SHORELINE EROSION AND SALINITY INCREASE

Shoreline erosion occurs naturally in coastal lagoons on shorelines exposed to strong wave action, determined by lengths of fetch and strengths of winds from certain directions. As a rule this erosion is balanced by deposition on the more sheltered sections of the shoreline, and there is a tendency for coastal lagoons to be re-shaped by the action of wind-generated waves and currents into a configuration related to the direction pattern of the local wind regime. This has happened in the Gippsland Lakes, where lagoons enclosed between successive coastal barriers have been modified in outline subsequently by wave and current action. Further consideration of those process is deferred to the next chapter, the problem here being to account for the accentuated erosion, that has developed on these lake shores during the past few decades (Figure 36).

At the present time the larger proportion (about 75&) of the shoreline of Lake King, Lake Victoria, and to a lesser extent Lake Wellington, is being eroded: approximately 136 kilometres of the Lake King shoreline (total length estimated at 160 kilometres); 80 kilometres of the Lake Victoria shoreline (Total length 104 kilometres) and 22 kilometres of the shoreline of Lake Wellington (total length 60 kilometres). The rest is either stable or advancing, local accumulation of beach deposits, the growth of deltas, and swamp land encroachment accounting for the advance. Erosion is in progress on an abnormally high proportion of the shoreline (Plates 20 and 21), a sharp contrast with the situation that Gregory recorded in 1903, when encroachment of the shoreline was widespread.

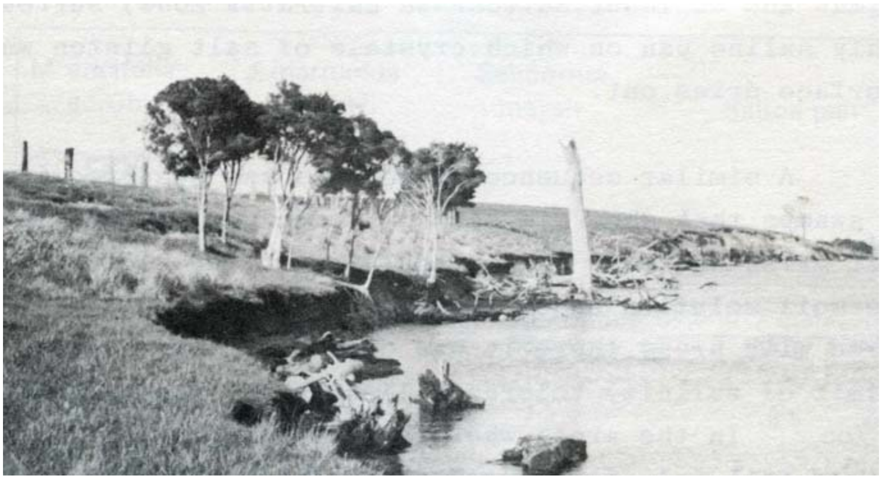

Plate 20 – Erosion on the north shore of Lake King (ECF Bird)

Erosion of deltas and swamp land has been correlated with the disappearance of shoreline reedswamp, and it is now necessary to account for this. The reedswamp bordering the Gippsland Lakes (Figure 31) is (and was) dominated by *Phragmites australis*, a plant found in swamps, along river banks, and around lake shores in may parts of the world and said to be the most widely-disturbed of the angiosperms (Goo 1947). It grows well in fresh and slightly brackish water, but is not strictly a salt marsh plant; in estuaries, it dies out before the river opens into the sea. Ecological studies have shown that its growth is limited by a number of factors, and as its disappearance from shallow water environments around much of the shoreline of the Gippsland Lakes may be related to development of at least ones of these limiting factors, each will be considered in the context of the present problem (Bird 1961a).

The extent of shoreline recession is difficult to judge, partly because of the problem of defining the shoreline where the lake fringe consists of reedswamp growing in water up to 2 metres deep, and partly because of the uncertain accuracy of past surveys. When the maps made by Smyth and Wilkinson in the eighteen-forties are compared with the present configuration, recession of up to 50 metres can be measured on swampy sectors. The changes have continued in the past twenty years, for measurements made in 1977 – 78 on transects originally surveyed at right angles to the shoreline at 46 locations around Gippsland Lakes in 1957 – 59 showed gains or losses, generally of up to a metre. The greatest changes were along the northern shore of the Mitchell delta west of Point Lardener, where recession of up to 5 metres has occurred in the past twenty years, and on the western flank of the Tambo delta.

Plate 21 – Erosion on the inner barrier south of Metung (ECF Bird)

The growth and spread of reedswamp is limited in water bordering the shores of lakes and the banks of rivers by wave and current scour. It is broader on sheltered sections and thins out, perhaps fading away completely, on sections exposed to strong wave action or scour by currents. There is no doubt that reedswamp has been extensive along the more sheltered sections of the shoreline of the Gippsland Lakes; it survives on the south-western side of Lake Wellington, but its disappearance from equally sheltered sections of Lake Victoria and Lake King (e.g. from Eagle Point Bay, south of the Mitchell delta) cannot be attributed to any increase in wave or current scour. Previously, under similar conditions of wind, wave, and current action reedswamp grew well in these situations, spreading into the lake to initiate swamp land encroachment. In the nineteen-sixties it was noticeable that sections of the lake shore where water weeds are abundant were more protected from wave attack: the fresh-water eel grass (*Vallisneria spiralis*) reduced wave activity off the reedswamp in the south-western part of Lake Wellington, and the marine grass wrack (*Zostera* spp.), abundant in many seasons in Lake King, played a similar role there, but whether or not the relative extent of freshwater *Vallisneria* and the marine *Zostera* had changes, the damping effect on wave action was seasonal, and least in winter when waves are often stronger. The presence of *Zosters* growth in Eagle Point Bay, off Sperm Whale Head, and in the Bunga Arm has failed to permit the survival of the shore, and failed to prevent erosion of the swamp that lay behind the former reedswamp fringe.

Current action is strong within the Gippsland Lakes in McLennan Strait, linking Lake Victoria to Lake King at Paynesville. These straits are of similar dimensions and form, but McLennan Strait retains a narrow fringe of reedswamp, fading on the outer bends of its two meanders, whereas McMillan Strait has lost its former reedswamp fringe and is now losing its bordering swamp land. It is clearly impossible to account for the pattern of reduction and loss of shoreline reedswamp in terms of increased exposure to wave and current action; it is, in fact, a question of die-back, rather than erosion of *Phragmites*, for there are sheltered sections of Lake Victoria (e.g. along Duck Bay, north of Banksia Peninsula) which have lost the reedswamp fringe, but are not suffering erosion because wave action is weak. Where surviving sections of the reedswamp fringe are traced laterally along the shore they become narrower and sparser before fading out completely, and where the reeds are sparse there are signs of s struggle against some unfavourable ecological condition: in some years they begin to grow well in spring, only to die sway in early summer.

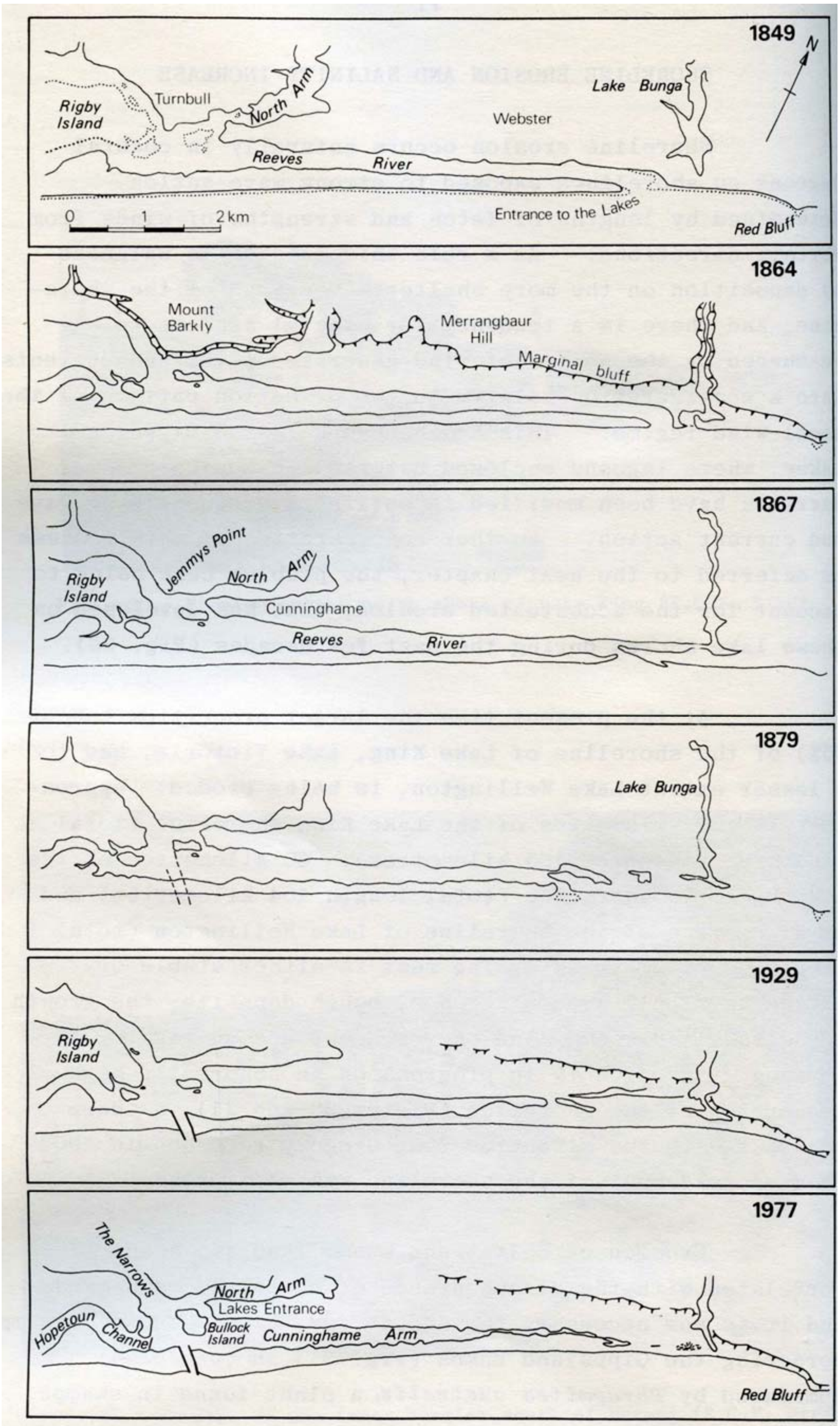

Figure 34 – Shoreline changes in the Cunninghame Arm
(incorporating data supplied by NB Miles)

Phragmites grows best on river silt, or in the organic-rich sediment which it tends to accumulate on lake shores; its growth is poorer where the substrate is sandy or gravelly. Die-back of *Phragmites* around the shores of Lake King cannot be attributed, however, to a change to less favourable substrate conditions, for the reeds have gone from areas where the substrate is still silt, clay, and organic matter, notably off the eroded shores of the Mitchell delta. In Lake Victoria the shores have become sandy, but this is a consequence rather than a cause of the disappearance of bordering reedswamp vegetation, for the sand is derived from the erosion of the margins of dune terrain, exposed after the removal by erosion of bordering swamp land following die-back of shoreline reedswamp.

A third factor is water depth. Under favourable conditions, *Phragmites* will spread into water up to 2 metres deep, and any change that deepens water along the shore would reduce the width of a reedswamp fringe. The reeds would disappear altogether if the depth of water adjacent to the shoreline became greater than 2 metres, but this cannot be the explanation of die-back of *Phragmites* around the Gippsland Lakes, for reeds have vanished from sections of the shore where there is still a broad tract of water less than 2 metres deep.

There is no doubt that reedswamp is damaged and locally destroyed by the activities of grazing animals and by man. On parts of the western shore of Lake Wellington, north of Marlay Point, there is good evidence that this has led to local erosion. Reedswamp adjacent to the shoreline has been grazed out, but sparse reeds persist in deeper water offshore which cattle cannot reach. Where the reeds have gone, erosion has ensued, its effects being aggravated by the cattle trampling. But at one point just north of the Marlay Point picnic reserve a small section of shoreline reedswamp persists, spreading into the lake, because it has been fenced off and cattle cannot reach it. On the southern shores of Lake Wellington, inaccessible to cattle, the reedswamp also persists. Grazing is therefore an important and contributory factor, but the reedswamp fringe has disappeared from sections of the shoreline of Lake Victoria and the southern shores of Lake King where cattle have not been grazing. Moreover, grazed reedswamp revives when grazing is withdrawn, but there is no evidence of its revival on parts of the shores of Lake Victoria and Lake King where there is no grazing pressure at the present time.

Reedswamp is damaged locally where swans and other water birds congregate and nest; it is damaged by fishermen and duck-shooters; it is destroyed locally by repeated cutting, burning, or wash from power boats; and it can be killed by water pollution. Each of these effects can be shown to have reduced the reedswamp fringe locally and to have led to erosion of swamp land or reclaimed pastureland behind it, but none provides an adequate explanation of the overall pattern of *Phragmites* die-back in the Gippsland Lakes.

Growth of *Phragmites* is certainly limited by high salinity in estuaries and lagoons on the Victorian coast. In estuaries it dies out before the river enters the sea, and in lagoons it is confined to the less saline areas. *Phragmites* dominates the extensive reedswamp at the mouth of the Tarwin River in South Gippsland, where it opens into the estuarine lagoon at Andersons Inlet, but it does not extend far along the shores of the lagoon, which is open to the sea at Inverloch. The evidence in Victoria, as elsewhere, suggests a limit of salinity tolerance somewhat below the salinity of the sea off Gippsland (about 25º/oo), but there are difficulties in stating a precise limit. One problem is that there are varieties (ecotypes) of *Phragmites australis* which vary in their response to salinity conditions, so that limits established for one clone may not apply to others. In the Gippsland Lakes the spread of *Phragmites* is mainly vegetative, the shoreline communities consisting of a relatively small number of clones, and it is possible to deduce an approximate limit of salinity tolerance for the varieties now present. The pattern of surviving reedswamp on the lake shores is clearly related to the present pattern and regime of salinity, for *Phragmites* survives only near river mouths and sections of the shoreline that are farthest from the sea-water inflow at Lakes Entrance. In order to avoid confusion it is necessary to emphasise that this analysis deals with *Phragmites* in the ‘standing-water’ situation, extending from the shoreline out into the lake. *Phragmites* grows above normal lake level at any points around the lakes, including Bullock Island, immediately inside the entrance (Figure 15), but in these habitats it plays no part in reedswamp encroachment or shoreline protection, and its occurrence and ecology above normal lake level are therefore not relevant to the present discussion.

The possibility arises that the die-back of shoreline reedswamp is a sequel to increasing salinity in the Gippsland Lakes following the cutting of the artificial entrance in 1889. Measurements of salinity variations in the water and in the substrate at two similar sites on the shore of Lake King, one with *Phragmites* surviving and the other with evidence of recent die-back, over the period November 1958 to May 1959 gave the results tabulated from the low value recorded in November to the high value obtained in the following May, at the end of s dry autumn.

Site	**Salinity º/oo**
With *Phragmites* growth	Substrate: 7.50 – 12.00
	Lake Water: 3.60 – 7.30
Where *Phragmites* has died back	Substrate: 12.00 – 21.20
	Lake Water: 12.40 – 18.90

These figures can give only a very general guide, but it appears that the variety of *Phragmites australis* present in the clones on the shores of Lake King cannot tolerate conditions where minimum salinity exceeds 12.0º/oo, about one-third of the salinity of the open sea, and maximum salinity 18.00º/oo, about two-thirds of the salinity of sea water. This range is equalled or exceeded over much of Lake King and the western half of Lake Victoria, and the measurements are therefore consistent with the general pattern of reedswamp die-back.

Supporting evidence for the link between *Phragmites* growth and salinity in the Gippsland Lakes came during the 1967 – 68 drought, when surface salinity in Lake Wellington rose to more than 10V/oo. Lake shore reed growth had been dense in December 1967, but had 'substantially died back by May 1968, due to… exceptionally high salinities in Lake Wellington' (Arnott 1968). Some revival has occurred subsequently, but there were reed-fringed until 1968, and are now eroding, and other sectors where *Phragmites* growth was dense in 1957 – 59 and is now poor and sparse: for example, near Roseneath Point. It is likely that the decline of the fresh-water eel grass *Vallisneria* in Lake Wellington, reported by Ducker *et al*. (1977), also dates from the 1967 – 68 drought. The surviving reedswamp no longer has the protection of calm water that existed when *Vallisneria* was abundant.

Similar features have been recorded in estuarine lagoons in other regions. In South Africa, Day (1951) linked the performance of *Phragmites* on the shores of estuaries partly enclosed by barriers ('blind estuaries') with salinity variations, commenting that 'in the St Lucia estuary there is a very dense and luxuriant growth of *Phragmites* in years when river flooding lowers the salinity, but during periods of drought the salinity increases and reed no longer grow' (see also Day *et al.* 1954). Chapman (1960) quoted data on the salinity tolerance of *Phragmites australis*, notably in tidal salt marshes, where it is typically a plant of the transition zone to freshwater vegetation, though subject to occasional inundation by the sea at high spring tides. Measurements of the salinity of the soil solution at the limit of *Phragmites* in such situations are often higher then 20º/oo, and it appears that the reeds are more tolerant of salt in a marshland soil then where they stand permanently in water up to 2 metres deep on a lagoon shore (Ranwell *et al.* 1964). It is possible to grow *Phragmites* in sea water in a laboratory culture, but its performance is very poor under these conditions, compared with growth in fresh or slightly brackish water. Taylor (1939) obtained growth to 77.5 centimetres in slightly brackish water but only 12 centimetres in sea water, and the poverty of growth in more brackish solutions may indicate a limit in field conditions on a lagoon shore well below sea water salinity. The physiological effects which limit *Phragmites* growth on a lagoon shore are not known, but the rate of salinity increase may be of more importance than the attainment of high concentrations. In Nugents Bay, on the north shore of Lake King was freshened in the spring of 1957, following heavy rain in the previous winter, *Pragmites* grew vigorously and spread along the shore of Nugents Bay, but in the following spring, after a winter with only half the 1957 rainfall total, Lake King was more saline and the growth of reeds was much poorer: there was some evidence of marginal die-back.

The hypothesis that the salinity of the Gippsland Lakes has increased during the past few decades, possibly as a consequence of the cutting of the artificial entrance, would also account for the die-back of swamp scrub vegetation and its replacement by salt marsh communities on the eroding sections of swamp land shores in Lake King and the invasion of pastureland salt marsh species on the eroding shores of the Mitchell and Tambo deltas. It would also solve the problem of the development of salt pan and salt marsh enclaves where swamp scrub has died back as the result of an increase in soil salinity on swamp land areas subject to flooding by lake water, which is now often strongly brackish. Formerly, when reedswamp and swamp scrub were developing and colonising theses swamp lands, floods must have been at least as regular in incidence, but they evidently did not lead to fixation of salt in the swamp soil. It appears that the floodwaters were once relatively fresh, and that their increasing salinity has brought about ecological changes within certain of the swamp scrub areas. It remains to examine the historical evidence bearing on the question of an increase in the salinity of the Gippsland Lakes during the past few decades.

The replacement of an intermittent natural outlet by a permanent artificial entrance to the Gippsland Lakes is likely to have led to a greater invasion of the lakes by sea water, and thus to increasing salinity compared with that during preceding centuries. In the geological past, as been shown, the lakes were a marine embayment and then a partly-enclosed estuarine area, before completion of the outer barrier brought them to their condition at the time of discovery: a condition which had persisted long enough for widespread development of swamp land by the encroachment process. Angus McMillan discovered the lakes in 1839, but the natural outlet to the sea was not found until 1841, when a party including John Reeve found an opening in the sandy barrier east of Jemmys Point with a depth of nearly 2 metres of water at low tide. It was approached from the lake side along a broad channel bordered by reeds and scrub, which they named the Reeves River, and which subsequently became known as the Cunninghame Arm. At low tide the outlet channel was narrow and intricate, and partly blocked by a sand bar. In 1843, H.B. Morris reported in the *Hobart Town Courier:*

> 'Unfortunately the outlet to the sea is not passable in ordinary seasons. A sand bar is dry across its mouth at low water. During the rainy season and when the four feet in depth and the whole morass of reeds before described is covered with water and, in fact forms part of the lake.'

During 1844, a dry year, the outlet became narrower and shallower as sand was washed in from the sea, and eventually it was possible to walk across it dry-shod, even at high tide. But by 1849, when George Smyth prepared a *Coastal Survey Plan* of the area (Figure 34), it had reopened in a position 2.5 kilometres west of Red Bluff (about 5.7 km east of the present artificial entrance) and was about 650 metres wide at high tide, narrowing to a 250 metre channel as the tide fell. During the next few years, reports by the harbourmaster, Captain Ferguson, showed that the outlet migrated to and fro along the shore, varying in form and dimensions, and at times being sealed off completely be sand deposition. Early settlers used the sea route from Melbourne, and ships had to pass through the natural outlet in order to reach the Gippsland Lakes, and sail on to the townships of Bairnsdale and Sale. It was often a difficult passage. In the early eighteen-fifties the outlet was more often closed than open, and in 1855 W.T. Dawson, of the Lands and Survey Department, described conditions in these words:

> 'When the bar at the entrance is closed… the water rises to a great height in the lakes and the country for a distance of one hundred miles back is flooded. It was the custom of the settlers to cut through the bank when the flood attained its maximum height, and the rush of waters very quickly cleared a channel through which even large vessels could sail in'

By 1855 the outlet had moved about a kilometre east of the position mapped by Smyth, and it was navigable in 1858, when schooners began to sail regularly in and out of the Gippsland Lakes. In the next few years the outlet migrated farther east, and in 1861 it lay within 200 metres of the cliff at Red Bluff, the eastern-most position recorded (Rawlinson 1863). Diminishing outflow from the lakes during the dry summer of 1861 – 62 resulted in shallowing, and eventually sealing of this outlet, and it remained closed until May 1863, when river flooding again raised the level of the lakes to overflow and open a new outlet at Lake Bunga. This persisted for more than a year. When it shallowed, ships were wrecked, and one schooner ran around on a sand bar that built up to strand her, high and dry, for several months. During the next few years the outlet was open intermittently at various points within a sector up to 2 kilometres west from Lake Bunga. Steamers were now in use, and a pilot boat was stationed to guide ships through a gap that changes continually in width and depth: an 1866 report describes a steamer making vigorous dash with a full head of steam to get into the lakes. As the townships at Bairnsdale and Sale grew, and traffic to and from lake-side settlements increased, dependence on so variable a passage in and out of the lakes became more and more unsatisfactory. Demand grew for the cutting of a permanent artificial entrance, and after a survey of the outer barrier the site for the present entrance opposite Jemmys Point was chosen in 1869.

The procedure was to build timber training wall on either side of the proposed channel, and to excavate the intervening sand, but there were many difficulties and delays, and twenty years had passed before the storm of 14th June 1889 swept away the remaining sand and opened the present entrance. Meanwhile fluctuations of the natural outlet had continued. In 1867, having been sealed off, it was reopened by floodwaters at a point nearly 5 kilometres west of Red Bluff, the westernmost position recorded. The outlet here was for a time so wide and deep that the necessity fro an artificial cut came under question. However, by 1877 it was again sand-encumbered and shallowing, and during the next twelve years it waxed and waned in relation to lake outflow and wave conditions. In August 1889, soon after the artificial entrance had opened, the natural outlet had become finally sealed off, and the reeves River, which had led to it, shrank and was partly overrun by dunes. Cunninghame Arm persists as a residential backwater of a channel no longer maintained by through currents (Bird 1961b, Bird and Lennon 1973). Modern changes in geomorphology and vegetation here have been traced by Miles (1977) who used historical maps and dated air photographs to compare features in 1883, 1929, 1940 and 1958 with those surveyed in the field in 1977 (Figure34).

The artificial entrance was well sited, for the natural scour set up by ebb and flow of marine tides, augmented by lake outflow, maintains a navigable channel of average depth 6 to 9 metres and maximum depth over 20 metres: considerably deeper than the 3 to 4 metre channel predicted by the designer, Sir John Coode, in 1879. Coode had expected a maximum tidal current of about 42 cubic metres per second, whereas the tide flow that developed after the entrance opened was much greater, about 500 metres per second (Fryer 1971).

The bordering timber jetties began to disintegrate after 21896, and it was found that the marine shipworm *Teredo nausitoria*, was boring into them. Thus weekend, they were damaged by storms waves, and between 1903 and 1913 it was necessary to replace them by walls of granite and concrete which protruded seaward from the high tide shoreline, the western pier by 140 metres and the eastern by 122 metres, the pier heads being 76.2 metres apart.

Meanwhile, sand deposition had occurred off the artificial entrance to produce a looped sand bar (Fryer 1973). This bar remains, a submerged feature that varies in position and depth with the contest between ocean swell tending to wash sand into the entrance and outflowing currents which drive it back. There is less than 3 metres of water over it at low tide, and during stormy weather, when heavy seas break on it, ships were unable to enter or leave the harbour. Training walls have been built out from beneath Jemmys Point to channel and intensify the current flow and direct it out of the entrance in tan attempt to clear away the sand bar, but the effects were slight and the bar remains in position. In 1963 an unsuccessful attempt was made to blast it away by denoting submarine explosives. Possibly it could be removed by constructing an offshore breakwater, of type built off Ventura Country Harbour in California, designed to modify wave patterns in such a way as to concentrate sand deposition away from the harbour entrance, an so maintain a navigable channel (Beach Erosion Board 1961). Alternatively, it might be possible to disperse the sand bar by means of fluidisation, the reduction of sand viscosity by injecting water into the sand bar along a submerged pipeline, in the manner suggested by Hagyard *et al*. (1969) for Westport Harbour, New Zealand.

It was expected that the opening of the entrance would lower the general level of the lakes by about 0.6 metres, enabling lake-shore and valley-floor swamps reclaimed for agricultural use (Cringle 1866). Such a fall did indeed occur, for newspaper reports in July 1899 noted that outflow through the new artificial entrance had lowered the level of the lakes in mid-winter to close to the usual summer level, with the result that the silt bars off the Mitchell River had become suddenly shallower and a hindrance to boat traffic serving Bairnsdale. Subsequently, oscillations of lake level have been modified by this replacement of a intermittent natural outlet by a permanent artificial entrance. Flooding still occurs but waters escape quickly through the artificial entrance without having to build up and spill out over the barrier to reopen a natural outlet. Lake levels are now generally low, and directly related to sea level at Lakes Entrance. Historical records show that when the natural outlet was sealed, lake levels built up; and under these conditions of accumulating rain and river water the lakes must have become almost fresh. They are still freshened briefly by river flooding, but major floods like those of December 1934, June 1952, and February 1971, each of which subsided within a few days, would have caused widespread and prolonged submergence of low-lying terrain around the lakes by freshened water in the phase prior to the opening of the artificial entrance. Before 1889 the episodes to reopen a natural outlet produced at first a strong outflow from the lakes into the sea, temporarily suppressing tidal effects and excluding sea water from Reeves River. After the floodwaters had escaped and lake levels had stabilised, tidal effects revived in Reeves River, and in dry weather sea water began to invade to compensate for diminished fluvial inflow and increasing evaporation losses. Contemporary descriptions (below) record brackish water in Lake King and Lake Victoria (but not Lake Wellington) in dry summers. However, the natural outlet used to be sealed off by sand deposition under these weather conditions, thereby halting the inflow of sea water before the lakes became very brackish. After opening of the artificial entrance this inflow of sea water was able to continue unimpeded in dry phases, raising the salinity of the lakes (including Lake Wellington) to high levels, as in the drought of 1967 – 68. In the absence of records of lake salinity prior to 1889 it is nor possible to prove that a salinity increase had occurred, but in terms of this analysis it is a matter of great probability; indeed, it would be difficult to see how such an increase could be prevented in this situation.

The documentary evidence, as far as it goes, supports this inference. When McMillan reached the shores of Lake King in the dry summer of 1839 – 40 he found the water ‘rather salt’, but not too saline for horses to drink. It is doubtful if horses would drink it at the level of salinity now attained in a dry summer (15º/oo to 20º/oo in the ‘average’ summers of 1957 – 58 and 1958 – 59). When Brodribb reached Lake Wellington in late summer (March) 1841 he found the water drinkable, and survey plans compiled in the eighteen- forties labelled Lake King as ‘brackish and salt’. Acheson in 1861 reported that Lake Wellington was ‘fresh at all times’, and in February 1874, after a long spell of dry weather, Skene and Smyth made the following observations:

> ‘The waters of Lake Wellington are fresh, those of McLennan’s Strait brackish in the upper part and salt near Lake Victoria. In ordinary seasons the tide [i.e. the influx of salt water] makes into Lake Victoria as far as the Strait. Though the waters of Lake Victoria are salt we observed that they were discoloured…We have had of late much dry weather; for several months preceding out visit the fall of rain was inconsiderable and the rivers were not discharging as much water as they usually do in the month of February.’

The measures of the contrast between past and present conditions is the fact that the waters of Lake Wellington are now far from fresh, particularly after the weather conditions described by Skene and Smyth, when surface salinity over much of the lake exceeds 5º/oo, and may attain 10º/oo. Lake Wellington is, in fact, more brackish than the eastern part of the Baltic Sea where the shores of southern Finland have an extensive reedswamp fringe (Luther 1951). In February 1959, when rainfall recorded at Bairnsdale was 19.6 millimetres, considerably below the 40 – year mean of 53 millimetres, and salinity conditions in Lake Wellington should have been comparable with those described eighty-five years previously by Skene and Smyth, the author made a boat trip along the route followed by these surveyors from Sale down the Latrobe and across Lake Wellington, then through McLennan Strait into Lake Victoria. Their description needed revision to match 1959 conditions. The waters of the

Latrobe River were fresh at Sale, but distinctly brackish, and salinity increased through McLennan Strait. Lake Victoria had clear, blue salt water, the cloudy suspension of fine-grained sediment having been precipitated in the more saline environment. Salinity at depth was generally greater than salinity in the surface water (see table), indicating that denser sea water had been spreading into the lakes at depth, and gradually mixing with the less saline surface water.

	Salinity (º/oo)	
	Surface	Near Floor
Off the Latrobe River Mouth	4.8	9.0
Centre of Lake Wellington	5.1	5.6
East Lake Wellington	4.9	4.9
West end McLennan Strait	4.9	8.0
East end McLennan Strait	6.2	17.3
West Lake Victoria	17.8	20.8

(Source: State Rivers & Water Supply Commission records for samples taken on 1st March 1959)

Salinity continued to increase in Lake Wellington in 1959 until July, when surface salinity at the centre of the lake attained a maximum of 9.2º/oo. It appears that salt water spreads farther into the lakes now than it did before the artificial entrance was opened, and that much higher salinities are now attained in the lakes during dry summers. In the 1967 – 68 drought, surface salinity in the centre of Lake Wellington rose from 1.2/oo in February 1967 to 10º/oo in December of that year, and on to a maximum of 16.7º/oo in May 1968, the highest so far recorded in this lake. As has been noted, analysis of records kept between 1957 and 1976 indicate a trend towards increasing salinity in the Gippsland Lakes over that period.

While the opening of the artificial entrance has been primarily responsible for salinity increase, other factors have contributed to the present pattern and intensity of salinity in the Gippsland Lakes. Abstraction of river water for use in irrigation, particularly in the Sale District, has reduced the inflow of fresh water to the lakes. After completion of Glenmaggie Reservoir in 1924 the discharge of the Macalister River was reduced by about 19%, which represents a reduction of about 3% in the mean annual fluvial inflow to the lakes (Fryer 1971). In total, irrigation schemes probably reduce the direct flow of fresh water into the lakes by up to 5%, although a proportion of this water passes back into the rivers or into the lakes after use. Pumping of river water for irrigation is greatest in the summer months, when river flows are diminishing and evaporation losses high, and this undoubtedly results in the spread of brackish water farther into the Gippsland Lakes than would otherwise have been the case. It is also likely that irrigation water flowing back into the rivers or on into the lakes contains salts dissolved from cultivated and fertilised soils.

Mention has been made of brackish runoff from salt marsh and saline areas west and south of Lake Wellington during floods, and the artificial drainage channel leading from saline Lake Kakydra into the northern end of Montgomery Bay, in Lake Wellington, discharges brackish water. During 1957 – 59 this was monitored by the State Rivers and Water Supply Commission and found to average 0.27º/oo salinity, with a range from 0.04 to 1.45º/oo: an anomalous high value of 5.90º/oo in July 1858 was probably due to brackish water seeping back up the channel from Lake Wellington, which than had a surface salinity of 9.57º/oo.

In assessing the effects of irrigation usage and brackish runoff on salinity in the Gippsland Lakes it should be noted that the main irrigation area and most extensive drained salt marsh lie west of Lake Wellington, the least brackish of the lakes. The pattern and regime of salinity in the lakes is consistent with the idea that the bulk of the salt comes from sea water invading at Lakes Entrance.

The ecological effects of the opening of the artificial entrance were not immediately felt after 1889, possibly because there were a series of above–average–rainfall years, during which salinity incursion would have been kept down. It is probably significant that the first definite records suggestive of biological changes within the Gippsland Lakes date from, or are locally recollected as dating from, around 1914, and particularly during droughts in the nineteen-twenties. By then, there was evidence of die-back of *Melaleuca ericifolia* in lake-shore swamps near Lakes Entrance. Growth of eel grass, *Zostera* app., had become abundant in Lake King early in the present century, but in 1920 the first major invasion by the plague crab, *Paragrapsus gaimardii*, was recorded (Bury 1954). Since than there have been fluctuations in the extent and vigour of *Zostera* growth from year to year, apparently in inverse ratio to fluctuations in the numbers of plague crabs, which are said to uproot, and possibly feed on, the eel grass (Wood 1959). In the nineteen-fifties, for example, crabs were abundant and *Zostera* growth patchy; in the nineteen-sixties, crabs were scarce and *Zostera* growth unusually rich: but a direct relationship has never been proved. Both organisms are characteristic of marine to estuarine rather than freshwater environments. Other indications of a change towards more marine conditions in Lake King and Lake Victoria are the plagues of jellyfish that infest the lakes; the invasion of the marine shipworm *Teredo naustoria*, said to be responsible for the collapse of the Wy Yung bridge on the Mitchell River above Bairnsdale in 1956 and the disappearance of *Vallisneria* from Lake Wellington since the 1967 – 68 drought. Additional evidence of salinity increase comes from the fact that valley and lake-shore swamps around Lake King have not been reclaimed fro agricultural use following the lowering of lake level predicted in 1886 as a consequence and benefit of the opening of an artificial entrance: lake level is lower, but the swamps are now excessively saline.

In 1952 a Parliamentary Public Works Committee appointed by the Government of Victoria reported into an inquiry into the effects of salinity in the Gippsland Lakes on the bordering lands and on the fishing industry, and whether any works should be constructed to limit the effects of salinity. Faced with much conflicting evidence, the committee concluded that 'there has not been an appreciable increase of salinity in the Gippsland Lakes as a result of the construction of the artificial entrance'. In the light of the analysis presented here, it is difficult to agree with this, and the evidence published in the committee's report (1952) scarcely justified their conclusion. The committee appeared to have been much influenced by evidence of fluctuations in the extent and proportions of various estuarine and marine species of plants and animals in the lakes during the past century, but the point at issue is whether these communities were present before the artificial entrance was opened, and on this no evidence was quoted. The fact that saline land and salt marshes exist beyond Lake Wellington is nor relevant to the problem, since the salinity here is not related to the evaporation of floodwaters, but rather an inheritance from earlier marine phases, coupled with accessions of cyclic salt to enclosed depressions from which water cannot drain, and within which salinity has been maintained or increased by repeated evaporation. The suggestion that lake-shore erosion in the Gippsland Lakes is <u>entirely</u> a consequence of salinity increase following the opening of the artificial entrance is clearly incorrect. Some 'natural' erosion would have taken place anyway, and other factors, such as grazing, have undoubtedly contributed, notably in Lake Wellington, to the destruction of shoreline reedswamp and erosion of the shores. But the extensive erosion that has developed around the shores of Lake King and Lake Victoria is due mainly to die-back of reedswamp, and the pattern of die-back indicates that this is due mainly to ecological changes resulting from a salinity increase in the lakes.

The relationship between salinity conditions, reedswamp development, and shoreline evolution in coastal lagoons deduced from this study of the Gippsland Lakes is also demonstrable in other coastal lagoons. In western Victoria, improvement of the harbour entrance at Port Fairy and deepening of the channel leading into Belfast Lough, a lagoon at the mouth of the River Moyne, had similar consequences. In 1810, when the explorer Wishart arrived here, the shores of the lagoon were fringed by reedswamp backed by scrub and eucalypt forest (Earle 1973), but improvements to the harbour of Port Fairy by building and extending stone jetties at the entrance to get rid of an offshore sand bar and the dredging of the lower reaches of the River Moyne to allow ships to sail up it into Belfast Lough resulted in a salinity increase which led to the destruction of bordering reedswamp and scrub and its replacement by salt marsh communities. As in the Gippsland Lakes, this ecological change has led to erosion of the lagoon shores.

The relationship is also demonstrable in reverse, where coastal lagoons that were formerly saline have been converted into freshwater lakes by construction of barrages to exclude sea water. In the estuarine lagoons at the mouth of the Murray, in South Australia, barrages were completed in 1940 to seal off gaps in the enclosing barriers and exclude sea water. Previously, the sea entered Lake Alexandrina and Lake Albert freely, particularly during dry summer periods when fresh water discharge from the Murray was low. The building of barrages were stimulated by the evidence that during droughts brackish water was spreading into the Lower Murray and invading irrigation works. Late in summer of 1938 – 39, surface salinity in Lake Alexandrina reached 28.5º/oo, the salinity of the open sea being a little above 35º/oo. There were extensive tracts of salt marsh bordering the lakes, liable to inundation by the brackish water. In 1940, after the completion of the barrages, salinity dropped sharply to 1.42º/oo, and it has continued to decline, falling to a lowest annual maximum of 0.08º/oo in 1955 – 56. The lakes are now sufficiently fresh to be used as a source of water for irrigation of adjacent pastureland, and the freshening of the lakes has been followed by the development of reedswamp (mainly *Phragmites australis*) now spreading around the shores and advancing into the lakes: the process of swamp land encroachment had been initiated, following a reduction in lake salinity (Bird 1962c). A similar sequence followed the exclusion of the Mediterranean Sea from the coastal lagoon known as the Étang de Vaccarès, on the Rhône delta in southern France, by barrage construction. Shorelines that were eroding when the lagoon was brackish are now bordered by extensive reedswamp encroaching on the freshened lake.

The conclusion is therefore reached that salinity has increased in the Gippsland Lakes since the opening of the artificial entrance, salt water spreading farther than it did formerly, and attaining salinity level in Lake King and Lake Victoria which are beyond the tolerance of the reedswamp vegetation that previously bordered much of the shoreline. Flooding from these brackish lakes has led to salinity increase in depressions swamp land, marked by die-back of swamp scrub and replacement by salt marsh vegetation and unvegetated salt pans.

Comparison with the Murray-mouth lakes suggests that the sealing of the artificial entrance or the construction of barrages to exclude sea water would freshen the Gippsland Lakes, allowing reedswamp to revive and resume its former role in initiating swamp encroachment. Such a change would possibly benefit the users of adjacent farmland by reducing salinity damage and eventually providing a new source of irrigation water, but a productive estuarine fishery would be severely curtailed, and a useful port on a long and dangerous section of the Victorian coast lost, if such works were carried out, and it is quite possible that their effects would be offset by the formation of a new natural entrance on the narrow section of the outer barrier near Ocean Grange. The construction of barrages would be difficult in any case, because of the absence within reasonable depth of foundation rock as suitable as the hard calcarenites at the Murray mouth, and it is unlikely that the project would be economically justifiable. The more valuable sections of eroding shore are being protected by walls and groynes, and the Soil Conservation Authority of Victoria is conducting plant trials in the hope of finding vegetation that can be introduced to replace the lost reedswamp fringe on other sections of the shore. The ecological niche of a tideless lagoon shore with brackish water is not easily filled: trials with *Spartina townsendii* have been disappointing, because this species thrives best on tidal salt marshes, and does not take well to the lagoon shore environment. A possibility worth further investigation is the breeding or importation of salt-tolerant ecotypes of *Phragmites*, or other salt-enduring reedswamp species, which evidently grow well in lagoons and salt lakes thought to be more brackish than Lake King, notably in the Middle East and Central Asia.