6 specimens: size range 17-22mm standard length
This species is undescribed, but has been known to scientists for many years. It occurs in coastal streams of southern Qld, NSW, Victoria and SA. It is found in brackish waters in estuaries to altitudes of a few hundred metres and is common in coastal northern areas of its range. It prefers relatively calm waters and lives over mud, rocks, woody debris or in weedy areas. This species is carnivorous, feeding on a wide variety of insects, larvae and micro-crustaceans. It attains a maximum size of about 5cm and commonly occurs to 3.5-4 cm.

PHYLUM MOLLUSCA

Family Amphibolidae
site 1a: 14 specimens collected by fine mesh seine
site 6: 3 specimens collected by fine mesh seine
Salinator fragilis is a small snail (maximum size of about 1cm)
Salinator fragilis is a small snail restricted to estuaries and coastal lagoons. It has a thin, fragile shell with a narrow band around the edge and is an air-breather. It is often abundant on sand and mudflats and occurs in all Australian states (Ponder et al. 2000).

Family Hydrobiidae
site 1b: 1 specimen collected by fine mesh seine
site 2: 1 specimen collected by fine mesh seine
site 6: 16 specimens collected by fine mesh seine
Tatea rufilabrus is a small gastropod shell (maximum size about 5mm) that is restricted to estuaries and coastal lagoons, being found in association with algae and other plants, in leaf litter, under logs and rocks. It has a tall spire with many whorls. It is distributed from southern Qld to southern WA and Tasmania (Ponder et al. 2000).

6 Conclusions

Myall Quays Lake is now six years old and changes to the water quality parameters, ecological communities and habitats have occurred as it has matured.

6.1 Water Quality

Water quality parameters have been sampled from five sites within the lake since 1996. As previously, the lack of replication at each sampling site makes it difficult to assess variability at each site or vertical stratification of the lake environment. Vertical stratification, especially saline or dissolved oxygen levels, can significantly affect the composition and distribution of the biological assemblages.

The salinity levels of the lake are similar to those collected during the baseline survey and are typical of an estuarine environment. The salinity levels fluctuate more widely than previously and the lake experiences periods of almost freshwater conditions. The lake is influenced by runoff, groundwater, stormwater, saline river water inputs and vertical stratification of salt and freshwater after heavy rainfall. It would appear from the data analyses that rainfall levels have a greater influence on levels of salinity in the lake than tidal influences. It is unknown wether the low levels of salinity during certain sampling events are a result of flushing by rainfall events or increased stratification of the water column. The fluctuations in saline concentrations of the lake would effect the ecological assemblages of the lake by making the environment favourable only to species adapted to survive in highly variable saline conditions.

The nutrient samples collected could not be compared to the baseline survey or the ANZECC Guidelines due to the omission of certain components necessary for comparisons. Nitrogen levels deceased during 2000 but started increasing towards 2002. Generally it is known that nitrogen is the nutrient that limits plant growth in marine environments and sometimes in estuarine environments where salinity is low or variable.

Dissolved oxygen levels in the lake are considered depressed when compared with the baseline survey and the recommended Guidelines for estuarine environments. During the baseline survey dissolved oxygen levels were within the recommended guidelines but levels collected during subsequent sampling events were below the recommended levels and generally the dissolved oxygen levels have decreased over time. Dissolved oxygen concentrations measured in the lake reflect the equilibrium between the oxygen consuming processes (respiration) and oxygen-releasing process (eg. photosynthesis). The dissolved oxygen levels sampled indicate that there is a disturbance to these processes. Dissolved oxygen levels are highly dependent on temperature, salinity, biological activity and rate of transfer with the atmosphere. It is common in highly productive systems such as estuaries to have periods of oxygen depletion particularly where stratification occurs. Dissolved oxygen levels are highly influenced by diurnal variety particularly where significant levels of nutrient enrichment occurs. Low levels of dissolved oxygen have the potential to adversely effect fishes. While DO levels are depressed on average in the lake, this could be caused by a variety of reasons such as nutrient enrichment of the lake, stratification, atmospheric absorption and diurnal variation relating to sampling timing. Generally average DO levels are below those recommended in the ANZECC guidelines.

The pH levels in the lake on average fell within the recommended guidelines for marine and aquatic assemblages.

Levels of faecal coliforms present in the lake were above the recommended guidelines for recreation and primary contact on a number of occasions during water quality sampling. A number of reasons for the high levels of coliforms present in the lake were suggested by NSW Health including; rainfall events, septic tank seepage into the environment, stormwater input and urban runoff. Rainfall did appear to influence the average levels of coliforms present in samples. Levels were highest at site 2 near the office while site 1 near the stormwater drain did not experience levels as consistently high. So conclusions as to the exact entry of coliforms into the lake could not be established.

NSW Health indicated that levels such as those recorded are not unusual and are common following rainfall events. It is recommended that following rainfall events primary contact with lake water is avoided for 48 hours. (pers comm NSW Health). The commonly high levels of coliforms in the lake have the potential to increase nutrient levels in the water column and result in blooms of nuisance algae species.

6.2 Seagrasses and Macroalgae

Four species of aquatic plants (excluding riparian plants) were present in the lake during this survey, the seagrass *Ruppia polycarpa* and three macroalagae; *Lamprothamnion papulosum*, *Chara spp* and *Ulvaria oxysperm*. The baseline survey identified seven aquatic species (excluding riparian plants) present including *R. polycarpa and L. papulosum*. The number and type of species present and their distribution and densities have changed since the baseline survey. The seagrass *R. polycarpa* is the dominant plant throughout the lake forming continuos beds across the lake. The previously dominant *L. papulosum* has become restricted to sparse beds in the western end of the lake and has been replaced by the similar charophyte, *Chara spp* in the middle and eastern end of the lake. During the baseline survey the beds were restricted to the shallows along the shoreline but now plants are present throughout much of the lake only narrowing to the lake edges in the eastern end.

The increased colonisation of *R. polycarpa* may be related to the salinty fluctuations experienced within the lake. This seagrass is adapted to wide ranges in freshwater and saline conditions enabling it to thrive in variable saline conditions.

The Charophytes, *L. papulosum* and *Chara spp* prefer nutrient poor, calcium rich environments and are highly sensitive to nutrient enrichment. While *Nitella subtilissima* is no longer present in the lake *Chara spp* appears to be flourishing. Charophytes are now present throughout the lake and their increased colonisation may be the best indication that faecal coliforms influxes have not significantly increased nutrient levels in the lake. Likewise, no blooms of nuisance macroalgae species such as *Cladophora sp* have occurred that would indicate nutrient enrichment, rather this species is no longer present in the lake.

6.3 Fishes and Invertebrates

Seven species representing 6 families were recorded from the lake as compared to nine species during the baseline study. A total of 304 fishes were collected compared to 839 during the baseline study. This difference could be partly related to the use of slightly differing sampling techniques or differing abundances of fish species in different seasons (the baseline survey was completed in January and this survey was undertaken in September). As was outlined in the baseline survey, the lake is still young and changes in the faunal composition of the lake are not surprising. The physical (eg habitat) and chemical (eg salinity, pH) variables controlling fish occurrences and abundances appear to be still changing in the lake.

Two species collected in the most recent survey that were not collected in the baseline survey were the flathead gudgeon *Philypnodon grandiceps* and the saline tolerant common jollytail *Galaxias maculatus.* Three species of goby and the common silver belly were collected during the baseline survey but were not collected during the most recent survey. The wide range of salinities recorded in the lake would favour estuarine species that can tolerate such changing conditions. It is expected that if fish sampling were undertaken on a more regular basis, more species would be recorded than have been on the previous two occasions. It is likely that some fishes are not permanent residents of the lake and only enter it when conditions are favourable to their needs.

The Myall Quays Estate Lake appears to be supporting a small number of resident fishes that are probably present year round and breed within the lake. These fishes include the flathead gudgeon, dwarf flathead gudgeon, blue-spot goby and southern blue-eye. Sea mullet may only be present in considerable numbers at specific times of the year and probably migrate out of the lake to spawn at sea.

6.4 Summary

The ecosystem within the lake is now six years old and the water quality and ecological communities within it have changed in composition, abundance and distribution over time. The species present in the lake are adapted to a changing physical environment, with fluctuations in salinity, nutrients and dissolved oxygen occurring as a complex result of freshwater influxes (rainfall and stormwater), tidal flows and other causes.

The physical characteristics of the lake appear to have changed since the baseline survey. The lake appears to be less effected by tidal influence and increasingly by rainfall events. While salinity levels within the lake have remained similar in general to the baseline survey, the lake experiences extreme fluctuations in concentrations following rainfall events. At times the lake experiences conditions of almost freshwater ranges. This will effect the species able to live in the lake. pH levels fall within the recommended ANZECC Guidelines, however the dissolved oxygen levels appear to be becoming depressed over time. On average levels of faecal coliforms within the lake have been within the guidelines, however on a number of occasions during sampling events total levels have been above those recommended for primary contact.

During the study seven species of fish were collected. The lake appears to be supporting a small number of resident fishes that are probably present year round and breed within the lake. These fishes include the flathead gudgeon, dwarf flathead gudgeon, blue-spot goby and southern blue-eye.

The aquatic flora of the lake is maturing and has become more widespread throughout the lake. Four species of aquatic plants (excluding riparian plants) were present in the lake during this survey, the dominant seagrass *Ruppia polycarpa* and three macroalagae; *Lamprothamnion papulosum*, *Chara spp* and *Ulvaria oxysperm*.

7 Recommendations

AMBS suggest that water quality sampling of the lake continue and that future samples be replicated within the sites to allow more stringent statistical analysis. The sampling should include orthophosphate and kjeldahl nitrogen so that nutrient levels can be compared to the ANZECC guidelines. The monitoring of nutrient levels could prove important in the future to monitor the effects of runoff of faecal coliforms into the lake.

Based on the ANZECC guidelines for recreational water quality on a number of occasions in the last few years the faecal coliform levels in the lake were above the recommended levels for primary contact (swimming). These guidelines direct that a minimum of five samples are taken at regular intervals not exceeding a month and four out the five samples must contain less than 600 organisms/100mL. AMBS suggest that Crighton Properties regularly monitoring the lake for faecal coliforms following rainfall events following the sampling frequency above.

AMBS suggest that monitoring of the ecological assemblages of the lake continue to be carried every few years. Assessments of fish habitat in the lake and inflowing waters may help to provide information on the suitability of any necessary habitat changes.

Further fish surveys at more regular intervals would confirm or deny whether the above mentioned fishes are permanent residents. As the lake currently only has a small number of habitats (i.e. mainly sand, mud, algae), the introduction of new habitat such as growing mangroves at the seaward end may encourage more fishes into the lake. There is currently little protection for larger fishes (ie over 10cm) within the lake from bird predation. The introduction of additional native aquatic vegetation (eg. mangroves) or artificial habitat (eg woody debris or artificial structures) may encourage the growth and survival of fishes by providing shelter and food.

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Appendix A Site Locations

Appendix B Site Photograph

Appendix C Maps of Aquatic Vegetation

Appendix 3.

Appendix 3.

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Freshwater ecology and fisheries

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10 August 2002

ECOLOGICAL PRINCIPLES AND DEVELOPMENT OPTIONS FOR THE MYALL QUAYS WATERWAY

Background

The success of the Myall Quays development will be judged by the natural values that it supports and these values can be optimised by integrating environmental, social and commercial principles. Planning for the development should be based on an understanding of the principles that govern the ecology of comparable brackish lagoon systems, as well as the engineering, town planning and other considerations. The following notes aim to outline the aquatic ecological principles that should be considered and planning options that may be available. They are underpinned by the assumption that water is the key resource to be managed for best usage, rather than a waste product of development or a problem to be dealt with. Key objectives include biological diversity, fisheries-based recreational opportunities and environmental amenity for residents.

The tidal and saline regimes will drive ecology

The most basic planning issue for the aquatic system relates to the levels of salinity and tidal flushing, and their variations. Clearly, these attributes will be dynamic and result from the interaction of freshwater runoff, groundwater and incursions from the Myall River estuary via the small connecting drains from the lake.

The tidal and saline regimes will drive the waterway's ecology, determining the types of plants and animals that can be supported, and their patterns of diversity and abundance. If it were possible to create full tidal ventilation, the system would come to mimic that seen in the adjacent estuary. At the other extreme, if tidal incursion were prevented, a freshwater system similar to the existing runoff detention ponds would result. For several reasons, a saline regime intermediate between these two extremes seems desirable. Other regional brackish systems such as Smiths Lake or the Mall Lakes provide potential models. It is important to recognise that, in practice, the saline regime will vary substantially as the various controlling inputs change with the weather and tides. Reflecting this variation, the waterway's ecology will also be dynamic, with only a limited range of plant and animal species able to cope with these fluctuating conditions.

Towards the saline end of the water-quality spectrum, those fish that are 'euryhaline' – meaning they can tolerate changing salinities - will dominate the wetlands fish community. Typically they might include two or three mullet species, estuarine herring, two eels, bream, silver biddies, blue-eyes, gobies and perhaps flathead and a few other infrequent species. Alternatively, a predominantly freshwater system would occasionally support some of these species plus two or three gudgeons, smelt, eels and Australian bass. The level and stability of the saline regime would similarly determine the composition of aquatic vegetation and the invertebrate fauna.

A desirable management objective would be to represent a variety of aquatic systems. This could be achieved by maintaining tidal, saline conditions in the lagoon while promoting a freshwater 'riverine' regime in the in-flowing tributary sections. Such a combination would enhance biological diversity, visual amenity and recreational opportunities for Myall Quays residents.

Options for managing saline and tidal regimes

Each of the key inputs – runoff, groundwater and tidal incursion – are more or less amenable to planned manipulation to achieve an optimal outcome. Runoff can potentially be detained or diverted to some degree, groundwater could (in theory at least) be raised or lowered, and tidal incursion through the drains can be restricted or enhanced. These possibilities suggest some useful management and design options.

1. Tidal control

It appears highly desirable to install facilities to control the extent of tidal incursion through the lagoon's drains. This would allow the lagoon's water levels and water quality to be manipulated. If it were appropriate, salinity could be regulated closer to that of the adjacent Myall River. Potential problems such as nuisance blooms of algae or low dissolved oxygen could be managed directly by tidal flushing should they occur.

A simple 'drop-log' control structure would be needed to control tidal incursion. These are simple concrete 'U'-shaped structures, slotted to carry timber or concrete drop-logs, and sized to conform to the drain. Manually adding or removing drop-logs can either increase or reduce the amount of tidal incursion. The maximum height needed would be the median high-tide level, so that visual impact would be slight. It might be desirable to control both the main drains from the lagoon.

To optimise control over water quality, it would be desirable to deepen the drains slightly so that greater tidal flow can be available if needed. Deepening by 300mm – 400mm would probably be sufficient.

2. Limiting upstream salinity

To produce stable freshwater conditions in the tributary riverine reaches of the waterway it will be necessary both to design appropriately sized channels and also to control saline inputs to these upstream areas. The number and surface area of these riverine areas may need to be modelled in order to balance them against the frequency and volume of runoff events and to maintain water quality by continued through-flow. But it seems clear that only a small number (one, two or three) should be created, perhaps with a long, sinuous path to enhance their individual area. A uniform, low gradient is needed to ensure outflow, and this could resemble the upper Myall River reaches above Bulahdelah.

In the diverse, freshwater/brackish waterway system suggested, salt intrusion into the riverine areas from the lagoon would need to be prevented. This would arise from gravity-driven saline stratification in the lagoon, and could be prevented by creating a shallow sill at the junction of each riverine tributary with the lagoon. A narrow rocky sill across the stream, perhaps built with rip-rap material over a clay core, should limit depth to about 300mm at this point. This would prevent deep saline layers from intruding upstream and help maintain freshwater conditions. Similar sills might also be desirable upstream to retain stable freshwater pools.

Aquatic habitats should be optimised

The diversity of aquatic habitats will determine the biological diversity that can be supported by the waterway. Similarly, the quantity of habitat will control the abundance, diversity and resilience of biological populations. Of course, both these quantity and quality relationships depend on the assumption that water quality will be maintained at suitable levels of dissolved oxygen, pH, nutrients, toxicants and salinity and these conditions should be encouraged by enhancing tidal flushing of the lagoon. Continuing effective operation of the small runoff-treatment ponds is also clearly important.

In the suggested freshwater/brackish system, habitat quality can be predicted from several key attributes: depth, physical structure (including macrophyte growth), the nature of substrates, and the extent of the littoral zone (i.e. the near-shore areas where the land and water meet). Flow velocity is unlikely to be a significant factor except in and adjacent to the drains or during extreme-runoff periods. Creating diversity should be a guiding principle in planning the design of the key attributes.

Options for enhancing the amount and quality of habitat

Depth profiles should be varied as much as practicable while bearing in mind the need to ensure adequate flows and mixing. The littoral zone is a critical area for food-web production, mainly based on the growth of algae and macrophytes, so that extensive areas with low-gradient batters are valuable within the upper one metre of the water column.

Physical structure is a critical aspect of habitat and can be derived from several sources. Submerged logs and mounds of rockwork would both provide valuable structure, especially when distributed in the upper two metres of the water column. Within practical limits, the more structure, the better.

Beds of macrophytes and algae can also contribute greatly as structural habitat and food-web source areas. Their growth will be determined by the stability of water quality and other factors. In creating the waterway it would be important to introduce desirable aquatic plants early in the process to pre-empt weed growth. Desirable plants in the brackish zone could include Ruppia and Zostera, with Phragmites and Vallisneria in freshwater areas. Emergent littoral rushes and reeds should also be experimentally planted. It could be productive to engage a botanical consultant to provide detailed advice on these aspects.

Options to incorporate diverse substrates seem limited, given the sandy character of the area, other than for the rockwork mounds suggested earlier. But this aspect deserves consideration in any underwater structural works such as culverts. Rip-rap and other rock-based construction methods will contribute far more habitat value than formed concrete.

The size of the littoral zone can be increased in the lagoon by creating a complex, strongly curved shoreline, with many small bays and inlets. A sinuous stream path would have the same effect in the riverine section. These simple options can produce substantial habitat benefits and will also enhance visual amenity.

Fringing terrestrial native plants, including trees, shrubs, rushes and grasses, contribute to food resources for many fish. They also reduce temperature fluctuations, control excessive wind effects and contribute greatly to amenity. Landscaping options should be investigated, using local native plant communities as a guide.

The network of small runoff-treatment ponds also has potential habitat value. Enabling fish passage over their small control weirs could activate this. A suitable device would be a small-scale rock-ramp fishway on a slope of 1:20.

Recruitment processes control fish populations

Recruitment involves the addition of new individuals to the populations. These counteract population losses from emigration and mortality. Three sources of recruitment are possible in the Myall Quays development.

1. Immigration from the Myall River

Estuarine fish species will enter and leave the waterway via the drains. Fish of many species will enter as juveniles, grow for a period in the lagoon, and then emigrate, often to spawn elsewhere. Mullets, bream, eels and herring are examples.

2. Local spawning

Some species, especially the smaller ones like gobies, smelt and gudgeons, are likely to spawn and recruit within the waterway. The extent of this local recruitment will depend on availability of suitable habitat, especially plant beds and rocky substrates, together with an appropriate water quality.

3. Fish stocking

Some success has already been reported with the stocking of hatchery-propagated Australian bass, and this is a way of maintaining numbers of this popular species. Wild bass may colonise the waterway naturally, but local populations are in severe decline and it would be useful to boost numbers artificially. Bass will tend to move towards the freshwater habitats.

Options for enhancing recruitment

An extra benefit from deepening the drains as suggested earlier would be the enhancement of fish recruitment from the Myall estuary. Increasing depth and flow through the drains should result in significantly greater fish immigration.

The various options suggested for enhancing habitat attributes could all be expected to aid local recruitment of fish through increased spawning and nursery areas, as well as a stronger, more diverse food web.

The bass-stocking option is worthwhile. Hatcheries should be asked to provide juvenile fish bred from local broodstock. It may be best to stock small numbers annually.

Continuing growth of knowledge is critical

The ecology of aquatic systems such as the Myall Quays waterway is dynamic and it is not possible to predict the composition of biological communities with certainty. Furthermore, such communities undergo substantial fluctuations driven by weather, conditions in the estuary and other poorly predictable influences. And, in addition, it must be expected that an artificially created waterway will go through a long process of ecological development, with large trends in its physical, water-quality and biological attributes over a period of years or decades.

Options to improve knowledge

To manage such a dynamic system effectively and minimise the various inherent risks, it is essential that knowledge of the system should be as comprehensive and thorough as possible. This shows the need to utilise existing knowledge about comparable systems, such as that gathered at the University of New South Wales' Smiths Lake field station.

It is also necessary to have effective ongoing monitoring to understand how the hydrological, water-quality, physical and biological components of the system are responding through time. Various consultancy reports already achieve some of these objectives. It seems desirable to complement this process through an association with a suitable university, and an ongoing series of student scholarships would be an effective means of achieving this at relatively low cost. It should be stressed that the value of such knowledge would increase exponentially through time, regular observations over a long period are far more valuable for most of the important topics. A sequence of student projects on the waterway's biology, hydrology, water quality and ecological processes would be an extremely useful tool for management.

Appendix 4.

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MEMORANDUM

3 May 2007

John Harris [John.h.harris@bigpond.com]

Peter Childs [peter@crighton.com.au]

To: Dr John Harris, Peter Childs

From: Dr Peggy O'Donnell

Re: Results of Fish Survey, Myall Quay Lakes

John and Peter,

Sampling in Myall Quay Lake was completed as requested on 26 and 27 April, 2007.

Methodology used was as described in our proposal of 24 April 2007, and subsequent conversation with John Harris regarding recording information on the relative abundance of aquatic macrophytes. Data are attached as an Excel file with 3 worksheets, and a pdf file containing site photographs. Additional sampling details are provided below:

Seine netting

Seine netting was conducted along the shoreline at 8 locations. GPS coordinates for sampling locations at given in Table 1 (Excel spreadsheet attached). The seine used measured 25 m long x 2 m deep, with a mesh size of 5mm. The net was run out from the shore in a U-shape using a boat and then hauled up on to the bank. Fish were collected in the cod end and placed in a tub with water, in order to minimise handling and stress. Identification, measurements and enumeration were done and all native fish were then released. Those species not readily recognisable were preserved in formalin and returned to the laboratory for identification checks.

Gill netting

This technique was used to capture fish in deeper areas of the water body. Nets were made of a rectangular panel measuring 30m (50mm mesh x 0.25mm diameter) x 1.8m deep. Four gill nets were deployed along the middle of the lake with GPS points taken at the start and end of each panel. GPS coordinates for sampling locations at given in Table 2 (Excel spreadsheet attached). Gill nets were placed either perpendicular or horizontal to the shore. Deployment times were 90 minutes, with times deployed listed in Table 2. Captured fish were identified to species, measured and released. Those fish species not readily identifiable in the field were preserved in 10% formalin and checked in the laboratory.

Macrophytes

Aquatic plants and algae were identified using a visual assessment of percentage cover based on King and Barclay (1986):

1 – present - low density (< 15% cover),

2 – common - medium density (15% - 50% cover), or

3 – abundant - high density (> 50% cover).

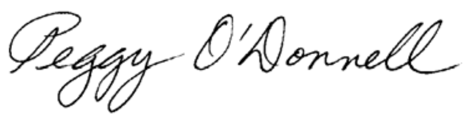
Macrophytes present in the sampling area along the bank were inspected and ranked using this classification. Algae and seagrass were inspected along the shoreline, and were also categorised based on species and amounts collected in the seine and gill nets. The seagrass *Ruppia* spp. was recorded at only one of the sampling sites.

Additional Information

Photos of several of the sampling sites were taken, including macrophytes. These are found in the attached pdf file. Note that photographs of algae and seagrass were limited due to poor instream visibility.

I would be happy to provide any further detail you may require.

Regards,



Dr Peggy O'Donnell

Senior Environmental Scientist, Manager

Table 1 - Field sampling locations and time of each seine net shot. Datum: WGS84 - Zone 56H.

Sample	Easting	Northing	Date	Time
SEINE 1	420583	6155610	26/04/2007	13:15
SEINE 2	420571	6386708	26/04/2007	13:45
SEINE 3	420978	6386366	26/04/2007	14:50
SEINE 4	421001	6386403	26/04/2007	15:15
SEINE 5	420599	6386606	27/04/2007	8:40
SEINE 6	420793	6386419	27/04/2007	9:10
SEINE 7	420969	6386597	27/04/2007	9:40
SEINE 8	420678	6386536	27/04/2007	10:15

Table 2 - Field sampling locations, depths and time for the start and end of each gill net set. Datum: WGS84 - Zone 56H.

	Start					End			
Sample	Date	Time	Easting	Northing	Depth (m)	Time	Easting	Northing	Depth (m)
GILL 1	26/04/2007	12:55	420973	6386428	3.4	14:25	420970	6386399	3.3
GILL 2	26/04/2007	13:05	420829	6386389	3.5	14:35	420814	6386373	3.4
GILL 3	27/04/2007	8:15	420586	6386780	2.1	9:45	420563	6386763	3
GILL 4	27/04/2007	8:18	420642	6386597	3.1	9:48	420629	6386572	3.5

Data entered by:HLS 30/04/2007
Data checked by:HLS & MP 02/05/2007
Data corrections entered by:MP 02/05/2007

Table 3 - Survey data for seine and gill net fish samples. Caudal fin legth was measured for up to 10 individuals of larger species. # denotes an exotic species.

Family Name	Species Name	Common Name	Seine shot 1		Seine shot 2		Seine shot 3		Seine shot 4		Seine shot 5		Seine shot 6		Seine shot 7		Seine sh
			Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)	No. Individuals	Caudal Fin Lengths (mm)
FISH																	
Poeciliidae	*Gambusia holbrooki*	Mosquito fish#								3				1			
Psuedomugilidae	*Psuedomugil signifer*	Pacific blue-eye								9				2			
Mugilidae	*Mugil cephalus*	Sea mullet		40	1				115	1	65, 80, 80, 75, 60, 70, 50, 65, 70, 70	65	125, 155, 80, 50, 50, 70, 50, 45, 45.	9			50, 50, 50, 60, 50, 40, 60, 45, 50, 80
Mugilidae	*Myxus elongatus*	Sand mullet															
Sparidae	*Acanthopagrus australis*	Yellow-finned Bream	329	1	130	1							150	1			
Gerreidae	*Gerres subfasciatus*	Silver Biddy	105, 110, 140, 130, 155, 120, 135, 110.	8	165, 138, 125, 125, 85, 110.	6	130	1	170	1	125, 140.	2	130, 120, 120.	3	145	1	
Gobiidae	*Philypnodon grandiceps*/ sp.	Flathead gudgeon/Dwarf flathead gudgeon		90		83		3		78		95		130		18	
Gobiidae	*Psueudogobius sp.*	Blue spot goby		1										8		1	
Gobiidae	*Afurcagobius tamarensis*	Tamar River goby				10		4				1				2	
Gobiidae	*Amoya bifrenatus*	Bridled goby												2			
Gobiidae	*Favonigobius exquisitus*	Exquisite sand goby		6		3		17		1		4		7		1	
MACROINVERTEBRATES																	
Palaemonidae		Estuary Shrimp						2				2		11			
Gastropoda	Unidentified species																
Notes			2 large mullet observed jumped out of net.														

Data entered by:HLS
Date data entered:30/04/2007
Data checked by:HLS & MP
Date data checked:02/05/2007
Data corrections entered by:MP
Date corrections entered:02/05/2007

Table 3 - Survey data for seine and gill net fish samples. Caudal fin legth was measured for up to 10 individu

			ot 8	Gill Net rep 1		Gill Net rep 2		Gill Net rep 3		Gill Net rep 4	
Family Name	**Species Name**	**Common Name**	**No. Individuals**	**Caudal Fin Lengths (mm)**	**No. Individuals**	**Caudal Fin Lengths (mm)**	**No. Individuals**	**Caudal Fin Lengths (mm)**	**No. Individuals**	**Caudal Fin Lengths (mm)**	**No. Individuals**
FISH											
Poeciliidae	*Gambusia holbrooki*	Mosquito fish#									
Psuedomugilidae	*Psuedomugil signifer*	Pacific blue-eye	20								
Mugilidae	*Mugil cephalus*	Sea mullet	22			420	1				
Mugilidae	*Myxus elongatus*	Sand mullet		290	1	290	1				
Sparidae	*Acanthopagrus australis*	Yellow-finned Bream									
Gerreidae	*Gerres subfasciatus*	Silver Biddy									
Gobiidae	*Philypnodon grandiceps*/ sp.	Flathead gudgeon/Dwarf flathead gudgeon	112								
Gobiidae	*Psueudogobius sp.*	Blue spot goby	1								
Gobiidae	*Afurcagobius tamarensis*	Tamar River goby									
Gobiidae	*Amoya bifrenatus*	Bridled goby									
Gobiidae	*Favonigobius exquisitus*	Exquisite sand goby	4								
MACROINVERTEBRATES											
Palaemonidae		Estuary Shrimp	1								
Gastropoda	Unidentified species		1								
Notes								No fish found		No fish found	

Data entered by:HLS
Date data entered:30/04/2007
Data checked by:HLS & MP
Date data checked:02/05/2007
Data corrections entered by:MP
Date corrections entered:02/05/2007

Table 4 - Relative abundance of macrophytes recorded at each sampling site in Myall Quays Lake. 1 = Present; 2 = Common; 3 = Abundant. Blank cells indicate absence from sampling site. Growth forms: 1 = Floating attached; 2 = Submerged; 3 = Emergent.

Type	Scientific name	Common name	Growth Form	Seine shot 1	Seine shot 2	Seine shot 3	Seine shot 4	Seine shot 5	Seine shot 6	Seine shot 7	Seine shot 8	Gill net rep 1	Gill net rep 2	Gill net rep 3	Gill net rep 4
Algae															
Chlorophyta (Green Algae)															
	Cladophora sp., *Spirogyra* sp., *Rhizoclonium* sp.		2		3		1	2	2	1	3				
Cyanobacteria/Rhodophyta															
	Unid. filamentous Blue-Green/Red algae														1
Seagrass															
	Zostera capricorni	Eel grass	2	1		1	2			1	1				
	Ruppia polycarpa	Sea tassel	2								2				
Saltmarsh															
	Sarcocornia quinqueflora		2							2					
Macrophyte															
	Juncus sp.	Common rush	3	2	3	3	2	3	3	1					
	Triglochin striata	Streaked arrow-grass	3						1		1				
	Ceratophyllum demersum	Hornwort	2	1			2								
	Phragmites australis	Common reed					1								
Bed description				Mostly bare muddy sands	bare sands with silt/muds	Mostly bare sand with silt detritus			Sand and mud with fine detritus	Muddy sands					Black algae sample taken

Data entered by:HLS 30/04/2007
Data checked by:HLS & MP 02/05/2007
Data corrections entered by:MP 02/05/2007

Plate 1. Upper: tidal inlet.

Plate 1. Lower: looking North with tidal inlet near right.

Plate 2. Upper: sand mullet from seine net shot 4.

Plate 2. Lower: Seine net shot at site 5. Photo looking North, away from tidal inlet.

Plate 3. Upper: seine net shot Site 7 including *Juncus* sp. and *Sarcocornia quinqueflora.*

Plate 3. Lower: *Sarcocornia quinqueflora* at seine Site 8.

Plate 4. Upper: Medium density *Juncus* sp. on embankment located at seine net shot 1.

Plate 4. Lower: High density *Juncus* sp. instream and on embankment at seine net shot 6.

Plate 5. Upper: Setting gill net from boat.

Plate 5. Lower: Seine net shot 8 site looking towards tidal inlet. *Ruppia* spp. growing on shallow sand sandbars around the enclosures.

Appendix 5.

Map of sampling sites in Myall Quays Lake, 26 and 27 April 2007. S = Seine shot, G = gill net set.