DISTINGUISHING NATURAL AND ANTHROPOGENIC INFLUENCES: A CASE STUDY OF LAKE ALEXANDRINA

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INTRODUCTION

The outlet of Australia's largest river system, the Murray-Darling, is an expansive and intricate coastal region spanning over 660 km^2. It consists of 2 large shallow lakes - Lake Alexandrina and Lake Albert, numerous tidal channels and islands, and the Coorong - a narrow saltwater lagoon. The Murray Mouth, itself, is flanked on either side by a continuous barrier system, the Sir Richard Peninsula to the west and the Younghusband Peninsula to the east (Figure 1). The coast was formed in response to Holocene eustatic sea-level rise which stabilised ca. 6,000 yr BP near its present position. This led to the progradation of the sand barriers which entrap flows of marine and freshwater within the Murray estuary.

For thousands of years there has been a continual interplay of coastal, estuarine and fluvial processes in this area, depending on the amount of flow from the Murray-Darling River system or the extent of marine incursion through the Murray Mouth. Over the period of the last 150 to 200 years however, European settlement within the river catchment and local area has substantially altered these processes. Currently, between about 10,000 and 11,000 GL/year[1] are diverted from the River Murray system for human use. Of this, about 90 % is generally used for irrigation, 6 % for rural domestic and stock uses and 4 % for urban needs (Murray Darling Basin Commission, 1990). Past, and to a lesser extent present, practices have been to return more-saline irrigation waste water back to the river, which then also mixes with sewage discharge from urban and rural centres such as Albury-Wodonga or Loxton. Added to these practices are river transport and recreational boating. With the intention of facilitating all of the water usage, 9 locks and weirs were built in or alongside the river for its regulation, and Lake Victoria downstream from the Murray-Darling junction was completed in 1928 to provide river storage for South Australian water flow entitlements.

At the Murray Mouth, a suite of barrages was built by the Engineering and Water Supply (SA Water) in the late 1930s across the tidal channels and lower Lake Alexandrina. These barrages were constructed specifically to create a predominantly freshwater lake environment upstream of the Murray Mouth for irrigation of the surrounding area. While successful in this initial purpose, the influence of the barrages on the environment has been to cause fundamental long-term changes in the flow regime and ecology of the Murray Mouth area (Harvey, 1988; Bourman and Barnett, 1995).

These structural changes and water-use practices which affect the river and its mouth form part of a focus on Total Catchment Management (TCM) and Integrated Coastal

[1] 1GL = 1,000,000,000 litres

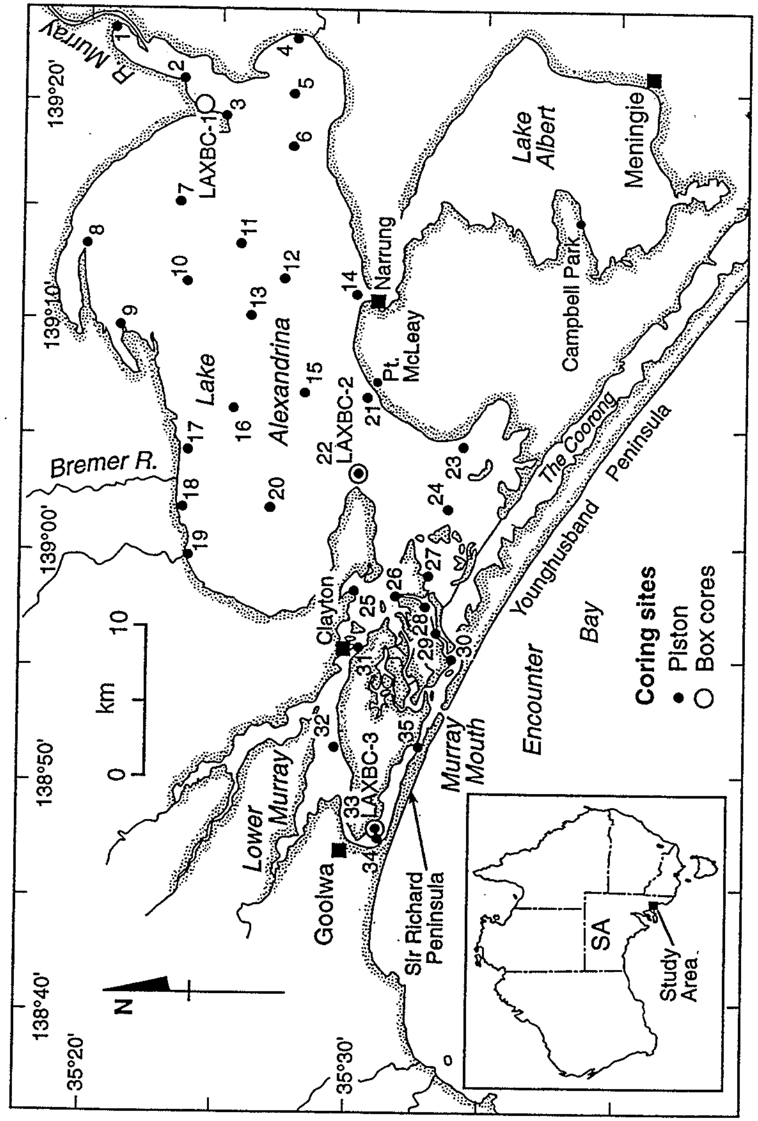

Figure 1. Location map of Lake Alexandrina and the Murray Mouth. Location of piston cores given by ● and box cores given by O; Cores 22 and LAXBC-2, and 33 and LAXBC-3 at the same locations are represented by ⊙. Lake Alexandrina is a shallow water lake with the deepest water (≥4m) following the river channel through the centre of the lake to the Lower Murray channel region.

Zone Management (ICZM) of the region. However, in formulating future water management strategies, any prior damage caused to the environment due to human intervention needs to be assessed. And yet, how are the impacts of human influence determined over and above natural conditions? How are natural cycles assessed initially, and importantly, are these taken into consideration when environmental issues are placed on political or government agendas? This paper aims to address such questions by outlining some of the environmental changes apparent in Lake Alexandrina and at the Murray Mouth. In so doing, many of the difficulties in assessing environmental impacts caused directly by humans are highlighted.

ENVIRONMENTAL CONCERNS

Within the Lake Alexandrina and Murray Mouth area, the main environmental concern is that of water. This involves a plethora of issues ranging from water and sediment supply through to nutrient status and ecological diversity. The concerns over these are briefly summarised as:

1) *Water Quality*: potential increases in nutrient levels, salinity, turbidity and siltation due to European settlement.
2) *Eutrophication*: possible increases in blue-green algal blooms, specifically *Nodularia* sp. and *Microcystis* sp. as a result of human interference. SA Water has been conducting water quality and algal monitoring in the area (Dennis Stephenson, *pers. comm.*).
3) *Erosion and Deposition*: increases in erosion along parts of the lake shoreline have occurred with emplacement of the barrages and formation of a permanent freshwater lake (in fact, one land holder has placed a wall of tyres along part of the north east shoreline of Lake Alexandrina adjoining the Cooke Plains area). Counteracting areas of erosion, in the lower lake tidal channels and areas close to the barrages, there is an increase in the deposition of sediments and reed growth (e.g., at Bird Island). In addition, despite the numerous locks upstream acting as sediment traps, land clearing and soil loss in the Murray catchment could lead to further increases in the overall sedimentation rate (Bourman and Barnett, 1995).
4) *Ecological Diversity:* any alterations to the predominantly freshwater lake may cause a decline in the diversity of life forms; in particular, the phytoplankton which would then have ramifications through the food chain, for example, fish species and birds. It is of note that the area is part of the JAMBA (Japanese Australian Migratory Bird Agreement), CAMBA (Chinese) and RAMSAR (Wetlands of International Significance) agreements.
5) *Dryland Salinity:* clearing of native vegetation surrounding the lakes has led to an increase in recharge to the water table, which is estimated to be rising between 5 and 10 cm/year. Given this trend, most of the low-lying land (<5 m AHD) in the area will be at risk to dryland salinization within the next 50 years. The holding of water to 0.75 m (AHD) by the barrages is not considered to have a major impact on land salinization as most of the groundwater discharges to surrounding salt lakes (Barnett, in press).

NATURAL VERSUS ANTHROPOGENIC ENVIRONMENTAL INFLUENCES

Long before European settlement, Aborigines from the Ngarrindjeri tribe lived in the area. Their previous impact on the environment is generally relatively unknown apart from their lore, middens and some evidence of bush burning from charcoal in the sediments. More important is the impact of European settlement in the last 150 to 200 years, and how this has altered the natural environmental cycles of the region. In order to try to differentiate natural from anthropogenic influences, a number of investigative approaches can be applied ranging from documented historical records of European settlement, photographic interpretation and analysing geologic data from the sediments at depth in Lake Alexandrina and at the Murray Mouth.

Historical records

Historical accounts of early settlement often yield valuable information on rural practices and occurrences in the past. One such example is that compiled by Faull (1981) on the history of the Milang region in which it is recorded that by the 1850s copper was mined along the Bremer River which flows into Lake Alexandrina (refer Figure 1), and that superphosphate was introduced to the area around the 1890s. In one of the first published articles on blue-green algae, Francis (1878) documented a *Nodularia spumigenia* bloom in Lake Alexandrina during February 1877. He noted that the water was unfit for drinking by cattle and other animals, often leading to "*rapid and terrible death*". He wrote that it formed:

> " *a thick scum like green paint, some two to six inches thick, and as thick and pasty as porridge*".

Other sources of information include old photographs of the area, for instance, those owned by SA Water and the South Australian Department of Lands. Many of these show the construction of the barrages across the mouth of the lower Murray lakes in the 1930s (Figures 2a and b). Others show various configurations of the mouth throughout time (refer Bourman and Barnett, 1995). Aerial photographs of the mouth and lower lakes have been run from as early as the mid 1930s and continue to the present, with the most recent 1:10,000 series (1995) commissioned by the Coastal Management Branch and flown along the southeast coast of South Australia. These photographic series record not only geomorphological changes but also land-use activities such as land clearing and construction.

There are some problems with this type of approach however, as European settlement around Lake Alexandrina and the lower Murray only spans back 100 to 150 years. This compares unfavourably with other studies of anthropogenic influences in lake areas, particularly those from the Northern Hemisphere. Lake Bjäresjösjön in Sweden, for example, has been studied extensively to provide over 2,700 years evidence on the cultural landscape and the presence of human occupation (Gaillard *et al.*, 1991). Apart from the lack of long-term anthropogenic influence in the Australian context, a further complicating factor in many environmental studies is that it is not until a number of decades have passed that the impacts of previous actions become obvious. This '*lag time*' is especially true for the Murray River region where the wide ranging problems associated with increased dryland salinity in the Murray Basin have only become obvious in the last 2 to 3 decades (Murray Darling Basin Commission, 1990).

Empirical data

There is a current monitoring program being carried out by the Australian Centre for Water Quality, SA Water, in Lake Alexandrina at Milang for complete chemical analysis on a monthly basis and algal populations on a weekly and fortnightly basis. Additional algal surveys are conducted in Summer at Goolwa, Clayton, Pt McLeay, Narrung, and in Lake Albert at Meningie and Campbell Park (refer Figure 1 for locations). However, caution

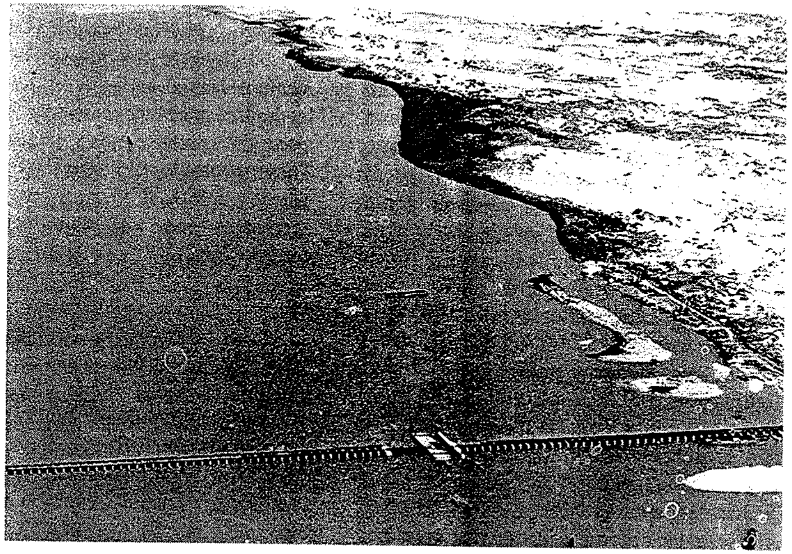

Figure 2a. Aerial photograph showing construction of the Goolwa Barrage during the 1930s. At this time, much of the Sir Richard Peninsula was extensively grazed by cattle. Since then the area has been rehabilitated and is now a Conservation area (Source: SA Water).

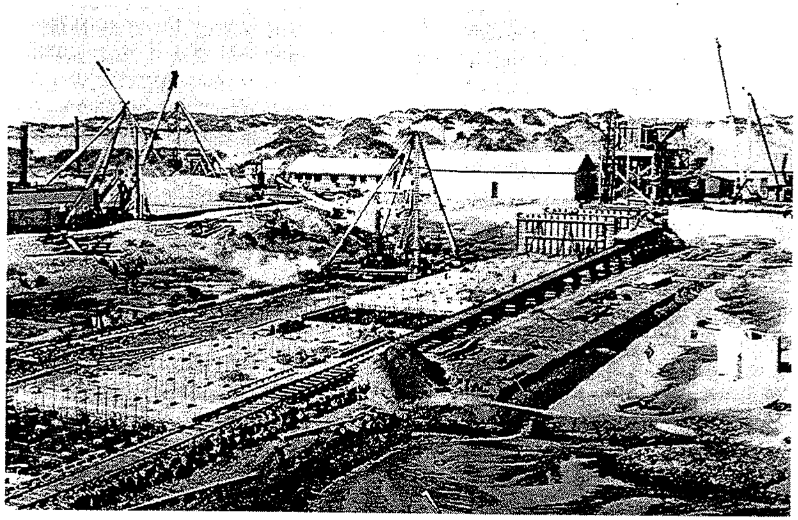

Figure 2b. Barrage construction in the 1930s was a massive undertaking designed to provide freshwater to local farmers and regulate Murray River flow. However, the barrages are now antiquated and their overall effectiveness is questionable with management options favouring the opening of Goolwa Barrage over others such as Mundoo Barrage (Source: SA Water).

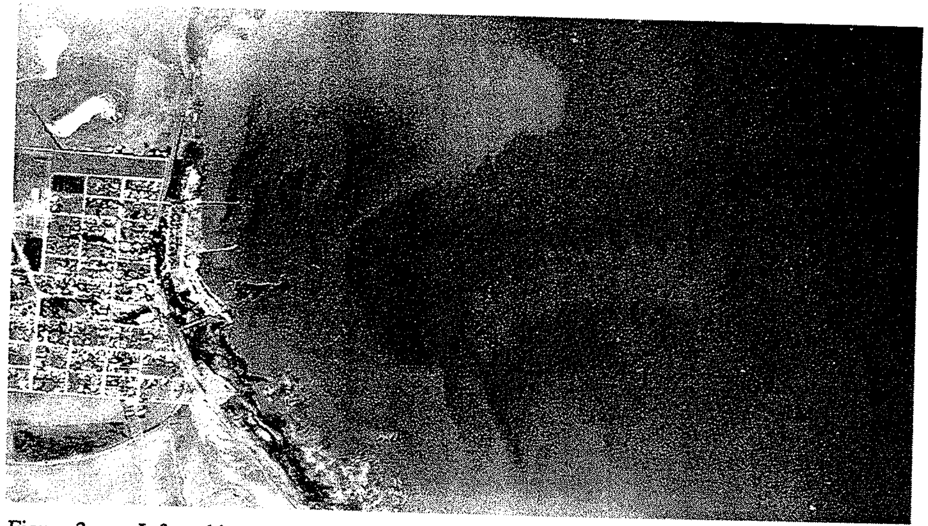

Figure 3. Infrared image of an algal bloom in Lake Alexandrina near Milang during 1991. The bloom shows the eddying water circulation patterns, and this highlights the problem of water quality sampling. Different concentrations of nutrients and toxins will be recorded depending on where the water samples are taken (Source: SA Water).

must be taken when interpreting this data as being representative of the region, due to time and depth variations while sampling and to the changing water circulation patterns in the lake. Figure 3 shows an infrared image of an algal bloom off Milang. It can be clearly seen that concentrations of the algae and associated toxins will differ depending on where the samples are collected.

Sediment cores

For Lake Alexandrina and the Murray Mouth, one of the most useful approaches for environmental interpretation is a geological investigation of sediments. Lake and estuarine sediments contain organic and inorganic fractions which can provide much information on the environmental history of an area. Sediments often consist not only of sand, silt and clay particles, but also the remains of many species of flora and fauna. In particular, the outer frustule of diatoms (Bacillariophycaea, or unicellular algae) are often included in sediments. Diatoms can be found living in a variety of ecological conditions, so that their species assemblage in the sediment profile can indicate prior water quality, especially that of salinity, pH and nutrient status. In this way, the sediments in Lake Alexandrina and at the Murray Mouth can provide windows into the past, both in the long term (1,000s of years) and short term (100s of years), in order to compare and contrast natural and human influences.

Sediment coring in the area has been carried out (Barnett, 1993, 1994), and involved collecting up to 35 piston cores throughout Lake Alexandrina in a grid-like pattern and 3 box cores from the northern, central and southern locations along the river channel (Figure 1). The piston cores were collected by hammering irrigation pipe into the sediment from the side of the boat and then using a piston corer to extract the sediment, while the box cores were collected using SCUBA. The size of the cores ranged from only 10s of cm

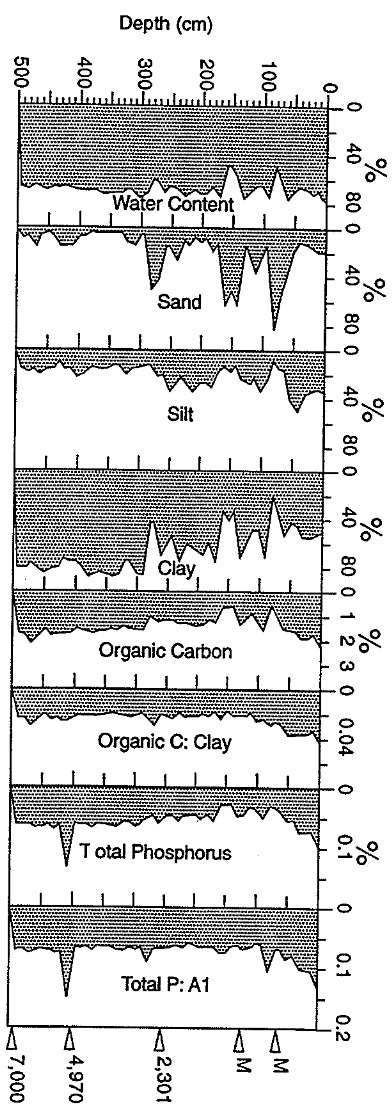

Figure 4. Sediment analyses for Core 22 in Lake Alexandrina. These include water content, sand-silt-clay ratios, organic carbon and total phosphorus. The core was dated to 7000 yr BP using ^{14}C techniques. Increases in organic carbon/clay and total phosphorus/aluminium are apparent toward the sediment surface, but most likely commenced before European settlement and are the result of early diagenetic processes at the sediment-water interface.

to 5 m depending on the type of sediment intersected and coring conditions.

Sediment sampling

Sampling of the cores was carried out at regular intervals. The piston cores were sampled every 10 cm at thicknesses of 2 cm (e.g. 0-2 cm, 10-12 cm), whereas all of the box cores were sampled (e.g. 0-2 cm, 2-4 cm for the northern and central cores, and 0-1 cm, 1-2 cm for the southern core). The qualifier here is that by using this approach, the sampling interval determined the type of information obtained. For example, by sampling 2 cm in every 10 cm, only 20 % of an entire piston core could be analysed, and each 2 cm sample represented in some cases 100s to 1000s of years. Even so, the main goal of establishing trends was achieved due to the number of samples taken. This was also then supported by sampling all of the box core sediments to gain sedimentation rates.

Sediment analyses

In order to determine some of the long-term natural cycles occurring in Lake Alexandrina and at the Murray Mouth, and then contrast those with cycles occurring during European occupancy, a number of sediment analyses were selected. These included:

- sediment size analysis (sand, slit and clay ratios) to assess any changes to the energy regime and sediment transport,
- ^{14}C and ^{210}Pb dating to give ages of the sediments and sedimentation rates,
- organic carbon content as a proxy for the abundance of plant matter both from within the catchment and the lake/mouth area,
- phosphorus concentrations to determine nutrient levels (nitrogen was not analysed due to its solubility in the cores),
- copper, zinc, iron and manganese concentrations (in the 3 box cores only) to provide baseline levels of naturally occurring heavy metals, and
- diatom identification for any indication of different species emerging or changes in species diversity.

Most of these analyses were conducted on 6 piston cores, one of which (Core 22) is shown in Figure 4.

Overall, the cores revealed that there was a decrease in clay and an increase in silt and sand toward the sediment surface. This most likely resulted from sediment progradation during the Holocene and infilling of Lake Alexandrina (Barnett, 1993). The organic carbon and phosphorus profiles varied with clay abundance, however, when these were normalised to clay, increases in organic carbon and phosphorus toward the surface became apparent. Using ^{14}C and ^{210}Pb-based sedimentation rates, such increases were found to commence *prior* to the advent of European settlement, although additional increases were also observed in the upper 10 cm of sediment which correspond roughly to the last 60 to 80 years (Barnett, 1993).

The box cores revealed quite different results over the last 150 years. In the northern region of Lake Alexandrina (Figure 5a; LAXBC-1), organic carbon/clay appears to have fluctuated over time whereas in the central channel region (Figure 5b; LAXBC-2), an increase in organic carbon/clay toward the surface is apparent. In contrast, phosphorus/clay and copper concentrations in the northern region have increased over the last 75 years, compared to the central channel region where phosphorus/clay and copper concentrations are highest between 1873-1885 and 1955-1967 (Figures 5a and b). This suggests that overall only minor anthropogenic loading to the sediments has occurred, and that the naturally occurring high concentrations of phosphorus as well as copper were probably caused by previous episodes of lake eutrophication and

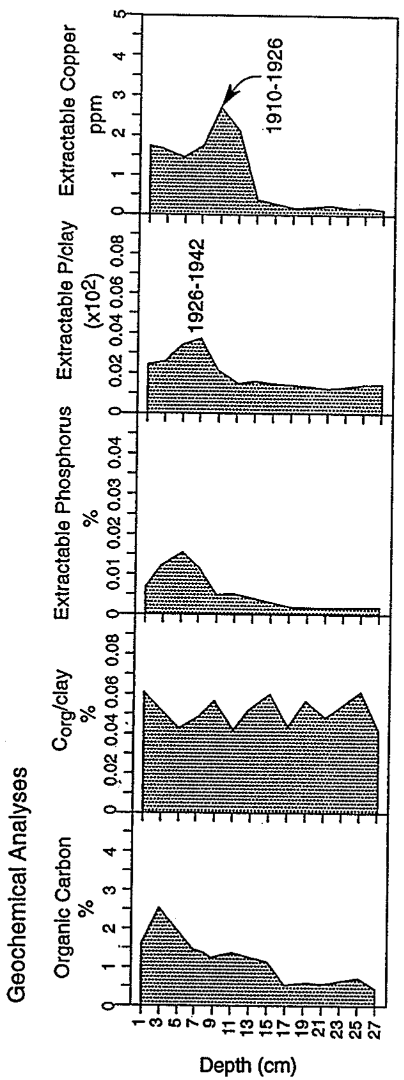

Figure 5a. LAXBC-1 from the northern channel region of Lake Alexandrina. While organic carbon appears to increase toward the surface when it is normalised to clay there is little actual increase. Extractable phosphorus (and extractable phosphorus/clay) and copper do increase with peaks in concentration ^{210}Pb dated to between 1926-1942 and 1919-1926, respectively.

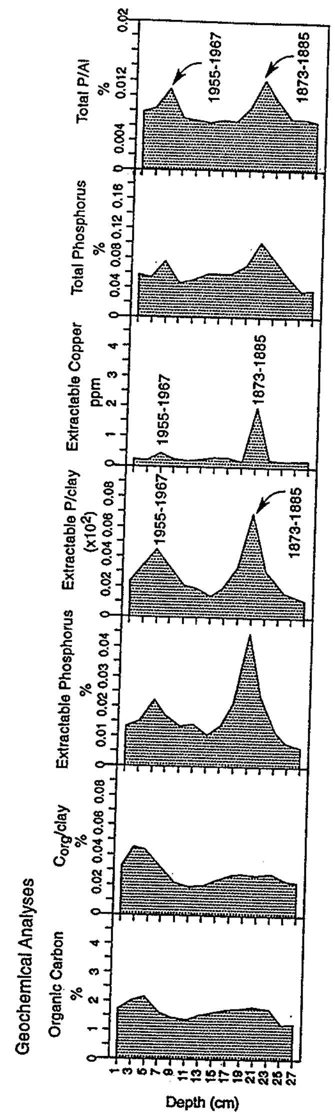

Figure 5b. LAXBC-2 from the central channel region of Lake Alexandrina. Organic carbon (and organic carbon/clay) increases toward the sediment surface although extractable phosphorus (and extractable phosphorus/clay) and copper have greater concentrations at depth, ^{210}Pb dated to 1873-1885 and 1955-1967. These time intervals coincide with periods in which large blue-green algal blooms and ENSO events were recorded.

algal blooms (Barnett, 1994).

Diatoms

Diatom analyses of the sediments were carried out on Core 22 to determine environmental and ecological changes occurring over the last 7,000 yr BP (Barnett, 1994). Three main salinity zones could be distinguished in the core. From ca. 7,000 to 6,000 yr BP, the diatom assemblage is diverse and represents a relatively open estuary before the formation of the continuous sand barriers. From about 6,000 yr BP onward, the diatoms indicate a mostly freshwater to estuarine environment but with wide fluctuations in salinity. In contrast, in modern times, the diatoms represent the most freshwater phase for Lake Alexandrina and exhibit little diversity in species abundance. Figures 6a and b are SEM micrographs of two of the diatom species used to indicate salinity concentrations in the sediments. Over 50 species of diatoms were identified to construct the diatom stratigraphic profile.

In essence, the diatom stratigraphy changes from a diverse saline-freshwater assemblage 1,000s of years ago to a less diverse mostly freshwater assemblage, particularly in the modern sediments. While much of this trend can be explained by sea-level rise and sand barrier progradation, the extent that human activities have influenced this trend, especially barrage construction across the Murray Mouth, remains uncertain.

DISCUSSION

While all of the above methods can be combined to try to reconstruct the past and determine the extent of environmental change, the problem of separating natural cycles from anthropogenic influences still remains. One of the first steps to address this is to contrast past patterns with current ones. This was attempted for Lake Alexandrina sediments for nutrient loading and heavy metals input. Following on from the work of Kemp *et al.* (1976) for Lake Erie sediments, a sediment enrichment factor normalised to aluminium was applied to the sediments - using a depth horizon where ^{210}Pb is supported by its parent ^{226}Ra, representing approximately 100 years - to determine if there were any increases in element concentrations at the surface. However, using this technique, little if any sediment enrichment was apparent. This is partly due to analysing sediments that have accumulated at distance from major point sources of pollution. Another problem is that is it not possible to assume a constant baseline before the advent of humans, since element concentrations vary depending on the natural processes in effect. Therefore, in order to distinguish between natural and anthropogenic element accumulation rates, a number of these processes such as 1) the contribution of sediment mixing, 2) sediment-water interactions, 3) groundwater flow, 4) early diagenesis, and 5) eutrophication to pre-European settlement concentrations must be considered before past concentrations can be accurately assessed.

The issue of eutrophication is important in this region. In particular, the number of blue-green algal blooms in Lake Alexandrina appears to be rising with blooms in February 1990, January to May 1991 (*Nodularia* sp.) and November 1993 to March 1994 (*Anabaena* sp.) (P. Baker, *pers. comm.*). In order for these blooms to occur, ideal conditions of high nutrient levels and periods of low river flow are required. Lake Alexandrina is already a naturally eutrophic to hypereutrophic lake (refer Geddes, 1984). In addition, Whetton *et al.* (1990), point out the link between low river discharge of the Darling and El Niño Southern Oscillation (ENSO) events. It is interesting to note here that the *Nodularia* bloom in 1877 (Francis,

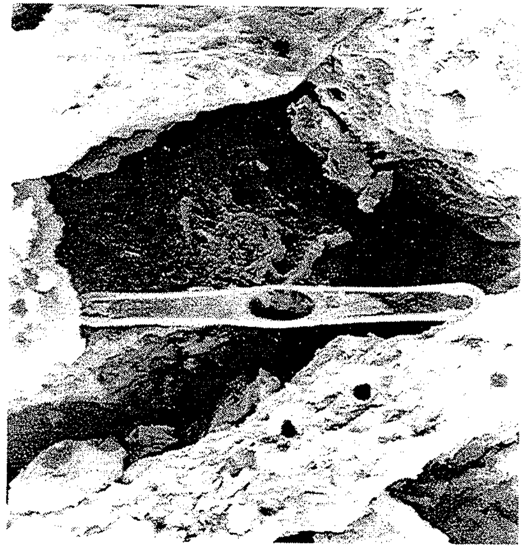

Figure 6a. Scanning electron micrograph of *Grammatophora oceanica* Ehr. (≈40 μm) present at 490 cm depth (ca. 7,000 yr BP) in core 22. This particular species is representative of an open marine environment. This is an internal view showing the elliptical opening at its centre.

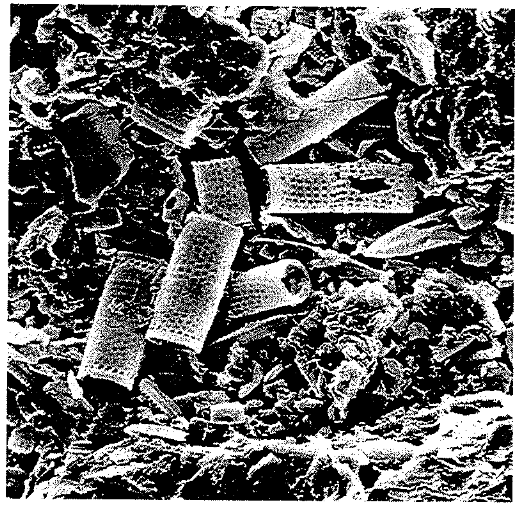

Figure 6b. Scanning electron micrograph of *Aulacoseira granulata* (each ≈20 μm in diameter) present throughout the core, although more abundant in the upper profile. This species represents predominantly freshwater conditions. It is shown here in girdle view, with an outer proteinaceous membrane adhered to some of the frustules.

1878) occurred during such an ENSO event[2]. *Nodularia* sp. and *Gomphosphaeria* sp. blooms were also recorded in Lake Alexandrina in 1965/66 during periods of low River Murray flow (Engineering & Water Supply Department, 1983). Whether the increase in blooms results purely from an interplay of natural conditions or is now also a result of additional nutrients into the Murray system is not clear. Even so, it is likely that unless anthropogenic nutrient loading is minimised, the frequency of blue-green algal blooms will continue to rise.

One of the most promising methods for distinguishing natural cycles and anthropogenic contributions in lakes and estuaries is in the study of diatom assemblages through time. Given accurate diatom taxonomy to species level, statistical techniques involving factor correspondence and multivariate analyses (e.g. Fritz, 1990; Fritz *et al.*, 1991) can be applied to indicate water quality, especially salinity, pH and nutrient status. However to do this, more data acquisition is required on a regular basis. As pointed out by Bradbury (1984), the study lake itself is the best analogue for paleolimnological interpretation, and diatom ecology and sedimentation patterns should be researched by monitoring lake conditions and setting sediment traps and transects. This would require intensive sampling over a period of years to decades and may explain why in many places, including Lake Alexandrina and the Murray Mouth, this type of approach is yet to be carried out.

In grappling with the evidence, or lack of evidence, for anthropogenic contribution to environmental change, what becomes apparent is the need for appropriate management of a region based on qualified research. Generally, most scientists are trained to be analytical and conservative which often restricts what they conclude. This in itself is then often interpreted by others as a lack of information on the environmental significance of an area, and therefore on why that the area should be protected from further development. It is for this reason that the *Precautionary Principle* is so important. A paucity of information should not be viewed as a reason for continued development or uncontrolled use of the environment. It is also important that a high calibre of research be maintained in order for competent and independent Environmental Impact Assessment (EIA) to take place. Until the provision of EIA is an independent process and not carried out by those with vested interests, the environment will continue to lose out to economic considerations. Only when environmental change, both natural and human-induced, is fully factored into economic costs will a balance of resource sharing be achieved.

In conclusion, with continued attempts to distinguish between natural and anthropogenic influences, a greater resolution of environmental change is inevitable. This will have a two-fold effect. Not only will it be possible to curtail or mitigate human activities that are detrimental to the environment, but it will also mean that the overall cost of future environmental changes, factored into economic costs, can be markedly reduced.

[2] While Whetton *et al.* (1990) use Darling River discharge from 1884-1984, the Southern Oscillation Index between Darwin and Tahaiti is negative for 1877.

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