2004

Recent sedimentation and geomorphological changes, Lake Illawarra, NSW, Australia

Craig R. Sloss
Queensland University Of Technology, csloss@uow.edu.au

Brian G. Jones
University of Wollongong, briangj@uow.edu.au

Colin V. Murray-Wallace
University of Wollongong, cwallace@uow.edu.au

Bryan E. Chenhall
University of Wollongong, bryanc@uow.edu.au

Recent sedimentation and geomorphological changes, Lake Illawarra, NSW, Australia

Abstract

Assessing recent changes in landforms associated with Lake Illawarra was achieved by identifying changes in geomorphological features observed in early mapping of the region, aerial photographs and satellite imagery. Quantifying rates of sedimentation associated with prograding fluvial bay-head deltas and within the central basin of Lake Illawarra was established within the framework of amino acid racemisation, radiocarbon, and cesium 137 dating. Results indicate that sedimentation rates associated with fluvial bay-head deltas range from 31 mm/yr proximal to the delta front and fall to between 3 and 7 mm/yr in the pro-delta region. This is a significant increase in sedimentation rate when compared to the underlying estuarine mud (<1mm/yr). Data obtained from the central lagoon facies also support a significant increase in the rate of sedimentation over the last 200 years with pre-European settlement sedimentation rates of ca. 0.3 mm/yr increasing to 0.52 m/yr for the period associated with initial settlement and a sedimentation rate of ca. 4.5 mm/yr for the past 50 years. As indicated by the aerial photos, remotely sensed imagery and post-European sedimentation rates, the sedimentary infill of Lake Illawarra and the morphological change associated with the fluvial influenced facies and inlet processes have increased significantly over the last 200 years. However, results only imply that recent morphological change and increased sedimentation is due to anthropogenic effects, and further research is needed to separate natural sedimentary processes as opposed to accelerated sedimentation due to human modification of the landscape.

Keywords

nsw, illawarra, australia, lake, changes, sedimentation, recent, geomorphological, GeoQuest

Disciplines

Medicine and Health Sciences | Social and Behavioral Sciences

Publication Details

Sloss, C. R., Jones, B. G., Murray-Wallace, C. V. & Chenhall, B. E. (2004). Recent sedimentation and geomorphological changes, Lake Illawarra, NSW, Australia. Wetlands (Australia), 21 73-83.

RECENT SEDIMENTATION AND GEOMORPHOLOGICAL CHANGES, LAKE ILLAWARRA, NSW, AUSTRALIA

Craig R. Sloss*, Brian G. Jones, Colin V. Murray-Wallace, Bryan E. Chenhall

School of Earth and Environmental Sciences, University of Wollongong, NSW 2522, Australia.

ABSTRACT

Assessing recent changes in landforms associated with Lake Illawarra was achieved by identifying changes in geomorphological features observed in early mapping of the region, aerial photographs and satellite imagery. Quantifying rates of sedimentation associated with prograding fluvial bay-head deltas and within the central basin of Lake Illawarra was established within the framework of amino acid racemisation, radiocarbon, and cesium 137 dating. Results indicate that sedimentation rates associated with fluvial bay-head deltas range from 31 mm/yr proximal to the delta front and fall to between 3 and 7 mm/yr in the pro-delta region. This is a significant increase in sedimentation rate when compared to the underlying estuarine mud (<1mm/yr). Data obtained from the central lagoon facies also support a significant increase in the rate of sedimentation over the last 200 years with pre-European settlement sedimentation rates of *ca*. 0.3 mm/yr increasing to 0.52 m/yr for the period associated with initial settlement and a sedimentation rate of *ca*. 4.5 mm/yr for the past 50 years. As indicated by the aerial photos, remotely sensed imagery and post-European sedimentation rates, the sedimentary infill of Lake Illawarra and the morphological change associated with the fluvial influenced facies and inlet processes have increased significantly over the last 200 years. However, results only imply that recent morphological change and increased sedimentation is due to anthropogenic effects, and further research is needed to separate natural sedimentary processes as opposed to accelerated sedimentation due to human modification of the landscape.

INTRODUCTION

Establishing the extent of geomorphological change and sedimentation rates for the last 200 years will assist in ascertaining the impact of European settlement on sedimentation within Lake Illawarra. Settlement in the catchment commenced in 1817 and since that time the catchment has undergone extensive clearing for agricultural, industrial and urban purposes to the point that the lagoon is now entirely ringed by a significantly modified landscape (Chenhall *et al.* 1995; Hagan and Wells, 1997). Such extensive landuse modification has led to an acceleration of sedimentation in the shallow lagoon. This has produced significant environmental impacts such as shoaling and choking of navigation routes, increased nutrient loads leading to proliferation of algal blooms, increased turbidity and the degradation of estuarine flora and fauna, as well as a loss of aesthetic appeal (Chenhall *et al.* 1995). The extent of morphological change has been ascertained by comparing early maps of the region with changes in recognised geomorphological features on aerial photographs taken since 1961. The rates at which morphological change is occurring may be compared with sedimentation rates in near-surface sediments that have been established within the geochronological framework of aspartic acid racemisation and radiocarbon dating, together with ^{137}Cs profiles. Obtaining quantitative data on geomorphological change and sedimentation rates since European settlement helps to assess the impact the anthropogenic effects have on sedimentary processes in Lake Illawarra. An understanding of such anthropogenic influences will also assist in modelling for future management issues associated with accelerated sedimentation.

STUDY AREA

Lake Illawarra is a shallow elongate coastal lagoon located 80 km south of Sydney. It covers an area of *ca*. 34 km^2 and fills a coastal depression scoured into the Late Permian Shoalhaven Group and Pleistocene sediments. The lagoon has a maximum depth of 3.7 m with an average depth of 1.9 m (Roy and Peat, 1975). Water depth, high salinity, and wind-generated currents and waves, control the distribution of surface sediments in the lagoon (Jones *et al*., 1976; Jones, 1994), which displays a characteristic tripartite facies division consisting of fluvially-influenced facies, a central lagoon facies and marine-influenced facies (Roy, 1984; Nichol, 1991; Dalrymple, 1992; Dalrymple *et al*., 1992).

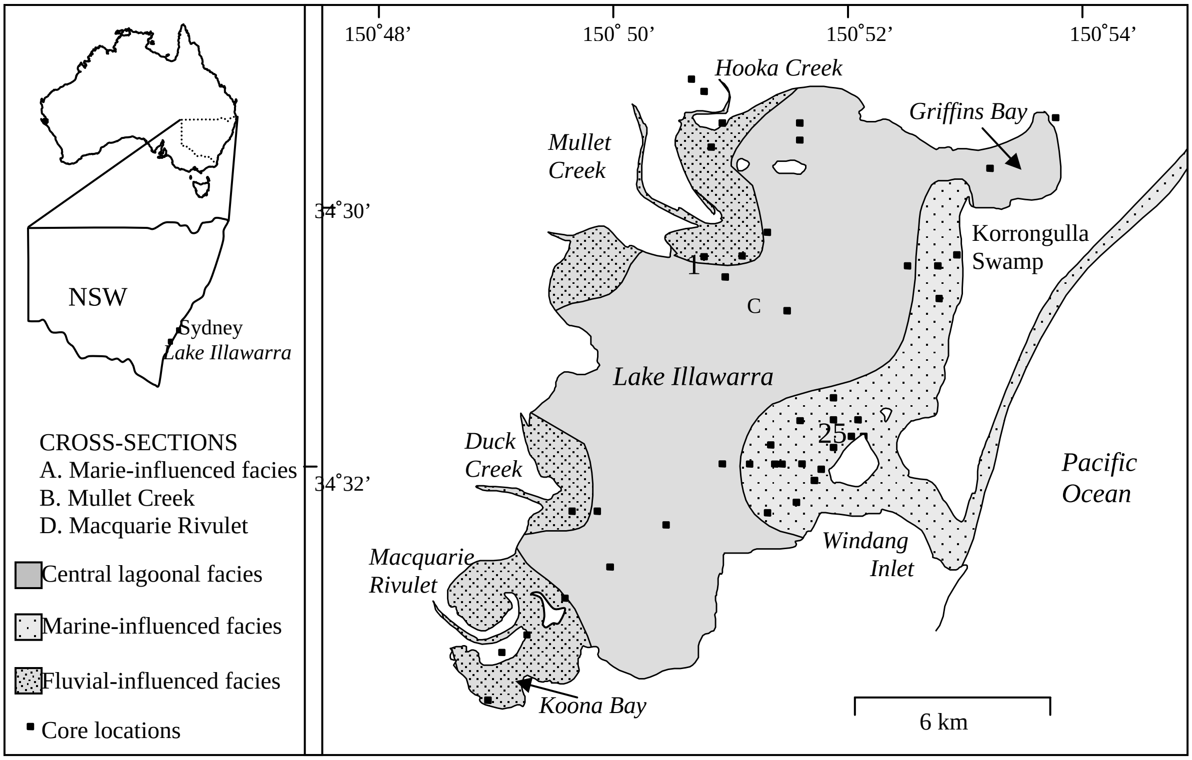
FLUVIAL GEOMORPHOLOGY AND SEDIMENTATION

The fluvially-influenced facies is dominated by bay-head deltas prograding into the central lagoon via Hooka and Mullet Creek to the northwest, Duck Creek and Macquarie rivulet to the southwest and numerous smaller creeks that enter the lagoon around the northern, western and southern margins (Fig.1). Fluvially-influenced bay-head delta deposits are dominated by clean, poorly sorted medium- to coarse-grained lithic sand. Reworking of fluvial sediment by internally wind-generated waves and currents result in the deposition of lithic muddy-sand around the northern, western and southern lagoon margins at water depths of <1 m.

Mullet and Hooka Creek deltas:

Mullet Creek has a subaqueous lobate fluvial delta that extends *ca*. 0.6 km east-southeast from the mouth of Mullet Creek and has an maximum width of *ca*. 1 km (Fig. 2). It has a single fluvial channel and a delta that is characteristic of a wave-dominated system. In a wave-dominated system, wind-generated waves and currents tend to rework sediment within the estuarine environment. The reworked sediment is moved alongshore, and the fine fraction that remains in suspension is transported into the deeper portions of the receiving basin (Coleman 1976; Bhattacharya and Walker 1992). This produces the lobate delta morphology and smooth shoreline characterised by shore-parallel bars or ridges which are evident adjacent to the northern margin of the Mullet Creek delta.

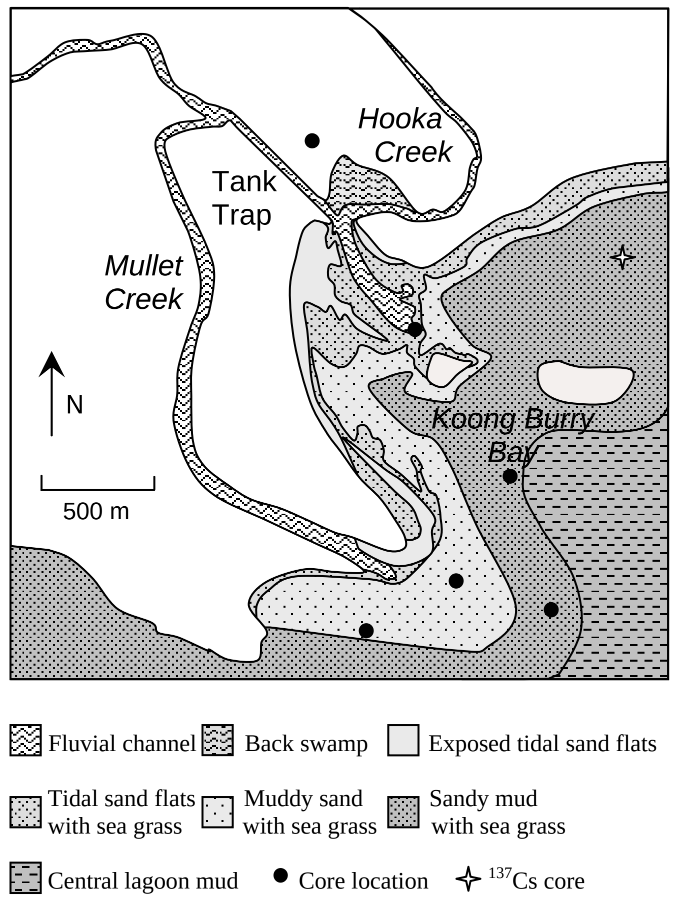
Figure 1: Location map, tripartite facies divisions and core locations, Lake Illawarra.



Aspartic acid racemisation derived ages obtained on fossil molluscs preserved in sedimentary successions extending into framework for quantifying sedimentation rates. An articulated *Notospisula trigonella* from a core depth of 65 cm in the prodelta of Mullet Creek yielded an aspartic acid derived age of 200 ± 10 yr (VC3). This indicates that the rate of prodelta sediment accumulation over the last 200 years has been *ca*. 3.3 mm/yr. This is probably a minimum rate of prodelta accumulation since the main flow has been diverted for the past 60 years into Hooka Creek and sedimentation rates may have been as high as *ca*. 7 mm/yr during active delta progradation. Nevertheless, this is a major increase compared with sedimentation rates associated with the underlying estuarine mud that accumulated at a sedimentation rate of <1 mm/a over the previous 2500 years (Sloss *et al*., in press).

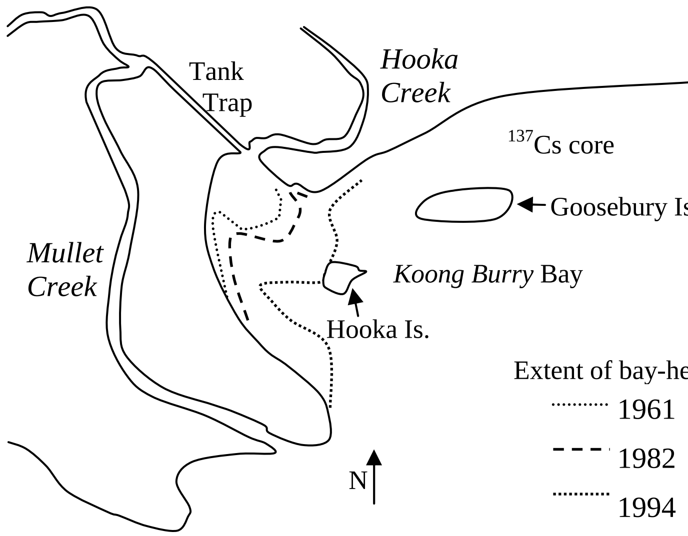
The establishment of the sediment Tank Trap in 1941, that redirected flow from Mullet Creek into the northern part of Koong Burry Bay, has significantly increased sedimentation in the Hooka Creek region as evident in the aerial photographs from 1961 to 1994 (Fig. 2). Interpretation of aerial photographs has shown that bay-head delta progradation significantly increased between 1961 to 1994 with the development of a small bifurcating fluvial delta in the shallow basin. The 1982 aerial photograph shows a small subaerially exposed delta had developed, which had significantly increased in size in the 1994 aerial photographs (Fig. 3). Sedimentation has resulted in significant shoaling between the prograding deltas and Hooka Island (Fig. 3).

Figure 2: Facies division in the Mullet and Hooka Creek area



Estimation of sedimentation rates within the Hooka Creek bay-head delta region have been ascertained from a combination of aspartic acid-derived ages and a ^{137}Cs profile (Figs 2 & 3). An aspartic acid derived age of 70 ± 5 yr on an articulated *N. trigonella* obtained at a depth of 0.5 m, proximal to Hooka Creek pro-delta, indicates a sedimentation rate of 7.14 mm/yr over the last 70 years (UWGA-826, Core VC15, Fig. 3). This rate of sedimentation decreases with distance from the delta as indicated by ^{137}Cs data obtained from the northern region of the lagoon (Fig. 3). The ^{137}Cs data indicate a sedimentation rate of 3.5 mm/yr for the last 30 years. While this rate of sedimentation is significantly less than the rate proximal to Hooka Creek bay-head prodelta, the rate of sedimentation is still significantly higher than the sedimentation rates for the underlying lagoonal sandy mud, as indicated by an aspartic acid derived age of 2800 ± 120 yr obtained on an articulated *A. trapezia* from 1.03 m below the sediment water interface (*ca*. 2 mm/yr; UWGA-827, Core VC15). This indicates that the diversion of the main flow from Mullet Creek to Hooka Creek via the Tank Trap has had a profound influence on sedimentation in the Hooka Creek region, as well as the northwestern region of Lake Illawarra as a whole (Fig. 3).

Figure 3: Progradation of the bay-head delta associated with Hooka Creek and the Tank Trap, mapped from aerial photographs from 1961 to 1994, showing a significant increase in sedimentation rates.



Macquarie Rivulet delta

The river-dominated Macquarie Rivulet delta is located in the southwest of the lagoon extending *ca*. 1.3 km into the lagoon. The elongate morphology of Macquarie Rivulet delta is in stark contrast to the wave-dominated delta morphology associated with Mullet Creek (cf. Figs 2 & 4). Macquarie Rivulet enters the lagoon in a relatively sheltered embayment and experiences lower wind and wave energy. In addition, Macquarie Rivulet has a higher discharge than Mullet Creek and, as a result, the system is dominated by river flow. This results in bifurcating channels with lobe and river-mouth switching producing thinner and more lobate sub-deltas characteristic of river-dominated systems (Fig. 4). The net result is a significantly indented coastline with multiple extended distributaries producing the "birdsfoot" morphology as, for example, in the Mississippi River delta, USA (Coleman and Wright 1975; Bhattacharya and Walker 1992).

The extent of the progradation and development of the birdsfoot delta is evident by observing morphological change that has occurred since initial mapping of the delta in 1857 and compared with aerial photographs from 1982 (Fig. 5).

Lithostratigraphic evidence indicates that the prograding fluvial sands lie directly over cohesive estuarine mud of Holocene age. Radiocarbon and aspartic acid derived ages indicate that the current prograding delta is a relatively recent deposit. A radiocarbon age on *A. trapezia* from basal deltaic sands yielded an age of 350 ± 80 cal yr BP (Wk-7903; core VC8). This relatively recent episode of sedimentation is also supported by an aspartic acid derived age of 330 ± 20 yr on an articulated *N. trigonella* collected from basal deltaic sands within the delta front (UWGA 629; core VC7). The rate

Figure 4: Facies divisions and core location for the Macquarie Rivulet region

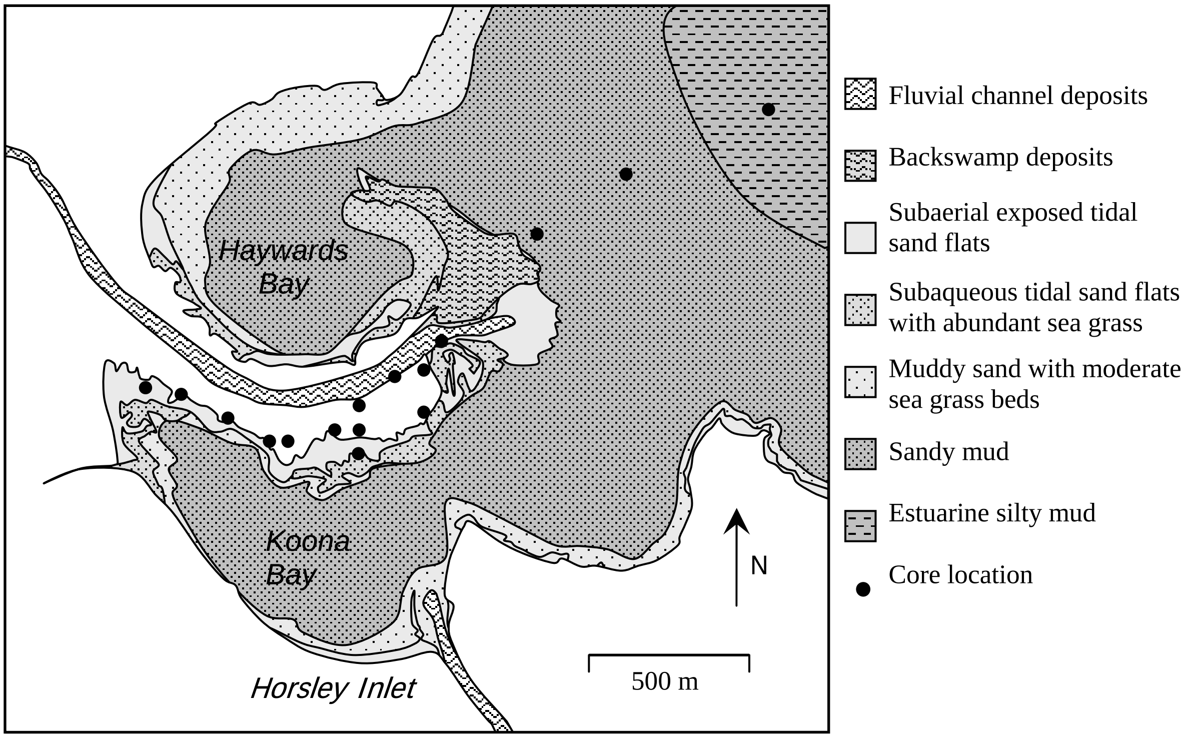
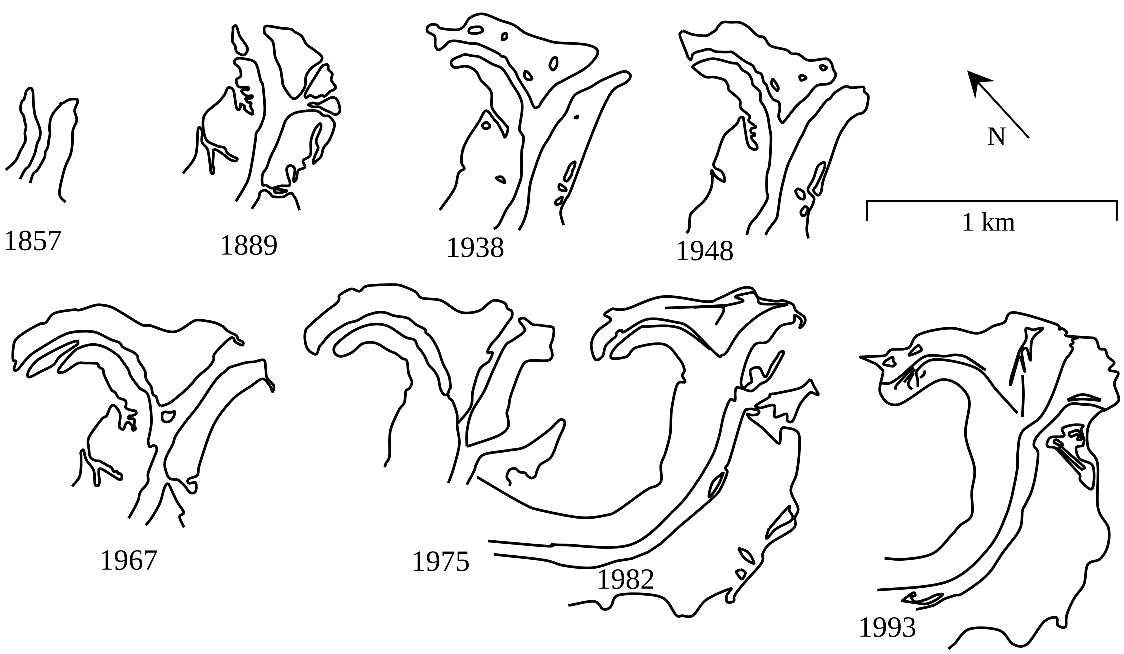


Figure 5: Evolution of Macquarie Rivulet delta 1857 – 1993 (modified after Young 1986).



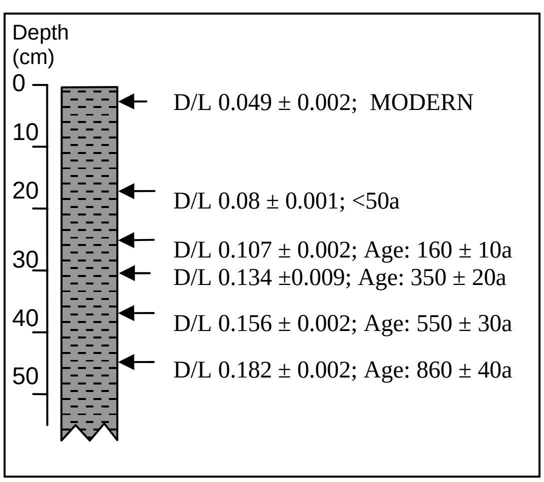
of relatively recent sedimentation associated with Macquarie Rivulet delta can be ascertained from the results obtained from aspartic acid derived ages obtained from fossil molluscs and ^{137}Cs data. An aspartic acid derived age of *ca*. 40 yr on *N. trigonella* at a core depth of 125 cm (UWGA-628; core VC7) indicates sedimentation rates of 31 mm/yr in the pro-delta region. This is a significant increase in sedimentation rate compared with the period between 300 years ago until about 40 years ago of approximately 4.5 mm/yr. An aspartic acid derived age on an articulate *A. trapezia* (UWGA-826) at a depth of 50 cm farther into the lagoon basin with a decrease in sedimentation rate in the distal prodelta region to a rate of 6.6 mm/yr for the last 75 years. Similar results were obtained from the ^{137}Cs profile in a short core collected in Haywards Bay to the north of the main Macquarie Rivulet delta with a sedimentation rate of 6 mm/yr. In Koona Bay, just south of the active distributary, a ^{137}Cs profile suggests sedimentation at 4 mm/yr. This is again consistent with sedimentation rates observed in the pro-delta environment near Hooka Creek and indicates a decreasing sedimentation rate with increasing distance from the active delta front.

CENTRAL LAGOON

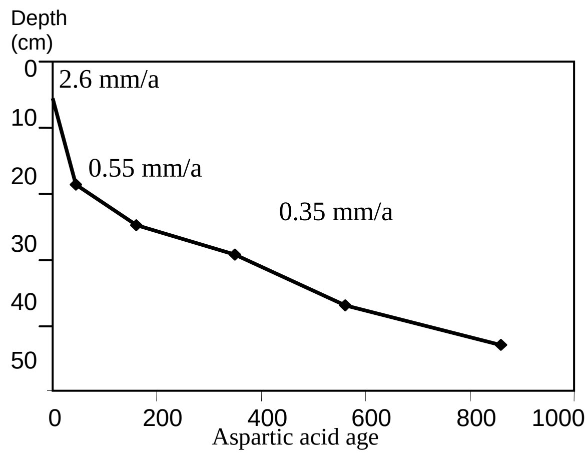
Three cores collected within the central lagoon facies (VC4, VC5 and VC6) indicate that the estuarine muds accumulated at an average rate of *ca*. 1 mm/yr (0.8-1.6 mm/yr). This slow rate of sedimentation is similar to rates observed in estuarine muds that accumulated in the Mullet Creek area between 4000-2000 years ago. The relatively uninterrupted sediment supply and abundance of *N. trigonella* in life position make the central lagoon an ideal site to test the potential of aspartic acid racemisation as a high-resolution dating technique for relatively recent sedimentation. This is evident from aspartic acid-derived ages obtained from articulated *N. trigonella* from the top 50 cm of the central lagoon core (core VC4; Fig. 6; Sloss *et al*., in press).

Figure 6:**(a)** Top 50 cm of central lagoon core showing increasing Asp D/L ratio and calibrated age down core; and **(b)** Asp D/L ratio in relation to depth within the top 42 cm of core VC4- in the central lagoon facies showing the dramatic increase in sedimentation rate over the past 900 years.

(a) Central lagoon facies: core VC4



***(b)** Sedimentation rates for the central lagoon facies: Core VC4*



These results indicate that the average rate of sedimentation for backbarrier lagoonal mud was *ca*. 0.35 mm/yr for the 600 year period prior to European settlement (Fig. 2b). The period between *ca*. 160 years and *ca*. 50 years which corresponds with primary land clearing for agricultural development, shows an increase in sedimentation rate to 0.55 mm/yr. The period from *ca*. 50 years to the present, characterised by a dramatic increase in urban and industrial development within the Lake Illawarra catchment, shows an increase in sedimentation rate to 2.6 mm/yr (possibly half of which can be attributed to a lower compaction within the uppermost portion of the core; Fig. 6). These aspartic acid derived ages establish a chronology for assessing sedimentation rates in geologically-young estuarine successions (Sloss *et al*., in press). In the case of Lake Illawarra, the results indicate a dramatic increase in sedimentation rates associated with post-European settlement and extensive industrialisation and urbanisation of the Lake Illawarra catchment (Hagan and Wells, 1997).

MARINE SEDIMENTATION

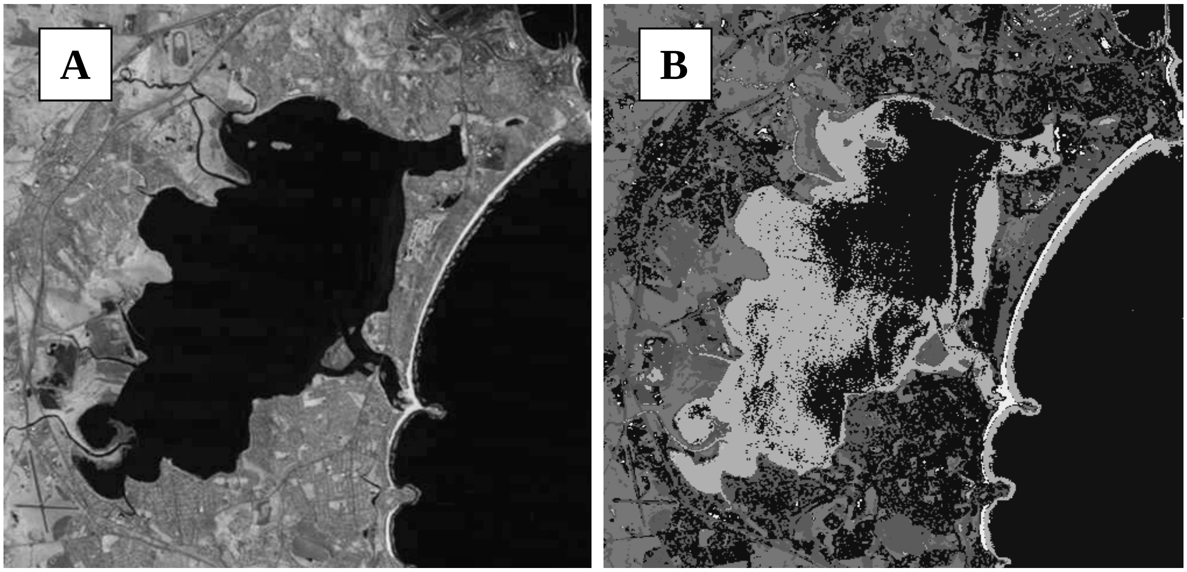
The marine influenced facies is predominantly composed of clean to slightly muddy quartzose sand from the barrier and flood-tidal delta on the eastern side of the lagoon (Roy and Peat, 1975; Jones *et al*., 1976; Jones, 1994). The subtidal portion of the barrier on the eastern margin of the lagoon extends from Cudgeree Hole in the south to Purry Burry Point in the north and is composed of aeolian sand sourced from the adjacent dune systems, and earlier marine deposits, reworked by wind-generated currents and waves. The flood-tide delta, south from Cudgeree Hole to Wyjack Bay has formed mainly by the direct supply of marine sands transported into the lagoon by flood-tide currents, but may contain small proportions of reworked dune sands.

The 3.7 km long inlet at Windang connects the lagoon to the open ocean. The channel is dominated by tidal flow, which is, in turn, controlled by shoaling at the entrance channel and along the inlet channel. Prior to the construction of the training wall, the mouth of the entrance changed regularly due to sediment movement associated with tides, wave action, wind-transported sediment and long-shore drift. If shoaling in the entrance is severe then the influence of the flood and ebb tide is reduced. While this reduces the capacity to move sand from the open ocean into the channel, it also reduces the capacity for the transport of sediment within the channel and can result in increased shoaling, which increases frictional drag creating a positive feedback mechanism. In addition, the training wall prevents the entrance from opening to Warilla Beach during the summer when northeasterly winds and waves move sand into the inlet channel entrance. This will further enhance shoaling in the entrance channel and lead to closure of the entrance (Fig. 7). When increased shoaling occurs, potential problems such as the restricted passage of marine life and reduced flushing of floodwaters and pollutants will also occur.

SEDIMENTATION IN LAKE ILLAWARRA

The increased sedimentation rate since European settlement can also be traced using remotely sensed images of Lake

Figure 7: (**a**) 1995 Landsat MSS false colour composite image using Bands 3, 4, 5. (**b**) Supervised parallelepiped classification of pixel values showing major land use patterns around the lake margin and sediment distribution within the Lake Illawarra basin waters.



Illawarra and the immediate landscape. This is evident from the Landsat image of Lake Illawarra taken in 1995, which highlights both landuse as well as the spatial distribution of suspended sediment within the lagoon (Fig. 7 a & b).

A parallelepiped classification of the optical properties of individual pixels using the Landsat MSS false colour composite image highlights the area within the lagoon associated with shallow water and the distribution of suspended sediment (Fig. 7b). The western margin of the lagoon is in-filling under the influence of the fluvial deltas, with the heaviest concentrations associated with Macquarie Rivulet, Duck Creek and Hooka Creek. The large amount of suspended sediment in the central lagoon is sourced from fine detritus being transported into Lake Illawarra from Macquarie Rivulet and moved northwards due to internal wind-generated currents. The classified image also highlights the shoaling of the entrance and inlet channel, as well as the movement of marine sand into the lagoonal basin (Fig. 7b). The sediments associated with the flood-tide delta shows two distinct extensions into the basin. These extensions are associated with a series of relict sub-aqueous marine incursions. Also highlighted in the classified image is the northward movement of marine sand sourced from the present inlet and the reworking of aeolian sand along the barrier due to internally-generated wind-wave currents.

CONCLUSIONS

Accelerated sedimentation associated with deforestation and rural expansion, as well as the development of industrial and urban areas around Lake Illawarra, has had a dramatic affect on sedimentation rate and deltaic development associated with fluvial runoff. This accelerated sedimentation poses significant environmental problems, particularly in the regions of Macquarie Rivulet, Duck Creek and Hooka Creek where bay-head delta progradation has resulted in sedimentation rates up to 7 mm/yr. If these sedimentation rates continue unabated then significant shoaling and loss of deeper aquatic habitat will occur, accompanied by a development of progressive wetlands and saltmarsh. This will also have a significant impact on the aesthetic quality and recreational use of the lagoon, and impact on the tourist trade as well as the environment. In contrast to the fluvially influenced sedimentation, shoaling associated with the marine inlet is mainly attributed to natural processes. Nevertheless, the impact of shoaling poses the same problems associated with the fluvial influenced zones. Overall, sedimentation in Lake Illawarra is a story of in-filling of a barrier estuary. This has been occurring since the initial formation of the barrier estuary associated with the last postglacial marine transgression and subsequent Holocene sea level highstand from *ca*. 7900 – 5000 years ago. However, as indicated by the aerial photos, remotely sensed imagery and post-European sedimentation rates the sedimentary infill of Lake Illawarra and the morphological change associated with the fluvial influenced facies and inlet processes have increased significantly over the last 200 years.

ACKNOWLEDGEMENTS

The School of Earth and Environmental Sciences, University of Wollongong; the Research Centre for Landscape Change, University of Wollongong; an Australian Postgraduate Scholarship; and an Australian Institute of Nuclear Science and Engineering (AINSE) Postgraduate Award provided financial and fieldwork support.

REFERENCES

Bhattacharya, J. P., and Walker, R.G., (1992). Deltas. *In* Walker, R.G., and James, N.P. *Facies Models: Response to Sea Level Change*, pp 157-178. Geological Association of Canada, Toronto.

Chenhall, B.E., Yassini, I., Depers, A.M., Caitcheon, G., Jones, B.G., Batley, G., and G.E., Ohmsen, G.S., (1995). Anthropogenic marker evidence for accelerated sedimentation in Lake Illawarra, New South Wales, Australia. *Environmental Geology*, **26**, 124-135.

Coleman, J.M., (1976). *Deltas: Processes of Deposition and Models for Exploration*. Continuing Education Publication Company Inc, Champaign.

Dalrymple, R.W., (1992). Tidal Depositional Systems. *In* Walker, R.G., and James, N.P., (eds) *Facies Models; Response to Sea Level Change*. pp. 195-218, Geological Association of Canada, Toronto.

Dalrymple, R.W., Zaitlin, B.A. and Boyd, R., (1992). Estuarine facies models: conceptual basis and stratigraphic implications. *Journal of Sedimentary Petrology*, **62**, 1130-1146.
Hagan, J., Wells, A., (1997). *A History of Wollongong*, pp. 23-71. University of Wollongong Press, Wollongong.

Jones, B.G., Eliot, I. G. and Depers, A.M., (1976). Sediments in the Lake. *In Illawarra Lake Environmental Project Management Advisory Committee*

Report, pp. 20-40. Wollongong City Council and University of Wollongong.

Jones, B.G., (1994). *In* Depers, A.M., Yassini, I. and Clarke, A. (eds). *Recent Sediments in Lake Illawarra: Implications for Management*, pp. 22-23. Department of Geology, University of Wollongong and the Illawarra Catchment Management Committee, Wollongong City Council, Wollongong.

Nichol, S.L., (1991). Zonation and sedimentology of estuarine facies in an incised valley, wave dominated, microtidal setting, New South Wales, Australia. *Canadian Society of Petroleum Geologists Memoir*, **16**, 41-58.

Roy, P.S. and Peat, C (1975). Bathymetry and bottom sediments of Lake Illawarra. *Records of the Geological Survey of New South Wales*, **17**, 65-79.

Roy, P.S., (1984). Holocene estuary evolution- stratigraphic studies from southeastern Australia. *In* Dalrymple, R.W., Boyd, R., and Zaitlin, B.A. *Incised-Valley Systems: Origins and Sedimentary Sequences*, pp. 241-264. SEPM Society of Sedimentary Geology, Special Publication, **51**, 241-264.

Sloss, C.R., Murray-Wallace, C.V., Jones, B.G., Walin, T., (in press). Aspartic acid racemisation dating of mid-Holocene to recent estuarine sedimentation in New South Wales, Australia: a pilot study. *Marine Geology*.

Young, R.W., (1986). *Infilling of Lake Illawarra*. Lake Illawarra Management Committee, No. 2, Febuary 1986