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Kathryn H. Taffs
Southern Cross University

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KATHRYN H. TAFFS

School of Resource Science and Management
Southern Cross University
PO Box 157, Lismore, NSW 2480, Australia
Ph (02) 66203045
Email: ktaffs@scu.edu.au

Abstract: Wetland degradation in the Upper South East of South Australia is an urgent management concern. Scant recent environmental data is available for the region and long term monitoring data is lacking. Usually a palaeoecological analysis is able to reveal environmental change in the medium to long term past. However, the region is not conducive to palaeoecological investigation due to a fluctuating upper groundwater aquifer and alkaline soils which have destroyed most microfossils. It was found that the diatom assemblage was preserved in the wetlands of the region for the period of European settlement. Analysis of the diatom assemblage enabled production of an inferred salinity curve. In combination with a small amount of historical information that was available, the salinity trend for the wetlands, for the period of European agricultural activities, was identified. It was found that while groundwater salinity has been increasing, the wetland areas have experienced a freshening of surface water. This is due to an increase of through flow of surface water, a result of constructed drainage systems flushing salts from the wetlands. Despite the freshening of wetlands they continue to degrade due to the changed hydrology, an impact of the drainage structures.

Key Words: diatoms, palaeoecology, human impact, salinity, wetlands, Upper South East of South Australia

Introduction

Many regions of Australia are currently experiencing environmental degradation and have little or no records of the pre European environment. In addition, records of environmental change can be short term and of poor spatial quality. In these instances, a fine resolution palaeoecological record can often provide information on recent environmental change as an alternative source to historical records (Hunter *et al.*, 1988; D'Costa *et al.*, 1989; Birks, 1993; Birks, 1996). However, this is not feasible at all sites, usually due to poor preservation of microfossils or low resolution biostratigraphy, which may be a result of alkalinity, erosion, disturbance or sedimentation rates. In such instances, where both historical and palaeoecological information is incomplete but there is an urgent need for knowledge of an areas environmental history, alternative sources of information must be sought to provide the most comprehensive environmental history available.

The above describes the current situation in the Upper South East of South Australia (Figure 1). The Upper South East has experienced extensive dryland salinization as a result of European agricultural activities, presumably due to large scale vegetation clearance (Young, 1976; Nance and Speight, 1986; Barnett, 1989; Environmental Impact Assessments Branch, 1995). The South Australian Government is under considerable pressure to install regional management strategies in an attempt to curb further salinization. However, pre European impact conditions are unknown, as is the extent of European impacts. To set effective rehabilitation goals within regional management strategies it is important to determine the “natural” state of the Upper South East environment and the causes, directions and extent of its deterioration (Doe, 1983; Wasson and Clark, 1985; Clark, 1990; Dovers and Dargavel, 1991; Creagh, 1993; Crosby, 1995; Powell, 1996).

An attempt to construct the environmental history of the Upper South East through a fine resolution palaeoecological analysis was made. However, the soils of this region are alkaline (typical pH 10) and have a shallow but fluctuating groundwater table. Most microfossils have been destroyed or extensively deteriorated. It was found that the diatom assemblage was the only available option to investigate the environmental history of the wetlands in the Upper South East.

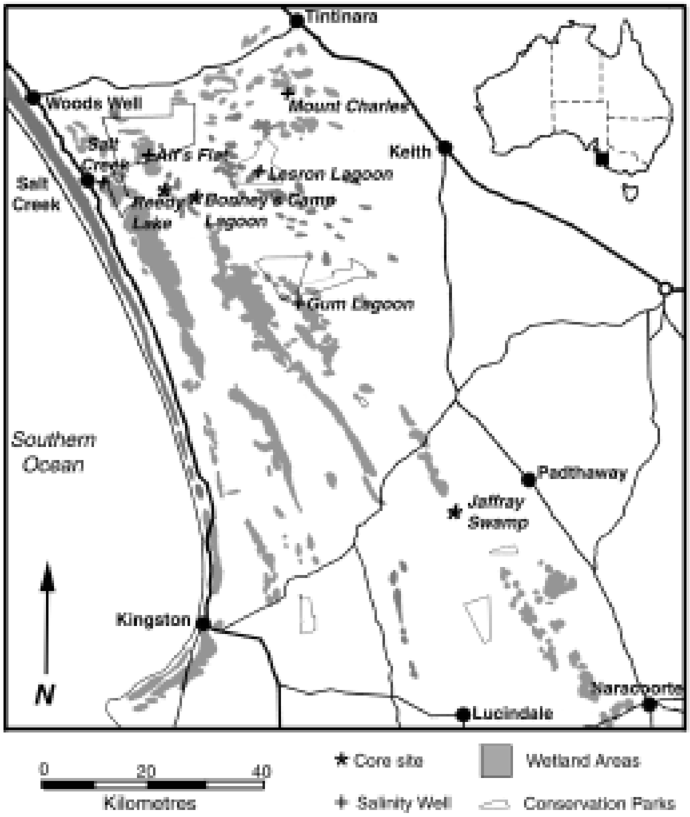
Diatoms are increasingly being utilized as indicators of environmental change because they are abundant in all aquatic environments and are highly sensitive to water quality changes (Gasse *et al.,* 1987; Battarbee, 1988; Round, 1991; Battarbee *et al*., 1997; Kelly *et al*., 1998). In particular diatoms are becoming increasingly used to reconstruct past changes in salinity (Hecky and Kilham, 1973; Fritz *et al*., 1991; Gasse *et al*., 1997; Gell, 1997). Diatoms have well defined ecological optima and tolerances enabling reconstruction of water quality changes over long periods of time (Battarbee, 1986; Birks, 1994; Moser *et al*., 1996). They are well preserved within palaeoecological sites, where other evidence is most likely to be degraded, because their external structure is composed of silica which is very resistant to degradation in alkaline conditions, especially where wetting and drying of the soil column occurs (Round, 1964; Moser *et al*., 1996).

A secondary advantage of the use of diatoms, is that changes in diatom inferred salinity from stratigraphic records can be readily compared with historical documents to determine the extent to which salinity change is related to climate or human activities (Fritz *et al.*, 1991; Gasse *et al.*, 1997). In this study the historical records of the Upper South East were also investigated in an attempt to relate any detected salinity change to natural or anthropogenic causes.

This study identified the impact of dryland salinity upon the wetlands of the Upper South East of South Australia through analysis of the wetland diatom assemblage. This task was made feasible by the existing salinity calibration set for south eastern Australia constructed by Gell (1995). In addition, the historical record was investigated and was compared to the diatom inferred salinity trends.

The study area and background information

The Upper South East is the area of South Australia south of the River Murray mouth and north of the Padthaway Ridge (Figure 1). The region has a unique environment primarily due to a combination of topography, climate and groundwater resources. The topography is composed of a series of sand ridges running parallel to the modern coastline. These ridges are stranded coastal dune systems formed during sea level fluctuations of the Pleistocene period. Topographic uplift of the region throughout the Quaternary has resulted in the preservation of the dune remnants. The ridges are no higher than forty meters and are situated upon a plain with an east to west gradient. In addition, there is a secondary topographic fall to the north west of generally less than 1:5000 (Bakers Range/Marcollat Watercourses Working Group, 1991). The innermost and oldest ridge has been dated at 700 000 years old (Cook *et al.*, 1977). The ridges become progressively younger westward towards the modern coastline. They are approximately ten kilometers apart and continue west of the present coastline. Between the ridges are extensive swampy plains within the interdune corridors. These corridors were originally estuarine but have developed into ephemeral lacustrine swamps. They are infilled with estuarine to lacustrine marls and clays which formed during and following the transition from marine to lacustrine wetlands (Schwebel, 1984).



The climate of the Upper South East is a Mediterranean one, with dry summers and wet winters. The rainfall varies latitudinally with higher rainfalls recorded in the south, and is moderately high with an average of 500 to 550 mm per year. Rainfall exceeds evaporation during the winter and spring months, resulting in surplus surface water supplies for that period (Jensen, 1983). The groundwater resources of the Upper South East of South Australia are essentially contained within two major aquifer systems: an upper, unconfined surface aquifer, and a deeper confined aquifer (MacKenzie and Stadter, 1992). The deep aquifer is recharged in western Victoria and regional groundwater movement is in a west north westerly direction (Bakers Range/Marcollat Watercourses Working Group, 1991). The unconfined, surface aquifer is locally recharged from rainfall. Depth to the water table varies considerably throughout the region, groundwater being shallowest in the interdune areas.

Surface water drainage has been unable to develop along the east to west gradient because the dune systems hamper the path of water flow towards the sea. Surface water is instead diverted to the north west along the interdune corridors, forming several large linear wetlands (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). The wetlands extend over one hundred kilometers in length and are composed of a chain of swamps which become connected in periods of flood as surface water moves north north west (Figure 1). The wetlands terminate in swamps in the north of the study area.

Vegetation clearance in the Upper South East did not begin until the late 1940s. Prior to this the region was used only for pastoral squatting. However, development of the region to the south was well progressed and influenced the hydrology of the Upper South East through drainage strategies (Taffs, submitted). Vegetation clearance, grazing and cropping has altered the natural environment: eighty eight per cent of native vegetation has been cleared (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993) and many drainage lines have been constructed (Taffs, submitted). The removal of native vegetation is believed to have caused a rise of the groundwater table and hence the development of dryland salinization (Assessments Section, 1980; Barnett, 1989; MacKenzie and Stadter, 1992; Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993).

A realization of the link between vegetation clearance and dryland salinization by land owners culminated after 1981 when a large flood inundated the region and left problems of flooding and dryland salinization for several years afterwards. Local landowners then requested that an environmental impact assessment be conducted by the State Government to develop regional management strategies. Even at the completion of the environmental impact assessment conclusive evidence as to the extent, development and increase of dryland salinization was not evident (Environmental Impact Assessments Branch, 1995). This paper aims to illustrate how the use of diatoms can contribute to determining the degree of environmental change that has occurred within the period of European impact upon wetlands in the Upper South East of South Australia.

Methods of sampling and analysis

In June 1995 three cores from key wetland areas of the Upper South East were extracted (Figure 1). A core 70 cm deep was extracted from Jaffray Swamp which was selected as representative of the eastern portion of the study area (within Marcollat watercourse). The Jaffray Swamp depositional environment may be responding to changes occurring in western Victoria as Jaffray Swamp is fed by Morambro Creek which originates on the Victorian side of the state border (Figure 1). A core 80 cm deep was extracted from Bonney’s Camp Lagoon which was selected as representative of a wetland in the main portion of the Bakers Range watercourse, and hence receives through flow of surface water from the south. Lastly, a core from Reedy Lake which was 60 cm deep was extracted. Reedy Lake is a ground water fed lake and is perched on the edge of the Bakers Range watercourse and should reflect regional changes of groundwater quality. Sediment from the cores was described using Gunn *et al.* (1988).

Contiguous $1 cm^3$ sediment samples were taken from each core. Diatom extraction was conducted following the method of Gell (1995). The diatoms were identified from information and photographic plates in Krammer and Lange-Bertalot (1986, 1988, 1991a and 1991b) and Foged (1978). Canonical Correspondence Analysis (CCA) was used to ordinate the samples, using the calibration set of Gell (1995) to determine the diatom inferred salinity of the sample. All ordinations were performed using the computer program CANOCO (version 3.12) for diatom species which attained a relative abundance > 2 %.

In addition, chemical analysis of the samples was conducted to determine the organic and calcium carbonate content of each sample of each core. The procedure of Bengtsson and Enell (1986) was followed for duplicate samples using three milliliters of fresh sample. Sediments were dated using Lead-210 dating and Accelerated Mass Spectrometry (AMS) Carbon 14 techniques. Lead dating was conducted by the Department of Chemistry, University of Melbourne according to the method outlined by Smith and Hamilton (1985). AMS pre processing was conducted by the Quaternary Dating Center at the Australian National University and then dated at the Australian Institute of Nuclear Science and Engineering (Grants No. 94/171, 95/064). In addition *Pinus radiata* pollen was extracted from sediment samples using the method of Ogden (1996) as an indicator of the time of European settlement.

In addition to the palaeoecological analysis, historical records of the salinity changes in the Upper South East were collated. The only sources of information were agricultural land capability assessments made prior to World War Two (Taylor, 1933; Melville and Martin, 1936; compiled by Foale and Smith, 1991) and a salinity map constructed from recent aerial photograph interpretation (Upper South East Dryland Salinity and Flood Management Plan Steering Committee, 1993). More recently groundwater water quality from discrete locations across the Upper South East (South Australian Department of Primary Industries and Resources) have been monitored and selected well results are illustrated (Figure 5).

Stratigraphy and diatoms

Jaffray Swamp

The Jaffray Swamp core was composed of a clay substrate with varying amounts of sand (Figure 2). The organic content illustrates minor fluctuations at depth in the core, a peak at 15 cm and an increase of organic material peaking at the surface of the core. These fluctuations may indicate a change in the water depth, changes in aquatic vegetation, or an influx of organic material which has influenced the productivity of the lake. The carbonate content of this core was low throughout, gradually decreasing towards the surface of the core. An AMS date of 1230 ± 110 BP (OZC256) was obtained at 40 cm. At a depth of 5 cm an AMS date of "modern" (ANSTO sample no. OZC255) and a Lead-210 date indicated an age of 100 years. The pine pollen rapidly diminishes at a depth of 15 cm indicating that this portion of the sediment core may have been deposited within the period of European influence (Figure 2).

The core from Jaffray Swamp (Figure 2) gave the best preservation of diatoms of all the wetlands. The diatom record was well preserved to a depth of 42 cm, below which dissolution began occurring and the diatom count was no longer considered accurate (Barker *et al.*, 1994). A total number of 31 diatom taxa were found in the Jaffray Swamp core, 26 of which occurred at abundances of greater than 2 %. The dominant species were benthic. At the base of the core (30–42 cm) the diatom assemblage was dominated by *Diploneis elliptica, Epithemia adnata* and *Navicula lanceolata*. *Cocconeis placentula* dominated the 7-30 cm section of the core. In the upper levels of the core (0-7cm) the diatom assemblage was dominated by *Cocconeis placentula*, *Cyclotella meneghiniana* and *Navicula cincta form minuta*. Other species were present at very low levels throughout the core.

The salinity history was inferred using Gell's (1995) calibration set. The inferred salinity curve indicated fresh water (< 3 ppt) conditions existed below 25 cm, with a peak in salinity occurring at 32 cm demonstrated by the increase in the *Epithemia adnata* population. A change from fresh water conditions to brackish

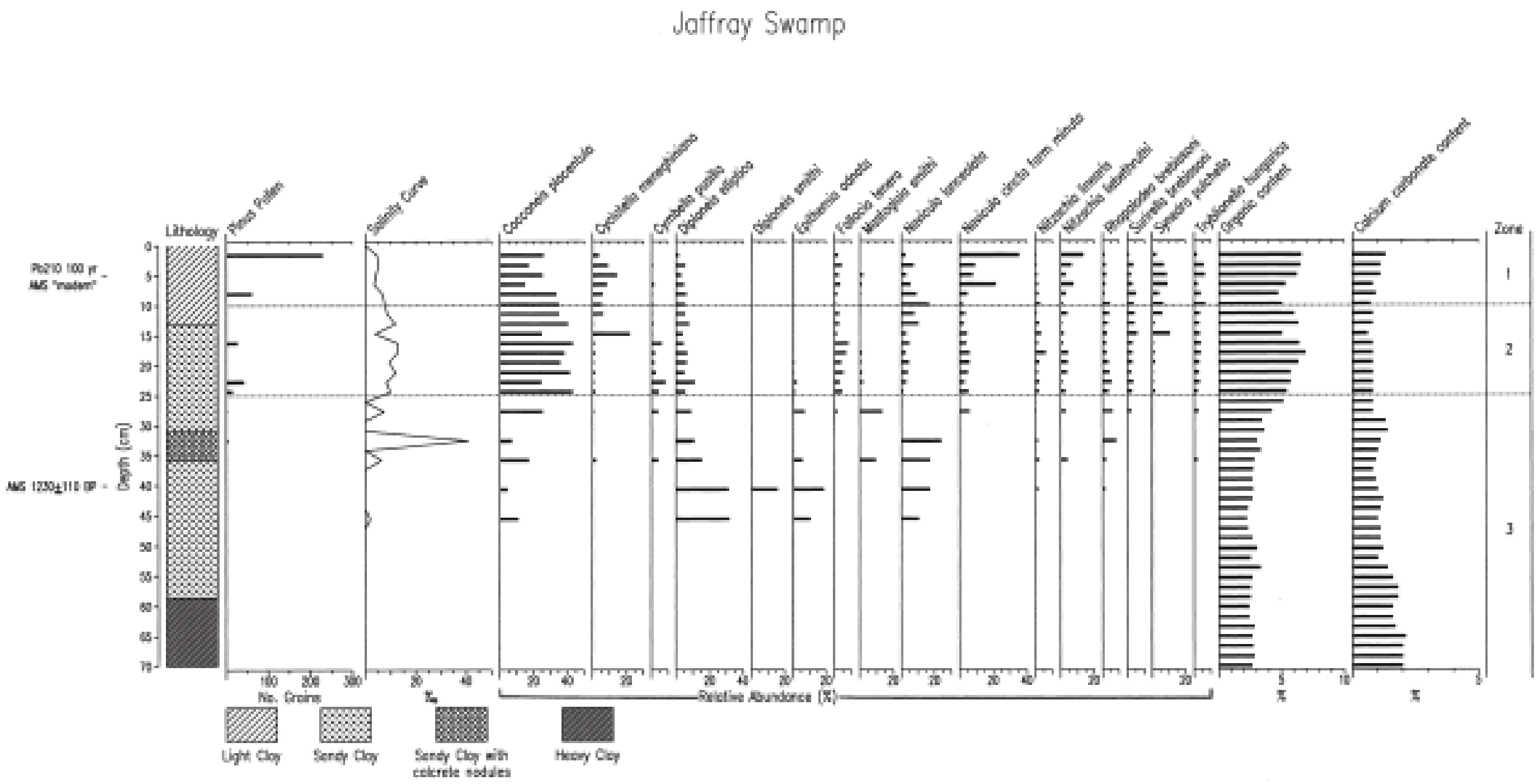


Figure 2 Jaffray Swamp sediment core illustrating core stratigraphy, diatom-inferred salinity curve, dominant diatom species and chemical results.

(> 15 ppt) occurred above 25 cm depth and returned to fresh water conditions at 10 cm and above. The period of European occupation appears to correspond with the change from brackish to fresh lake water, indicating that European activities in this wetland have not produced a significant increase in surface water salinity. Neither the organic nor the carbonate content fluctuations correlate with the period of European occupation suggesting fluctuations of these factors are a result of natural climatic change.

Bonney's Camp Lagoon

The Bonney's Camp core (Figure 3) was composed of light clay from the base of the core (80 cm) to 59 cm. The central section (22 to 57 cm) was composed of sand, presumed to be aeolian deposited dune sand material. Between 8 and 23 cm was composed of loamy sand, which changed to clayey sand at the surface of the core. The change in stratigraphy from clay substrate to sand substrate and back to clay substrate suggests that this lake has experienced two wet, ephemeral periods (zones one and three) and one dry, aeolian influenced period (zone 2). Similarly, the organic and carbonate content of the sediments peak in zones one and three and are very low in zone two, also suggesting climatic changes. Dates indicate that the surface layer of clayey sand at Bonney's Camp wetland may have been deposited within the period of European influence. AMS dates of 390 ± 90 BP at 15 cm (OZC471), 200 ± 115 BP at 6 cm (OZC253) and "modern" at 1 cm (OZC254) were supplemented by a Lead-210 date of 100 years at 2 cm. A reduction of pinus pollen at 8 cm all indicated the surface sediment horizon has been deposited in the period of European influence (Figure 3).

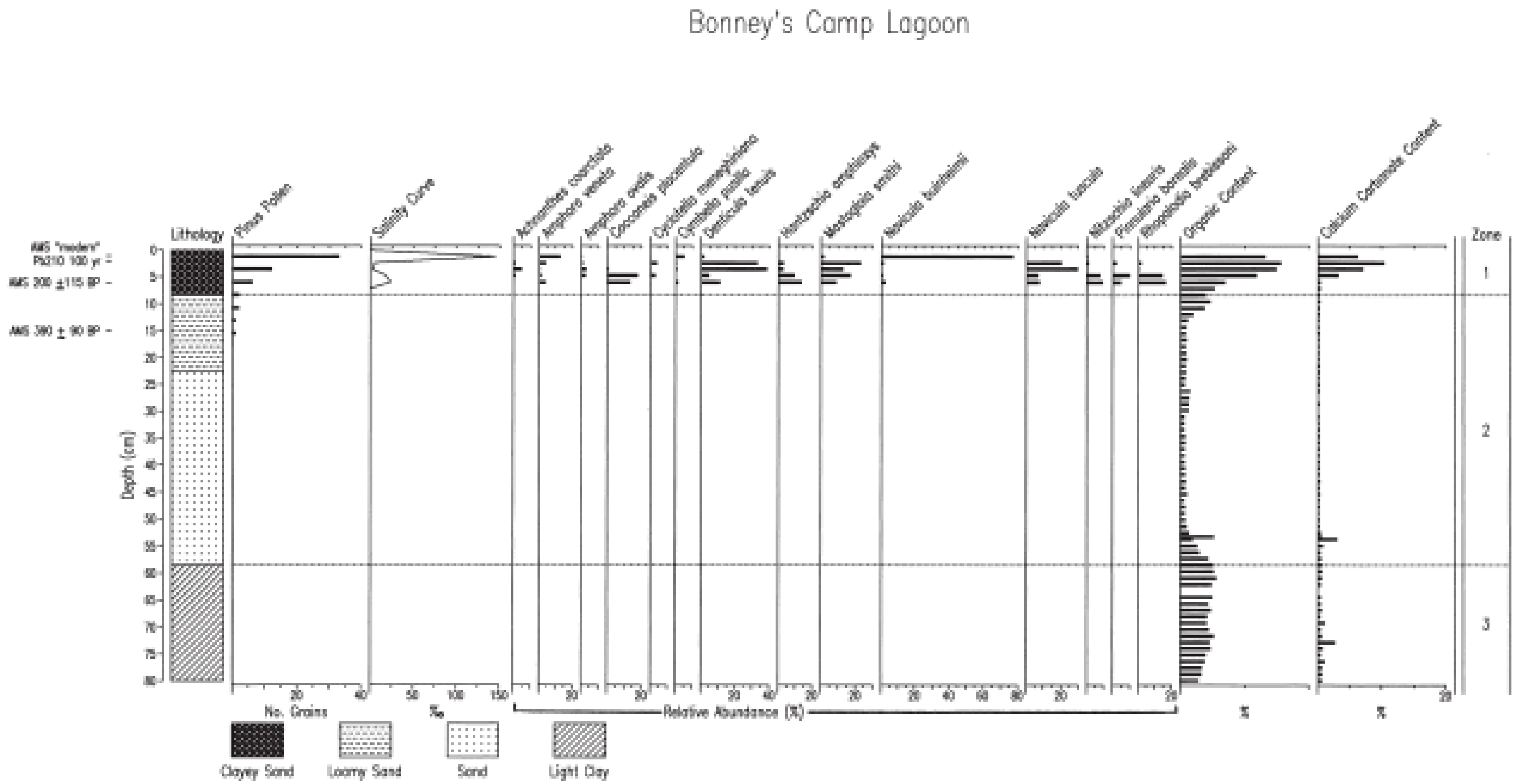


Figure 3 Bonney's Camp sediment core illustrating core stratigraphy, diatom-inferred salinity curve, dominant diatom species and chemical results.

Diatoms were well preserved in the surface samples of Bonney's Camp Lagoon (Figure 3) but not very well below a depth of 8 cm, thus providing a salinity record of the surface samples only. A total number of 40 diatom taxa were found in the Bonney's Camp core, 16 of which occurred at abundances > 2%. The dominant species were benthic. At the base of the diatom record (6 to 8 cm) the diatom assemblage was dominated by *Cocconeis placentula*, *Nitzschia linearis*, and *Rhopalodia brebissoni*. *Denticula tenuis*, *Mastogloia smithi* and *Navicula tuscula* dominated the central section of the diatom record (3 to 6 cm), and the diatom assemblage in the surface sample (0 to 3 cm) was dominated by *Amphora veneta* and *Navicula bulnheimii*.

The inferred salinity curve constructed from the diatom assemblage shows a general decrease of salinity towards the surface of the core, except for a dramatic increase in the surface sample. All dating techniques indicated that the entire diatom record was contained within the past 250 years. The surface increase in salinity may be due to the contemporary lake conditions at the time of sampling, as the water level in the lake was shallow after a dry year when the lake would be more saline than normal. If the surface layer is omitted, the diatoms in the lake indicate a trend of decreasing salinity during the period of European settlement.

The record from Bonney's Camp Lagoon appears to reflect both climate change and human impacts. The chemical and stratigraphic changes in zone two and three are likely to be climate induced. The surface samples, correlating with the period of European activities, indicate that salinity has been reduced over time at this location during the probable period of post European occupation.

Reedy Lake

The Reedy Lake core (Figure 4) was composed of sandy loam interspersed with one layer of sandy clay loam (7 to 14 cm). The lack of variation in the stratigraphy suggests that the sediments may have all been deposited in an environment very similar to that of the present. Despite the homogeneity of the substrate there are several fluctuations in the carbonate levels. Peaks occurred at 60 cm, 22 cm and 5cm. The organic content increased towards the surface of the sediment core. In Reedy Lake a Lead-210 date of 100 years was obtained at 4 cm, the same depth at which *Pinus pollen* reduced indicating that the period of European settlement is contained within the upper few centimeters of sediment (Figure 4).

Diatom preservation was adequate for analysis of only the top seven centimeters of Reedy Lake (Figure 4). A total number of 31 diatom taxa were found in the Reedy Lake core, 13 of which occurred at abundances of > 2%. The dominant species were benthic. The diatom assemblage in the 5-7cm section was dominated by *Amphora veneta*, *Denticula tenuis* and *Diploneis smithi*. The central section of the diatom core (3 to 5 cm) was dominated by *Achnanthes coarctata*, *Hantzschia amphioxys* and *Navicula cincta forma minuta*. The diatom assemblage of the surface of the core was dominated by *Mastogloia smithi and Navicula tuscul*a.

The inferred salinity curve constructed from the diatom assemblage indicated increasing salinity levels, which reached a peak at the surface of the lake sediments (the present). The increase in salinity correlates with the period of European occupation as determined by the dating results.

Reedy Lake

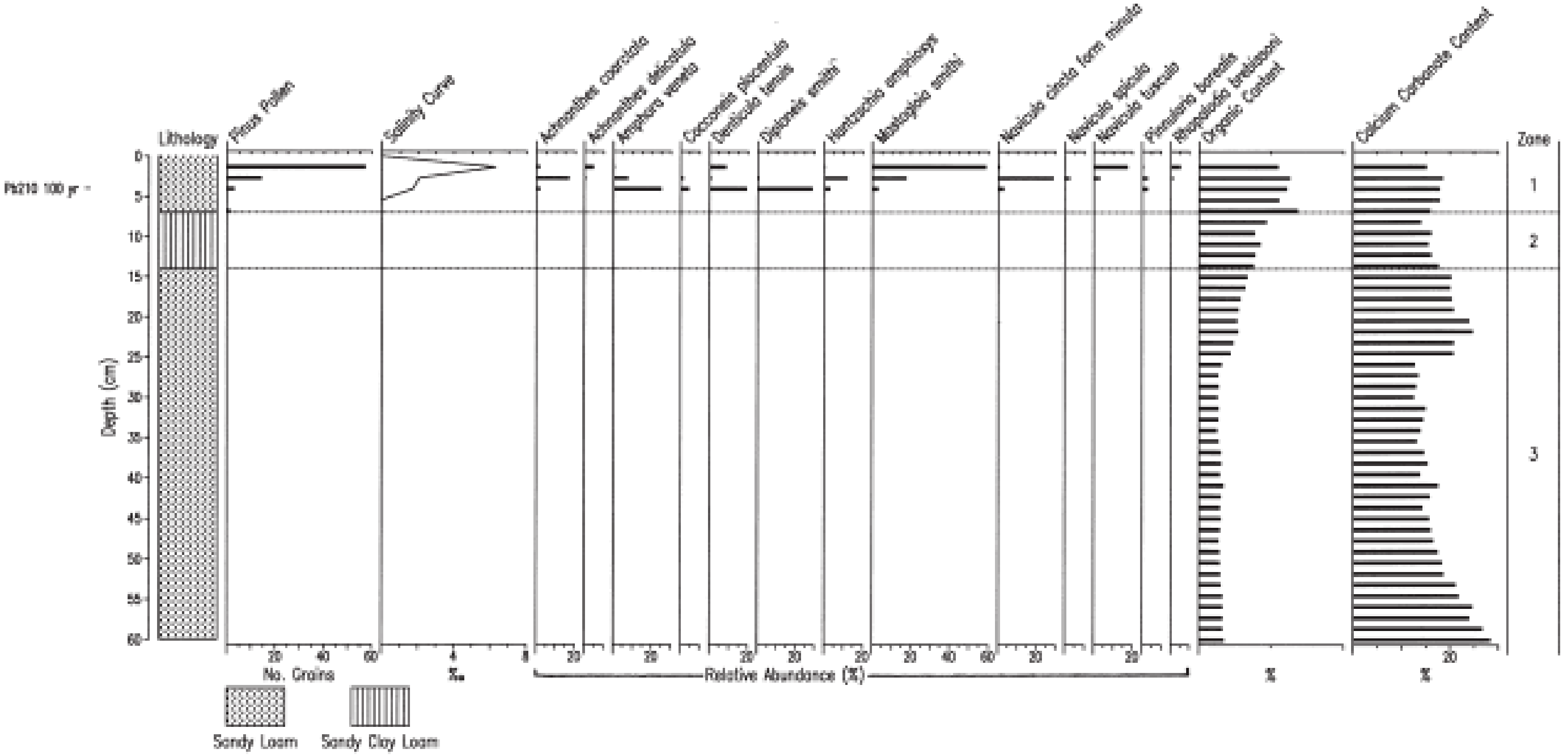


Figure 4 Reedy Lake sediment core illustrating core stratigraphy, diatom-inferred salinity curve, dominant diatom species and chemical results.

Historical Records

Table 1 illustrates the change in soil salinity of selected wetlands (Figure 1) as determined by comparing the land capability assessment maps compiled by Foale and Smith (1991) with the Upper South East Dryland Salinity and Flood Management Plan Steering Committee's (1993) salinity map (constructed from aerial photograph interpretation). Results indicate that the Salt Creek and Alf's Flat wetlands experienced an increase in soil salinity, whereas Gum Lagoon, Lesron, and Mount Charles wetlands experienced no change in salinity classification. Salt Creek and Alf's Flat were classed as "open water" on the Melville and Martin (1936, cited in Foale and Smith, 1991) classification, and the method of assigning a salinity classification to open water was not defined. All wetlands in Table 1 are terminal wetlands where excess surface water accumulates until it infiltrates to the groundwater or evaporates. Hence, it is highly likely that the soil salinity would be increasing in these areas. Lesron and Mount Charles wetlands were classed as saline prior to European interference with the natural environment and were therefore never suitable for agricultural purposes. The comparison of the soil salinity maps (Table 1) has many problems as they have been mapped from different sources, one from field mapping and the other using aerial photography. However, this source of information demonstrates how limited information on pre and past European salinity levels for the region are.

Groundwater salinity records obtained from the South Australian Department of Primary Industries and Resources suggest that only in some areas has there been an increase in salinity (Figure 5). The bore near to Alf's Flat (Figure 5a) and Jaffray Swamp (Figure 5d) illustrate seasonal fluctuations in groundwater salinity but also an overall trend of an increase of salinity with time. The bore near Bonney's Camp (Figure 5b) and Gum Lagoon Conservation Park (Figure 5c) in contrast, show an overall decrease in salinity. There are definite seasonal trends in the pleizometer records but longer term monitoring is required to provide any definitive evidence of long term trends. Records of greater periods of time are not available in this region.

Table 1 Change in the soil salinity classification of selected wetlands

Terminal Wetland	1936 Salinity Classification (Foale and Smith, 1991)#	1993 Salinity Classification (USEDSFMPSC, 1993)*	Change in Salinity Classification
Salt Creek (Tilley Swamp watercourse)	Not Saline	Moderately saline	Increase
Alf's Flat (Bakers Range watercourse)	Not Saline	Moderately Saline	Increase
Gum Lagoon (Marcollat watercourse)	Moderately Saline	Moderately Saline	No Increase
Lesron CP (Duck Island watercourse)	Highly Saline	Highly Saline	No Increase
Mount Charles (Mount Charles watercourse)	Highly Saline	Highly Saline	No Increase

Compilation from Taylor (1933) and Melville and Martin (1936) land capability assessments.
* Soil Salinity classification from infra red aerial photography, produced by the Upper South East Dryland Salinity and Flood Management Plan Steering Committee (1993).

The historical sources of information on the salinity trends in the Upper South East are not conclusive. Nor do they support the widespread belief that an increase of wetland salinity has occurred in the Upper South East, concurring with the diatom inferred salinity curves.

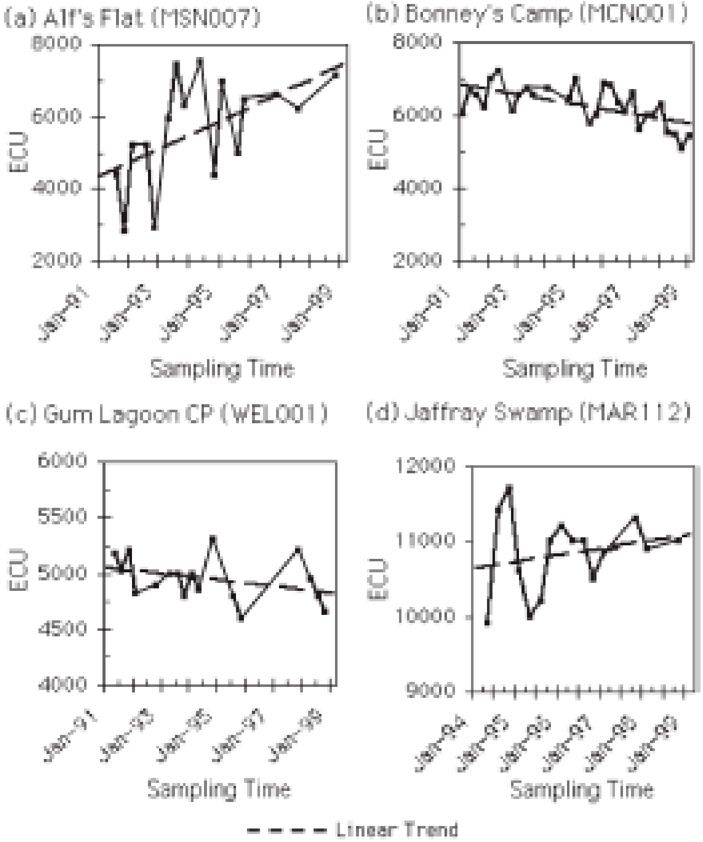


Figure 5 Salinity curves for selected well sites. Linear trend was constructed using line of best fit.

Discussion

Diatoms were the only microfossil preserved in the alkaline soils of the Upper South East and while they were unable to provide environmental trends over long periods of time, they were the only available indicator that could be utilized to reveal environmental change in the medium term past. The stratigraphy and chemical analysis results of the selected Upper South East wetland cores indicate long term hydrological fluctuations. However, the diatom record was not sufficiently preserved at depth to provide detail of the identified long term environmental change. The diatom inferred salinity reconstruction was able to provide an indication of the salinization trend for the period of European settlement, as indicated by the AMS carbon and Lead 210 dating techniques, and the presence of *Pinus* pollen. The historical information relating to salinity change was insufficient on its own to accurately identify wetland salinization trends, but in combination with the diatom inferred salinity curves was sufficient to confirm suggested trends. Hence, diatoms are important for the management of the wetland resources of the Upper South East.

The Jaffray Swamp sediment core illustrates declining salinity during the period of European settlement. Similarly, Bonney‘s Camp Lagoon shows the same trend, excluding the modern, surface sample. These wetlands were selected to be representative of the Marcollat and Bakers Range watercourses respectively. Hence, the diatom record indicates that these wetlands are actually experiencing a freshening of surface water. The historical ground water salinity data, however, show increasing salinity near Jaffray Swamp and decreasing salinity near Bonney’s Camp. It is suggested that with vegetation clearance and the continual cycle of dryland salinization groundwater salinity of the region is rising. Evidence of such is provided by Barnett (1989), Foale and Smith (1991) and the Environmental Impact Assessments Branch (1995). In contrast to the above mentioned wetland sediment cores, Reedy Lake sediment core shows an increase of salinity in the modern samples. This lake is a groundwater fed lake, perched on the edge of the interdune corridor and does not receive surface water from the main Bakers Range watercourse. It appears that this lake salinity reflects regional groundwater salinity trends.

The declining salinity of wetland surface water may be due to the progressive construction of a surface water drainage network, which channels surface water northward through the chain of swamps (Taffs, submitted). The drainage system has increased the amount of surface water and the rate at which surface water moves through the wetlands. The hydrological change is flushing salts from the wetland ecosystems resulting in an improvement of their water quality compared with that experienced prior to European settlement. The current degradation of wetlands is therefore not due to surface water salinity but rather a combination of other factors resulting from vegetation clearance and grazing activities.

Conclusions

While regional groundwater salinity may be increasing in the Upper South East, due to the impact of European settlement or contemporary climate change, the effect of drainage in the main wetland areas has been to reduce wetland surface water salinity. Current wetland degradation is not due to dryland salinization but rather to hydrological changes that may relate to the water depth and surface water movement through the wetland areas, both a result of drainage activities.

Reconstruction of the diatom assemblage to provide information on the salinization trends in the Upper South East proved useful for the period of European settlement. As the only available palaeo indicator preserved in this region, information retrieved from their assemblage could prove invaluable to the management of the Upper South East of South Australia’s wetlands, particularly as trends could not be determined from the scant historical records available. In combination, the diatom assemblage and the historical information were sufficient to determine recent trends of environmental change.

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References

Assessment Section. 1980: *The effect of drainage in the South East of South Australia. South Australian.* Department for the Environment, Adelaide.

Barker, P., Fontes, J.C., Gasse, F. and Druart, J.C. 1994: Experimental dissolution of diatom silica in concentrated salt solutions and implications for palaeoenvironmental reconstruction. Limnology and Oceanography **39,** 99-110.

Bakers Range/Marcollat Watercourses Working Group. 1991: *Dryland salinity impacts and related groundwater and surface water management issues in Counties Cardwell and Macdonnell, South East South Australia, Adelaide*. Department for the Environment, Adelaide.

Barnett, S. R. 1989: The effect of land clearance in the Mallee region on River Murray salinity and land salinization. *BMR Journal of Geology and Geophysics* **11,** 205-208.

Battarbee, R. W. 1986: Diatom analysis. In Berglund, B.E., editor, *Handbook of Holocene Palaeoecology and Palaeohydrology*, Chinchester: John Wiley and Sons, 527-563.

Battarbee, R. W. 1988: The use of diatom analysis in Archaeology. *Journal of Archaeological Science* **15,** 621-644.

Battarbee, R. W., Flower, R. J., Juggins, S., Patrick, S. T., and Stevenson, A. C. 1997: The relationship between diatoms and surface water quality in the Hoylandet area of North-Trondelag, Norway. *Hydrobiologia* **348,** 69-80.

Bengtsson, L., and Enell, M. 1986: Chemical Analysis. In Berglund, B.E., editor, *Handbook of Holocene Palaeoecology and Palaeohydrology*, Chinchester: John Wiley and Sons, 423-451.

Birks, H. J. B. 1993: Quaternary palaeoecology and vegetation science - current contributions and possible future developments. *Review of Palaeobotany and Palynology* **79,** 153-177.

Birks, H. J. B. 1994: The importance of pollen and diatom taxonomic precision in quantitative palaeoenvironmental reconstructions. *Review of Palaeobotany and Palynology* **83,** 107-117.

Birks, H. 1996: Contributions of Quaternary palaeoecology to nature conservation. *Journal of Vegetation Science* **7,** 89-98.

Clark, R. L. 1990: Ecological history for environmental management. *Proceedings of the Ecological Society of Australia* **16,** 1-21.

Cook, P. J., Colwell, J.B., Firman, J.B., Lindsay, J.M., Schwebel, D.A. and von der Borch, C.C. 1977: The late Cainozioc sequence of south east South Australia and Pleistocene sea-level changes. *BMR Journal of Australian Geology and geophysics* **2,** 81-88.

Creagh, C. 1993: Past Clues to Future Climate. *Ecos* **75,** 16-19.

Crosby, A. W. 1995: The past and present of environmental history. *American Historical Review***,** 1177-1189.

D'Costa, D. M., Edney, P., Kershaw, A.P. and DeDeckker, P. 1989: Late Quaternary palaeoecology of Tower Hill, Victoria, Australia. *Journal of Biogeography* **16,** 461-482.

Doe, B. R. 1983: The past is the key to the future. *Geochimica et Cosmochimica Acta* **47,** 1341-1354.

Dovers, S., and Dargavel, J. 1991: Environmental History - a confluence of disciplines. *Australian Historical Association Bulletin* **66-67,** 25-30.

Environmental Impact Assessments Branch. 1995: T*he Upper South East Dryland Salinity and Flood Management Plan: Assessment Report*. Department of Housing and Urban Development, Adelaide.

Foale, M., and Smith, D. 1991: *People, Water and Salt: An historical account of the incidence of flooding and salinity in the Upper South-East of South Australia.* Department of Environment and Planning, Adelaide.

Foged, N. 1978: Diatoms In Eastern Australia. *Bibliotheca Phycologica* **47**.

Fritz, S. C., Juggins, S., Battarbee, R. W., and Engstrom, D. R. 1991: Reconstruction of past changes in salinity and climate using a diatom-based transfer function. *Nature* **352,** 55-57.

Gasse, F., Fontes, J.C., Plaziat, J.C., Carbonel, P., Kaczmarska, I., De Deckker, P., Soulie-Marsche, I., Callot, Y. and Dupeuble, P.A. 1987: Biological remains, geochemistry and stable isotopes for the reconstruction of environmental and hydrological changes in the Holocene lakes from north Sahara. *Palaeogeography, Palaeoclimatology, Palaeoecology* **60,** 1-46.

Gasse, F., Barker, P., Gell, P. A., Fritz, S. C., and Chalie, F. 1997: Diatom inferred salinity in palaeolakes: an indirect tracer of climate change. *Quaternary Science Review* **16,** 547-563.

Gell, P. A. 1995: *The development and application of a diatom calibration set for lake salinity, western Victoria, Australia*. Unpublished PhD thesis, Monash University.

Gell, P. A. 1997: The development of a diatom database for inferring lake salinity, Western Victoria, Australia: towards a quantitative approach for reconstructing past climates. *Australian Journal of Botany.* **45,** 389-423.

Gunn, R. H., Beattie, J.A., Reid, R.E. and van de Graaff, R.M.H. 1988: *Australian Soil and Land Survey Handbook: guidelines for conducting surveys*. Inkata press, Sydney.

Hecky, R. E., and Kilham, P. 1973: Diatoms in alkaline, saline lakes: ecology and geochemical implications. *Limnology and Oceanography* **18,** 53-71.

Hunter, M. L., Jacobson, G. L., and Webb, T. 1988: Paleoecology and the coarse-filter approach to maintaining biological diversity. *Conservation Biology* **2,** 375-385.

Jensen, A. 1983: *The effects of drainage on groundwater behaviour in Counties Cardwell and Buckingham and the effect on the Coorong*. Department of Environment and Planning, Adelaide.

Kelly, M. G., Cazaubon, A., Coring, E., Dell'Uomo, A., Ector, L., Goldsmith, B., Guasch, H., Hürlimann, J., Jarlman, A., Kawecka, B., Kwandrans, J., Laugaste, R., Lindstrøm, E-A., Leitao, M., Marvan, P., Padisák, J., Pipp, E., Prygiel, J., Rott, E., Sabater, S., van Dam, H. and Vizinet, J. 1998: Recommendations for the routine sampling of diatoms for water quality assessments in Europe. *Journal of Applied Phycology* **10,** 215-224.

Krammer, K. and Lange-Bertelot, H. 1986: *Susswasserflora von Mitteleuropa.* Bacillariophyceae i Teil: Bacillariaceae, Epithemiacaeae, Surrirellaceae. Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertelot, H. 1988: *Susswasserflora von Mitteleuropa.* Bacillariophyceae ii Teil: Bacillariaceae, Epithemiacaeae, Surrirellaceae. Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertelot, H. 1991a: *Susswasserflora von Mitteleuropa.* Bacillariophyceae iii Teil: Centrales. Fragilariaceae, Eunotiaceae. Gustav Fischer Verlag, Stuttgart.

Krammer, K. and Lange-Bertelot, H. 1991b: *Susswasserflora von Mitteleuropa.* Bacillariophyceae iv Teil: Achnanthaceae. Gustav Fischer Verlag, Stuttgart.

MacKenzie, G. A., and Stadter, F. 1992: *Groundwater occurrence and the impacts of various land management practices in the Upper South East of South Australia.* Department of Mines and Energy, Adelaide.

Melville, C.P. and Martin. 1936: *Report On The Agricultural Potential Of The Upper South East.* Department of Records, No. 62.

Moser, K. A., MacDonald, G. M., and Smol, J. P. 1996: Applications of freshwater diatoms to geographical Research. *Progress in Physical Geography* **20,** 21-52.

Nance, C., and Speight, D. L. 1986: *A Land Transformed. Environmental change in South Australia*. Longman Chesire Pty. Ltd., Melbourne.

Ogden, R. 1996: *The Impacts Of Farming And River Regulation On Billabongs Of The Southeast Murray Basin, Australia*. Unpublished PhD Thesis, Australian National University.

Powell, J. M. 1996: Historical geography and environmental history: an Australian interface. *Journal of Historical Geography* **22,** 253-273.

Round, F. E. 1964: The diatom sequence in lake deposits: some problems of interpretation. *Verh. Internat. Verein. Limnol.* **15,** 1012-1020.

Round, F. E. 1991: Diatoms in river water-monitoring studies. *Journal of Applied Phycology* **3,** 129-145.

Schwebel, D. A. 1984: Quaternary Stratigraphy and sea-level variation in the Southeast of South Australia. In Thom, B.G., editor, *Coastal geomorphology in Australia*, Sydney: Academic press, 291-311.

Smith, J. D., and Hamilton, T. F. 1985: Modelling of 210Pb behaviour in the catchment and sediment of Lake Tali Karng, Victoria, and estimation of recent sedimentation rates. *Australian Journal of Marine and Freshwater Research* **36,** 15-22.

Taffs, K.H. Submitted. The changing surface water hydrology of the Upper South East of South Australia: A historical reconstruction. *Australian Geographer.*

Taylor, J.K. 1933: *A Soil Survey Of The Hundreds Of Laffer And Willalooka,* South Australia. Report of the Division of Soils, CSIR, Bulletin No. 76, Melbourne.

Upper South East Dryland Salinity and Flood Management Plan Steering Committee. 1993: *The Upper South East Dryland Salinity and Flood Management Plan: Draft Environmental Impact Statement - for Public Comment*. Natural Resources Council of South Australia, Adelaide.

Wasson, R. J., and Clark, R. L. 1985: Environmental History for explanation and prediction. *Search* **16,** 258-263.

Young, A. 1976: V*egetation Clearance in South Australia*. Interdepartmental Committee on Vegetation Clearance, Adelaide.