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Southern Illawarra Fieldtrip
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**Introduction**

The Illawarra was one of the first places in the southern Sydney Basin to be settled after European occupation of Sydney in 1788. It is dominated by a plateau of Hawkesbury sandstone forming the spectacular escarpment. The scarp flanks the shoreline to the north of Wollongong and along the cliffed coast of the Royal National Park, exposing the underlying Permian/Triassic Wianamatta Shale and Illawarra Coal Measures. Access to the Illawarra by the early settlers was predominantly by sea. Significant exploration of this coast was undertaken by Matthew Flinders and George Bass in a small boat called Tom Thumb. They undertook the earliest hydrographic investigations of the entrance to Lake Illawarra.

The Illawarra has a mild climate. Extremes of temperature are moderated by the coastal location. Rainfall increases up the escarpment as a result of the orographic effect, increasing from about 1000 mm per annum near the coast, to 1800 mm per annum at the high point of Barren Grounds. Interannual variability is high with considerably less rainfall in El Niño years. Flash flooding down the short, steep creek systems draining off the escarpment follows intense rainfall with extensive flooding in 1984 when more than 800 mm of rain fell within 12 hours west of Dapto. Extensive flooding in Wollongong was also experienced in 1998. Temperatures are typically average annual maximum of 21.6 and average annual minimum of 12.6 °C. Sea surface temperatures off the coast of Wollongong average 18 °C, with mean summer of 22 °C and mean winter of 15 °C, mediated by the East Australian current. Winds are dominantly from the south in spring and summer and from west in winter. Northeasterly winds in spring can have important effects on beach wave climates.

Much of the Illawarra is covered by open eucalypt forest, but along the wetter parts of the escarpment, or where creeks cut through the sandstone into the more nutrient rich shales there are pockets of subtropical or temperate rain forest. The Illawarra provided large quantities of Red Cedar timber for Sydney and overseas markets, and more than 75% of the rainforests of the region have been cleared since the 1800s. The discovery of coal, sighted in seams interbedded with the sandstones in the cliffs at Coalcliff by Bass and Flinders in 1797, has meant that the region has had a long coal-mining tradition and resulted of the siting of a steelworks at Port Kembla. Port Kembla is major NSW port, exporting coal and wheat from central New South Wales. The southern end of Wollongong beach has been modified by a seawall and breakwaters protecting Port Kembla Harbour. Formerly known as Tom Thumb lagoon, construction for the harbour began in 1900.

The Illawarra forms the southern part of the Sydney Basin, and is composed of almost horizontal sedimentary rocks of Permian and Triassic age with interbedded Permian volcanic sequences in the area around Kiama (Figure 1). The escarpment rises to a maximum elevation of 600 m at Barren Grounds in the central Illawarra, and from the coast north of Wollongong, the escarpment is up to 20 km inland. The crest of the escarpment marks the watershed, and drainage on the plateau runs to the north with rivers to the west of Wollongong flowing into the Nepean River which drains to the sea through the Hawkesbury River, north of Sydney. By contrast, the coastal plain is crossed by numerous short river systems. Much of the low-lying coastal lands have proved productive agricultural land.
During this fieldtrip we will explore three different estuarine systems which are at different stage of infill, and which provide contrasting habitat for mangrove and salt marsh establishment: Lake Illawarra, the Minnamurra River, and the Shoalhaven River. Southeastern Australia is a wave-dominated coast with swell predominantly from the southeast, and each of these estuaries is bounded to seaward by a sandy barrier. Maps of the catchment boundaries, Quaternary geology (which includes depositional environments that influence the type of habitat available for wetland plants), and estuarine macrophytes are included at the back of this guide.

Waves on this coast have five sources, three of these are cyclonic associated with tropical cyclones (experienced to the north in Queensland), east-coast lows, and mid-latitude cyclones, and further waves associated with high pressure systems including the local sea breeze (Short, 1993). Waves resulting from tropical cyclones are most common in February and March; they come from the northeast, averaging 2.7 m high, but reaching up to 5 m high. East coast lows occur throughout the year but are more common in winter; waves are easterly and average up to 2.8 m high. Mid-latitude cyclones move across the southern Tasman Sea and generate most of the waves received on the NSW coast. Semidiurnal tides are microtidal with a mean spring tide range of 1.6 m, neap of 0.8 m and a maximum of 2.0 m, but tidal hydrodynamics vary into each of these estuarine systems.

**New South Wales estuaries**

The coast between Wollongong and Jervis Bay is an embayed coast comprising sandy beaches flanked by rocky headlands. The coast of New South Wales has evolved over the past 6000 years during which sea level has been relatively stable with respect to this part of the coast, in contrast to many parts of the world which may have continued to experience sea-level rise over this time. Marine sand has been moved landward during the Holocene transgression (sea-level rise) which culminated between 7000 and 7500 yr BP reaching a maximum elevation of +2 m AHD (Jones et al., 1979).

The numerous estuaries along the wave-dominated coast of southeast Australia have been classified into four types (Figure 1): i) barrier estuaries where a sand barrier incompletely occludes the mouth of an embayment; ii) saline coastal lakes often termed ICOLLs (intermittently closed and open lakes and lagoons), most of which are cut off from the sea by a sand barrier, and some of which undergo intermittent opening; iii) drowned river valleys (also called rias) which are generally deep, bedrock-fringed valleys with a predominantly submerged tidal delta at the mouth (such as Port Hacking, Port Jackson [Sydney Harbour]), and iv) open embayments where there is no major river feeding to the coast (Roy, 1984; Roy et al., 1994, 2001). The bedrock-dominated coast of Sydney contains a number of drowned river valleys, whereas the Illawarra coast contains barrier estuaries. An evolutionary model of estuary infill has been proposed and refined, based on comparison of the morphology of adjacent systems of different dimensions. A schematic representation of different stages in the infill of a barrier estuary is shown in Figure 2 (Roy, 1984). In the mature stage of infill, the river channel, which emptied into a lake in early stages of infill, becomes channelised across the infilled central mud basin, and discharges directly to the sea.
Figure 1. The principal types of estuaries and embayments that occur along the New South Wales coast, shown schematically in plan and profile. The sand wedge, forming a barrier in most cases and a tidal delta in the drowned river valley, has migrated landward during sea-level rise (marine transgression) and has adopted its present form over the past 6000 years (based on Roy, 1984).

Figure 2. Schematic representation of the stages of infill of a barrier estuary since sea level stabilised around 6000-7000 years ago (after Roy, 1984). Several systems that illustrate different stages of this infill sequence will be examined during this fieldtrip.
These estuaries have filled in, both with landward reworking of sand from the shelf and fluvial input of sand and mud from the catchment (Roy, 1984). Consequently they show the classic tripartite lithofacies zonation of estuaries located on wave-dominated, microtidal coasts with seaward shoreface and barrier environments composed of marine quartz sand with shell, landward fluvial delta composed of lithic and more angular sands, and a central mud basin with deltaic-estuarine deposition, predominantly fine-grained, and influenced by both marine and fluvial environments.

Several small river systems drain east, and each has a distinctive estuarine system at its mouth. Macquarie Rivulet has a catchment of 102 km² and drains into Lake Illawarra. Broughton Creek drains 163 km², and Kangaroo River drains 890 km² and these feed into the Shoalhaven River. These small systems bring relatively little sediment from the catchment and the nature of the estuarine system determines whether it makes it to the coast.

Lake Illawarra

Lake Illawarra is a fine example of a barrier estuary in the classification proposed by Roy (1984). This estuarine system has been subject of a number studies by staff and students at the University of Wollongong, including several ongoing studies. The lake occupies a broad valley, incised into the Permian Shoalhaven Group and a Pleistocene antecedent land surface during the sea level lowstand associated with the last glaciation. The Pleistocene surface comprises a complex network of coalescing, dendritic paleochannels draining to the east. Seismic reflection studies across the lake indicate the former courses of the two main river channels to flow into this system, Mullet Creek and Macquarie Rivulet (Sloss et al., 2005). The Lake Illawarra barrier estuary displays a characteristic tripartite facies division comprising fluvial-dominated bay-head delta facies, central lagoonal mud facies and marine-influenced sandy barrier facies (Figure 3).

The stratigraphy of lake deposits has been investigated using many vibrocores supplemented with additional auger holes, trenches, seismic data and sediment, and faunal analysis, together with a detailed chronology, using amino-acid racemisation ages constrained by strategically selected radiocarbon ages. This has enabled the definition of a five-stage geomorphic model for the infill of the barrier estuary (Figure 4). Molluscan faunal assemblages from the major sedimentary units indicate the paleoecological significance of the depositional environments and sedimentary successions recognised in the lake (Sloss et al., 2005, 2006).

The basal unit within Holocene sediments in the lake consists of a transgressive sand sheet of medium- to coarse-grained quartz and carbonate-rich marine sand. A nearshore molluscan fauna implies open marine conditions as the sea rose up to its present position around 6500 years ago. The modern sand barrier formed following the stabilisation of sea level and has restricted the influence of open marine oceanic water circulation to areas close to the entrance to the lake. In the present location of the inlet to Lake Illawarra, the shell-rich regressive marine deposit is overlain by medium-grained muddy, quartz-rich flood tide delta sand showing a significant decrease in marine influence.
Figure 3. Lake Illawarra showing tripartite facies division, and location of principal chronostratigraphic studies undertaken by Sloss et al., (2005).

Figure 4. Schematic infill of Lake Illawarra, indicating the five stage model based on the interpretations of Sloss et al. (2005, 2006).
The central mud basin of the lake contains the mollusc *Notospisula trigonella*. Mud deposits overlie the transgressive sand sheet, and these in turn are undergoing encroachment from the prograding fluvial delta deposits associated with the mouths of the two major creeks (Figures 3 and 4). The main Mullet Creek delta has been relatively inactive since the establishment of the Tank Trap in 1941 which redirected sediment from Mullet Creek into the northern part of Koong Burry Bay and the present location of the rapidly prograding Hooka Creek delta. Macquarie Rivulet, by contrast, enters the lagoon in a relatively sheltered embayment and experiences lower wind and wave energy. A river-dominated, birds-foot delta has developed at its mouth and it has built progressively into the lake.

Figure 5. Aerial photograph of Lake Illawarra, taken before the mouth was trained to remain open.

Lake Illawarra behaved as an ICOLL (e.g it closed intermittently) before the southern entrance training breakwater wall was constructed in 2000 and the northern wall was completed in 2007. The entrance used to be predominantly open, although occasionally closing completely, and a tombolo connected either Warilla Beach (south of the entrance) or Perkins Beach (north of the entrance) to Windang Island.
The entrance works were undertaken to increase tidal flushing, which was considered likely to improve the health of the lake, and to ensure that the entrance stayed open. Since 2007 the inlet has remained permanently open, and water levels in the lake have been recording an increasing tidal prism, resulting in an ‘unstable scouring’ entrance with sand moved from the inlet and deposited west of Bevans Island (which is west of the Princes Highway bridge) in the flood tidal delta (Couriel et al., 2013). The greater tidal penetration implies that intertidal wetland zones will adjust; future sea-level rise will lead to further changes in extreme water levels.

Around the margin of the lake, there are a number of flat, shallow embayments which provide ideal habitat for coastal Saltmarsh. These habitat areas undergo a range of fresh and saline water inundation in combination, and experience varying levels of seagrass wrack accumulation, resulting in a diverse range of estuarine species within these saltmarsh colonies. Mangroves are also found close to the entrance where there are a few individuals that have grown there for several decades, but which increasing establishment of younger plants.

Lake Illawarra is almost completely surrounded by residential, commercial, and, in places, industrial development. This development encroaches on the foreshore in many locations and contributes to a number of physical and chemical processes which threaten the local saltmarsh and mangrove populations. During its time as the caretaker for the lake, the Lake Illawarra Authority (LIA) worked on numerous projects to manage and protect these estuarine habitats, as well as to better educate the community about the values of these ecosystems. Projects ranged from investigations, management and planning, through to revegetation, rehabilitation and even employing civil engineering techniques to counteract the impacts from the catchment. These engineering techniques included small-scale installations of stormwater filters and channel dredging, as well as large-scale projects, such as the construction of artificial wetlands and the training of the entrance of the lake. A number of monitoring programs were also undertaken by the LIA which allowed a substantial data to be collected during the installation of these works, and provides some records of trends and changes to the lake foreshore and surrounding catchment.

**Minnamurra River estuary and its infilled valley**

The Minnamurra River estuary is approximately 130 km south of Sydney. The Minnamurra River rises on the Hawkesbury Sandstone plateau. The river descends an escarpment and reaches an elevation close to that of sea level at the village of Jamberoo, more than 12 km inland from the Pacific Ocean. Steep topography to north and south of these lowlands is composed of outcropping Bombo Latite and Broughton Formation. The river has a catchment area of 142 km² and a relief of 770 m. The lower reaches of the Minnamurra River cross the almost completely infilled former barrier estuary comprising Holocene sands and muds in an area called Terragong Swamp. The swamps were drained in the early twentieth century and now support dairy farming. The mouth of the river is microtidal with tidal influence apparent up to 6 km upstream.
The Minnamurra River meanders between several sandy landforms as it exits to the sea (Figure 6). These sand barriers have been described as a triple barrier, but may be more correctly interpreted as a single barrier which prograded eastwards over the past 6000 years, and which has now been dissected by the river. As the barrier developed during the Holocene; it partially enclosed the entrance of the estuary, resulting in the back-barrier environment undergoing a transition from an environment open to direct marine influences to being one of reduced marine influence (Carne, 1989).

The low-lying plains of Terragong swamp, upstream of the landward most part of the barrier, were covered by she-oak swampland (*Casuarina glauca*) before clearing and drainage. During excavation of a north-south trench for a gas pipeline across the estuarine plains of the Minnamurra valley particularly striking specimens of whole oysters, *Ostrea* sp., up to 15 cm in length and in their position of growth were found indicating that progressive infill of cutoff embayments during the evolution of the estuarine system. Some evidence for extensive well-vegetated saltmarsh, mangrove or terrestrial woodland ecosystems has been identified by Jones (1990) in a pollen study of the late Holocene vegetation changes of the Minnamurra River estuary. Further insights into the Holocene evolution of the estuary are provided by analysis of foraminifera (Haslett et al., 2010).

During the early to mid-Holocene the river channel flowed into a deep central mud basin. Initially bedload would have been deposited on the delta front immediately at the channel mouth but this would have extended across the central mud basin (the Terragong Swamp area that is now productive dairy farming land). Subsequently as the mud basin became largely infilled the river channel meandered across the valley reworking the estuarine deposits. The estuarine depositional environment is overlain by the prograding fluvial delta. Rates of infilling have not been uniform, and slowly infilling parts of the estuary were often bypassed as the fluvial delta front built seaward, forming cut-off embayments.
A model of the evolution of the Minnamurra system is shown in Figure 7. The system has undergone a transition from a wave-dominated estuary with central mud basin to an infilled mature wave-dominated estuary that is now river-dominated. Infill has been progressive; sediments that have infilled the lower Minnamurra valley have been derived primarily from the catchment, with a secondary contribution from offshore and a minor in situ component comprising biotic sediments such as shell and organic
material. The intertidal areas near the mouth contain mangroves, saltmarsh and tidal flats and relict cut-off embayments, similar to those still infilling at the corner of the meandering channel system. Intertidal areas near the river mouth are presently covered with mangrove, but mapping from aerial photographs records a pattern of extension of mangroves into the adjacent salt marsh (Figure 8).

Figure 8. Aerial photograph of the Minnamurra mangrove and saltmarsh wetland taken in 2011 (left, courtesy Nearmap), and GIS polygon mapping of the vegetation (Oliver et al., 2012).

Several studies of the small stand of mangrove and saltmarsh near the mouth of the Minnamurra River estuary have been undertaken. This is one of the earliest sites at which surface elevation tables (SETs) were established, and preliminary results of sedimentation and surface elevation change are described by Rogers et al. (2006). Subsequently, mapping has been undertaken to delineate the extent of each vegetation community from a time-series of aerial photographs using geographical information systems, showing the gradual incursion of the mangrove, *Avicennia marina*, into more landward saltmarsh communities over the past several decades (Oliver et al., 2012). This was compared with measurements of elevation change and accretion using the surface elevation table-marker horizon technique, enabling modelling of the potential response to sea-level rise. The observed patterns of change have continued into the twenty-first century, and have been compared with simulations of how this wetland system might respond to future sea-level rise, adopting several different approaches and the upper and lower bounds of IPCC sea-level rise projections. The modelling results show considerable variability in response depending on the parameters adopted.
The Shoalhaven River is one of the more major rivers in southern New South Wales, draining a catchment of 9,260 km². Its headwaters rise in the Southern Highlands at 1300-1400 m above sea level and about 40 km inland of Batemans Bay, within the Lachlan Fold Belt (see Figure 10). The upper catchment, within Ordovician metasediments and Silurian-Devonian volcanics and granites, is steep with constricted valleys, there is a middle catchment of low relief (100-200 m) through which the river flows northeast, and then there is a narrow gorge upstream of Nowra. The spectacular scenery associated with the sandstone landscape, the southern limit of the Sydney basin, west of Nowra has been captured in the paintings of Australian artist, Arthur Boyd. It comprises the Nowra Sandstone, a coarse-grained quartzose sandstone, and finer grained siltstone in the Berry Formation and the Wandrawandian Siltstone. From Nowra, the river traverses a series of low-lying plains. The Quaternary mapping of these plains indicates that they have infilled during the Holocene (see Figures below).
Export of Red Cedar logs from the Shoalhaven River commenced in 1811. At the time the region was settled by Alexander Berry, the Shoalhaven River exited to the Tasman Sea at Shoalhaven Heads. The river was intermittently open, and the shoals at its mouth proved treacherous to navigate. Consequently Berry, an early settler in the region had his convict workers construct a 200 metre-long artificial canal, now termed Berrys Canal, separating Comerong Island from the rest of the estuarine plains. Since 1822, the river has exited through Crookhaven Heads, the mouth of the smaller Crookhaven Creek. In the past, flash flooding was a feature of the Shoalhaven River, but this has been smoothed as a result of construction of the Tallowa dam upstream of Nowra. In the estuarine reaches salinity is substantially reduced by flood waters.

The Quaternary plains of the Shoalhaven River represent a mature stage of infill of a wave-dominated, microtidal (1.6 m) barrier estuary. The low-lying alluvial plains east of Nowra are the results of estuarine infilling behind the sand barriers of Comerong Island and Seven Mile Beach during the last few thousand years. Drilling and carbon dating have revealed marine sands adjacent to this eastern sand barrier and extensive muds, deposited beneath most of the plains. Most of the estuarine sedimentation occurred 5500-3500 radiocarbon years BP (Woodroffe et al. 2000, Figure 11). The general estuarine pattern is characterized by decreasing grain size from coarse sand in the upper estuary to coarse silt just before Shoalhaven Heads. Towards Shoalhaven Heads, grain size increases again to medium sand due to the penetration of marine sand transported by waves and wind (Carvalho and Woodroffe, 2014).
Figure 11. Stratigraphy summary of subsurface drilling investigations of the Shoalhaven plains, indicating radiocarbon dates (after Woodroffe et al., 2000).

The lower Shoalhaven River is flanked by extensive low-lying plains that have developed as a result of infill during the past few thousand years. A schematic interpretation of the progressive infill is shown in Figure 12. Although the area of the barrier estuary is on a similar scale to that of Lake Illawarra, the Shoalhaven has almost completely infilled because there has been a greater supply of sediment from the more extensive catchment.
The estuarine plains extend over an area of about 125 km² from Nowra to the sea and are subject to inundation during floods. Extensive flood mitigation works in the 1960s involved construction of drains and the pastures established have been important dairy-farming areas. The plains are composed of Holocene estuarine sediments; they are impounded behind sandy levees that flank the river, and the former courses of several distributaries are apparent on aerial photography of the region. Drainage of the underlying pyritic sediments (potential acid sulphate soils) has led to acidification of waters which has had an impact in terms of fish kills.

![Figure 12. Stages in the evolution of the Shoalhaven River over the Holocene. Note the similarity of the former central mud basin to the present morphology of lake Illawarra. This system has infilled more rapidly because of the larger catchment, and thus river sand is brought to the coast and has contributed to the progradation of the Seven Mile Beach strandplain (based on Woodroffe et al., 2000 and Umitsu et al., 2001).](image)

The natural course of the Shoalhaven estuary has been modified and its flow artificially diverted to exit at Crookhaven Heads, after the construction of Berry’s canal (200 m long) in 1822, forming Comerong Island (Young et al. 1996). The former mouth of the river at Shoalhaven Heads is predominantly closed by deposition of a sandy berm. The former mouth at Shoalhaven Heads opens intermittently after large floods. The mouth at those times can be up to 400 m wide, but gradually closes as sand is returned to the shoals from the adjacent beach and nearshore. Meanwhile, riverbank erosion continues to widen Berrys Canal (Figure 13).

As part of an estuarine management plan, Shoalhaven City Council has maintained a dry notch (2 m AHD) at Shoalhaven Heads for allowing either natural breaching, or mechanical opening during emergency flood events, as occurred recently in July 2013. Using remote sensing archives, Carvalho and Woodroffe (2013) have created a historical perspective of periods of close entrance alternated with open states, when
the deposition of sand by wave action was inferior to the river power to breach the entrance. They showed that the river mouth at Shoalhaven Heads was also opened in 1961, 1974-1980, 1988-1994 and at the end of 1999 (Figure 13). It has been calculated previously that the average bed sediment transport of the Shoalhaven River is of the order of 100,000 m³y⁻¹, with a similar figure representing the transfer from the immediate beach berm to the foredunes by aeolian transport. It has been estimated that this average annual supply of sediments from the river would produce beach progradation of the order of 1 m y⁻¹, and that the maximum transport flux of sand deposited in the littoral zone at Shoalhaven Heads is about 350,000 m³y⁻¹ with a northward component of 60% of this value (DPW, 1977).

Figure 13.. Aerial photography of Shoalhaven Heads, showing the river mouth closed when the first photographs were acquired in 1949, open in 1961, closed in 1972 and 1981, in the process of closing again in 1993, and closed with substantial establishment of mangroves to the north of Comerong Island in 2002 (Carvalho and Woodroffe, 2013).

The Shoalhaven River has a sandy bed downstream of Nowra, and braids around several sandy islands (Pig Island, Numbaa Island). Further downstream, it diverts through Berrys Canal and in its lower course contains a number of muddy, mangrove-covered islands. Riverbank erosion is considered a problem at several points along the Shoalhaven, and mangrove can be seen colonising the banks, and in locations where it has been planted.
References


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