# Ecology and management of the Lake Wellington wetlands, Gippsland Lakes: A report on the R&D project, 2003-2006

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A companion handbook, outlining the early results of the project, was printed in 2005: *Managing water regimes in high-value wetlands: general approaches, emerging technologies and specific applications*

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This handbook has been produced from the results of a four-year R&D project undertaken on the wetlands that fringe Lake Wellington in the Gippsland Lakes of south-eastern Victoria. The project was funded by Land & Water Australia, Murray-Darling Basin Commission, West Gippsland Catchment Management Authority, Department of Sustainability and Environment, Parks Victoria, Gippsland Coastal Board, Field & Game Australia, BHP Billiton, Esso and Gippsland Water.


The information contained in this handbook is intended to assist in improving public knowledge, building capacity in the broader community, and prompting discussion about wetland management. It has not been fully peer reviewed and readers should obtain professional advice before acting on any of the information contained in this document. Dr Richard Davis and Nadeem Samnakay, both from Land & Water Australia, and Andrew Schulz and Dr John Wright, both from Parks Victoria, have commented incisively on earlier drafts of the handbook.

# Executive summary

This handbook summarises the results of a four-year R&D project undertaken by staff at Victoria University and Monash University on the wetlands that fringe Lake Wellington in the Gippsland Lakes of south-eastern Victoria. The project was funded by: Land & Water Australia, Murray-Darling Basin Commission, West Gippsland Catchment Management Authority, Department of Sustainability and Environment, Parks Victoria, Gippsland Coastal Board, Field & Game Australia, BHP Billiton, Esso, and Gippsland Water.

A shorter companion report, outlining the early results of the project, was circulated in 2005: *Managing water regimes in high-value wetlands: general approaches, emerging technologies and specific applications*.

Dowd Morass was the main field site, although some R&D was undertaken also at Clydebank Morass. Covering 1500 ha, Dowd Morass is one of the largest wetlands in the Gippsland Lakes Ramsar site. Swamp Paperbark (*Melaleuca ericifolia*) and Common Reed (*Phragmites australis*) are the two dominant vegetation types in the morass, with smaller areas of Eelgrass (*Vallisneria americana*, a submerged angiosperm) and fringing areas of mud flats and salt-tolerant plants, including taxa such as *Disphyma clavellatum, Distichlis distichophylla, Hemichroa pentandra,* and *Sarcocornia quinqueflora.*

Four factors have resulted in marked changes to the spatial and temporal characteristics of wetting and drying cycles in Dowd Morass:

1) changes in land-use since the mid 19th century and construction of water storages in the Thomson River basin;
2) the creation of the artificial entrance at Lakes Entrance in 1889;
3) an extensive series of internal levee banks, built in the 1970s, which divided the morass into a series of compartments with markedly reduced internal connectivity;
4) and active management of the wetland's hydrology to enhance the breeding of colonial waterbirds and minimise saline intrusions from Lake Wellington and the adjacent La Trobe River. These various factors have conspired to reduce the condition of the diverse vegetation types in the wetland.

The R&D project had nine main components:

- Provide a historical background to Dowd Morass, including a description of the site's history, hydrology, water quality, sediment quality and vegetation;
- Determine the values that the wetland offers to the local community;
- Describe historical changes in the morass's vegetation over the past four decades, using historical aerial photographs;
- Unravel the impact of water regime on wetland condition, focussing on vegetation attributes;
- Determine the relative roles of sexual and asexual reproduction in the vegetation of Lake Wellington wetlands, including an analysis of the germination requirements of the main plant species;
- Quantitatively assess two approaches to wetland rehabilitation: a) landscape-scale manipulation of water regime, and b) active revegetation;
- Describe the ecological interactions between Swamp Paperbark and Common Reed; and
- Embed all these activities in a *bona fide* adaptive management framework; and
- Develop a robust communication and capacity-building program.

Working with local community groups was an integral component of the R&D project. Not only did community groups contribute greatly to repairing the internal levees for the experimental water-level drawdown, but they were a critical element in the revegetation trials. Very early in the project (February and May 2003), informal presentations were given to two of the main community groups in the region: Sale and District Field Naturalists, and Field & Game (Sale and District branch). Both groups were highly aware of the Lake Wellington wetlands, perceived them as integral to the rest of the Gippsland Lakes complex, and rated them as being in only fair condition. A wide range of reasons were given for the wetland degradation, including the presence of exotic species, salinity and an inappropriate water regime.

Water quality in Dowd Morass is often poor: continuous (data logger) and irregular spot measurements of electrical conductivity indicate that the salinity of water has fluctuated between <1 and over 20 mS $cm^{-1}$ between 1992 and 2006. Nutrient concentrations can be very high, possibly as a result of the large colonial waterbird rookery in the south-west of the morass. Potential and actual acid-sulfate soils are present in Dowd Morass, and values of soil pH of <2 were recorded in one site. Acid-sulfate soils are probably distributed widely around the Gippsland Lakes area and have the potential for major environmental impacts. Particular care had to be exercised during experimental water-level manipulations to ensure there were no adverse ecological impacts of drawing down the morass's water level to improve the health of the wetland vegetation.

An intensive set of vegetation assessments showed that the most important variable driving species composition in Dowd Morass was water regime. Continuous data loggers allowed us to differentiate between four water regimes in the wetland: transects with Water Regimes 1 and 2 had a higher percentage cover of Swamp Paperbark and Common Reed than transects with Water Regimes 3 and 4. Water regimes also corresponded well with species diversity. Areas with Water Regimes 1 and 2 had, on average, more plant species (16 and 8 species per transect, respectively) than areas with Water Regimes 3 and 4 (5 and 3 species, respectively). Wetland areas experiencing Water Regimes 1 and 2 had higher overstorey and understorey cover than areas with Water Regimes 3 and 4: the high understorey cover of Water Regime 4 was related to the presence of Common Reed in the understorey. Water regime also affected strongly the number of seedlings of the Swamp Paperbark in the understorey.

There was some anecdotal evidence that Swamp Paperbarks in the Gippsland Lakes have preferentially invaded areas previously occupied by Common Reed in an 'encroachment succession' pathway. This encroachment would have been facilitated both by changes to historical water regimes and on-going salinisation of the Gippsland Lakes. Using aerial photographs for 1964, 1973, 1982, 1991 and 2003, we showed that Swamp Paperbark had increased in area by 73% since 1964. In the most deeply flooded regions of the morass, the response of Swamp Paperbark was characterised by an initial increase in cover followed by a long period of stasis. In the most recent aerial photographs, there was some evidence of vegetation collapse in the south-west of the wetland. In contrast to the expansion of Swamp Paperbark, areas of Common Reed declined from 485 ha to 346 ha over this time span, representing a ~ 30% decrease in extent. Common Reed had been replaced primarily with *M. ericifolia.* The overall consequence of the two sets of changes was a shift in dominance from Common Reed communities to Swamp Scrub, despite near-permanent flooding.

Fundamental studies of the biology of the main plant species in Dowd Morass were an important aspect of the project and allowed us to explain some of the historical changes in floristics and other aspects of the wetlands' ecology. The importance of sexual versus non-sexual pathways for plant recruitment was a key component of these studies. Many earlier studies of wetland vegetation have stressed the role of seed banks in the recovery of wetland plant communities, especially after draw-down events. The underlying theme of much of this work seems to be that the production of seeds, and their subsequent dispersal, is the critical factor in explaining the distribution and regeneration capacity of different wetland plant species, particularly in response to disturbance. Although there is no doubting the importance of this research effort, the paradox is that wetlands are almost always dominated by plants that have a clonal (non-sexual) growth habit and reproduce vegetatively.

We analysed the proportion of plants that possessed the clonal growth habit at Clydebank Morass in 2004. Of the 90 plant species present in Clydbank Morass, about two-thirds were native and the remainder introduced. Exactly one half of all plant species were clonal and 95% of all aquatic plant species were clonal. A molecular technique, inter simple sequence repeats, was used to determine whether individual trees observed in the historical aerial photographs of Dowd Morass were genetically homogeneous or, instead, composed of many plants of mixed parentage. The results clearly indicated that the individual trees were genetically separate and internally homogeneous. Sexual reproduction seems limited to a narrow "window of opportunity" when environmental conditions were appropriate and allowed a new bout of colonisation into otherwise unvegetated areas or areas dominated by other plant species.

The environmental requirements for successful germination from seed of Swamp Paperbarks and Eelgrass was investigated in a series of laboratory experiments to elucidate this "window of opportunity". Greatest germination of Swamp Paperbarks seed occurred with surface-sown seed, in darkness at a mean temperature of 20°C and salinity < 2 g $L^{-1}$. Germination rates fell rapidly at a near-constant rate with increasing salinity. Lower temperatures, while moderating the inhibitory effects of salinity, markedly reduced germination. In contrast, higher temperatures increased the inhibitory effects of salinity and light and reduced overall germination rates. Although about 10% of seeds still germinated at a salt concentration of 16 g $L^{-1}$, no seeds germinated at a salinity of 32 g $L^{-1}$.

Given the role that historical water regime played in controlling the condition of vegetation at Dowd Morass, we wanted to better understand the potential for modifying the current water regime to improve the vegetation condition, especially Swamp Paperbarks, in the wetland. With the assistance of staff from Parks Victoria and volunteers from Field & Game (Sale and District), gaps in the wetland's internal levees were repaired so that the east and west sides of Dowd Morass were physically isolated. This division within the wetland provided a unique opportunity to undertake a landscape-scale experimental manipulation of water level and to test the impact of water-level drawdown on the condition of wetland vegetation. We used the levees and regulatory structure on the channel and regulator to the La Trobe River to drain the area on the west side of the levee (≈ 500 ha) and to keep areas on the east side of the embankment (≈ 1000 ha) full of water as a control.

The first attempt at drawdown was in the summer of 2003-2004. Water was drained from the morass via the culverts into the La Trobe River; evaporation over the following summer removed most of the remaining water. This attempt at landscape-scale hydrological manipulations was thwarted by vandalism of the regulatory structure in March 2004; the resultant influx of water from the La Trobe River increased water levels by approximately 30 cm in the morass. A second drawdown was attempted over the summer of 2004-2005 in the following year. This time, water was drained as much as possible through the La Trobe River culvert and two large diesel-driven pumps were then used to pump the remaining water into the La Trobe River and across the levee separating the drawdown and control sides of the wetland.

It was difficult to determine the impact of these two landscape-scale water-level manipulations. Weather conditions confounded our attempts at controlling water levels, and hydrological impacts were confounded by related changes in salinity in the water column and sediments. Nevertheless, less than 10% of the morass sediment was exposed before drawdown but during 2005 more than 60% of the area along the shoreline and more than 30% of sites in other parts of the morass were exposed for between 2½ months and 5½ months. These patterns of wetland drying resulted in the number of understorey species declining between 2003 and 2006, probably as a result of increased salinity. There was a shift in species composition away from freshwater plants such as Marsh Pennywort *(Hydrocotyle verticillata)* towards more salt-tolerant species such as Goosefoot *(Chenopodium glaucum*).

The drawdown temporarily increased the number of understorey species present in all areas. The cover of understorey species also increased. Some species established rapidly on the exposed sediments, especially introduced annual grasses and salt-tolerant species. The response, however, was rather limited, possibly as a result of a depleted soil seed bank, seasonality, increased salinity and low soil pH. There was, however, a marked improvement in wetland condition during drawdown, which was lost during the rapid and deep re-flooding that occurred soon after water levels had dropped. This effect is most clear in the vegetation data for mid 2006. By mid 2006, the species composition along transects was very different to what was initially recorded in 2003.

The second approach to wetland rehabilitation was active revegetation with tubestock of Swamp Paperbark seedlings. Four sets of revegetation trials were undertaken from 2004-2006, testing various aspects of the effect of water depth, seedling age, planting method and location on revegetation success. Almost all seedlings planted in wet or damp sediments died. In contrast, planting the Swamp Paperbark tubestock into raised vegetated hummocks increased markedly their survival. This finding is consistent with our field observations that *M. ericifolia* seedlings and juveniles predominantly occur on hummocks that are raised, even slightly, out of the surrounding water. Hummocks offer a refuge from the stressful combination of waterlogging, salinity and soil acidity occurring in the surrounding sediments. In late 2006, experiments were undertaken to examine the effects of acid-sulfate soils and liming on seedling survival: it is intended that these trials will be monitored over the coming years. We conclude that, unless intrinsic edaphic (e.g., salinity, pH) and hydrological (e.g., water quality and water regime) factors are fully understood, revegetation trials in coastal Swamp Paperbark wetlands are likely to be unsuccessful.

# 1. Lake Wellington and its wetlands

## The Gippsland Lakes

Lake Wellington is the westerly most lake in the Gippsland Lakes complex of south-eastern Australia. The Gippsland Lakes are Australia's largest navigable inland waterway. They include three main water bodies:

- Lake Wellington (138 km$^2$) in the west, fed by the La Trobe, Thompson, Macalister and Avon Rivers, and linked by the meandering McLennan Strait to
- Lake Victoria (110 km$^2$), and
- Lake King (92 km$^2$).

Lake King, in the east, is fed by the Nicholson, Mitchell and Tambo Rivers. As well as these three main water bodies, there are a number of smaller lagoons associated with the extensive swamps that occur on the low-lying depositional coastal plain; Lake Reeve, an intermittent salt marsh, and Lake Coleman are the largest of these other water bodies. Together, the lakes have a shoreline 320 km long and drain a catchment that covers about one-tenth of the area of Victoria[1,2].

The first European to see the Gippsland Lakes was probably Angus McMillan[3]. He became aware of their existence by learning sufficient of the Aboriginal language before his series of expeditions to north, central and south Gippsland in the mid 19th century. In his second expedition, starting in December 1839, he came across the lakes' northern shore. In the spring of 1842, John Reeve discovered the location of the lakes' natural entrance to the sea, near abouts the present Lakes Entrance. Subsequently the Gippsland Lakes area was rapidly colonised and the lakes became a key navigational asset, initially due to the need to provision the gold diggings in the hinterland.

Long before Europeans arrived, however, the Gippsland Lakes were used by the Kurnai people. In the early 1840s, Charles Tyers, the Commissioner for Crown Lands, estimated that more than 1000 Kurnai were living near the lakes. They were physically isolated from other tribes and, more importantly, from European contact. The Gippsland Lakes provided them with an abundance of food and other resources[3].

Although commonly called the Gippsland 'Lakes', the complex is really a group of coastal lagoons, large areas of shallow water that have been partly or wholly sealed off from the sea by a series of depositional barriers[1]. The current shape and location of the Gippsland Lakes is a relatively recent phenomenon. They were separated from the Southern Ocean only in the Quaternary Period (the last 1.6 million years), by the deposition of a succession of sandy barriers[2]. When the area was first settled by Europeans in the 1840s, the lakes were linked with the sea by a shifting and intermittent outlet through the sand barriers between Cunninghame and Red Bluff at the easterly part of Lake King[1]. They would open to the sea during large floods but, to improve navigability, an artificial entrance was cut to the ocean in 1889 at Lakes Entrance, about 5 km from the natural entrance. Sand deposition soon sealed off the old natural outlet. One consequence of opening the artificial entrance was to increase the salinity of the Gippsland Lakes, which previously were relatively fresh being fed by the rivers flowing into Lakes Wellington and King and having only an intermittent linkage with the ocean[2, 4]. A second consequence[5] of the opening is that average water levels in the Lakes have decreased by about 60 cm.

A substantial part of the Gippsland Lakes is recognised under the Ramsar Convention as being of international significance for its wetlands and their large (~20,000) waterbird populations[6]. The Gippsland Lakes Ramsar site was listed in 1982 and covers an area of 58,824 ha. It consists of the Lake Wellington, Victoria, King, Bunga, Tyers and Reeve wetland systems, as well as Macleod Morass and some areas of land adjacent to these wetlands. The largest single component in the Ramsar site is Lake Wellington and its wetlands.

Figure 1.1: Ibis rockery in Swamp Paperbark at Dowd Morass.

## Lake Wellington wetlands

The wetlands associated with Lake Wellington cover an area of 12,510 ha (excluding Lake Wellington itself) and represents about 75% of the wetlands in the greater Lake Wellington catchment[7,8]. About 7,310 ha of the wetlands are on Crown land.

They include important wetland sites such as:

- Dowd Morass (1,500 ha)
- Clydebank Morass (1,420 ha)
- Lake Coleman (2,000 ha), and
- Sale Common (300 ha).

Table 1.1 shows the Crown land wetlands included in the Lake Wellington wetlands complex[7], and Figure 1.2 shows the relationship of Dowd Morass to other wetlands in the nearby area.

The map shows also the complex system of land management that applies to these various wetlands.

| Wetland | Land status | Approximate area (ha) |
|---|---|---|
| Heart Morass | State Game Reserve | 360 |
| Dowd Morass | State Game Reserve | 1,500 |
| Clydebank Morass | State Game Reserve | 1,420 |
| Lake Coleman | State Game Reserve | 2,000 |
| Sale Common | State Game Refuge | 300 |
| Lake Melanydra | Water Reserve | 60 |
| Lake Kakydra | Drainage Reserve | 180 |
| Victoria Lagoon – Lake Betsy | Unreserved Crown Land | 350 |
| Morley Swamp | Unreserved Crown Land | 200 |
| Red Morass | Unreserved Crown Land | 200 |
| Backwater Morass | Unreserved Crown Land | 400 |
| Shores of Lake Wellington | Public Purposes Reserve | 300 |

Table 1.1: Crown land wetland areas in the Lake Wellington region[7].

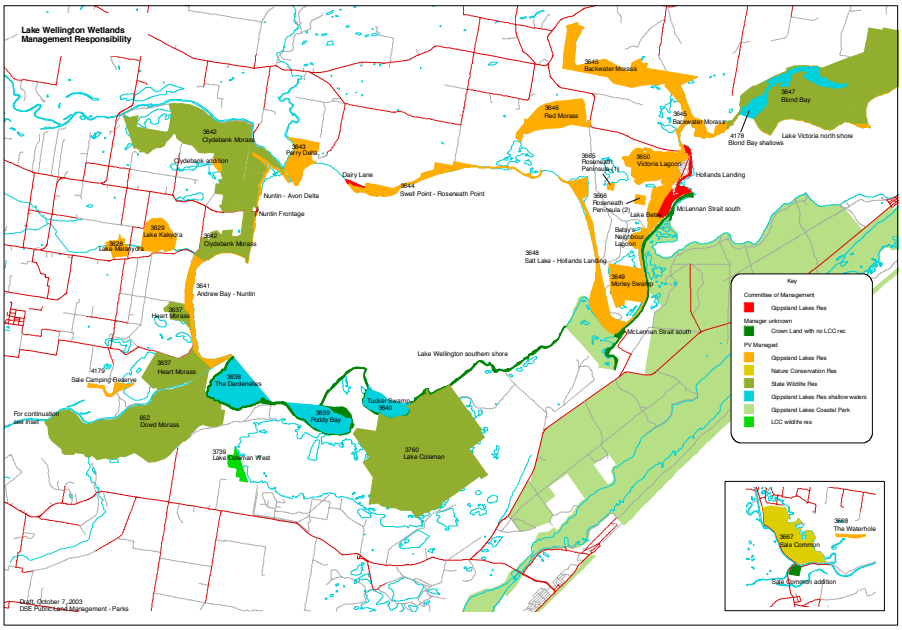



Figure 1.2: Wetlands associated with Lake Wellington. Dowd Morass is indicated with the red arrow. The various agencies responsible for managing these wetlands are shown as well. Source: Parks Victoria.

# 2. Dowd Morass

Covering 1500 ha, Dowd Morass is one of the largest wetlands in the Gippsland Lakes Ramsar site. As shown in Figure 1.1, it is located on the western shores of Lake Wellington, near Sale in eastern Victoria ($38^0$07'S $147^0$10'E). Swamp Paperbarks *(Melaleuca ericifolia)* are a conspicuous feature of the vegetation of Dowd Morass (Figure 2.1).

## History of Dowd Morass

An unpublished report by the State Rivers and Water Supply Commission[9] showed that alienation of land in Dowd Morass began in 1888 and was complete by 1942. Almost all the eastern-most areas of the wetland were resumed for wildfowl preservation in 1968 as the Dowd Morass Wildfowl Reserve, leaving the western-most portions in private ownership. Attempts were made, unsuccessfully, at various times after 1959 to purchase these privately owned areas.

A series of levee banks approximately 0.9-1.9 m AHD were constructed within the morass in 1973 when it was in private ownership. These levees were large enough to support substantial pieces of earth-moving equipment (Figure 2.2). Their size and robustness proved very useful when we tried to manipulate water levels in the Morass as part of a comprehensive rehabilitation trial (Section 11). The levees almost completely separate the eastern and western sections of the wetland and we call the five areas so created, Areas A-E (Figures 2.3 and 2.4). The levees were constructed "with a view to drainage and development for agricultural purposes"[9], as well as to prevent overbank flows from the La Trobe River and prohibit brackish water from Lake Wellington entering the western side of the morass (Keith Heywood, *pers. comm.*). Two artificial drains were constructed sometime in the early 1970s to establish a hydraulic connection between Dowd Morass and the La Trobe River.

In 1975 the State Government of Victoria purchased the wetland as a State Game Reserve, and breaches were created in the levees to improve water circulation within the morass. In 1987, the managing agency (Parks Victoria) installed gated culverts on the larger of the two artificial drains (Drain 1, Figure 2.3) so that water levels could be better managed[10].

### Long-term changes to water regime

Prior to European settlement, Dowd Morass would have filled with sediment-laden fresh water from the La Trobe River during flood, and with less turbid water of variable salinity from Lake Wellington when wind conditions were suitable and when the water level of Lake Wellington exceeded the shoreline level of Dowd Morass (~ 0.3 m AHD)[10]. Surface-water levels in the wetland would have fluctuated also in response to the seasonal patterns of precipitation, runoff and evaporation. It has been proposed that, prior to European settlement, Dowd Morass and other wetlands in the Lake Wellington complex would have dried out about every five years[8].

Four factors have resulted in marked changes to the spatial and temporal characteristics of wetting and drying cycles in Dowd Morass. First, changes in land-use since the mid 19th century and construction of water storages in the Thomson River basin, particularly Lake Glenmaggie (completed 1926) and the Thomson Dam (completed 1983) have reduced flow variability in the lower La Trobe River and particularly the frequency of smaller floods[11].

Second, the creation of the artificial entrance at Lakes Entrance altered the salinity regime in the adjacent Lake Wellington and decreased by about 60 cm the average water level in the Gippsland Lakes[5].

Third, the internal levee banks divided the morass into a series of compartments with markedly reduced internal connectivity.

Fourth, the water regime in Dowd Morass has been actively managed since the wetland became a State Game Reserve in 1975 (Andrew Schulz, *pers. comm.*). The morass was flooded in 1975 as a result of the connection with the La Trobe River through the larger of the two artificial drains, since the culverts at that time did not control water flow. The wetland has been kept fully flooded almost continuously since then, except for a period in 1983 when it would have dried completely but for the digging of a channel by persons

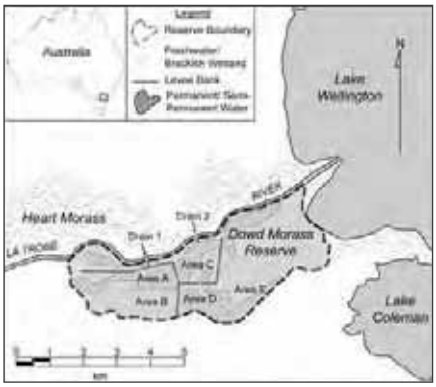



Figure 2.3: Dowd Morass, showing the location on internal levees and the resultant division of the wetland into five discrete zones.

Figure 2.1: Swamp Paperbarks *(Melaleuca ericifolia)* in a near permanently inundated area of Dowd Morass. The water is about 0.5 m deep.

Figure 2.2: Internal levees that internally divide Dowd Morass are large enough to support large pieces of equipment. This photograph shows the team that installed the pumps for the water-level draw-down described in Section 11.

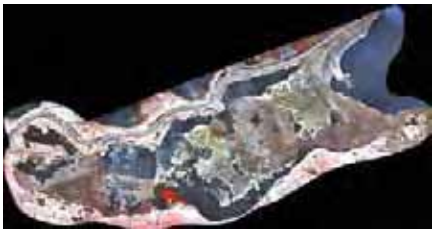


Figure 2.4: Photomosaic of Dowd Morass, complied from a series of colour infra-red photographs taken in 2003. The levees can be seen dividing the wetland into a number of discrete compartments. The main north-south levee (Heywood's embankment) is indicated with the red arrow.

Figure 2.5: Stands of Swamp Paperbark, *Melaleuca ericifolia*.

Figure 2.6: Dense swards of Common Reed, *Phragmites australis*, in the background with submerged beds of Eelgrass, *Vallisneria americana*, in the foreground.

unknown and the flooding of the wetland with moderately saline water from the La Trobe River. In 1987 the culverts were repaired with help from the regional Field & Game club, and these structures were further improved in 2000 with the fitting of stainless steel flaps that allow control of the direction of water movement into and out of the wetland from the adjacent river. From 1987 to 1997 the morass was managed to maintain stable water levels for breeding colonies of colonial waterbirds, by not drawing down water levels from September to December each year.

By 1997 it was realised that this management regime was flawed as it never allowed the wetland to dry. In March 1997 wetland managers were so concerned about the declining condition of Swamp Paperbark resulting from the near-permanent inundation that, during the summer of 1997-98, Parks Victoria initiated a water-level drawdown by draining the wetland through culverts to the La Trobe River. A drawdown of about four months was achieved, but the trial manipulation was curtailed because brackish water from Lake Wellington backed up the Latrobe River during a major flood in Lake Wellington in mid-1998. Saline water from Lake Wellington entered Dowd Morass via the Dardenelles (a shallow opening between the Morass and Lake Wellington: Figure 2.3) and overbank flow along the La Trobe River[10]. Since then water levels have been managed to prevent similar incursions of saline water into the wetland from Lake Wellington and saline sections of the La Trobe River. Section 4 of the Handbook provides more detailed information on recent (past ~ 30 years) changes to the hydrological and salinity regime of Dowd Morass.

# Vegetation communities

Four plant communities dominate vegetation in Dowd Morass:

- Extensive woodlands of Swamp Paperbark, *Melaleuca ericifolia*;
- Dense swards of Common Reed, *Phragmites australis*;
- Beds of Eelgrass, *Vallisneria americana,* a submerged angiosperm; and
- Fringing areas of mud flats and salt-tolerant plants, including taxa such as *Disphyma clavellatum*, *Distichlis distichophylla*, *Hemichroa pentandra*, and *Sarcocornia quinqueflora*.

These vegetation types are shown in Figures 2.5 and 2.6.

Figure 2.7 shows a recent aerial photograph of the north-western part of Dowd Morass, where stands of Swamp Paperbark can be seen clearly amongst the dense patches of Common Reed.


Figure 2.7: Aerial photograph of a section of Dowd Morass, showing areas of Common Reed (CR) and Swamp Paperbark (SP). Individual Swamp Paperbark trees are clearly visible (an example is marked with the red arrow).

## Impact of altered water regime on wetland plant communities

The drastic alterations to the wetland's water regime over the past half century have had marked impacts on the condition and extent of these various plant communities.

As long ago as 1966, ECF Bird[12] argued that the artificial opening at Lakes Entrance would result in the inevitable salinisation of the entire Gippsland Lakes complex. It was predicted not only that the salt-tolerant Swamp Paperbark would replace the more salt-sensitive Common Reed, but also that areas of fringing chenopod-dominated saltmarsh would become more extensive.

The more-or-less constant inundation has had severe impacts on health of Swamp Paperbarks; adult trees are now dying and, for reasons that become clearer later in the report, juvenile plants are failing to recruit into the population. A typical case of Paperbark death is shown in Figure 2.8, where an adult plant has toppled over and is falling into the water.

## The rationale for this R&D project

Dowd Morass presents a fascinating example of wetland degradation in south-eastern Australia. It is a wetland of international significance, yet is increasingly degraded because of an inappropriate water regime and secondary salinisation. The R&D activities outlined in this report commenced in 2003, and aimed to quantify the ecological condition of the Morass and the factors contributing to its degradation, and then to investigate realistic methods for arresting and, it was hoped, reversing these changes.

Figure 2.8: An example of the impact of altered water regime on Swamp Paperbarks, with the death of the original adult plant and suckering occurring from the remaining tissues.

# 3. Community assessment of Lake Wellington wetlands

Working with local community groups was an integral component of the R&D project. Not only did community groups contribute much time and effort in repairing the levees for the experimental water-level drawdown (Section 11 of this handbook), but they were a critical element in our revegetation trials (Section 12).

To gauge the Gippsland community's assessment of the Lake Wellington wetlands, we undertook a series of informal workshops and presentations throughout the entire R&D project. The venues and dates of these meetings are shown in Section 14.

Very early in the project (February and May 2003), we gave informal presentations in the evening to the two main stakeholder community groups in the region: Sale and District Field Naturalists, and Field & Game (Sale and District branch). At the conclusion of each meeting we distributed a short questionnaire of 12 Likert-type questions. The return rate for each group was 85% (18 from 21 at Field Naturalists' meeting; 29 from 34 at Field & Game meeting). Likert questions are questions in which the respondent is asked to rate their answer on a scale (e.g., from 1 = bad to 5 = excellent, with intermediate levels of fair, average and good etc) rather than providing a simplistic Yes/No reply.

Both community groups were highly aware of the wetlands that fringe the Gippsland Lakes, with scores exceeding 4 out of the highest possible score of 5 (Question 1).

Question 2 asked the meeting attendees how they valued Gippsland's wetlands. As expected there was a wide range of reasons expressed, but among the most common were aesthetics, recreation and environmental values. Sport was rated highly by Field & Game members but very lowly by Field Naturalist members. Interestingly, 60-80% of respondents rated "pollution filter" as a wetland value.

Question 3 asked whether the wetlands were an integral part of the Gippsland Lakes. Almost all (rating of > 4.5 out of 5) thought the wetlands were integral to the larger Gippsland Lakes, an interesting finding for those charged with managing the lakes complex.

Questions 4, 5 and 6 addressed wetland condition. Field & Game members thought the wetlands were in poorer condition than did the Field Naturalists, although both groups tended to the view that the wetlands were in "fair" condition only (Question 4). Field & Game members perceived a decrease in wetland health over time, whereas Field Naturalists returned a Likert score of exactly 2.5 out of 5, indicating that they perceived no net change in condition. However the error bars associated with responses were large for Question 5, indicating a widely variable response among members of each group.

A wide range of factors were proposed for causing wetland degradation (Question 6): carp were an almost ubiquitous explanation, followed by an inappropriate water regime, salinity and plant loss. Weed invasions were problematic for Field Naturalists but less so for Field & Game members. Interestingly, excess bird numbers were identified by 21% of Field & Game members as contributing to wetland degradation. It is likely, however, that ibis rather than waterfowl were the birds identified as being too abundant. What would seem to be an esoteric cause of degradation – acid sulphate soils – was identified by 17% and 24% of Field & Game and Field Naturalists, respectively. Nevertheless, tourism was ranked about as highly as acid-sulfate soils as a cause of degradation.

Questions 7 to 9 addressed issues concerning the presentations and are not relevant to this handbook.

Question 10 examined the relevance of the R&D project to the health and management of the wetlands. Gratifying, the two groups returned scores of 4.6 and 4.7 out of 5, indicating they thought the R&D project to be highly relevant to Gippsland's wetlands.

Question 11 asked whether the members of the two groups would like to be further involved in the project. Over three-quarters of respondents (76% for Field & Game, 83% for Field Naturalists) wanted to be involved. When asked what activities most interested them (Question 12), the most common topics were revegetation and bird counts, followed by water-quality monitoring and frog counts. Publicity activities rated poorly.

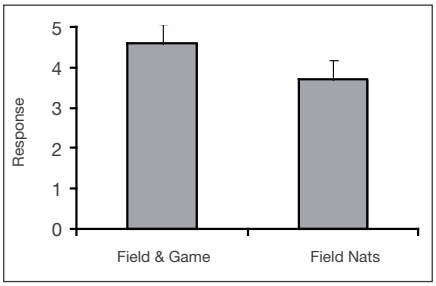



Figure 3.1: How aware are you of the wetlands fringing the Gippsland Lakes? Score: 1 = Totally unaware, to 5 = Highly aware.

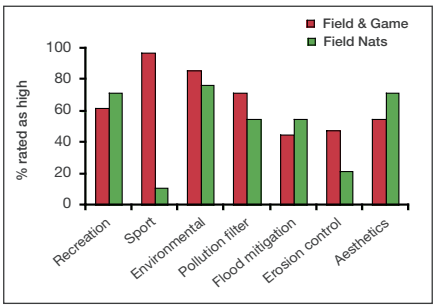



Figure 3.2: What values do these wetlands have for you?

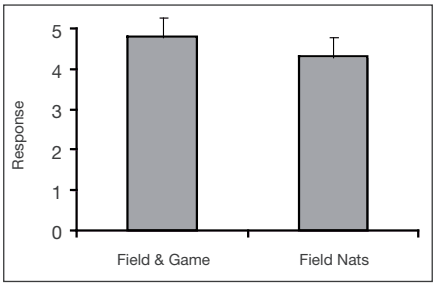



Figure 3.3: Are these wetlands an integral part of the Gippsland Lakes? Score: 1 = Totally separate, to 5 = Wetlands integral to lake system.

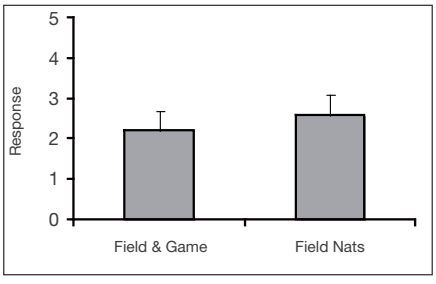



Figure 3.4: How degraded are these wetlands? Score: 1 = Highly degraded to 5 = Pristine.

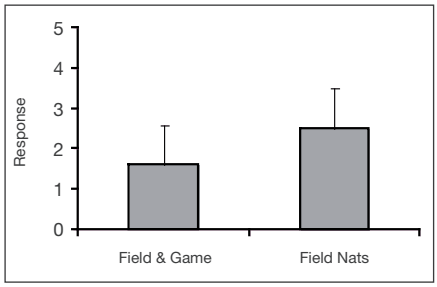



Figure 3.5: Have you observed any changes in the health of the wetlands over time? Score: 1 = Becoming less healthy, to 5 = Becoming more healthy.

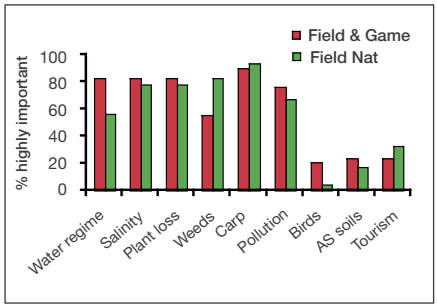



Figure 3.6: What factors have been responsible for wetland degradation? AS = acid-sulfate soils.

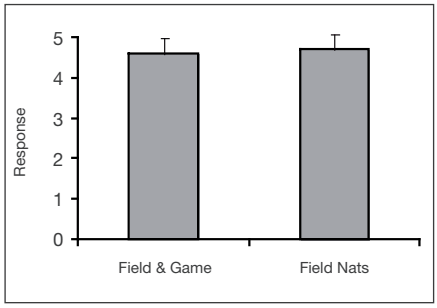



Figure 3.7: How relevant is the R&D project to the health and better management of the wetlands? Score: 1 = Not relevant, to 5 = Highly relevant.

## Results

The findings of these two small questionnaires provide a fascinating insight into community attitudes to wetlands of the Gippsland Lakes. Both groups were highly aware of the wetlands, perceived them as being integral to the rest of the Gippsland Lakes complex, and rated them as being in only fair condition. A wide range of reasons were given for wetland degradation, some of which (e.g., the impacts of carp) did not align closely with our understanding of the prime causes of wetland degradation.

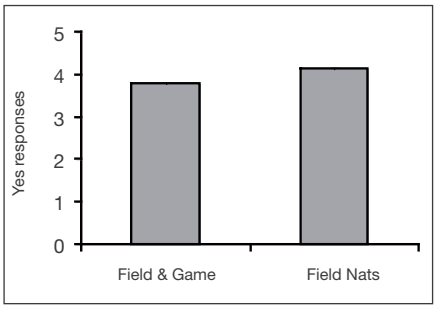



Figure 3.8: Would you like to be involved further in the project?

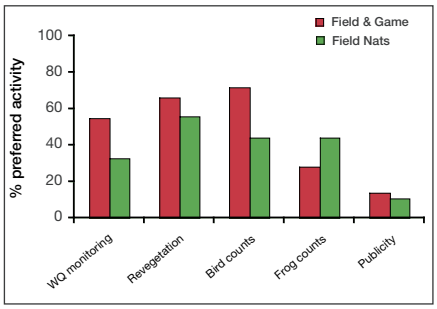



Figure 3.9: How would you like to be involved in the project?

Other responses were highly insightful; for example the adverse role of altered water regime was reported by 83% of Field & Game members. Noting the desire of most members of both groups to be involved more deeply in the R&D project, we collaborated closely with them over the subsequent years in the experimental water-level drawdown (Section 11) and revegetation trials (Section 12).

We regard this preliminary assessment of the community's understanding of its regional wetlands as a critical and novel component of the R&D project.

Traditionally there are strong divisions not only between the social and technical sciences, but also even within the technical sciences. For example, it is rare for R&D projects to include hydrological, water-quality, botanical and faunal components. Moreover, ecological studies are often undertaken in almost complete isolation from critical social and economic considerations; deplorable though this is, there are undoubtedly good explanations for why contrasting disciplines rarely talk to each other. Nevertheless, improved management of high-value natural resources can only benefit from close collaboration across disciplines; indeed sustainable natural-resource management is inextricably linked with the views and attitudes of community stakeholders.

Communicating the progress and results of the R&D project were always a high priority. Three fact sheets were produced during the project, a web site established (**www.wetland-ecology.info**), and the two technical Handbooks printed and distributed. Overviews of the R&D project and its findings were presented to a wide range of organisations, including West Gippsland CMA, Corangamite CMA, Wimmera CMA, Glenelg-Hopkins CMA, Goulburn-Broken CMA, Gippsland Taskforce, Watermark, Wellington Shire Council, Department of Primary Industries, Department of Sustainability and Environment, Arthur Rylah Institute, Victorian EPA, National Acid-sulfate Soils Working Group, University of Ballarat, Griffith University, Field & Game Victoria and Sale & District Field Naturalists.

# 4. Recent hydrological and salinity regimes in Dowd Morass

## Water levels over past three decades

As noted in the earlier section of this Handbook, a series of levee banks approximately 0.9-1.9 m AHD were constructed in Dowd Morass in 1973 when it was in private ownership. These levees almost completely separated the eastern and western sections of the wetland. Our analysis of aerial photographs (Section 8) showed that surface water covered only 12% (182 ha) of the wetland in 1964. Water covered 7% (121 ha) of the wetland when the levees were constructed in 1973.

In 1975 the State Government of Victoria purchased the wetland as a State Game Reserve and breaches were created in the levees to improve water circulation within the Morass. By 1982 the extent of open water at Dowd Morass increased to 31% of the total area (515 ha). This estimate is likely to be conservative because it is difficult to detect with aerial photographs the presence of surface water underneath a Swamp Paperbark canopy.

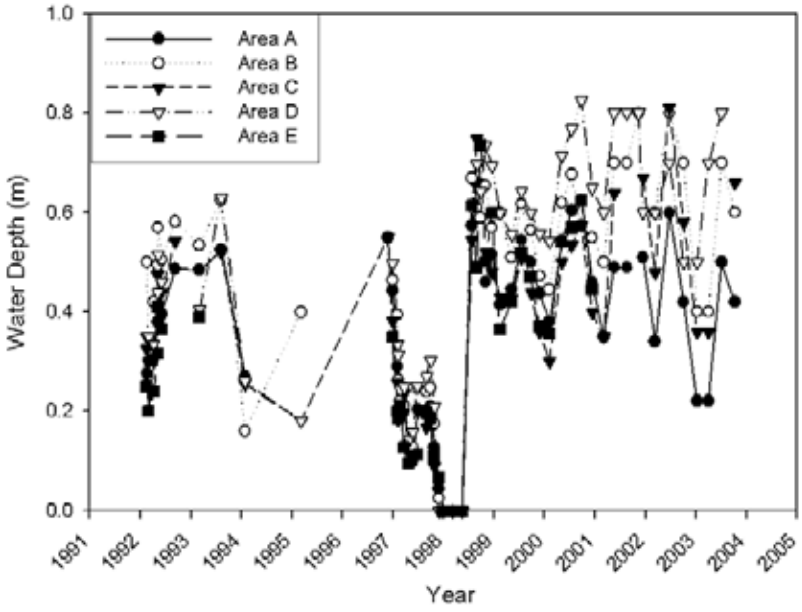



Figure 4.1: Historical (since 1991) patterns in water levels in various sections of Dowd Morass.

Spot measurements of water levels in Dowd Morass are available from 1992 to 2003 but should be interpreted with caution as they are episodic and have not been calibrated independently (Figure 4.1). These data do, however, support the notion that Dowd Morass has been flooded permanently since at least 1992, with the exception of the drawdown in 1997-1998. These data also demonstrate that water levels in Areas A – E of the Morass have fluctuated between 0.2 and 0.6 m over this period. Moreover, water levels in Areas A – E rose and fell in concert, suggesting these areas are relatively well connected.

As noted in section 2 of this handbook, Parks Victoria staff were concerned in the mid-late 1990s that the near-permanent inundation was having adverse impacts on Swamp Paperbarks in Dowd Morass, particularly in the area of the ibis rookery. A drawdown of water levels was initiated in 1997 by draining water through the culverts to the La Trobe River. Water levels were drawn down during the summer of 1998 and the wetland was dry for 173 days. Unfortunately, this drying time was not sufficient to achieve the management goals of restoring the Swamp Paperbark community in the rookery area of Dowd Morass, and seedling recruitment was still poor.

In March 1998, the management agency opened the gated culverts joining Dowd Morass with the La Trobe River in order to allow water to flow into the wetland. The La Trobe River was low at that time and there was only a small flow into the Morass. During a flood of Lake Wellington in mid-1998, brackish water from Lake Wellington backed up the La Trobe River and entered Dowd Morass via the Dardenelles and overbank flow along the La Trobe River (see section 1 for details). The effect on wetland salinity of this saline intrusion can be seen in Figure 4.2.

Since reflooding in 1998, water levels in Dowd Morass have been maintained between 0.3 and 0.8 m, deeper even than pre-drawdown levels (typically 0.2-0.6 m). Partly the intention of maintaining such deep water in the morass was to avoid the risk of future intrusions of saline water from Lake Wellington. Mostly however, it was to provide the environmental conditions necessary for colonial waterbirds to breed successfully.

## Salinity regimes over the past three decades

Spot measurements of electrical conductivity suggest that the salinity of water in Dowd Morass fluctuated between <1 and over 20 mS $cm^{-1}$ between 1992 and 2003. The effects of the saline intrusion from Lake Wellington are evident in Figure 4.2, with salinities reaching 20 mS $cm^{-1}$ in late 1998 and early 1999.

After the short-lived drying event in 1997-1998, the average salinity of surface water in Dowd Morass not only has increased but has become more variable. Prior to 1998 surface water salinities were generally below 8 mS $cm^{-1}$ except for one period in 1995; average surface water salinities have increased after the drying trial and saline intrusion of 1998. Differences across sites within the wetland also have become evident, with Area E > Area D > Area C > Area B > Area A (Figure 4.2). This pattern may reflect the influence of saline intrusions from Lake Wellington extending into Areas E, D and C, but exerting little effect in Areas A and B.

With the help from Parks Victoria, we installed sensors and data loggers in 2003 to continuously monitor salinity in two sections of Dowd Morass: Area B – the 'impact' site destined to be drawn-down as part of the landscape-scale water-level manipulation (Section 11 of this Handbook) and Area D – the control site where water levels were kept high (see Figures 2.4 and 2.5). Figure 4.3 shows the data generated using these data loggers.

It is clear from the continuous records shown in Figure 4.3 that salinities in both areas of the Morass have consistently exceeded 5 mS $cm^{-1}$. The short-term impacts of episodic events such as storms (e.g., 24 April 2004, February 3 and July 9-10 2005) are also evident.

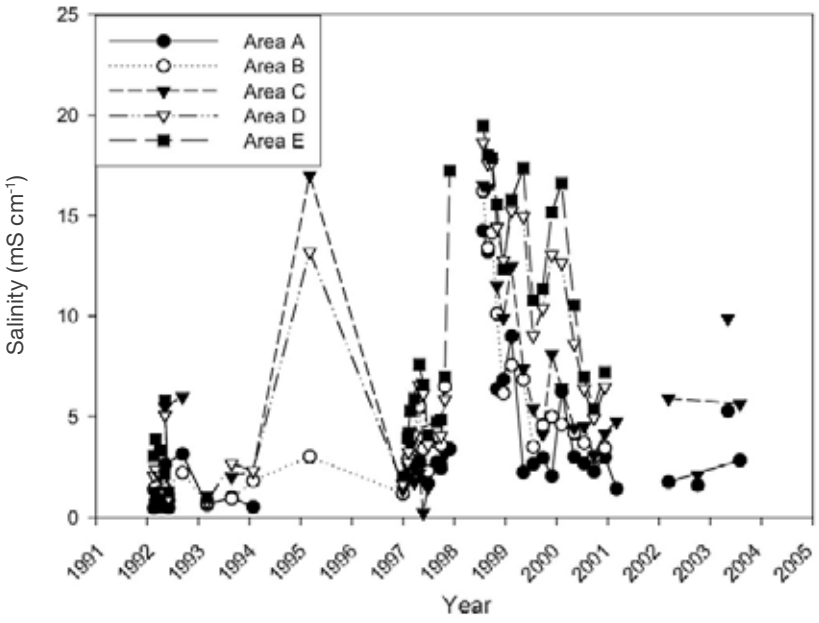



Figure 4.2: Historical (since 1991) salinity patterns in various sections of Dowd Morass.

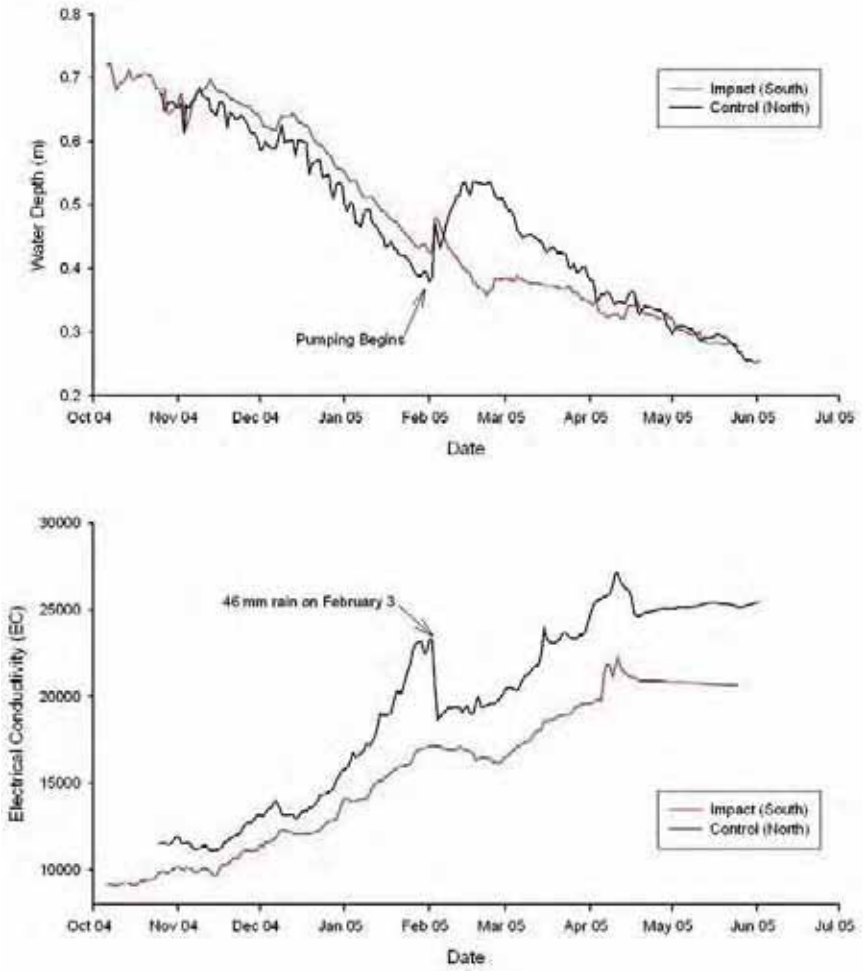



Figure 4.3: Continuous monitoring of water levels (upper graph) and salinity in the central and drawndown (impact) sections of Dowd Morass from October 2004 to July 2005.

# 5. Water quality in Dowd Morass

Monitoring water quality was not a major component of the R&D program. We decided not to devote significant resources to water-quality monitoring for two reasons. First, the budget and numbers of available staff would not allow intensive analyses of water quality, especially of nutrients. Second, Dowd Morass has been monitored historically by the EPA and Parks Victoria and has been a Victorian WaterWatch site since at least 1992. Thus a reasonably good dataset for water quality exists already for the wetland.

## Summary of historical water-quality data

The report in 2001 by Sinclair Knight Merz[14] contained a full analysis of all water-quality monitoring data for Dowd Morass from 1991 to 2001. Table 5.1 shows a summary of these data.

The obvious point is the skew and substantial range in most of the water-quality variables. For example, the mean salinity was just over 4.0 mS $cm^{-1}$ but the median was only 2.12 mS $cm^{-1}$ and the maximum recorded value was nearly 20 mS $cm^{-1}$. Similarly, water-column pH could vary between 2.8 and 8.9, turbidity from < 1 to nearly 600 NTU, and Total phosphorus from near the limit of detection to 0.23 mg P $L^{-1}$. Interestingly, the pH of the water column could drop to less than 3 pH units: possible reasons for this fall are discussed in Section 6 on sediment quality.

Some value can be obtained from examining the ratio of nitrogen to phosphorus. Marine phytoplankton with a balanced nutrient supply commonly have an N:P ratio of about 7:1 by mass, and marine vascular plants commonly have a ratio of about 13:1 by mass[13]. Severe departures from these ratios in plant tissues often indicate physiological nutrient limitation; if the cellular N:P ratio in algal cells is markedly above 7:1 or that in vascular plants is greater than 13:1, phosphorus limitation is predicted. The mean N:P ratio in the water column at Dowd Morass was about 7:1. This might be taken to indicate that neither nitrogen nor phosphorus were limiting to algal growth, but the wide variability in absolute concentrations suggests that both nitrogen and phosphorus might become limiting nutrients at different times.

| Date of sampling and wetland area | Total nitrogen (mg N $L^{-1}$) | Total phosphorus (mg P $L^{-1}$) |
|---|---|---|
| **June 2003** | | |
| A | 0.59 ± 0.06 | 0.03 ± 0.005 |
| B | 2.82 ± 0.20 | 0.39 ± 0.05 |
| C | 0.52 ± 0.06 | 0.02 ± 0004 |
| D | 1.62 ± 0.26 | 0.04 ± 0.011 |
| **November 2003** | | |
| A | 3.32 ± 0.40 | 0.23 ± 0.06 |
| B | 4.30 ± 0.25 | 0.41 ± 0.08 |
| C | 3.62 ± 0.19 | 0.22 ± 0.022 |
| D | 2.67 ± 0.10 | 0.07 ± 0.007 |

Table 5.2: Water-column nutrient data for four areas at Dowd Morass. Means ± standard errors are shown, n=5. The various areas are shown in Figure 2.4.

| Variable | Mean ± standard error (n) | Maximum | Minimum |
|---|---|---|---|
| Water temperature | 19 ± 1 (219) | 35 | 9 |
| pH | 6.6 ± 0.1 (214) | 8.9 | 2.8 |
| Dissolved oxygen (mg $L^{-1}$) | 8.5 ± 0.3 (25) | 10.5 | 5.3 |
| Salinity (mS $cm^{-1}$)* | 4.02 ± 0.33 (223) | 19.45 | Not given |
| Turbidity (NTU) | 91 ± 10 (127) | 580 | < 1 |
| Total phosphorus (mg $L^{-1}$) | 0.23 + 0.02 (138) | 1.55 | 0.02 |
| Total Kjeldahl nitrogen (mg $L^{-1}$) | 1.58 ± 0.2 (9) | 2.40 | 0.73 |
| Ammonium (mg $L^{-1}$) | 0.04 ± 0.02 (7) | 0.10 | < 0.01 |
| Nitrate plus nitrite (mg $L^{-1}$) | 0.09 + 0.04 (16) | 0.67 | < 0.01 |
| * seawater = ~ 50 mS $cm^{-1}$ | | | |

Table 5.1: Summary of water-quality data for Dowd Morass, pooled over all sites, from 1991 to 2001. These data were obtained by the EPA, Parks Victoria and WaterWatch, and analysed by Sinclair Knigh Merz[14].

## R&D project nutrient data

As part of the R&D project we did measure a number of important water-quality variables early in the project. As shown in Table 5.2, concentrations of Total nitrogen and Total phosphorus in the water column of Dowd Morass varied widely from area to area. It is interesting that the highest nutrient concentrations were detected in Area B, the site of the ibis rookery. The two species of ibis that nest at Dowd Morass are the Straw-necked Ibis *(Threskiornis spinicollis)* and the Australian White Ibis *(Threskiornis molucca)*; Figure 5.1 shows the rookery in mid 2006 and Figure 5.2 shows the poor water quality, indicated by the algal bloom, in this region of the wetland.

Figure 5.1: Rookery in Area B of Dowd Morass in mid 2006.

Figure 5.2: Algal bloom in Area B (the rookery) at Dowd Morass. The plant growing on the Swamp Paperbark hummock is *Chenopodium glaucum*.

## Sundry pollutants

Because the bombing range of the Sale RAAF base is located next to our sites in Dowd Morass, we checked the water and sediments for a wide range of explosives residues. Samples were collected in December 2004 and analysed by ALS Environmental (Sydney), a NATA-accredited laboratory. All the following explosives residues were below the limit of analytical detection: HMX, RDX, 1,3,5-trinitrobenzene, 1,3-dinitrobeneze, tetryl, 2,4,6-TNT, 4-amino 2,6-DNT, 2-amino 4,6-dinitrotoluene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, nitrobenzene, 2-nitrololuene, 3-nitrotoluene, 4-nitrotoluene, nitroglycerine and PETN.

The sample size was, however, small in this survey and more definitive conclusions regarding the extent of contamination will have to await a more exhaustive survey.

# 6. Sediment quality in Dowd Morass

## Carbon, nitrogen and phosphorus contents

Sediments in Dowd Morass have about 10-15% w/w carbon and 0.7-1.2% w/w nitrogen (Table 6.1). Phosphorus concentrations are also high, typically over 0.5 mg g $DW^{-1}$ (= 0.05% w/w).

| Wetland area | Nutrient content (mg g $DW^{-1}$) | | | C:N:P ratio (by mass) |
|---|---|---|---|---|
| | Carbon | Nitrogen | Phosphorus | |
| A | 128 | 7.0 | 0.20 | 640:35:1 |
| B | 151 | 6.9 | 0.87 | 173:8:1 |
| C | 94 | 7.0 | 0.58 | 162:12:1 |
| D | 153 | 12.3 | 0.61 | 250:20:1 |

Table 6.1: Mean carbon, nitrogen and phosphorus content of sediments in four areas at Dowd Morass.

The N:P ratio in Dowd Morass sediments ranged from about 8:1 to 35:1 (by mass). The high N:P ratio in sediments of Area A would suggest that, if nutrients were regenerated in proportion to their abundance in the sediments, plants may well be limited by the low availability of phosphorus. In other words, there is abundant nitrogen relative to phosphorus in the sediments.

Conversely, vascular plants in Area B may be N-limited because of the low N:P ratio of 8:1. It is possible, of course, that nutrients did not limit the growth of aquatic plants: the episodic very high turbidities shown in Table 5.1 suggest that light limitation may be an important factor for submerged aquatic plants in the morass.

| Sediment variable | Depth (cm) | Wetland area | Date | | | |
|---|---|---|---|---|---|---|
| | | | 2003 | 2004 | 2005 | 2006 |
| Soil moisture (mL g $DW^{-1}$) | 0-10 | B | 2.3 + 0.2 | 2.5 + 0.1 | 2.4 + 0.2 | 3.6 + 1.0 |
| | | D | 2.2 + 0.5 | 2.1 + 0.1 | 3.0 + 0.3 | 2.2 + 0.4 |
| | | Shoreline | 2.5 | 2.2 + 0.1 | 2.4 + 0.5 | 2.6 |
| | 10-20 | B | 2.1 + 0.1 | 2.2 + 0.1 | 2.1 + 0.1 | 2.2 + 0.1 |
| | | D | 2.2 + 0.2 | 2.1 + 0.1 | 2.1 + 0.1 | 2.2 + 0.1 |
| | | Shoreline | 2.2 | 2.0 + 0.1 | 2.0 + 0.2 | 2.3 |
| Soil EC (mS $cm^{-1}$) | 0-10 | B | 3.8 + 0.4 | 6.6 + 1.2 | 12.4 + 0.8 | 11.1 + 2.1 |
| | | D | 3.6 + 0.9 | 6.2 + 0.5 | 13.2 + 1.4 | 13.4 + 2.5 |
| | | Shoreline | 4.2 | 5.7 + 0.5 | 10.2 + 2.0 | 9.8 |
| | 10-20 | B | 3.0 + 0.3 | 5.9 + 0.5 | 7.5 + 0.7 | 8.6 + 1.5 |
| | | D | 3.8 + 0.6 | 8.4 + 1.0 | 9.7 + 1.0 | 12.6 + 0.7 |
| | | Shoreline | 2.9 | 5.1 + 0.6 | 6.3 + 0.5 | 9.6 |
| *In situ* soil salinity (mS $cm^{-1}$)* | 0-10 | B | 8.2 + 0.7 | 13.1 + 0.9 | 24.2 + 2.1 | 17.1 + 3.6 |
| | | D | 8.3 + 1.1 | 16.7 + 1.6 | 22.2 + 1.0 | 30.8 + 1.7 |
| | | Shoreline | 8.3 | 13.0 + 1.1 | 21.4 + 0.8 | 18.9 |
| | 10-20 | B | 7.1 + 0.6 | 12.4 + 0.9 | 17.1 + 1.4 | 19.7 + 2.5 |
| | | D | 8.3 + 0.8 | 20.6 + 1.7 | 23.3 + 1.7 | 29.0 + 1.6 |
| | | Shoreline | 6.5 | 12.6 + 1.2 | 15.4 + 0.6 | 20.7 |

* seawater = ~ 50 mS $cm^{-1}$

Table 6.2: Soil moisture, electrical conductivity and *in situ* soil salinity for sediments in three areas of Dowd Morass from 2003 to 2006. Means ± standard errors are shown, n=5.

## Soil salinity

Sediments in Dowd Morass are often extremely salty. Table 6.2 shows the soil moisture, soil electrical conductivity and *in situ* soil salinity for sediments in Areas B and D, as well as along the shoreline of the wetland, from 2003 to 2006. By way of comparison, seawater has an electrical conductivity of about 50 mS $cm^{-1}$; thus the value 30.8 + 1.7 mS $cm^{-1}$ recorded for Area D in 2006 represents an *in situ* soil salinity of well over one-half seawater.

## Soil pH and the presence of acid-sulfate soils

Acid-sulfate soils are soils that produce sulfuric acid ($H_2SO_4$) when exposed to the air. In Australia, potential and/or actual acid sulfate soils are found along almost the entire coastline with the main exception being the steep limestone cliffs of the Great Australian Bight. Acid-sulfate soils are especially common along the eastern seaboard and there are many examples where their disturbance has created severe environmental problems: Trinity Bay East near Cairns (Qld) and Tuckean Swamp near Ballina (NSW) are the most well-known examples.

The key component of acid-sulfate soils is pyrite ($FeS_2$), a highly insoluble crystalline form of iron sulfide produced (usually within the past 10,000 years) by the reaction of ferrous sulfide (FeS) with sulfur. In coastal areas the ferrous sulfide has been produced in earlier brackish-water swamps, such as mangroves, paperbark swamps and saltmarshes, by sulfate-reducing bacteria oxidising the abundant organic material produced in these highly productive environments.

The overall reaction by which sulphuric acid is produced in acid-sulfate soils is as follows:

$$2\ FeS_2 + 7.5\ O_2 + 7\ H_20 \longrightarrow 2\ Fe(OH)_3 + 4\ H_2SO_4$$

The sulfuric acid produced when acid-sulfate soils are activated moves through the soil, stripping iron, aluminium and manganese, as well as dissolving, in the worst cases, heavy metals such as cadmium. This noxious mixture makes the soil highly toxic and, combined with the very low pH (< 3), renders the growth of most plants impossible[15]. An exception is sugar cane, which can withstand the low soil pH and high aluminium concentrations. This tolerance accounts for the siting of sugar-cane fields along the Australian east coast, where other crops perish and even native vegetation is killed by the acidic conditions and high aluminium concentrations.

Sufficient sulfuric acid can be produced from acid-sulfate soils that it seeps into adjacent waterways, resulting in drastic reductions in pH, massive fish kills and the death of estuarine invertebrates, including economically important species such as shellfish. Fish kills linked to the disturbance of acid-sulfate soils have been reported frequently for large estuarine rivers in northern NSW (e.g., Clarence River). Acid-sulfate soils generally do not present a serious management problem as long as they are kept waterlogged. They become problematic when wetlands are drained, for example when drains are dug through wetlands and other coastal areas, causing the watertable to drop rapidly and surface soils to dry out and oxidise. Large spoil heaps, raised along the edges of the drains, also can produce acid for many years after the drain has been excavated.

The release of sulfuric acid from these spoil dumps typically occurs after drought-breaking rains, which raises the watertable back to its original (pre-drought or pre-drainage) level and washes the acid and dissolved metals out of the surface layers of the soil. In many cases, reverting to the earlier hydrological regime is not sufficient to cure the problem, as large volumes of acid often remain in the soil and there may have been irreversible changes to the soil structure due to drying, acidification and oxidation.

If potential or actual acid-sulfate soils are present, it may be unacceptable to instigate a strong wetting and drying cycle in a hydrologically-altered wetland because of the risk of severe damage to downstream estuarine ecosystems should the wetland drain even partially and the sediments start to oxidise. Johnston et al. (2003)[3], for example, reported that some extensive fish kills in the Clarence River estuary of northern NSW were caused by an oxygen-depletion event which was, in turn, caused by anoxic and iron-rich surface waters draining from two acid-sulfate soil backswamps.

Re-establishing more natural wetting and drying regimes is planned for a number of wetlands in the Gippsland Lakes, especially those in the Lake Wellington wetlands complex (e.g., Dowd Morass, The Heart Morass). The existence of actual or potential acid-sulfate soils in these areas may present the single most important factor limiting the degree to which these wetlands can be episodically dried out and reflooded. Revegetation attempts are also likely to be compromised by the presence of acid-sulfate soils. It is possible also that acid release, perhaps combined with acute oxygen depletion, could account for some of the fish kills experienced in the Gippsland Lakes (John Ginivan, DSE, *pers. comm.*). Finally, the presence of acid-sulfate soils has major ramifications for coastal development and infrastructure; sulphuric acid is no friend of concrete, steel reinforcing or road materials.

Because of the risk posed by the uncovering of actual acid-sulfate soils or the activation of potential acid-sulfate soils in the Morass, we undertook a series of investigations to determine the likely acid-producing effects of water-level drawdown. The response to these findings was that we took a very cautious approach to drying parts of the wetland and monitored water quality (especially pH) regularly both in the areas of drying wetland and in control areas that were kept fully inundated. As it turned out, unexpected vandalism and unkind weather compromised the water-level drawdown, but this had the benefit that the risk of activating acid-sulfate soils was not a major issue. Nevertheless, these investigations did show that actual and potential acid-sulfate soils occur in the Lake Wellington wetlands. The evidence pointing to this conclusion is summarised in the following text, where each of the five investigations is outlined briefly.

The first approach was a review of prior studies. Some areas of the western end of Dowd Morass, along the pipeline easement, were tested for acid-sulfate soils as part of the assessment for the Eastern Gas Pipeline. Although acid-sulfate soils were not detected in Dowd Morass, potential acid-sulfate soils were detected in other Lake Wellington wetlands[14].

Second, we examined existing water-quality data for the tell-tale sign of very low pH in the water column of Dowd Morass. The 2001 report by Sinclair Knight Merz[14] contained a full analysis of water-quality monitoring data for Dowd Morass from 1991 to 2001. This report showed that the pH of the water column could drop as low as 2.8 in some cases; the cause was tentatively attributed to the presence of acid-sulfate soils (see also Table 5.1).

Third, we took 116 samples of surface sediments from across all areas of Dowd

Morass in mid 2003 and dried them to see whether they would release sulphuric acid when exposed to the air. The dried sediments were then mixed with water (10 g dry sediment to 50 mL distilled water) and shaken for 2 hours. The pH of the supernatant was measured as acid-sulfate soils would generate a low pH supernatant as the iron sulfides were oxidised upon exposure to air. The mean pH of the supernatant water was 5.05, with maxima and minima of 5.58 and 3.69, respectively. These data suggest that there is some prospect for acid conditions to be created in the wetland should sediments be dried fully, with the potential for the pH of the overlaying water to drop to below 4 pH units.

Fourth, we collected 12 samples from all areas of the wetland in December 2003 and analysed them for Titratable Peroxide Activity (TPA), an analytical approach often used to indicate the presence of potential acid-sulfate soils. The method involves the use of 30% hydrogen peroxide to oxidise sulfides, usually pyrite, and produce sulfuric acid, as shown below:

$$FeS_2 + 7.5\ H_2O_2 \longrightarrow Fe(OH)_3 + 4H_2O + 2SO_4^{2-} + 4H^+$$

The TPA results are shown in Table 6.3. Since TPA values of > 50-100 mol $H^+$ per tonne of sediment may start to create acidity problems upon sediment oxidation, it would seem that there are sites in Dowd Morass that do contain potential acid-sulfate soils. However, the oxidation with peroxide can cause false positive results, suggesting that the data shown in Table 2 are a "worst case" scenario. TPA values of < 20-50 mol $H^+$ per tonne of sediment would not present an acid-sulfate soil problem. Even so, the single high value of nearly 200 mol $H^+$ per tonne of sediment indicates that large amounts of acid could be produced by certain sediments from the Morass.

Finally, four samples from contrasting areas of the wetland in 2006 were subjected to a full sulfidic analysis[16].

The location of these sites is shown in Figure 6.1. Sediment cores were taken to a depth of nearly 3 m with a dedicated drilling rig and sediment samples analysed at Southern Cross University, Lismore (NSW).

Site 1 was abandoned after drilling showed the presence of over-burden.

Site 2 was shown to have potential acid-sulfate soils present. Moreover, the absence of visible shell fragments suggested that the soils here had little or no self-neutralising capacity. Laboratory analysis confirmed the presence of potential acid-sulfate soils from 20 cm to 125 cm depth, and the likelihood of actual acid-sulphate soils in the surface sediments. Soils at this site contained more reduced inorganic sulphur than the action criterion established for acid-sulfate soils in NSW (0.1 g S per 100 g of soil). The pH of the soil was as low as 1.9 in this site. There was little clear indication of actual or potential acid-sulphate soils in surface sediments at Site 3. However, deeper soils (> 90 cm) may have potential acid-sulfate soils present. Similarly, there was good evidence for the presence of potential acid-sulfate soils in the deeper horizons (200-320 cm) at Site 4.

The conclusion we reach from these five sets of investigations is that potential and actual acid-sulfate soils are present in the Lake Wellington wetlands and probably also in wetlands and other coastal areas across the entire Gippsland Lakes region. In recognition of the likelihood of acid-sulfate soils being distributed widely around the Gippsland Lakes area and having the potential for major environmental impacts, Dowd Morass has been proposed as a routine monitoring site as part of the CSIRO's national acid-sulfate soils monitoring framework.

| Wetland area | GPS co-ordinates* | TPA (mol $H^+$ tonne sediment$^{-1}$) |
|---|---|---|
| A1 | 515684 / 5777786 | 195 |
| A3 | 515254 / 5777448 | 73 |
| A5 | 515822 / 5777514 | 25 |
| B2 | 515408 / 5776653 | 55 |
| B3 | 515363 / 5776889 | 53 |
| B5 | 515533 / 5776796 | 67 |
| C1 | 516067 / 5777645 | 22 |
| C2 | 516262 / 5777905 | 21 |
| C4 | 516713 / 5778441 | 16 |
| D2 | 516610 / 5777309 | 29 |
| D3 | 516391 / 5777334 | 31 |
| D5 | 516122 / 5776983 | 26 |

Table 6.3: Titratable peroxide activity (TPA) results for 12 sediment samples from Dowd Morass.

* WGS84 datum.

## Heavy metals

We undertook a limited range of analyses for heavy metals in the sediments of Dowd Morass in late 2004 (Table 6.4). This very limited sampling (n = 1-3) suggests that sediments in that part of Dowd Morass where our experiments were done were not heavily contaminated with heavy metals.

Only nickel concentrations exceeded the ISQC-Low trigger values proposed in the most recent ANZECC guidelines[17]. Moreover the guidelines suggest that trigger values should be relaxed when sediment organic carbon content was markedly higher than 1%: as the wetland sediments had 10-15% w/w carbon contents even the values for nickel are not likely to be problematic.

Because there have been reports of mercury contamination in the Gippsland Lakes[18], we examined in more detail the concentrations of mercury in Dowd Morass sediments. We took 17 sediment samples from across the wetland in mid 2006. The mean mercury concentration was 0.25 mg kg $DW^{-1}$, with a range from < 0.05 to 2.1 mg kg $DW^{-1}$.

| Heavy metal | Concentration in sediments (mg kg $DW^{-1}$) | | Relevant ANZECC trigger value[17] |
|---|---|---|---|
| | Area B | Area D | |
| Cadmium | < 0.2 | < 0.2 | 1.5 |
| Zinc | 44 | 50 | 200 |
| Copper | 16 | 21 | 65 |
| Lead | 30 | 39 | 50 |
| Chromium | 34 | 48 | 80 |
| Barium | 320 | 610 | none |
| Nickel | 28 | 34 | 21 |
| Antimony | < 1 | < 1 | 2 |
| Arsenic | 10 | 16 | 20 |
| Boron | 75 | 150 | none |
| Mercury | < 0.1 | < 0.1 | 0.15 |
| Selenium | 2 | < 1 | none |

Table 6.4: Concentrations of heavy metals in two areas of Dowd Morass. Samples were taken in late 2004.

The most contaminated sample came from sediments in Area A. Seven of the 17 samples had a mercury concentration below the limit of detection (0.05 mg kg $DW^{-1}$). These data would suggest very slight or patchy contamination of the wetland's sediments with mercury, possibly as a consequence of historical gold-mining practices in the catchment or from agricultural land uses.

We stress that more intensive sampling for heavy metals is needed to confirm these preliminary conclusions.


Figure 6.1: Location of the four sites used for a complete sulfidic analysis of Dowd Morass sediments[16].

# 7. The impact of historic water regime on vegetation condition

Figure 7.1: Part of the field-work team at Dowd Morass, about to embark on a day's data collection in winter 2006.

## Importance of water regime for species diversity and vegetation structure

Wetland managers typically have two goals for managing water regimes in wetlands. The first is to promote a response in a particular wetland species (such as a fish, bird or plant, often a threatened species or one of high economic or social value) or ecological service (such as nutrient interception). The second goal for managing water regimes is to maximize the overall condition of the wetland. Sometimes this is referred to as wetland 'health'. Although wetland managers often have the information required to achieve the first goal, often there is insufficient good-quality information to achieve the second. This component of the R&D project set about obtaining rigorous, detailed and quantitative information on the condition of vegetation at Dowd Morass, with a particular emphasis on the role played by water regime in controlling wetland 'health'.

In April 2003 we started to assess the species diversity and vegetation structure at Dowd Morass and the regeneration and health of the dominant Swamp Paperbark vegetation in relation to water regime (Figure 7.1). We used 45 randomly-placed permanent (50-metre long) transects located in Area B (20 transects), Area D (20 transects) and along the shoreline (5 transects). These areas were chosen because they would be the focus of later attempts at manipulating water levels in the wetland, as described in Section 11 of this Handbook. At each transect, we measured the condition of the overstorey and understorey, species diversity, health and regeneration of the Swamp Paperbark. We also recorded the depth of the water every 1 metre along the transects and used the dataloggers positioned in Areas A and D to calculate the approximate water regime that each transect would have experienced.

It is difficult to objectively describe water regimes in wetlands, so the approach we adopted deserves a brief description. The method was based on that developed by Brownlow *et al.* (1994)[19] for wetlands in South Australia. Water depth in metres was recorded at 1 m intervals along the 45 transects while the dataloggers in Areas A and D recorded water level and electrical conductivity hourly. In order to characterise water regime (change in water depth over time) for each transect, we established a relationship between four transects in each of two contiguous sections of the wetland and the datalogger in each respective section. Water depth at the zero point of each of eight transects was recorded within one hour of recording the water level (m AHD) at permanent dataloggers in respective areas of the wetland. We assumed that water level changed uniformly over time within any one contiguous area of the wetland; this assumption was tested and found to be valid. Once we had established the relative difference between permanent dataloggers and representative transects in each section, we could extapolate water regime for all transects based on hourly changes in water level recorded at the datalogger in the respective sections of wetland. Thus we calculated the mean depth of water at each transect point for each day over a one year period (18 June 2003 to 14 June 2004).

Although the water regime may have differed across years, we assumed that water regimes would have changed in close relationship to one another. The method also presumes that the topography of the wetland has not changed over time; this is probably a valid assumption for the short period (2003-2006) of our vegetation analysis. The transect point water depth measurements were pooled at the transect level, compiled into a series of 5-cm depth classes ranging from 0 (always dry) to 110 cm (deeply flooded). The percentage of time that points along the transect spent in each depth class was calculated as the frequency that one or more points lay within these depth classes over a one year period. Classification of water regime transect data was undertaken using the PATN statistical package using the Manhattan Metric. Agglomerative, heirarchical classifications of the historical water regime for each transect were produced using the Unweighted Pair Group Method of Averaging. Water regimes for transects were averaged within a classification group to get the average water regime for that group.

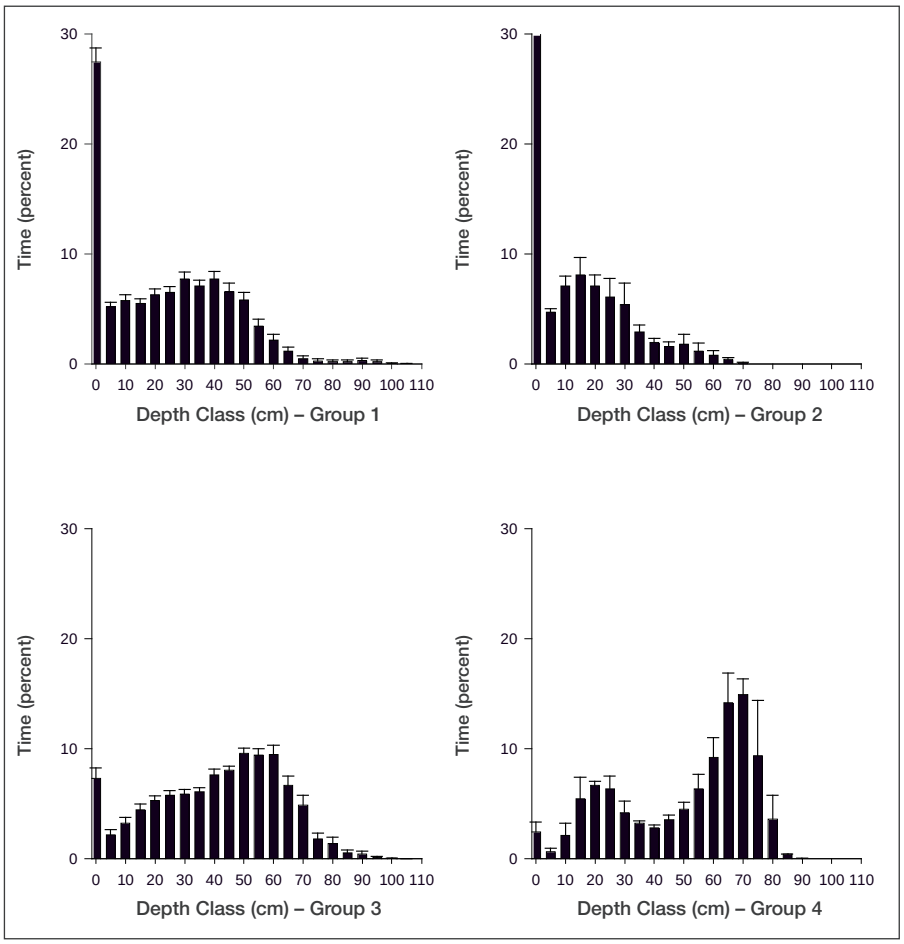
We recorded 47 plant species in the understorey of the Swamp Scrub community (Table 7.1). *Melaleuca ericifolia* was the most common species in both the overstorey and the understorey in this community (hence its name), followed by Common Reed *(Phragmites australis)*. Most of the species we recorded were herbs (25 species), followed by grasses (7 species) and rushes and sedges (5 species). Only one submerged plant species, Eelgrass or *Vallisneria americana,* was present at the time of recording. Most plant species were native (84%), indicating there had been little invasion of the wetland by exotic weeds.

Species diversity and vegetation structure differed between Area B, Area D and the Shoreline. The cover of the Swamp Paperbark was highest in the understorey of Shoreline transects (41% cover) and lowest in Area B (11%). More plant species were found in Area D (36 species) than Area B (30 species) or the Shoreline (19 species). Although Area D had more species than the other two zones of the wetland, the percentage cover of plants was higher in Shoreline sites than in Areas D and B.

| Life form | Species | Water regime 1 | Water regime 2 | Water regime 3 | Water regime 4 |
|---|---|---|---|---|---|
| Woody trees | *Melaleuca ericifolia* | 23.4 ± 4.7 | 29.8 ± 5.5 | 12.5 ± 1.9 | 15.0 ± 10.8 |
| Reeds | *Typha latifolia* | 0.4 ± 0.4 | 1.3 ± 1.3 | 1.1 ± 0.9 | 0 |
| | *Phragmites australis* | 12.2 ± 3.1 | 11.8 ± 10.2 | 5.2 ± 3.8 | 6.0 ± 0.7 |
| Rushes and sedges | *Carex sp.* | 1.6 ± 0.8 | 2.5 ± 1.9 | 0.7 ± 0.4 | 0 |
| | *Juncus pallidus* | 0 | 0 | 0.1 ± 0.1 | 0 |
| | *Cyperus lucidus* | 0 | 0 | 0.1 ± 0.1 | 0 |
| | *Baumea rubiginosa* | 1.1 ± 0.9 | 0 | 0 | 0 |
| | *Isolepis marginata** | 2.7 ± 2.6 | 2.3 ± 2.3 | 0 | 0 |
| Grasses | *Lachnagrostis filiformis* | 0.2 ± 0.2 | 0.8 ± 0.8 | 0.4 ± 0.4 | 0 |
| | *Paspalum distichum* | 0.6 ± 0.5 | 0.8 ± 0.5 | 0 | 0 |
| | *Poa labillardierei* | 0.4 ± 0.2 | 0.5 ± 0.5 | 0.1 ± 0.1 | 0 |
| | *Poa tevere* | 0.1 ± 0.1 | 0 | 0 | 0 |
| | *Hemarthria uncinata* | 0 | 0 | 0.1 ± 0.1 | 0 |
| | *Glyceria sp.* | 0.2 ± 0.2 | 0 | 0 | 0 |
| | *Grass sp. 1* | 0 | 7.5 ± 7.2 | 0 | 0 |
| Climbers | *Calystegia sp.* | 1.9 ± 0.7 | 3.8 ± 1.4 | 1.2 ± 1.2 | 0 |
| Herbs | *Triglochin procerum* | 2.3 ± 1.7 | 0.5 ± 0.5 | 0.1 ± 0.1 | 0 |
| | *Alisma plantago-aquatica* | 0 | 0 | 0.1 ± 0.1 | 0 |
| | *Alternanthera denticulata* | 1.2 ± 0.5 | 6.8 ± 5.8 | 1.1 ± 0.3 | 0 |
| | *Apium prostratum* | 0.8 ± 0.4 | 2.5 ± 1.2 | 0 | 0 |
| | *Aster subulatus** | 0.3 ± 0.1 | 1.0 ± 0.7 | 0.7 ± 0.3 | 0 |
| | *Atriplex prostrata** | 1.9 ± 0.9 | 1.8 ± 1.0 | 18.0 ± 2.5 | 0 |
| | *Bidens sp.* (?pilosa)* | 0.2 ± 0.1 | 3.0 ± 1.8 | 0.1 ± 0.1 | 0 |
| | *Chenopodium glaucum* | 5.3 ± 2.1 | 1.5 ± 0.9 | 2.4 ± 0.8 | 0 |
| | *Cotula coronopifolia* | 0.3 ± 0.2 | 1.8 ± 0.9 | 0.1 ± 0.1 | 0 |
| | *Hydrocotyle verticillata* | 0.7 ± 0.3 | 3.5 ± 1.7 | 0 | 0 |
| | *Lobelia alata* | 0.8 ± 0.6 | 1.8 ± 1.8 | 0 | 0 |
| | *Lycopus australis* | 0.6 ± 0.3 | 3.0 ± 1.7 | 0.3 ± 0.3 | 0 |
| | *Mimulus repens* | 0.2 ± 0.2 | 0 | 0 | 0 |
| | *Persicaria decipiens* | 0.5 ± 0.3 | 4.8 ± 2.9 | 0 | 0 |
| | *Ranunculus scleratus** | 0.1 ± 0.1 | 0.3 ± 0.3 | 0 | 0 |
| | *Ranunculus inundatus* | 0.6 ± 0.6 | 0 | 0 | 0 |
| | *Rorripa palustris** | 0.1 ± 0.1 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| **Herbs** *continued* | *Rumex sp.* | 0.1 ± 0.1 | 0 | 0.1 ± 0.1 | 0 |
| | *Samolus repens* | 0.1 ± 0.1 | 0.3 ± 0.3 | 0 | 0 |
| | *Senecio biserrata* | 0.4 ± 0.2 | 0.3 ± 0.3 | 0.2 ± 0.1 | 0 |
| | *Solanum nigrum* | 0.3 ± 0.2 | 0 | 0.1 ± 0.1 | 0 |
| | *Trifolium sp.* | 0 | 0.5 ± 0.5 | 0 | 0 |
| | *Urtica incisa* | 0.3 ± 0.1 | 1.0 ± 1.0 | 0.3 ± 0.1 | 0 |
| | *Berula erecta** | 0 | 0.3 ± 0.3 | 0 | 0 |
| | *Lilaeopsis sp.* | 0.1 ± 0.1 | 0 | 0 | 0 |
| **Floating or semi-aquatic** | *Azolla filiculoides* | 0.1 ± 0.1 | 5.0 ± 2.9 | 0 | 0 |
| | *Crassula helmsii* | 0.1 ± 0.1 | 1.3 ± 1.3 | 0 | 0 |
| | *Lemna disperma* | 0 | 4.5 ± 2.1 | 3.6 ± 2.1 | 0 |
| | *Wolffia sp.* | 0.2 ± 0.2 | 1.0 ± 1.0 | 0 | 0 |
| Submerged | *Vallisneria americana* | 5.9 ± 2.2 | 7.8 ± 5.1 | 2.5 ± 1.8 | 34.0 ± 8.0 |
| | *Algae* | 2.4 ± 1.3 | 0.5 ± 0.5 | 0.1 ± 0.1 | 0 |
| | *Total number of species* | 39 | 35 | 26 | 3 |

Table 7.1: List of species and their average percent cover ± standard error for each of four distinct water regimes along transects at Dowd Morass in 2003. An * indicates an introduced species.




We wanted to understand whether the differences in plant communities we observed across the various areas in the wetland could be attributed to systematic variations in water regime. Using the process described earlier, we identified four distinct water regimes that characterized these 45 transects (Figure 7.2).

These water regimes differ from each other mostly in the average depth of water and the amount of time when various sites were dry. To a considerable degree these different water regimes are characteristic of Areas B, D and the Shoreline region.

Transects that experienced Water Regimes 1 and 2 were predominantly located in Area D and along the Shoreline. These transects have raised areas that are exposed above the water for long periods of time and the water is almost always less than 30 cm deep.

In contrast, Water Regime 3 is characteristic of Area B: these transects

Figure 7.2: Four water regimes derived from the water-depth data of 45 transects at Dowd Morass. These diagrams represent the percentage of time that one or more points along a transect lie within a water depth class over a one year period, averaged across transects for each water regime.

are located in deep water and one or more points along each transect are covered with water 90% of the time. Water Regime 4 was experienced by only four transects located in Area D that spanned across an artificial channel.

Our analyses demonstrated that the most important variable that drives species composition along transects in the various regions of Dowd Morass is the water regime. Transects with Water Regimes 1 and 2 had a higher percentage cover of Swamp Paperbark and Common Reed than did transects with Water Regimes 3 and 4 (Table 7.1). Water regimes also corresponded well with species diversity of transects. Transects with Water Regimes 1 and 2 had, on average, more plant species (16 and 8 species per transect, respectively) than transects with Water Regimes 3 and 4 (5 and 3 species, respectively.

Transects with Water Regimes 1 and 2 had higher overstorey cover and understorey cover than transects in areas with Water Regimes 3 and 4 (Figures 7.3 and 7.4).

The high understorey cover of Water Regime 4 was related to the presence of Common Reed in the understorey. Water regime also affected strongly the number of seedlings of the Swamp Paperbark in the understorey. The shallow transects associated with Water Regime 2 had, on average, more *Melaleuca ericifolia* seedlings than transects that had experienced the other three water regimes. Shallow flooding (<30 cm deep on average), fluctuating water levels and the presence of sites above the water line allows species with different hydrological requirements to coexist in Dowd Morass (Figure 7.3). Maintaining such a water regime at Dowd Morass will promote maximum species richness and the overall health of the wetland vegetation. In deeply flooded areas, structures such as mounds and hummocks, which maintain topographic heterogeneity, provide the elevated areas on which plants with different water-regime requirements can establish.

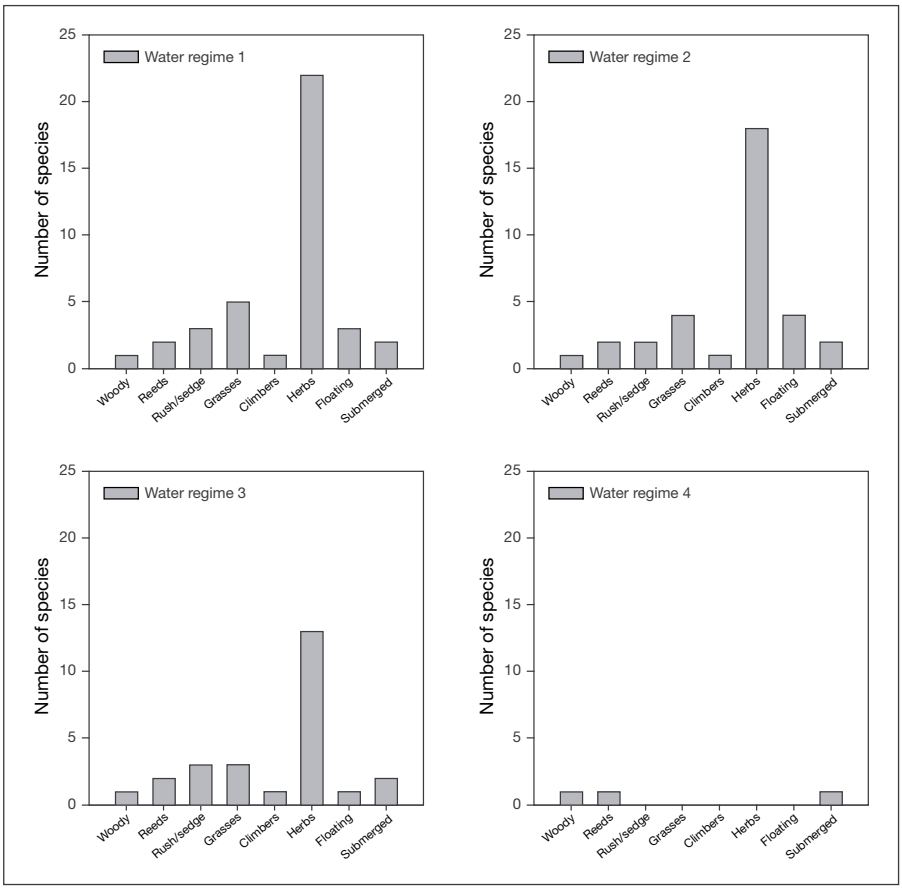



Figure 7.3: The number of species showing different growth forms under the four different water regimes in Dowd Morass. Water Regimes 1 and 2 contained representatives of all growth form classes, but with an emphasis on herbaceous taxa. Water Regimes 3 had fewer species but was still dominated by herbs, and transects experiencing Water Regime 4 did not have any species that required periods of drawdown to survive.

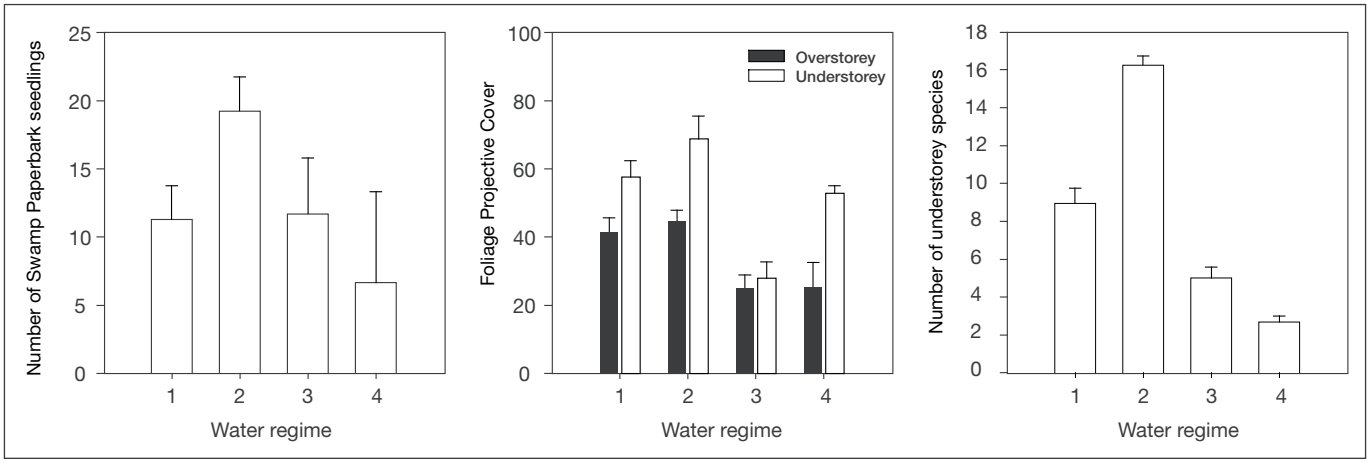



Figure 7.4: Key indicators of vegetation condition in relation to water regime. (a) Number of Swamp Paperbark seedlings; (b) Percentage foliage projective cover in the overstorey and understorey; and (c) Number of understory species in each of the four different water regimes in Dowd Morass.

# 8. Historical changes over the past 40 years

## Uncertainty regarding long-term vegetation changes in Dowd Morass

Earlier sections of this Handbook have shown how the water regime in Dowd Morass has been altered markedly from that which would have existed in pre-European times. In this aspect Dowd Morass differs little from many wetlands across the globe; the water regime of wetlands has been altered drastically throughout the world and these changes have been shown to have profound effects on the structure and floristics of plant communities. Increased water levels associated with flooding are often detrimental to wetland plants because they affect the germination and establishment of seedlings, as well as facilitating the death (by drowning) of adult plants.

There is some anecdotal and historical evidence that Swamp Paperbarks in the Gippsland Lakes has preferentially invaded areas that were occupied by the Common Reed in an 'encroachment succession' pathway. This process would have been facilitated by both changes to water regimes and the on-going salinisation of the Gippsland Lakes and the wetlands associated with Lake Wellington. There is, however, considerable uncertainty amongst natural-resource managers and the wider Gippsland community regarding the relative vitality of Swamp Paperbark and Common Reed in wetlands that fringe the Gippsland Lakes.

Wetland managers have anecdotally reported increased death of adult Swamp Paperbark and an absence of regeneration in Area B, the water bird rookery. Long-term declines in the distribution or condition of Swamp Paperbark is of great concern to regional natural-resource managers because it provides critical breeding habitat for JAMBA- and CAMBA-listed birds, including large colonies of colonially breeding Australian Ibis *(Threskiornis molucca)* that provide a basis of the Gippsland Lakes listing on the Ramsar Convention. Many users of the wetland, including those who have hunted in the morass for many decades, believe that shoreline areas of Dowd Morass near the La Trobe River have been recently invaded by extensive beds of Common Reed. Thus there exists considerable confusion as to what vegetational changes have taken place in the wetland over the past 30 years as a result of flooding.

The aim of the component of the R&D project reported in this section of the Handbook was to objectively describe the long-term changes that have occurred in the vegetation of Dowd Morass over the past four decades. We used historical aerial photography to assess the change in the cover of the dominant vegetation communities over time.

### Analysis of historical aerial photographs

We obtained aerial photographs from the Land Information Centre, Laverton, Victoria for the years 1964, 1973, 1982, 1991, and from Parks Victoria for 2003. Two sets of photographs (1964, 1973) were taken before the water regime was modified in 1975, and three sets (1982, 1991, 2003) were taken subsequently. These photographs were captured using black and white, colour and colour infrared film, at scales ranging from 1:6,000 to 1:20,000. Although earlier sets of aerial photographs were available for the 1940s and 1950s, the poorer quality of lenses and films and strong water-borne reflection in photographs taken prior to 1964 made them unsuitable for digitisation and accurate vegetation mapping.

Photographs were scanned as A3 images at a resolution of 600 dpi and each image was rectified using the Leica Photogrammetry Suite component of Erdas Imagine™ version 8.7 software. An unsupervised classification (Isodata algorithm, Erdas Imagine™) was used to separate each photo mosaic into land-cover classes. Eight groups most effectively separated the land-cover classes in the unsupervised classification. A supervised classification was not performed because of water–borne reflectance within and between photographs. Manual recoding of classified images resulted in four final land-cover classes: 'Swamp Paperbark', 'Common Reed', 'Open water' and 'Other'. These correspond to the plant communities identified at Dowd Morass, but the 'Open Water' category included all detectable surface water regardless of whether plants were present, and the 'Other' land cover class included the Forest Red Gum community, grasslands, herbfields and bare sediment.

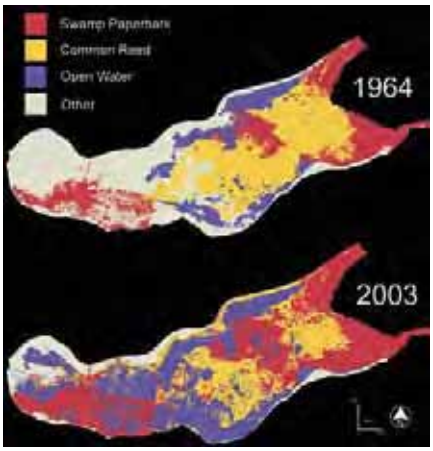



Figure 8.1: Distribution of various plant communities in Dowd Morass in 1964 and 2003. Red = Swamp Paperbark; Yellow = Common Reed; White = Other plant communities; and Blue = Open water.

To quantify the percentage error associated with the classification of land-cover classes, we placed 20 quadrats (0.5 ha) randomly on each image mosaic for each land-cover class. Land-cover classes within each of these quadrats were digitised by hand, and the cover of each land-cover class was compared to the cover of the land-cover classes from the Erdas Imagine™ unsupervised classification in the same quadrats.

The accuracy of the draft 2003 digital vegetation map was extensively ground truthed before producing the final digital vegetation maps. The cover in hectares of each land-cover class for each year was obtained from the corrected mosaics using Erdas Imagine™ Raster Attributes. Figure 8.1 shows the vegetation distributions for 1964, and similar maps were prepared for all subsequent years for which we had aerial photographs.

## What vegetation changes have taken place over the past four decades?

In contrast to our predictions, near-permanent flooding of Dowd Morass did not result in the widespread death of mature Swamp Paperbark plants nor did it inhibit regeneration. Indeed, Swamp Paperbark increased its cover by 73% since 1964 (Figure 8.2).

Swamp Paperbark did, however, demonstrate a variable pattern of response to flooding across the wetland (Figure 8.3).

In the most deeply flooded regions, the response of Swamp Paperbark was characterised by an initial increase in cover followed by a long period of stasis. In the most recent images, there is some evidence of vegetation collapse in the south-west (rockery area) of the Morass with gaps appearing in the canopy. In other regions of Dowd Morass, particularly those where Common Reed was present, Swamp Paperbark demonstrated a steady increase in cover over the entire period.

In contrast to this expansion of Swamp Paperbark, the area of Common Reed declined from 485 ha to 346 ha, representing a ~ 30% loss (Figure 8.2). Common Reed in these lost areas were replaced primarily with *M. ericifolia*. The overall consequence of the two sets of changes was a shift in dominance from Common Reed communities to Swamp Scrub, despite near-permanent flooding.

The spread of Swamp Paperbark into the wetland over the past four decades, in spite of a nominally unfavourable water regime, was probably a result of the availability of elevated areas in reed communities, which facilitated the survival of adult Swamp Paperbarks and allowed sexual recruitment even under near-permanent flooding.

On-ground observations made by wetland managers and community members suggested that areas of Common Reed were increasing and that Swamp Paperbark was declining. Our analysis using historical aerial photographs supports these observations in the areas of the Morass in which they were made.

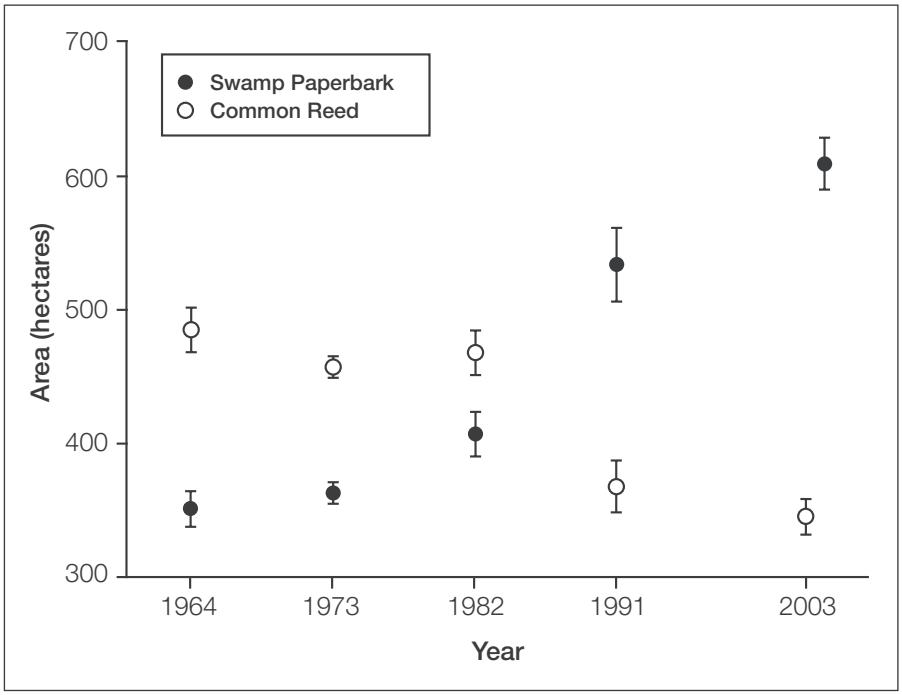



Figure 8.2: Changes in total area of Swamp Paperbark and Common Reed at Dowd Morass between 1964 and 2003.

However, the anecdotal observations do not reflect the overall pattern of change in plant communities across the entire wetland, which show clearly that Swamp Scrub has increased and the Common Reed community has declined over the 39-year period. Permanent flooding may have considerably altered the understorey vegetation in the morass, but this was not detected using historical aerial photography. We conclude that for large wetlands, particularly where areas are difficult of access, the analysis of historical aerial photographs is a useful tool for removing the spatial and temporal biases inherent in on-ground observations.

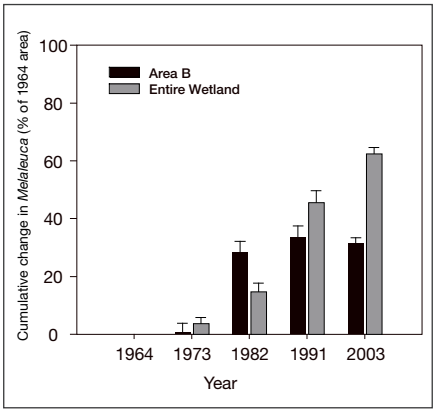



Figure 8.3: Cumulative change in cover of Swamp Paperbarks in Area B (the ibis rookery) and across the entire area of Dowd Morass.

# 9. The importance of clonality for wetland plants

## Sexual versus asexual reproduction in wetland plants

A broad dichotomy exists among vascular plants in that they may reproduce sexually or asexually. Many studies of wetland vegetation have stressed the role of seed banks in the recovery of the plant community, especially after draw-down events. The underlying theme of much of this work seems to be that the production of seeds, and their subsequent dispersal, is the critical factor in explaining the distribution and regeneration capacity of different wetland plant species, particularly in response to disturbance.

Although there is no doubting the importance of this research effort, the paradox is that wetlands are almost always dominated by plants that have a clonal growth habit and reproduce vegetatively[20-23]. Many of these species of plant (e.g., *Myriophyllum* spp: Figure 9.1) can spread rapidly and persist for very long periods through vegetative propagation, irrespective of seed production and germination.

Moreover, clonal growth and vegetative reproduction may occur in many ways, including the production of rhizomes, stolons, tubers, turions and plantlets, fragmentation of the plant body, and node rooting, and these attributes are widely distributed across wetland plant taxa. Despite the apparent ubiquity of clonality in wetland vegetation, relatively few studies have investigated the relative contributions of sexual versus asexual reproduction in aquatic vegetation communities.

We analysed the proportion of plants that possessed the clonal growth habit at Clydebank Morass in 2004.

Table 9.1 shows that 90 plant species were present at Clydebank Morass, of which about two-thirds were native and the remainder introduced. Exactly one half of all plant taxa present were clonal; 95% of all aquatic plant taxa were clonal.

| Characteristic | Number of species | Percentage |
|---|---|---|
| Total number of plant species present | 90 | 100 |
| Native species | 58/90 | 64 |
| Exotic species | 32/90 | 36 |
| Perennial species | 68/90 | 76 |
| Annual species | 22/90 | 24 |
| Native perennial species | 53/68 | 78 |
| Exotic annuals | 18/22 | 82 |
| Clonal species | 45/90 | 50 |
| Clonal species with exotics removed | 34/58 | 59 |
| Monocotyledon clonal species | 26/45 | 58 |
| Dicotyledon clonal species | 19/45 | 42 |
| Putative guerilla syndrome | 24/45 | 53 |
| Putative phalanx syndrome | 19/45 | 42 |
| Transitional guerilla-phalanx syndrome | 2/45 | 5 |
| Aquatic species | 20/90 | 22 |
| Clonal aquatic species | 19/20 | 95 |

Table 9.1: Characteristics of plant species present at Clydebank Morass during late summer and winter 2004.

Table 9.2 shows the wide range of clonal attributes these aquatic taxa possessed. Many taxa spread via rhizomes, but node roots and suckers were also important means of colonisation.

To further investigate the relationship between clonality and elevation from the water line, the distribution of clonal and non-clonal species was quantified along 20 transects that extended from the water line to the most elevated level of terrestrial vegetation at Clydebank Morass.

Figure 9.2 shows that clonal plant species dominated the vegetation at lower elevations (< 2.5 m) and that clonal proportions declined with increasing elevation > 3 m.

Decreasing soil moisture levels with increasing gradient elevation was the most significant reason for the decline in clonal species at elevations > 2.5 m. Introduced annual species from surrounding agricultural and pastoral land have also heavily invaded the wetland's boundaries and may in part account for the decline in clonal species above 2.5 m.

Figure 9.1: *Myriophyllum aquaticum*, an invasive clonal weed of the Lake Wellington wetlands.

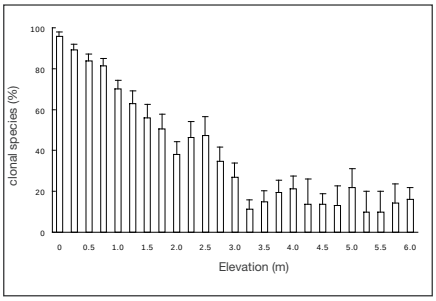



Figure 9.2: Percentage of clonal plant species at specific elevations at Clydebank Morass.

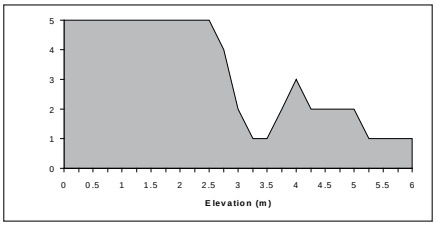



Figure 9.3: Percentage cover of clonal plant species at specific gradient levels at Clydebank Morass. The Braun-Blanquet scale is used, with a score of 0 indicating < 5 % cover; 1 = 5-10 %; 2=10-25 %; 3 = 25-50 %; 4 = 50-75 % and 5 = > 75 % cover.

| Family | *Species name* | Common name | Clonal attribute |
|---|---|---|---|
| Aizoaceae | *Disphyma crassifolium* | Rounded Noon-flower | Node roots |
| Asteraceae | *Cotula coronopifolia* | Water-buttons | Node roots |
| | *Leptinella longipes* | Coast Cotula | Stolons |
| Caryophyllaceae | *Spergularia media** | Greater Sea-spurrey | Non clonal |
| Chenopodiaceae | *Sarcocornia quinqueflora* | Beaded Glasswort | Stolons |
| Cyperaceae | *Baumea arthrophylla* | Soft Twigrush | Rhizomes |
| | *Bolboschoenus caldwellii* | Sea Club-rush | Rhizomes |
| | *Eleocharis minuta** | Variable Spike-rush | Stolon or rhizomes |
| | *Eleocharis pusilla* | Small Spike-rush | Rhizomes |
| | *Isolepis nodosa* | Knobby Club-rush | Rhizomes |
| Goodeniaceae | *Selliera radicans* | Shiny Swamp-mat | Node roots |
| Juncaceae | *Juncus pallidus* | Pale Rush | Rhizomes |
| | *Juncus kraussii* subsp. *australiensis* | Sea Rush | Rhizomes |
| Juncaginaceae | *Triglochin striatum* | Streaked Arrow-grass | Rhizomes |
| | *Triglochin procerum* | Water-ribbons | Tubers & rhizomes |
| Myrtaceae | *Melaleuca ericifolia* | Swamp Paperbark | Suckers & rhizomes |
| Poaceae | *Phalaris aquatica** | Toowoomba Canary-grass | Rhizomes |
| | *Phragmites australis* | Common Reed (Djarg) | Rhizomes |
| Scrophulariaceae | *Mimulus repens* | Creeping Monkey-flower | Node roots |
| Typhaceae | *Typha domingensis* | Cumbungi, Bulrush | Rhizomes |

* indicates an exotic species

Table 9.2: List of aquatic and wetland plant species present at Clydebank Morass and possession of clonal attributes.

Figure 9.2 is based on presence/absence data alone, and surveys that quantified percentage cover illustrate the dominance of clonal plants even more strikingly. Figure 9.3 shows the percentage cover of clonal species at specific elevations at Clydebank Morass, and reinforces the dominance and importance of clonal reproductive methods to spatial organisation, pattern formation, and species diversity within wetland plant communities.

## Clonality in Swamp Paperbark

Swamp Paperbark can form an extensive array of suckers (Figure 9.4) which, as they grow, give rise to the characteristic domed shape of adult plants (Figure 9.5). When *Melaleuca* wetlands are viewed from the air, it becomes evident that the adult plants individually cover very large extents and the zones where adult plants meet are sharply delimited (Figure 9.6).

Figure 9.4: Suckering from exposed roots of Swamp Paperbark.

Figure 9.5: Typical clonal growth habit of Swamp Paperbark, showing the domed canopy.


Figure 9.6: Aerial view of Swamp Paperbarks at Dowd Morass, showing the sharp demarcation between adjacent adult trees (indicated with the red arrows). The individual tress subject to molecular analysis are numbered 1-5.

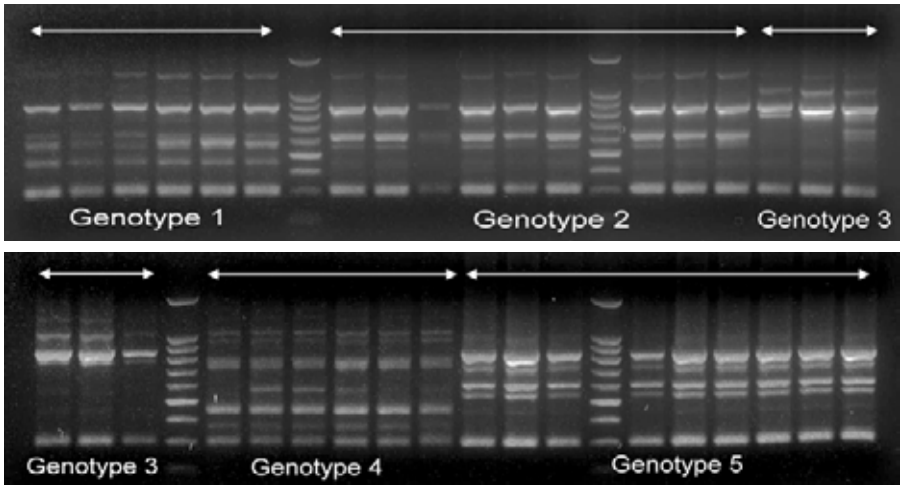



Figure 9.7: Inter simple sequence repeats analysis of five individual adult Swamp Paperbark tress from Dowd Morass. Each stand was genetically homegeneous but genetically distinct from its neighbours.

We used a molecular technique – inter simple sequence repeats – to determine whether the individual trees shown in Figure 9.6 were genetically homogeneous or composed of many plants of mixed parentage. The results (Figure 9.7) clearly indicated that the individual stands of Figure 9.6 were genetically separate and internally homogeneous.

## How does clonal *Melaleuca ericifolia* respond to long-term inundation?

A field survey was undertaken to investigate the effects of persistent inundation on the balance between clonal reproduction and sexual reproduction in the Swamp Paperbark community at Dowd Morass. It was hypothesised that the long-term inundation that this community has experienced would reduce the above-ground growth of adult Swamp Paperbarks and induce a shift from asexual to sexual reproduction.

Indeed, it was found that persistent inundation of adult *M. ericifolia* clones reduced annual growth and the cover of green foliage compared with their non-flooded counterparts. Clonal expansion was found to be limited by long-term inundation and is compensated by an increase in sexual reproductive effort, with greater infrutescence production increased capsule retension. Approximately 35% more capsules were held on infrutesences in branches from flooded clones compared with rarely flooded clones. Flooded clones were also more likely to hold seed within the aerial seedbank, as a greater percentage (~40%) were closed on flooded clones.

These observations showed clearly that adult Swamp Paperbarks can alter their reproductive strategy as a mechanism of persistence in response to permanent inundation. The implications are that long-term flooding of adult clones compromises clonal expansion and plant health, as well as increases sexual reproductive effort.

A water-level draw-down of long-term flooded *M. ericifolia* clones may not only stimulate vegetative growth, but is likely to promote regeneration via the release of seed from the abundant aerial seed bank of flooded clones. The topic of sexual recruitment in Swamp Paperbark is covered next in Section 10 of this Handbook.

# 10. Germination requirements of Swamp Paperbark

## How viable is canopy-held seed of Swamp Paperbark?

Swamp Paperbarks are serotinous plants, meaning that their seed is held in capsules on adult plants rather than as seedbanks held in the soil. We were interested in whether the seed of chronically flooded clones of Swamp Paperbarks remained viable over time.

To answer this question, we recorded the percentage germination of seed produced in ~ October 2002 by long-term flooded clones. This seed was collected and germinated in August 2004. Other seed collected at the same time was stored at 20°C in the laboratory until December 2005 to investigate whether seed viability declined with storage time. These results were compared with the percentage germination of seed produced by the same clones but stored on the canopy of trees until December 2005.

The findings were that germination was lowest (2% ± 0.7%) when seed was removed from the tree in August 2004 and immediately allowed to germinate. Storing seed in the laboratory for 16 months improved viability markedly, with mean percent germination increasing to 12%. In contrast, seed stored on the canopy until December 2005 exhibited the greatest mean percent germination (27% ± 2%) compared with fresh seed.

The implications for regeneration projects are that seed can be stored successfully for at least 1.5 years under dry conditions without reducing the success of germination. Seed held on the canopy of trees in the wetland did not decline in viability with time over at least three years. Therefore, following long-term flooding, the seed released during draw-down should germinate well, given other conditions are suitable.

## Detrimental effect of salinity and high temperature on germination

The question then arises as to what conditions are required for successful germination of Swamp Paperbark seeds. To answer this question, we examined the effects of a range of environmental conditions (salinity, temperature, light intensity and burial) on germination success under laboratory conditions.

Individually, light, salinity and temperature all exerted highly significant ($P < 0.001$) effects on germination. Since all interaction factors were highly significant, it is impossible to generalise about individual main effects without reference to the qualifying effects of other main effects. Nevertheless, some trends can be detected (Figure 10.1).

First, the greatest germination occurred with surface-sown seed, germinated in darkness at a mean temperature of 20°C and salinity < 2 g $L^{-1}$. At 20°C, maximum germination occurred at a salinity of 1 g $L^{-1}$; germination fell rapidly at a near-constant rate with increasing salinity. Lower temperatures, while moderating the inhibitory effects of salinity, markedly reduced germination. In contrast, higher temperatures increased the inhibitory effects of salinity and light and reduced overall germination rates.

The interactive effects of salinity, temperature and light can be seen clearly in Figure 10.1. At 30°C there was a rapid decrease in germination with increasing salinity. No germination was observed at a salinity of 16 g $L^{-1}$, and only about 5% of seeds germinated at 8 g $L^{-1}$ at this temperature. In comparison, nearly 50% of seeds germinated at 30°C in fresh water. At 20°C maximum germination success (40-50%, depending on light conditions) occurred at a salinity of 1 g $L^{-1}$ and germination fell at a roughly constant rate with increasing salinities. Although about 10% of seeds still germinated at a salt concentration of 16 g $L^{-1}$, no seeds germinated at a salinity of 32 g $L^{-1}$.

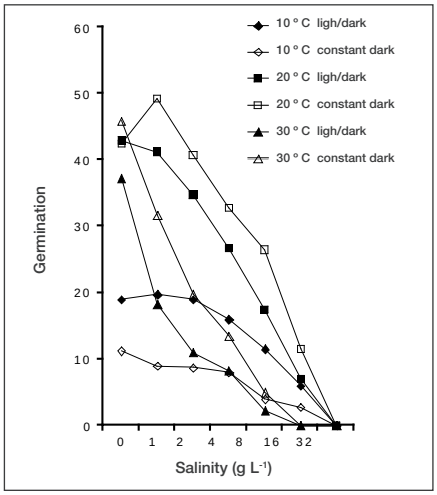



Figure 10.1: Interactive effects of salinity, temperature and light on the germination of Swamp Paperbark seeds.

Unlike the case at the highest incubation temperature, seeds at 20°C showed statistically significantly higher percentage germination in the light:dark cycle than in complete darkness. The inhibitory effect of increasing salinity was minimised at 10°C, but even so seeds failed to germinate at a salinity of 32 g $L^{-1}$.

Despite the very inhibitory effects of salinity on seed germination, seeds subjected to brief inundation with saline water germinated rapidly if flushed by, and subsequently grown under, freshwater conditions.

## Importance of hypocoytl hairs for seedling survival

Hypocotyl hairs are single-cell outgrowths from the base of the hypocotyl, not associated with the true root system of the plant. They are one means by which some plants increase seedling survival in difficult environments, and it was expected that we would find them in Swamp Paperbark seedlings.

Hypocotyl hairs were produced by the seedlings, but only under a limited range of environmental conditions: low salinity, water availability and temperature, and preferentially under darkness. There was some evidence that hypocotyl hairs were involved in water uptake and strong evidence that they were central to positive geotropism in the young seedling. Young seedlings that did not develop hypocotyl hairs quickly withered and died: it would seem that they are a prerequisite for the establishment of young seedlings in the Swamp Paperbark community (Figure 10.2)

Almost all the environmental conditions now existing in Dowd Morass would seem to be inimical to the production of hypocotyl hairs. These changes may well reduce the ability of Swamp Paperbarks to establish new plants via sexual means in Dowd Morass and other similar wetlands.

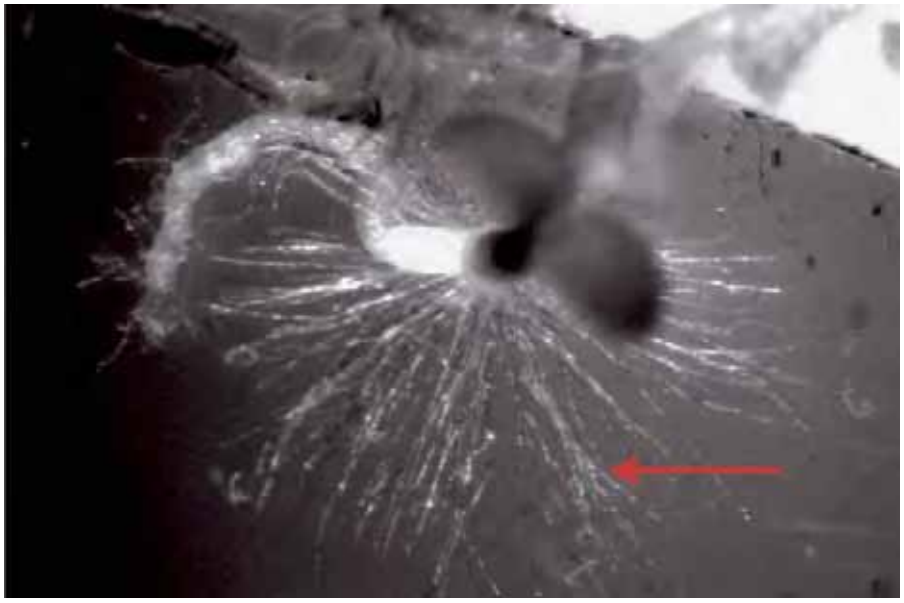


Figure 10.2: Hypocotyl hairs (shown with the red arrow) developing on young Swamp Paperbark seedlings.

## Conditions required for young plants to survive

A following section (Section 13) describes the mesocosms we established to elucidate how Swamp Paperbarks and Common Reed grew and interacted. Mesocosms are small ponds (3m x 3 m x 1 m deep) that allow us to control environmental conditions such as water level and salinity. They offer much of the realism of field-based experiments but with more control.

Using six replicate pools, we examined the response of 3-month old *M. ericifolia* seedlings to three water depths (exposed sediment, waterlogged, and submerged) at three salinities (2, 49 and 60 mS $cm^{-1}$).

We found that increasing water depth at the lowest salinity did not affect the survival of young plants, but it strongly inhibited their rate of growth. Completely submerged plants survived for 10 weeks at the lowest salinity but were unable to extend their shoots above the water surface. Seedlings demonstrated great tolerance to salinity when sediment was exposed – 90% of plants survived for 10 weeks at 60 mS $cm^{-1}$ even though soil salinities reached the extremely high values of ~ 76 mS $cm^{-1}$.

This salinity is well above the salinity of seawater. No mortality occurred in the exposed plants at 49 mS $cm^{-1}$ and small but positive relative growth rates were recorded after 10 weeks in this treatment. At the higher salinities, *M. ericifolia* seedlings were intolerant of waterlogging and submergence and all plants had died after 10 weeks at 60 mS $cm^{-1}$.

## Conclusion

We conclude from these experiments that, at low salinities Swamp Paperbark seedlings are highly tolerant of sediment waterlogging but are unlikely to tolerate prolonged submergence. At salinities above 49 mS $cm^{-1}$, the seedlings are intolerant of both waterlogging and submergence. The implication of these results for the better management of Dowd Morass is that waterlogging or submergence of young *M. ericifolia* plants with saline water will have adverse impacts on their survival. For optimal survival and growth of young plants, the salinity must be kept low, the soil exposed and prolonged submergence above the tops of the plants should be avoided.

# 11. Wetland rehabilitation 1 – landscape-scale manipulation of water regime

## What did we do?

Given the role that historical water regime played in controlling the condition of vegetation at Dowd Morass (Section 7), we wanted to better understand the potential for modifying the current water regime to improve the condition of plants, especially Swamp Paperbarks, in the wetland.

With the assistance of staff from Parks Victoria and volunteers from Field & Game (Sale and District), the gaps in Heywood's embankment were repaired so that the east and west sides of the wetland were physically isolated (Figures 11.1 and 11.2; see also Figure 2.4).

Figures 11.1 and 11.2: Close-up view of the deteriorating levee along Heywood's embankment (upper photograph) and team of volunteers from Parks Victoria and Field & Game who repaired the gaps in the levee (lower photograph).

This division within the wetland provided a unique opportunity to undertake a landscape-scale experimental manipulation of water level and to test the impact of water-level drawdown on the condition of the wetland.

We used the levees and regulatory structure on Drain 1 (the channel and regulator to the La Trobe River: Figures 2.4 and 2.5) to drain the area on the west side of Heywood's embankment (Areas A and B, ≈ 500 ha) and to keep areas on the east side of the embankment (Areas C and D, ≈ 1,000 ha) full of water as a control. Because of logistic limitations, we monitored vegetation only in Area B as the drawdown treatment and Area D as the control treatment. Had more resources been available, we would have monitored responses in Areas A and C as well. While Area D served as the necessary control site, we also analysed vegetation responses along the shoreline. Since the shoreline vegetation was generally in good to excellent condition, this third monitoring area served as the reference site.

The first attempt at drawdown was made in the summer of 2003-2004. We actively drained the water out of Areas A and B through Drain 1 (Figure 2.4) into the La Trobe River; evaporation over the following summer removed most of the remaining water. However, the regulating structure at Drain 1 was severely vandalised in March 2004; the resultant influx of water from the La Trobe River increased the water levels by approximately 30 cm in Areas A and B of the morass. This ruined our first attempt at a drawdown.

We attempted another drawdown over summer of 2004-2005. This time we drained the water out of Areas A and B through Drain 1 as much as we could, then used two large diesel-driven pumps to pump the remaining water from Drain 1 to the La Trobe River and from Area B to Area D.

Figures 11.3 to 11.7 show various stages in the installation of the two pumps. The pumps removed the equivalent of 1,250 Olympic-sized swimming pools of water from Dowd Morass over the summer of 2004-2005.

Using the methods outlined in Section 7 of this Handbook, we measured the condition of vegetation along the same 45 transects every year from 2003-2006.

Figures 11.3 to 11.7: Various stages in installing the two pumps at Dowd Morass to manipulate water levels during 2004-2005.

## Water levels and electrical conductivity

The impact of our attempts at hydrological manipulations on water levels in the morass is shown in Figure 11.8. Pumping resulted in increased water levels in Area D and decreased water levels in Area B for approximately two months. Subsequently, however, water levels dropped in both Areas B and D as a consequence of evaporation over the long, dry summer of 2004-2005 and the loss of water from Area D to Lake Wellington. A minor flood from Lake Wellington increased the water levels in Area D by about 40 cm in late June 2005, and water levels increased again in Area B in July 2005.

The drawdown resulted in increased electrical conductivity, a surrogate of salinity, of the surface water (Figure 11.8). The salinity increased most markedly in Area D, largely because this part of the wetland received brackish water from Lake Wellington. Over the four year period, the electrical conductivity of Dowd Morass rose from < 0.5 mS $cm^{-1}$ to > 25 mS $cm^{-1}$.

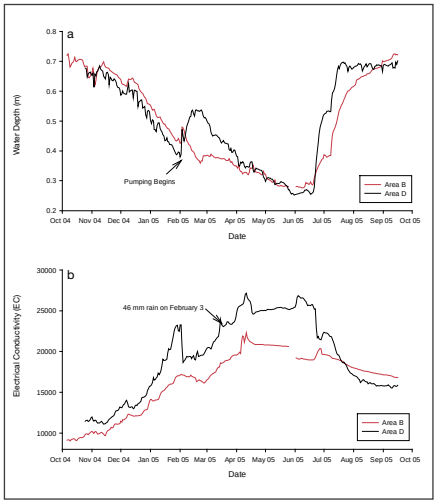



Figure 11.8 (above) : (a) Water depth and (b) electrical conductivity of surface water during pumping and reflooding at Dowd Morass. Pumping was commissioned in Areas A and B in February 2005 for four weeks. A flood from Lake Wellington increased the water levels rapidly in Area D, and an overbank flow over Heywood's embankment caused the water level to rise rapidly in Area B.

Figure 11.9 (right): Percentage ground cover (bare ground, logs, fixed vegetation and leaf litter) along 45 transects before (2003, 2004) and after (2005, 2006) drawdown of water levels in three areas of Dowd Morass: Area B, Area D and along the shoreline.

## Ground cover and response of understorey species to drawdown

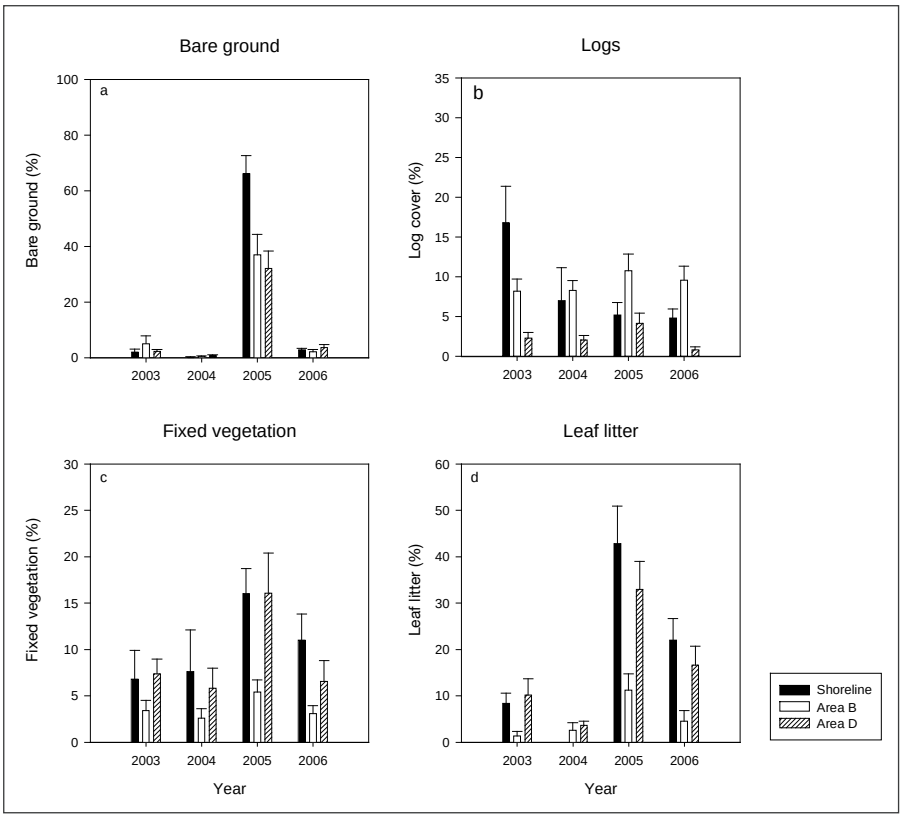
The nature of ground cover influences strongly the types of plant species that can germinate in a wetland and the overall availability of sites for germination. The decrease in water levels during the two hydrological manipulations certainly exposed the sediment in large areas of the wetland (Figure 11.9). Before drawdown less than 10% of the morass sediment was exposed, but during 2005 more than 60% of the area along the shoreline and more than 30% of sites in Areas B and D were exposed. The bare ground was exposed for 2½ months in Area D and 5½ months in Area B and along the shoreline. In addition, the cover of vegetation on the ground ('fixed vegetation') and leaf litter increased along the Shoreline and in Area D, but the response was less in Area B. Area B had a greater cover of logs in 2005 and 2006 than other areas.

Overall, the number of understorey species declined between 2003 and 2006, probably as a result of increased salinity (Figure 11.10). There was a shift in species composition away from freshwater plants such as Marsh Pennywort *(Hydrocotyle verticillata)* towards more salt-tolerant species such as Goosefoot *(Chenopodium glaucum)*. The drawdown temporarily increased the number of understorey species present in all areas. The cover of understorey species also increased. Some species established rapidly on the exposed sediments, especially introduced annual grasses and salt-tolerant species. The response, however, was rather limited, particularly in Area B, possibly as a result of a depleted soil seed bank, seasonality, increased salinity and low soil pH.

The improvements observed in wetland condition during drawdown were lost during the rapid and deep re-flooding that occurred soon after water levels had dropped. This effect is most clear in the 2006 vegetation data. By 2006, the species composition along transects was very different to what we had initially recorded in 2003 (Figure 11.11).

## Response of Swamp Paperbark to drawdown and reflooding

Before the drawdown, the cover of adult Swamp Paperbark was similar in Areas B and D (Figure 11.12). The drawdown increased the overstorey cover of Swamp Paperbark in Area D. In contrast, the cover of Swamp Paperbark in Area B declined over the four year period. There were few Swamp Paperbarks in the understorey of



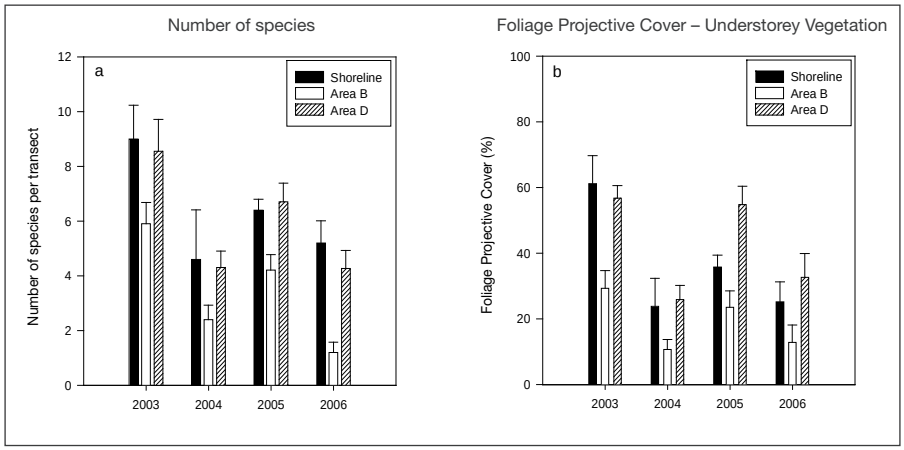



Figure 11.10: Number of understorey plant species before (2003, 2004) and after (2005, 2006) drawdown in Areas B, D and shoreline at Dowd Morass. The right-hand section of the figure shows the foliar projecive cover of the understorey vegetation before (2003, 2004) and after (2005, 2006) drawdown in these same three areas.

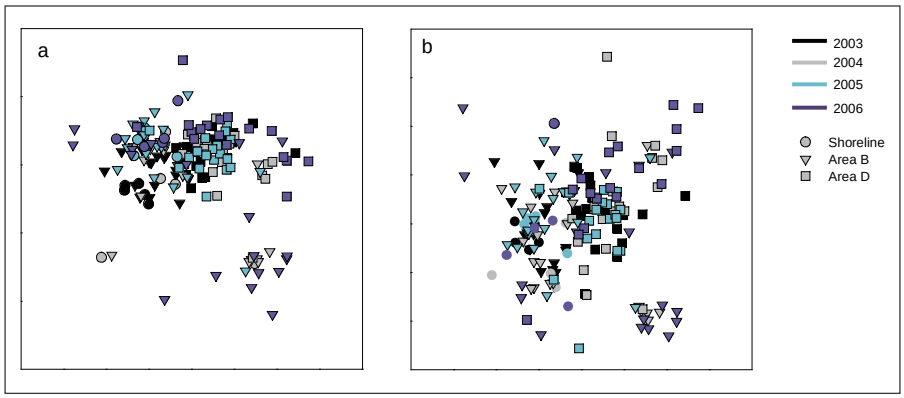



Figure 11.11: Multivariate analysis of changes in species composition before (2003, 2004) and after (2005, 2006) drawdown in Area B, Area D and along the shoreline of Dowd Morass. Each symbol represents the species composition of one of the 45 transects used in the vegetation surveys; symbols that are close together have similar species composition and symbols that are far apart have very different compositions. The original analysis was 3-dimensional: (a) shows axis 1 versus axis 2; (b) shows axis 2 versus axis 3.

any of the three regions of the wetland that were surveyed and the drawdown had very little effect on increasing the cover of Swamp Paperbarks in the understorey. We defined the understory as plants < 1 m high.

Other parts of this R&D program demonstrated that *Melaleuca ericifolia* releases only small amounts of seed throughout the year, but that a pulse of seed release occurs once water levels drop to less than about 15 cm. Although the seed from Swamp Paperbarks at Dowd Morass has very poor viability, we would have anticipated that the drawdown of water levels would have initiated an increase in the recruitment of Swamp Paperbark through this release of additional seed from the woody capsules on adult trees.

Indeed, we did observe a threefold increase in the recruitment of Swamp Paperbark through seeds and vegetative suckers in shoreline areas and in Area D in response to the drawdown (Figure 11.12). Here suckers and seeds were observed predominantly on bare sediment under the canopy of established Swamp Paperbark trees. Reflooding inhibited the regeneration of Swamp Paperbark along shoreline areas but the regeneration was maintained in Area D.

The drawdown did not increase the regeneration of Swamp Paperbark in Area B. This may be partly attributed to the poor overstorey cover of Swamp Paperbark in this area of the wetland, resulting in (a) limited seed available during drawdown and (b) a lack of overstorey for seedlings and suckers to establish under.

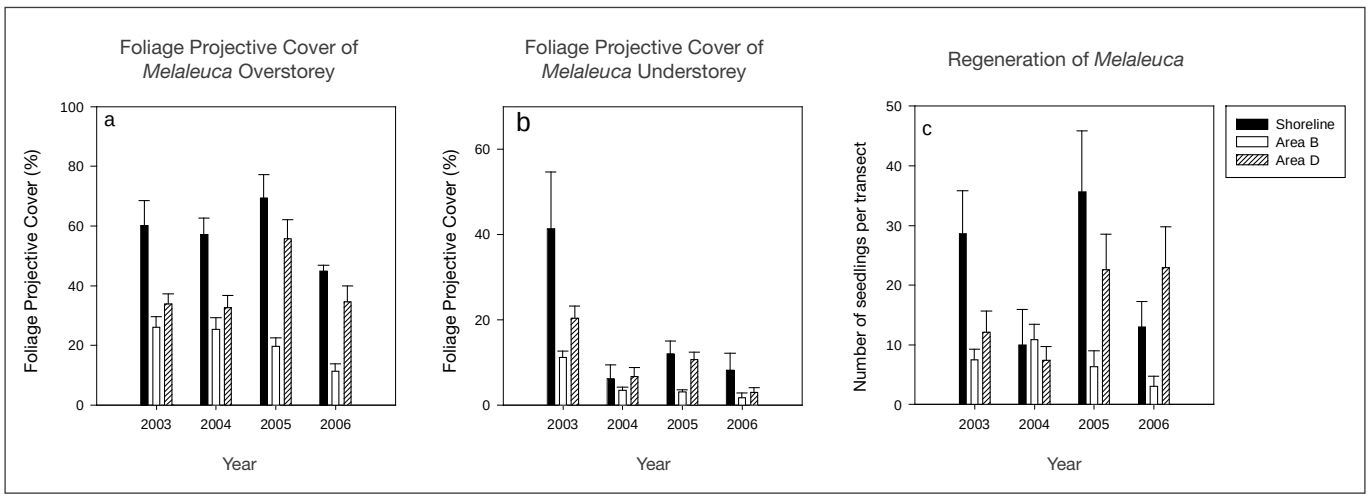



Figure 11.12. Response of Swamp Paperbark to drawdown and reflooding in Dowd Morass. Swamp Paperbark was surveyed in the understorey and overstorey along 45 transects in Area B, Area D and along the shoreline before (2003, 2004) and after (2005, 2006) water levels were drawn down. (a) shows the percentage cover of the overstorey of Swamp Paperbark; (b) the percentage cover of the understory (< 1 m high) of Swamp Paperbark; and (c) the regeneration of Swamp Paperbark as measured by numbers of seedlings and suckers.

# 12. Wetland rehabilitation 2 – active revegetation trials

The distribution and abundance of Swamp Paperbark has decreased markedly with the clearing and draining of wetlands along the entire coast of Australia, and a high priority of many management agencies is to rehabilitate wetlands that contain, or did contain, Swamp Paperbark and other *Melaleuca* species. Substantial resources, often involving community groups, are now allocated to revegetating degraded wetland sites, yet only rarely is the effectiveness of the rehabilitation strategies or on-ground procedures robustly assessed. Improved testing of revegetation methods and reporting the success or otherwise of revegetation trials will improve the effectiveness and accountability of projects aiming to rehabilitate degraded coastal wetlands.

With the assistance of Field & Game (Sale and District), Field Naturalists (Sale), Parks Victoria and other local community members, we overlaid a scientifically informed experimental design on a set of community-based planting trials to test the effectiveness of a range of techniques commonly used in wetland rehabilitation in south-eastern Australia.

## Experimental design

Four sets of revegetation trials were undertaken. The first trial, in March 2004, sought to test whether there were significant effects of planting under three different water regimes (dry sites; waterlogged sites: 1 cm deep water; and flooded sites: 9 cm deep water) and with tubestock of different age/height (4 month old: 16 cm seedlings and 6 month old: 50 cm seedlings). An example of a dry site is shown in Figure 12.1.

The second trial, in November 2004, examined the effects of planting seedlings with a Hamilton planter versus a simple mattock, as well as the importance of water level on revegetation success.

Hamilton planters extract a core of soil in the same cylindrical shape as seedling tubestock and are a standard tool for planting terrestrial vegetation in Australia. However, anecdotal evidence suggests that in clay soils, such as are common in wetlands, Hamilton planters smear the walls of the newly created hole, and this may prohibit lateral root expansion and result in a constricted root mass. Mattocks, which were used to dig a coarse hole in the soil, are also commonly used in revegetation trials and do not create smoothed wall holes. However, mattocks are typically regarded as more difficult, dangerous and time consuming to use, and this has led to the widespread use of Hamilton planters in terrestrial revegetation activities. In this second set of trials, we planted seedlings at two water levels: shallow flooding (mean water depth = 9 ± 1 cm) and deep flooding (mean water depth = 22 ± 1 cm). By comparing the results with the first trial, we could also infer the importance of season in determining the success of revegetation attempts.

Figure 12.1: Example of a dry site used for revegetation trials in 2004.

Figure 12.2: Tubestock seedling of Swamp Paperbark soon after planting.

In both trials, seed for the tubestock was collected from *M. ericifolia* stands at Dowd Morass to ensure local provenance and germinated in composted pine as the growing medium. Tubestock were established from seed by John Topp at Gippsland Indigenous Plants Pty Ltd (Valencia Creek) and grown in this medium in 5 cm diameter forestry tubes. Over 1,000 seedlings were planted on each of the first and second trials, then monitored for plant height and survival for 8-12 months (Figure 12.2).

In the third trial, also undertaken in November 2004, we had the simple aim of testing whether planting seedlings on hummocks increased survival in comparison with planting seedlings in adjacent waterlogged or flooded sediments. Hummocks are a conspicuous feature of Dowd Morass (Figure 12.3) and we predicted that survival would be better if seedlings were isolated from the surrounding water by being planted on these raised areas.

Fifteen *M. ericifolia* tubestock seedlings were planted in separate *Paspalum distichum* hummocks using mattocks and

Figure 12.3: Hummocks of *Paspalum distichlum* in Dowd Morass.

another 15 seedlings planted adjacent to each hummock in the surrounding water (mean water depth = 11 ± 1 cm).

Plant height and water depth were measured for each plant at the time of planting and at regular intervals for the following five months.

In the fourth trial, undertaken in November 2006, we wanted to see whether liming revegetation areas with dolomite lime had a beneficial impact on revegetation success. A series of 12 mounds were built in the wetland (each ~ 15 m long x 1 m wide x 0.5 m high) and ~ 400 tubestock seedling planted. One third were planted without any additional treatment and the remaining two-thirds with dolomite lime at either 25 g per seedling or 75 g per seedlings placed directly into the tubestock hole before the plants were inserted. The average pH of the hummock soil was 3.6 before the addition of lime. Monitoring the results of this fourth trial will continue into 2007. Figure 12.4 shows the artificially made earthen hummocks used in the fourth trial.

## How successful were revegetation trials?

The results of these various trials demonstrated that the age of tubestock plants and water depth were critical factors in the survival and growth of *M. ericifolia* seedlings. The taller, older seedlings could better withstand inundation since they could maintain a greater proportion of their foliage above the water surface. The depth to which plants are flooded immediately after planting also was an important factor in the survival of *M. ericifolia* seedlings. Once submerged, all the 4-month old seedlings had died within one month; in contrast, some 6-month old plants survived up to eight months fully submerged (Figure 12.5). The generally poor survival of plants may be attributed to the combined impacts of waterlogging, salinity and the presence of acid-sulfate soils. The impacts of these factors on seedlings can be minimized by selecting elevated planting spots, after consideration of microrelief, soil characteristics, species, water depth and local climate.

In contrast, planting tubestock into raised *Paspalum* hummocks increased markedly the survival of *M. ericifolia* seedlings. This finding is consistent with our field observations that *M. ericifolia* seedlings and juveniles predominantly occur on hummocks that were raised, even slightly, out of the surrounding water. Hummocks offer a refuge from the stressful

Figure 12.4: Artificial earthen hummocks used for the fourth revegetation trial. Twelve rows of hummocks were created, each ~ 15 m long x 1 m wide x 0.5 m high.

Figure 12.5: Typical dead Swamp paperbark at the end of the first set of revegetation trials.

combination of waterlogging, salinity and soil acidity occuring in the surrounding sediments. There may however be an adverse effect of hummocks on plant growth, since young plants on hummocks may become water stressed during periods of low rainfall if their roots do not rapidly locate deeper water sources.

We conclude that, unless intrinsic edaphic (e.g., salinity, pH) and hydrological (e.g., water quality and water regime) factors are fully understood, revegetation trials in coastal Swamp Paperbark wetlands using tubestock are likely to be unsuccessful. The effectiveness of revegetation efforts needs to be rigorously and quantitatively assessed, so that the process is demonstrably accountable and transparent. The mere act of planting large numbers of seedlings is insufficient as a rehabilitation strategy if the young plants do not mature into a self-sustaining population.

Figure 12.6: Swamp Paperbarks grow on raised areas known as hummocks in deeply flooded sites.

## The importance of hummocks

There are many hummocked areas within Dowd Morass that are elevated above the water surface. Hummocks may be caused by tree fall, root growth, litterfall, sediment and debris accumulation, and mounds formed by other plant species. Such raised sites confer a number of advantages to plants in anoxic or deeply flooded environments; they contain aerated soil above the surface water and provide access to different moisture regimes as the water level fluctuates. Indeed, in the deepest part of the wetland (Area B, the ibis rookery), mature *M. ericifolia* trees have survived 30+ years of near-permanent flooding by persisting on raised (5–91 cm), wide (40–200 cm) mounds, which elevate the root system towards the water surface (Figure 12.6).

The height of the hummocks increases with increasing water depth, and the roots of *M. ericifolia* are concentrated in the upper horizon (30–50 cm) of these hummocks. Minor reductions in the water level may also expose the plants to the atmosphere. Maintaining the hummock topography is probably vitally important for providing a range of elevations for different types of plant species to grow on in wetlands such as Dowd Morass.

# 13. Interactions between Swamp Paperbark and Common Reed

The analysis of the historical aerial photographs of Dowd Morass (Section 8) demonstrated that, over the past four decades, *Melaleuca ericifolia* has progressively replaced large stands of *Phragmites australis* (Figure 13.1). To understand why this change took place, we conducted a mesocosm (pond) experiment over the summer of 2004-2005. This experiment measured the growth of Swamp Paperbark and Common Reed when they were grown alone in pots compared with when they were grown together, under a range of contrasting environmental conditions.

Figure 13.1: Stands of Common Reed in front of a dense woodland of Swamp Paperbark.

The environmental conditions that we modified were salinity and soil redox. Redox potentials were modified because flooding and high amounts of organic matter depletes the oxygen content of wetland sediments and the resultant soil anoxia strongly affects plant performance and survival. Unlike Swamp Paperbarks, *P. australis* has a system of internal ventilation that pumps air from the shoots to roots and rhizomes; this "internal wind" increases the amount of oxygen available to below-ground organs and allows these plants to colonise strongly anoxic sediments in deep water or permanently waterlogged sediments.

Some oxygen also inevitably leaks into the surrounding sediment from the roots and rhizomes of the reeds, thus modifying the redox potential of the soil. We expected that Common Reed would be more tolerant to low oxygen levels in the sediment because of this ventilation system. Moreover, the leakage of oxygen into sediments from the roots and rhizomes of *P. australis* may benefit the growth of the *M. ericifolia* plants, which do not have this internal aeration system.

We grew plants of Common Reed *(*and Swamp Paperbark alone and together in outdoor ponds over the summer of 2004-2005 (Figure 13.2). Three of the ponds were filled with fresh water (~0.1 mS $cm^{-1}$) and three with saline water (~18 mS $cm^{-1}$, ~ one-third seawater).

In each pond, plants were grown in sediments with or without added cellulose and flooded ~ 7 cm above the water surface. Cellulose is a major component of plant tissues and we used it as a substitute for dead organic material. By adding extra cellulose we would provide more carbon substrates for bacteria in the sediments; they would grow rapidly and use up all the available oxygen in the soil. This would result in a decrease in the redox potential of the sediments in soils treated with added cellulose. To test the ability of *P. australis* to increase the oxygen content of the sediment we also placed pots without plants but with or without cellulose in each of the ponds to act as controls.

Quantitative measurements of redox potential are commonly divided into four categories[24]: oxidised soils have a redox of > +400 mV, moderately reduced soils are +100 to +400 mV, reduced soils from –100 to +100 mV, and highly reduced soils from –100 to –300 mV. The boundary between oxidising and reducing conditions is commonly marked by the $Fe^{2+}/Fe^{3+}$ couple, which at pH 7 corresponds to a redox potential of +270 mV.

In this experiment sediment redox values varied greatly over time and across treatments. The redox values of sediments with added cellulose fell rapidly after pots were submersed in water, falling from +390 mV at day 1 to ~0 mV by week 3. After this time redox values generally remained around 0 mV. For sediments without added cellulose, redox values fell more slowly and only briefly reached 0 mV, with values tending to remain between +50 to +150 mV. By March, near the end of the experiment, redoxes increased considerably above these values for most treatment groups. Under optimal conditions *P. australis* could pump ~ 2 ml of air per minute through a single stem, but this flux of air generally did not increase sediment redox potential. Similar findings have been reported by other researchers and it has been suggested that the oxygen transported by the plants to the soil is rapidly consumed by bacteria around the roots and rhizomes.

Soil salinities were always higher than the salinity of the water column They were highest in pots with *P. australis*, reaching 36 mS $cm^{-1}$, nearly two-thirds sea water. This increase in salinity is likely to be due to high shoot biomass of Common Reed, resulting in high rates of water use by the plants.

Figure 13.3 shows the response of *M. ericifolia* to cellulose and salinity when grown either alone or with *P. australis.* The main points to note are that the flooding of plants with one-third seawater reduced the biomass of *M. ericifolia* by ~ 60% compared with freshwater controls. Indeed about 15% of the Swamp Paperbark plants died in the saline treatments. The performance of Swamp Paperbark, however, was largely unaffected by the addition of cellulose – in other words, by more reducing sediments – regardless of salinity. We did note that

Figure 13.2: Common Reed and Swamp Paperbark plants growing in mesocosms.

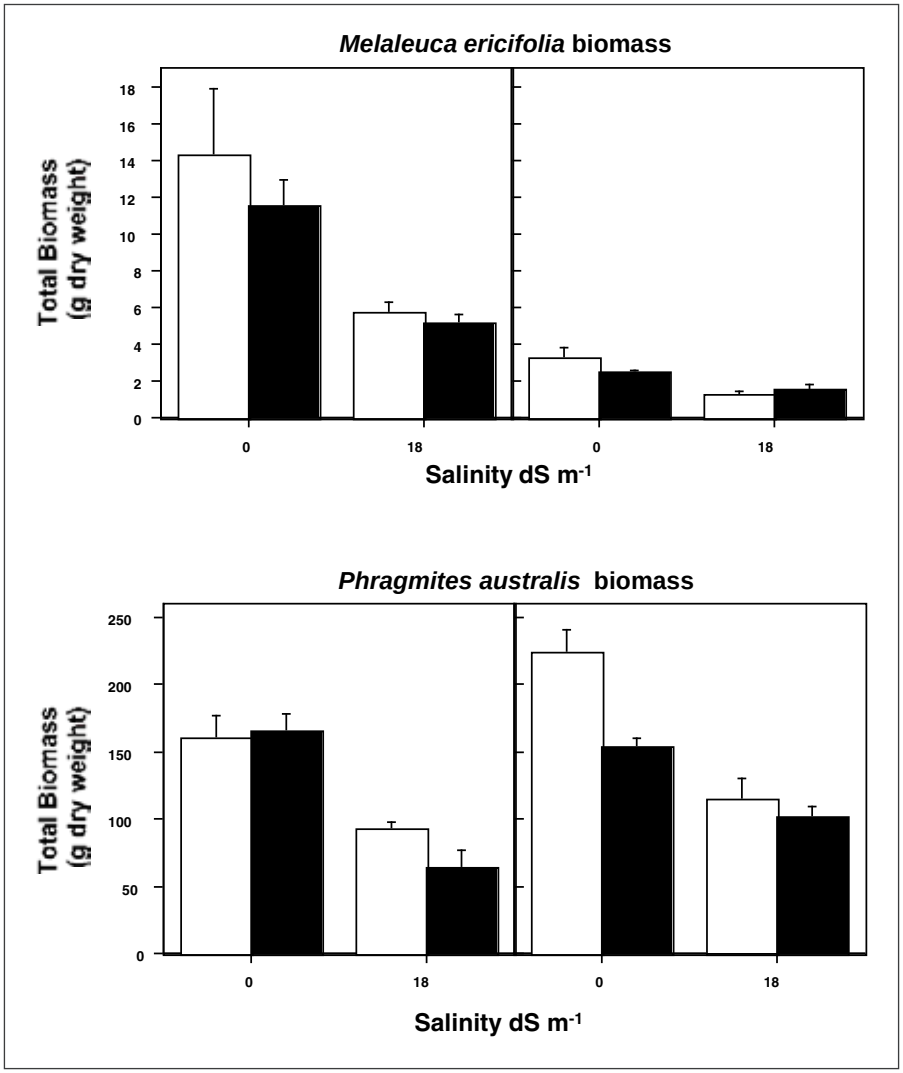



Figure 13.3: Biomass of Swamp Paperbark and Common Reed when grown alone or together, with or without added cellulose at two salinities. The clear histogram boxes show treatments without added cellulose: the black boxes show those with added cellulose.

Swamp Paperbark seedlings were easily blown into the water, indicating they required protected sites in order to establish, as offered within stands of Common Reed.

Figure 13.3 shows the inhibitory effect of salt on Swamp Paperbarks and confirms the results reported in various laboratory and mesocosm experiments (see Section 10).

Contrary to our expectations, however, Common Reed was more sensitive to cellulose additions than was Swamp Paperbark. Moreover the effects of cellulose were greater under the saline treatment than the freshwater treatment. Under freshwater conditions, cellulose reduced the height of *P. australis* stems, and in the one-third seawater treatment the total biomass of Common Reed was reduced. These finding indicate that the presence of high levels of organic matter, particularly under saline conditions, will reduce the vigour of stands of Common Reed. Overseas studies have also linked the die back of *P. australis* to the high levels of organic matter that can occur at nutrient-enriched sites.

Salinity reduced the biomass of *P. australis* plants by 40-60% but, unlike the case with the Swamp Paperbark, none died even though soil salinities reached over one-half seawater. Salinity reduced the number and height of Common Reed stems. This effect may lower the ability of *P. australis* stands to exclude competitors, possibly by creating gaps in the canopy which may permit invasion from other species, or by

Figure 13.4: Swamp Paperbark growing with (left) and without (right) Common Reed under saline conditions. The stronger growth of the Swamp Paperbarks in the absence of Common Reed is evident in the larger size of the *Melaleuca* plant in the right-hand pot.

reducing the height that invading species must reach before they are positioned above the Common Reed canopy.

There were some strong interactions between the Swamp Paperbarks and Common Reeds in the pond experiments. When grown together *P. australis* always suppressed the growth of *M. ericifolia,* but *M. ericifolia* seedlings persisted. This effect is shown in Figure 13.4.

## Conclusion

We conclude that, whilst Swamp Paperbark grew more slowly in the presence of Common Reed, it could still persist despite the strong competition created by the rapid growth *Phragmites*. Moreover *P. australis* is likely to offer physical protection to the young Swamp Paperbarks from wind or wave activity. Common Reed dies back over winter and must re-shoot from underground reserves; this seasonal response is likely to provide *Melaleuca* plants with a growth opportunity when competition for light and nutrients is minimal. If Swamp Paperbarks can persist and grow, even slowly, within Common Reed stands, it may eventually gain dominance because it will shade out the shorter grass. Such a process would account for the gradual replacement of reeds by Swamp Paperbark, as observed in the aerial photographs.

# 14. Communication and capacity building

Communicating the progress and results of the R&D project were always a high priority. Three fact sheets were produced during the period 2003-2004, as well as the 16-page information brochure *Managing water regimes in high-value wetlands: general approaches, emerging technologies and specific applications* in 2005.

Figure 14.1: Community information day at Sale Common.

A web site was established early in the project (**www.wetland-ecology.info**). We presented overviews of our work and findings to a wide range of scientists, natural-resource managers and community groups during the entire course of the project, commencing with talks to community groups in early 2003 and finishing with a series of final presentations in late 2006 and early 2007. Figure 14.1 shows one community-group meeting held at Sale Common in 2005. The following presentations were given to various groups during the course of the project:

### 2006

- National Acid-sulfate Soils Working Group, Sale

### 2005

- Gippsland Catchment Week, West Gippsland Catchment Management Authority, Sale
- Corangamite Catchment Management Authority, Colac
- University of Ballarat, Ballarat
- Wimmera Catchment Management Authority, Horsham
- Glenelg-Hopkins Catchment Management Authority, Hamilton
- Gippsland Taskforce, Sale
- Watermark, Sale
- Department of Primary Industries & Goulburn-Broken Catchment Management Authority, Tatura
- Field & Game Victoria, Sale

### 2004

- Wimmera Catchment Management Authority, Horsham
- Victorian EPA, Melbourne
- Griffith Univerity, Brisbane
- East and West Gippsland Catchment Management Authorities, Traralgon
- Glenelg-Hopkins Catchment Management Authority, Hamilton
- Goulburn-Broken Catchment Management Authority, Shepparton
- Corangamite Catchment Management Authority, Colac
- Wellington Shire Council (World Environment Day), Sale

### 2003

- Watermark Annual General Meeting, Sale
- Arthur Rylah Institute, Melbourne
- West Gippsland Catchment Management Authority, Traralgon
- Field & Game Victoria, Sale
- Sale & District Field Naturalists, Sale

### 2002

- Department of Sustainability and Environment, Maffra.

During the presentations to Catchment Management Authorities in 2004 and 2005, we took the opportunity to circulate a 2-page questionnaire about the preferred format for results from the R&D project to be circulated among user groups. The responses were divergent, but strong support was shown for colour printed documents distributed by the research team and the CMAs. This response led to the production and distribution of the 16-page information brochure in 2005 and the current Handbook.

As well as presenting the R&D project to a diverse range of community groups and other stakeholders, the following presentations were given at scientific conferences:

### 2006

- Boon PI, Raulings E, Morris K, Roache M, Hatton M, Robinson R, Salter J & Bailey PC. Summary of findings of R&D program. *Wetlands of the Gippsland Lakes R&D workshop 2.* Bairnsdale, 1 December.
- Boon PI (2006). Innovative techniques for managing multiple threats to high-value aquatic systems. *Co-ordination meeting of the Environmental Water Allocation R&D Program.* Land & Water Australia. Hindmarsh Island (South Australia), 27-29 November.
- Boon PI (2006). Macrophytes in shallow urban water bodies. *Water tension – a national workshop on water management for botanic gardens*. Botanic Gardens Australia and New Zealand. Royal Botanic Gardens (Melbourne), 25 and 26 October.
- Boon PI, Raulings E, Morris K, Roache M & Bailey PC. Wetland rehabilitation: rehabilitation of wetlands degraded by multiple stressors – altered water regime, salinity, and exotic species. *Wetlands of the Gippsland Lakes R&D workshop 1,* Bairnsdale, 30 May.
- Boon PI, Robinson R, Bailey PC, Raulings E, Morris K & Roache M (2006). Rehabilitation of brackish-water wetlands of the Gippsland Lakes (south east Australia): gauging the success of landscape-scale water-level manipulations and community-based revegetation trials. *Society of Wetlands Scientists 27th International Conference*

*(Catchments to Coast)*. Cairns, 9-14 July.

- Boon PI, Robinson R, Bailey PC, Raulings E, Morris K, Roache M & Hatton M. Rehabilitating Ramsar-listed wetlands of the Gippsland Lakes: how successful are landscape-scale water level manipulations and community based revegetation trials? *Coast-to-Coast Conference – Research for Coastal Management Special Symposium.* Melbourne, 22-26 May.

## 2005

- Raulings E, Morris K, Roache M, Boon PI & Bailey PC. Impacts of altered water regimes on emergent vegetation: analysis of vegetation succession using historical aerial photography. *Annual conference of the Ecological Society of Australia.* Brisbane, 28 November – 2 December.
- Morris K, Raulings E, Roache M, Bailey PC & Boon PI. How does *Melaleuca ericifolia* replace established stands of *Phragmites australis*? *Annual conference of the Ecological Society of Australia*. Brisbane, 28 November – 2 December.
- Roache M, Raulings E, Morris K, Boon & Bailey PC. Wetland condition assessment at the landscape scale: the use of landscape metrics. *Annual conference of the Ecological Society of Australia.* Brisbane, 28 November – 2 December.
- Robinson R, Boon PI, Bailey PC, Raulings E, Roache M & James E. How many plants of Swamp Paperbark *(Melaleuca ericifolia)* occur in a wetland and how fast do they spread? *Australian Society for Limnology Annual Scientific Congress.* Hobart, 29 November – 2 December.
- Boon PI, Bailey PC, Raulings E, Morris K, Roache M & Robinson R. Rehabilitation of brackish-water wetlands of the Gippsland Lakes: is the Design or the Self-design model of wetland restoration more useful? *Australian Society for Limnology Annual Scientific Congress.* Hobart, 29 November – 2 December.
- Boon PI & Bailey PC. Rehabilitation strategies for degraded high-value wetlands. *Land & Water Australia Contaminants Program.* Canberra, 13 April.

## 2004

- Boon PI. Landscape-scale manipulations of water regime to rehabilitate coastal paperbark *(Melaleuca ericifolia)* swamps. *Joint conference of the Estuarine and Coastal Science Association and the Estuarine Research Foundation.* Ballina, 20-24 June.
- Salter J, Morris KL, Bailey PC & Boon PI. The effect of long-term flooding on reproductive allocation and growth of the Swamp Paperbark, *Melaleuca ericifolia. Annual conference of the Ecological Society of Australia.* Adelaide, December.
- Salter J, Morris KL, Bailey PC & Boon PI. Not drowning, waving: how *Melaleuca ericifolia* responds to long-term inundation and implications for persistence. *Australian Society for Limnology Annual Scientific Congress*. Adelaide, December.

## 2003

- Boon PI & Bailey PC. Community attitudes to wetlands: a case study in the Gippsland Lakes region, Victoria. *Australian Society for Limnology Annual Scientific Congress.* Warrnambool, 1-5 December.
- Raulings E, Boon PI, Bailey PC, Morris KL & Roache M. Vegetation succession in the Swamp Paperbark, *Melaleuca ericifolia. Australian Society for Limnology Annual Scientific Congress.* Warrnambool, 1-5 December.
- Roache M, Boon PI & Bailey PC. Investigation of the effects of increasing salt concentration on macrophyte litter breakdown. *Australian Society for Limnology Annual Scientific Congress.* Warrnambool, 1-5 December.
- Salter J, Morris KL, Bailey PC & Boon PI. Interactive effects of salinity and water regime on the Swamp Paperbark. *Australian Society for Limnology Annual Scientific Congress.* Warrnambool, 1-5 December.
- Boon PI. Nature-based tourism, fresh waters and the Australian environment: is sustainability possible? *Ecotourism Association of Australia 11th National Conference.* Adelaide, 10-14 November.
- Salter J, Morris KL, Bailey PC & Boon PI. The interactive effects of salinity and water regime on the performance of *Melaleuca ericifolia*, the Swamp Paperbark. *Annual conference of the Ecological Society of Australia.* Armadale, December.
- Salter J, Morris KL, Bailey PC & Boon PI. The interactive effects of salinity and water regime on the performance of *Melaleuca ericifolia*, the Swamp Paperbark. *Australian Society for Limnology Annual Scientific Congress*. Warnambool, 1-5 December.

## 2002

- Boon PI. Multiple impacts on wetlands. Worth of Water: Environment, Society and Sustainability. *The Science Forums: University of Technology Sydney.* Sydney, 3 April.

# 15. References


1. Bird ECF (1978). *The geomorphology of the Gippsland Lakes region.* Ministry for Conservation, Environmental Studies Series Publication 186. Melbourne.
2. Bird ECF (1993). *The coast of Victoria.* Melbourne University Press, Melbourne.
3. Synan P (1989). *Highways of water. How shipping on the lakes shaped Gippsland.* Landmark Press, Drouin.
4. Ellis J & Lee T (2002). *Casting the net. Early fishing families of the Gippsland Lakes.* Lakes Entrance Family History Resource Centre, Lakes Entrance.
5. Gippsland Lakes Taskforce (2004). *State of the Gippsland Lakes.*
6. Department of Sustainability and Environment (2003). *Gippsland Lakes Ramsar Site. Strategic management plan.*
7. Nash N (1991). *Lake Wellington catchment wetlands salinity study.* Report prepared for the Lake Wellington Catchment Salinity Management Plan, Department of Conservation and Environment Central Gippsland Region.
8. Parks Victoria (1997). *Lake Wellington Wetlands. Draft management plan.*
9. State Rivers and Water Supply Commission (1972). *Dowd's Morass. Report on hydrological and legal aspects with particular reference to proposed extension of reserve for preservation of wildfowl.*
10. Sinclair Knight Merz (2003). *Dowd Morass salt and water balance and the impact of management options.* Unpublished report to Department of Sustainability and Environment and Parks Victoria, Maffra.
11. Gutteridge Haskins and Davey (1991). *Water supply options for the Lower Latrobe River wetlands.* Unpublished report (1492/29) to Latrobe Region Water Authority.
12. Bird ECF (1966). *Impact of man on the Gippsland Lakes. I*n Eyre SR & Jones GRJ (editors). Geography as human ecology. pp 55-73. Edward Arnold, London.
13. Atkinson MJ & Smith SV (1983). C:N:P ratios of benthic marine plants. *Limnology and Oceanography* 28: 568-574.
14. Sinclair Knight Merz (2001). *Lake Wellington catchment salinity management plan wetlands monitoring project. Part A: analysis and interpretation of wetland monitoring data.* Unpublished report to Department of Natural Resources and Environment.
15. Fitzpatrick R *et al.* (2000). Acid sulphate soil assessment – coastal, inland and minesite conditions. www.nlwra.gov.au
16. Crawford D (2006). *Field work investigating the presence of acid sulphate soils in the Dowd Morass.* Unpublished report by the Department of Primary Industries, Melbourne.
17. ANZECC-ARMCANZ (2000). *National water quality management strategy. Paper 4. Australian and New Zealand guidelines for fresh and marine water quality. Volume 1. The guidelines.* Environment Australia, Canberra.
18. Fabris G *et al.* (1999). Mercury and organochlorines in Black Bream, *Acanthopagrus butcheri,* from the Gippsland Lakes, Victoria, Australia: evidence for temporal increases in mercury levels. *Marine Pollution Bulletin* 38: 970-976.
19. Brownlow MD, Sparrow AD & Ganf GG (1994). Classification of water regimes in systems of fluctuating water level. *Australian Journal of Marine and Freshwater Research* 45: 1375-1385.
20. Sculthorpe CD (1967). *The biology of aquatic vascular plants.* Edward Arnold, London.
21. Hutchinson GE (1975). *Treatise on limnology. III. Limnological botany.* John Wiley, New York.
22. Grace JB (1993). The adaptive significance of clonal reproduction in angiosperms: an aquatic perspective. *Aquatic Botany* 44: 159-180.
23. van Groenendael *et al.* (1997). Comparative ecology of clonal plants. In: Silvertown JW *et al.* (editors) *Plant Life Histories: Ecology, Phylogeny & Evolution.* pp. 191-209. Cambridge University Press, Cambridge.
24. Boon PI (2006). Biogeochemistry, ecology and management of hydrologically dynamic wetlands. In DP Batzer & RR Shartiz (editors) *The ecology of freshwater and estuarine wetlands.* pp 115-176. University of California Press, Berkeley.