Environment Australia

National Wetlands R&D Program

"Implications of Nutrient Enrichment on Managing Primary Productivity in Wetlands"

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Contents

Executive Summary

There is some evidence that the aquatic vegetation of shallow lakes and wetlands can exist in a number of alternative metastable states, depending on the nutrient loading. We examined this concept experimentally using large (3000 L) mesocosms (experimental pools) in a well-vegetated shallow urban lake (Victoria Park Lake) in Shepparton, central Victoria. There was little or no effect of low nutrient loadings on the submerged macrophytes (mainly *Vallisneria americana*), but moderate or high loadings could cause the compete loss of plants. The loss was caused largely by extensive growth of the floating fern, *Azolla*, which resulted in marked decreases in the dissolved oxygen concentration and penetration of light into the water column. Nutrient loading also increased the abundance of phytoplankton, resulting in algal blooms. Epiphytic algae responded less to nutrient enrichment than phytoplankton, increasing only under high levels of enrichment. Most of the nutrients added to the mesocosms were bound to sediments, and did not appear as free forms in the water column. Harvesting the aquatic plants – a technique commonly used in managing shallow urban lakes – also had major effects on the macrophyte and algal communities. The results of the study have many implications for the management of wetlands and shallow lakes, including improved understanding of the factors controlling the biodiversity of aquatic environments, the effectiveness and risks associated with techniques routinely used to control aquatic plants, and the design of monitoring programs designed to give early warning of the effect of eutrophication on the vegetation of wetlands.

Preamble

Expressions of Interest for funding under the National Wetlands R&D Program, 1996/97 were called for in October 1996. The initial 2-page Expression of Interest submitted by the two Principal Investigators was short-listed for further consideration, and a comprehensive research proposal submitted in January 1997. The proposed commencement and completion dates of the Project were 1 December 1997 and 30 December 2000, respectively.

This research proposal was selected for funding under the Program, and a draft R&D Contract was forwarded in May 1997. Due to contractual and co-ordination difficulties, a contract was not signed until February 1998, with further clarifications on funding taking place in March, April, November and December 1998. The Project formally started in late February 1998, i.e. three months after the initial proposed commencement date.

Personnel and Equipment

Personnel

Four staff were employed in the project. The Principal Investigators were Dr Paul C. Bailey (Monash University) and Associate Professor Paul I Boon (Victoria University). Their salaries were covered by the respective University employers (and, in the case of PIB, by Sinclair Knight Merz when he was employed by them in 1999).

A full-time Post-doctoral Research Fellow, Dr Kay Morris, was recruited from the University of Adelaide, and a part-time (0.6) Research Assistant, Ms Leesa Hughes, from Victoria University. Dr Morris and Ms Hughes were employed from April 1998 - March 2001 and April 1998 - December 2000, respectively, using funds provided under the Grant. Associate Professor Boon spent his university sabbatical of July – December 1998 at Monash University, working full-time on the Project with the Research Team. Dr Bailey will likewise spend a portion of his sabbatical in January – June 2001 at Victoria University, working with Associate Professor Boon on publishing the results of the research.

Equipment

The major capital cost incurred in the Project was the construction of mesocosms, experimental “pools” that allow nutrients to be added to sections of a wetland and kept separate from the surrounding waters. Two sets of mesocosms were constructed:

- 12 replicated polyethylene mesocosms, each 12 m x 12 m, at Rafterys State Forest, on the floodplain of the Goulburn River near Shepparton, central Victoria; and
- 15 replicated fibreglass mesocosms, each 2 m in diameter, in Victoria Park Lake, Shepparton.

In addition to the two sets of mesocosms, sundry pieces of instrumentation were purchased, such as portable DO meters, laboratory autopipetters and other field equipment. As all chemical analyses were sub-contracted to independent laboratories (details given below), no other major pieces of analytical instrumentation were purchased under the Grant.

Milestones Achieved

Progress and/or Milestone Reports were submitted on the following dates:

- June 1998;
- December 1998;
- May 1999;
- December 1999; and
- May 2000.

All Progress/Milestone reports were submitted on time and were accepted by Environment Australia. Details on fulfilment of specific Milestones are presented in these various Milestone and Progress Reports, and will not be reported again here.

Quality Assurance Plan

A Management Committee was established at the commencement of the Project, composed of four people with specific expertise in the ecology and management of aquatic resources in south-eastern Australia:

- Associate Professor George Ganf, University of Adelaide;
- Dr John Beardall, Monash University;
- Dr Peter Newell, Victorian Environmental Protection Authority; and
- Mr Greg Raisin, NSW Department of Land & Water Conservation.

The Management Committee met with the Research Team twice during the Project:

- 7 & 8 July 1998 for an introduction to the Project, to discuss the proposed methodology and to visit the mesocosms constructed at Raftery State Forest; and
- 6 October 1999 to review progress to date and advise on the communication strategy.

Copies of the Agendas for the two meetings are attached in Appendix A. Feedback, both as verbal debate during the meetings and as formal written summaries of the Committee's considered opinion of the meetings, was incorporated into the research plan.

Approaches Developed

Novel use of mesocosms

A key feature of this research project is the use of large mesocosms to experimentally assess the effects of nutrient enrichment on aquatic plants and algae in wetlands. Most earlier studies of the effects of nutrients on aquatic systems have used correlational approaches, and these observational methods lack the predictive power of the experimental approach that we could achieve with the use of mesocosms. With the use of mesocosms parts of an existing wetland were isolated and subjected to various treatments, including an unmodified situation which acts as a control or reference.

Mesocosms were constructed from polyethylene swimming pool liners, dug into the wetland floor, in Rafterys State Forest, on the floodplain of the Goulburn River near Shepparton in mid 1998. Not only were these mesocosms were very large (12 m x 12 m), but 12 individual mesocosms were built in the wetland, allowing various nutrient treatments to be trialed and their effects gauged with replicated mesocosms per treatment. For example, with 12 mesocosms, we could trial 3 different nutrient treatments and have 4 replicates per treatment. Alternatively, we could trial 2 treatments and have 6 replicates per treatment. These mesocosms are shown in Figures 1 & 2. The use of replicated mesocosms improves the statistical power of any nutrient experiment and thus our confidence in the interpretation of our findings and their broader management implications.

As the Goulburn River did not flood (and in fact has not flooded since 1996, due to Australia being in a El Nino cycle for the past decade), we instigated the contingency plan outlined in the Research Proposal should this unfortunate complication take place. Possible alternative wetland sites were visited across Victoria, and a choice finally made to use Victoria Park Lake, an urban wetland-lake in Shepparton, as the new site of experimental nutrient manipulations. Following discussions with the Manager – Environment, at the Council of Greater Shepparton (Mr Graeme Long), a second set of mesocosms were built in this shallow lake. The advantage of building the new mesocosms in Victoria Park Lake was that, should the Goulburn River flood in the period covered by the Project, we could run both sites simultaneously. As the Goulburn River did not flood, we could increase the intensity of our experiments on the Victoria Park Lake site.

The new mesocosms were constructed from fibreglass and placed in the lake in October 1998. Fifteen mesocosms were built, each 2 m in diameter. These are shown in Figures 3, 4 & 5. These mesocosms have been used for all subsequent nutrient-enrichment experiments. The main submerged macrophyte in the lake is the strapweed, *Vallisneria americana*, which is widely distributed across Australia and presents a significant management issue in many lakes, due to its vigorous growth (Figure 6).

Nutrient enrichment in Victoria Park Lake

Two sets of experiments were undertaken using the fibreglass mesocosms in the lake. The first, running from November 1998 to March 1999, assessed the effects of the following three treatments:

- Control mesocosms (to assess the possible enclosure effect of the mesocosms themselves on the system);
- Low-dose nutrient-enrichment; and
- Harvested mesocosms, in which all submerged plants were removed from within the replicated mesocosms devoted to this experimental manipulation.

Nutrients were added to the nutrient-enrichment treatment as an initial dose of inorganic nitrogen and phosphorus (240 $\mu g\ N\ L^{-1}$ and 20 $\mu g\ P\ L^{-1}$), followed by a chronic low-dose treatment with the slow-release fertiliser, Osmocote® , at a loading of 5 $g\ N\ m^{-2}$ and 0.7 $g\ P\ m^{-2}$.

The following experimental variables were quantified in each of the mesocosms:

- Nutrients in the water column (N and P, inorganic and organic, dissolved and particulate);
- Submerged macrophytes (biomass and leaf-area index);
- Phytoplankton (algae in the water column, in terms of chlorophyll *a* concentrations, cell counts and taxonomic composition);
- Epiphytes (algae growing on plants, in terms of chlorophyll *a* concentrations and taxonomic composition);
- Physiochemical conditions (underwater light regimes, pH, dissolved oxygen concentrations, salinity); and
- Sediment conditions (nutrients, redox potential).

Although the variables were quantified at intervals ranging from 2-6 times per day (e.g., dissolved oxygen concentrations) to only at the beginning and end of the experiment (e.g., plant biomass), most were quantified every week or every fortnight.

The second experiment ran from October 1999 to March 2000, and used the following three treatments:

- Control mesocosms;
- Medium-dose nutrient enrichment; and
- High-dose nutrient enrichment.

Again, nutrients were added as slow-release fertiliser Osmocote®, the medium dose as 13 g N m^{-2} and 1.2 g P m^{-2} and the high dose as 34 g N m^{-2} and 3.2 g P m^{-2}. The variables quantified were as for the first experiment, except that we also used potted plants of *Vallisneria americana* in order to measure its growth rates *in situ*.

Importance of sediments

In wetlands and urban lakes, the sediments represent the major reservoir for nutrients. As algae migrate between the sediments for nutrient acquisition, and the water surface to access light for photosynthesis, in shallow systems the distance algae must migrate is small and hence nutrients sequested in the sediments are more accessible. In contrast, in deep lakes algae must migrate long distances, and hence the water column represents the major nutrient pool for algae.

Most studies of the effects of nutrient enrichment have addressed deep lakes (e.g., the UNESCO Vollenweider models predicting eutrophication and algal biomass), even though most lakes and all wetlands are shallow.

Accordingly, we assessed the capacity of the lake sediments to:

- Adsorb inorganic phosphorus on to clay particles and iron oxyhydroxides;
- Adsorb ammonium onto clay lattices;
- Regenerate ammonium from decaying organic matter; and
- Reduce nitrate (denitrification by anaerobic bacteria).

These experiments were conducted in the laboratory in 1999-2000, using *in vitro* incubations of freshly collected sediment with various concentrations of orthophosphate, ammonium and nitrate.

Student projects

The experiments outlined above provided the core of our research program. Interesting issues that arose during these experiments were examined through student projects. The following students undertook their research projects as a supplement to this Project:

- Yvette Barry (1998/99, BSc Hons), "The independent and interactive effects of nutrients and light availability on the growth and community composition of periphytic algae in Lake William Hovell, an oligotrophic sub-alpine reservoir.";

- Dion Gervasi (1998/99, BSc Hons), "Growth responses of the aquatic macrophyte *Potamogeton tricarinatus* to different sources of nitrogen.";

- Warren Davies (1998, PhD), "Zooplankton-phytoplankton interactions in wetlands under various degrees of eutrophy.";

- Paul Davies (1999/00, BSc Hons), "Interspecific breakdown interactions of three species of macrophyte in a wetland.";

- Nicole Willers (1999/00, BSc Hons), "Decomposition of carp carrion in wetlands." and;

- Susanne Watkins (2000/01, BSc Hons), "The potential for *Melaleuca ericifolia* to inhibit decomposition in wetlands."

Summary of Results and Their Management Implications

Detailed descriptions of results have been presented at various workshops and conferences (see below, Communication Strategy) and are currently being prepared for publication in the scientific literature (see *Peer-reviewed publications*). The following is a summary of the key findings.

Nutrients were rapidly assimilated by wetlands, even at medium-high dose rates. For example, in Experiment 1, the initial dose of inorganic nitrogen and phosphorus designed to give a concentration in the water column of 240 μg N L^{-1} and 20 μg P L^{-1} failed to generate a significant increase in nutrient concentrations in the water. Even the subsequent chronic enrichment with the slow-release fertiliser, at a loading of 5 g N m^{-2} and 0.7 g P m^{-2}, did not cause significant nutrient increases in the water column. Typical results showing this phenomenon are shown in Table 1.

Table 1. Concentrations of dissolved nutrients in the water column of Victoria Park Lake after nutrient enrichment (in November). Means ± standard errors are shown, n = 3. SRP = soluble reactive phosphorus.

Date	Treatment	Nutrient concentration (μg L^{-1})	
		Ammonium	SRP
November 1998	Control	137 ± 35	90 ± 26
	+ Nutrients	133 ± 14	77 ± 14
December 1998	Control	93 ± 27	113 ± 30
	+ Nutrients	263 ± 38	96 ± 17
January 1999	Control	237 ± 22	73 ± 43
	+ Nutrients	240 ± 0	47 ± 17
March 1999	Control	233 ± 71	43 ± 9
	+ Nutrients	250 ±31	130 ± 81

Management Implication 1.

The management implication of this finding is that it is incorrect to conclude that a wetland is not suffering from even medium-level nutrient enrichment on the basis of continued low concentrations of inorganic nutrients in the water column. Nutrients are sequested in other abiological and biological components before they are found free in the water. Only when these pools have been saturated will nutrients be found in the water column, and by then the wetland will already have suffered severe ecological harm.

Phytoplankton responded quickly to nutrient inputs, even though the concentrations of nutrients in the water column did not increase as a consequence of enrichment. For example, chlorophyll *a* concentrations rose from ~ 10 μg L^{-1} to over 100 μg L^{-1} after enrichment of the mesocosms (Figure 7). A chlorophyll *a* concentration of this magnitude represents a massive algal bloom

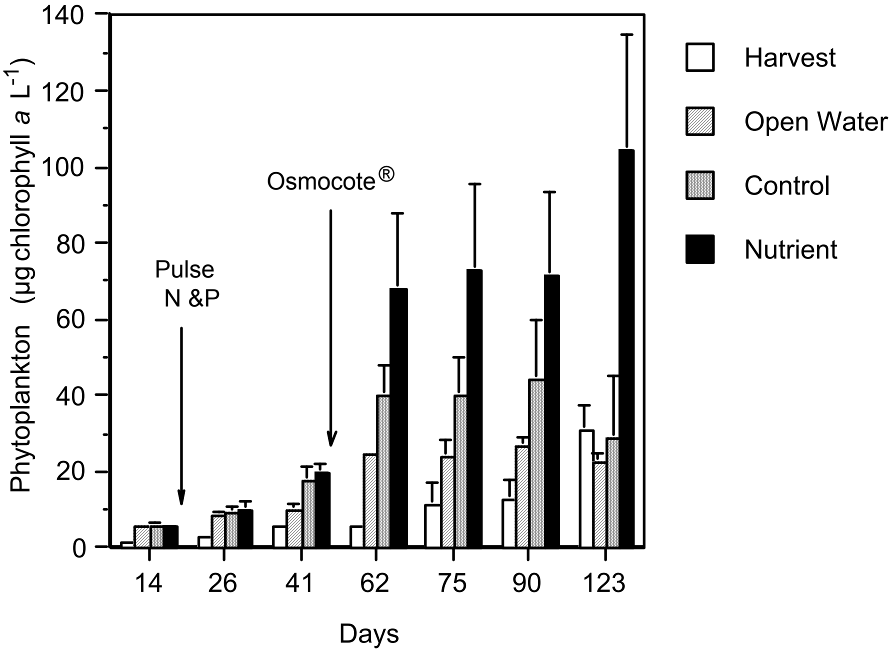

Figure 7. Mean phytoplankton abundance (µg chlorophyll *a* L^{-1}) over time following installation of mesocosms. Bars represent se, *n*=3. Arrows indicate the time at which the pulse of N & P or Osmocote® was added to nutrient mesocosms.

The taxonomic composition of the algae was highly diverse. Contrary to expectations, blue-green algae (cyanobacteria) were not the dominant algal group after nutrient enrichment, as green algae and euglenophytes were also abundant.

Management Implication 2.
Current monitoring programs, that address only blue-green algae, could easily miss significant algal blooms because the wrong "target" organisms are being studied.

In contrast to the case with the phytoplankton, the algae attached to the submerged plants (epiphytes) responded far less to nutrient enrichment. This was a surprising finding, as overseas (mainly European) models of the effects of nutrient enrichment on wetlands and shallow lakes stress the rapid and extensive growth of epiphytes in response to added nutrients. We did not find this or such a response. The taxonomic composition of these epiphytic communities was extremely diverse.

Management Implication 3.
It may be possible to use changes in the taxonomic composition of epiphytes as indicators of nutrient enrichment.

We identified two mechanisms which may account for reduced epiphyte abundance. Firstly, we found that epiphyte abundance on leaves of *Vallisneria americana* to be lower than that measured on artificial substrate. This suggests that the rate of leaf turnover in *Vallisneria americana* may be sufficient to prevent excessive build up of epiphytes. Higher rates of leaf loss in *Vallisneria* have previously been reported supporting this hypothesis. Secondly, epiphyte abundance was lower on leaves of *Vallisneria americana* taken from open water sites compared with those measured on leaves inside the mesocosms. This indicates that turbulence within dense stands of submerged macrophyte beds may help scour epiphytes from the leaf surface.

The submerged macrophytes (mainly *Vallisneria americana*) showed no positive response to low doses of added nutrients, increasing neither their biomass nor the concentrations of nutrients in their tissues. This is shown in Table 2, below.

Management Implication 4.
Macrophytes that are not nutrient limited will not serve as a sink for further nutrient inputs.

It is also evident from Table 2 that when *Vallisneria americana* had been removed from certain mesocosms in the Harvest Treatment applied in the first set of experiments at Victoria Park Lake, some regrowth occurred. A new plant, *Chara*, made an unexpected appearance.

Management Implication 5.
Wetlands or shallow lakes that have been harvested of their submerged plants (e.g., for aesthetic or recreational purposes) will show rapid regrowth of plants, including species that were not present earlier and which could be more problematic (e.g., in producing taste and odour problems) than the original species.

Table 2. Effects of harvesting plants from Victoria Park Lake on biomass of three species of aquatic macrophyte. Means ± standard errors are shown, *n* = 3. NP = Not Present.

Date and Treatment	Plant biomass (g DW m^{-2})		
	Vallisneria	*Potamogeton*	*Chara*
November 1998			
Premanipulation	308 ± 18	NP	NP
March 1999			
Control	400 ± 25	11 ± 2	NP
+ Nutrients	398 ± 42	23 ± 5	NP
Harvested	71 ± 33	19 ± 16	113 ± 4

In contrast to the case with low nutrient doses, medium and high nutrient doses applied in the second set of experiments at Victoria Park Lake resulted in the rapid and complete loss of the submerged macrophytes. In response to the higher nutrient doses the floating fern *Azolla* grew rapidly in the majority of mesocosms and soon covered the entire surface (Figure 8); the cause of macrophyte death was smothering of the wetland surface by *Azolla*.

The simplest explanation of this *Azolla* coverage is that the mesocosms provided a artificial and sheltered environment that facilitated *Azolla* growth, but this cannot be the *bona fide* cause, since *Azolla* also covered large sections of water in the lake external to the mesocosms and has been observed to cover entire wetlands in sites ranging from the Mitta Mitta River in north-east Victoria to Lindsday Island, near Mildura in western Victoria.

Moreover, the coverage by *Azolla* had a marked effect on the physiochemical characteristics of the water column. In *Azolla*-covered mesocosms, the underwater light regime was very different from the Control mesocosms not covered by *Azolla*, and the water column was very deficient in dissolved oxygen (i.e., became anoxic).

Significant algal blooms also occurred at higher levels of nutrient enrichment and in some instances formed extensive algal scums on the water surface (Figure 8). This also reduced light and dissolved oxygen concentrations in the water column and resulted in a drastic reduction in macrophyte biomass. Changes in light and dissolved oxygen concentration in control mesocosms and nutrient mesocosms, with either high or low *Azolla* cover are shown in Figure 9.

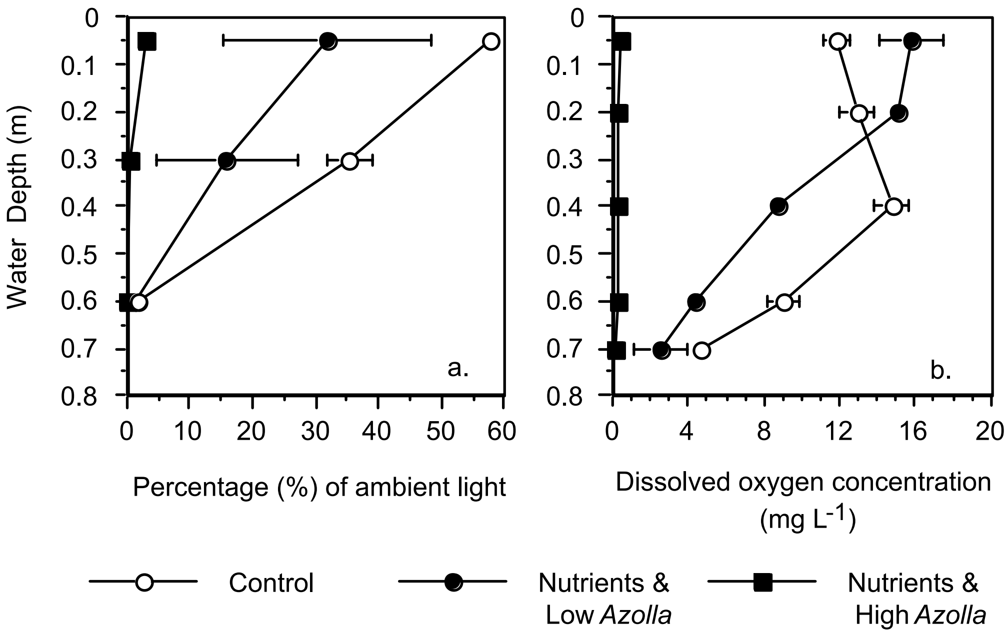

Figure 9. Light penetration through the water column expressed as a percentage of ambient light (a), and dissolved oxygen concentration (b), with increasing water depth. Data are means; bars represent se; *n* = 5, 3 and 7 for Control, Nutrients and Low *Azolla* and Nutrients and High *Azolla*, respectively. High *Azolla* refers to mesocosms in which 50% or more of the water surface was covered by *Azolla*.

Two explanations can be proposed to link the spread of *Azolla*, death of *Vallisneria*, and altered physiochemical conditions:

- The death of the *Vallisneria* was due to reduced light availability arising from the dense blanket of *Azolla*, and the fall in dissolved oxygen concentrations occurred as a consequence of *Vallisneria* death; or

- *Vallisneria* died as a direct result of the fall in dissolved oxygen concentrations, caused by the blanket of *Azolla* restricting the diffusion of oxygen across the water-air interface.

It is difficult, however, to discriminate between these two explanations, since reductions in photosynthesis with shading will also reduce oxygen production, exacerbating oxygen deficits imposed by the blanket of *Azolla*.

Management Implication 6.
Irrespective of the cause, the catastrophic loss of submerged macrophytes soon after nutrient enrichment has a number of very serious management implications:

- Anoxia resulted in fish kills, with large dead fish being observed in the affected mesocosms;
- Production of taste and odour problems in the anoxic mesocosms, especially following the decay of the plant and animal life;
- Loss of habitat, initially provided by the submerged macrophytes, and consequences for survival of herbivorous zooplankton which graze of algae, when the *Azolla* cover is eventually scattered over the following winter; and
- A considerable loss of biodiversity following loss of submerged plants from wetlands.

Earlier it was noted that the concentrations of inorganic nutrients in the water column failed to increase markedly in response to addition of even moderate inputs of nitrogen and phosphorus. The question arises: Where do these nutrients go? The laboratory experiments with sediments provided an answer: the additional nutrients are quickly adsorbed by the sediments of the wetland. Figure 10. shows the kinetic response of phosphorus uptake by sediments: added SRP is rapidly adsorbed onto clay particles and iron oxyhydroxides.

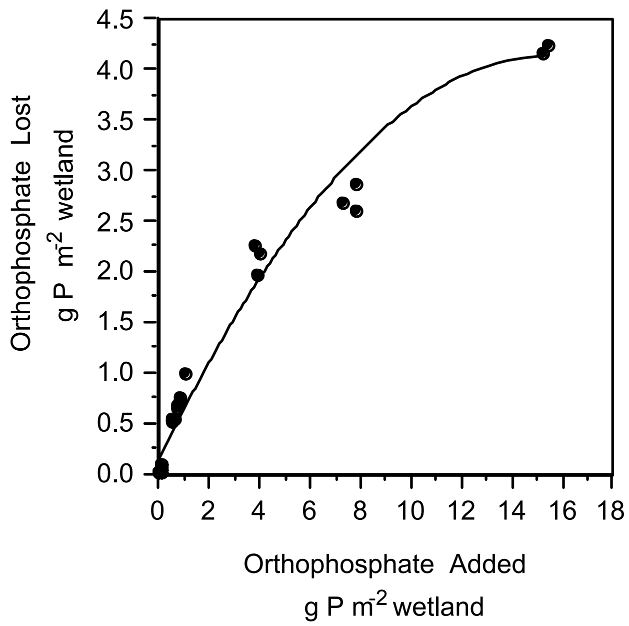

Figure 10. Amount of orthophosphate lost to the sediments (g P m^{-2} wetland) as a function of the amount of orthophosphate added after 24 hours incubation. bars represent se, *n*=5.

Scaling-up calculations indicate that uptake by the sediments can account for all the nutrients that were added to the mesocosms in the low- and medium dose experiments. It is noteworthy that it was with these two levels of nutrient additions that increases in nutrient concentrations in the water column were not observed; increases were only detected in the high-dose treatment, when the adsorptive capacity of the sediments had been exceeded.

Management Implication 7.
Routine monitoring of concentrations of dissolved inorganic nutrients in the water column will not detect nutrient enrichment. The concentration of inorganic nutrients in the water column will only become evident once the capacity of the sediment to bind nutrients becomes exhausted and when biological processes such as uptake by primary producers is saturated. It is likely that only after considerable changes to the ecosystem have taken place will increases in inorganic nutrients occur. By this time algal blooms are evident, floating plants have proliferated and the loss of macrophytes is eminent.

Although one could determine the susceptibility of a wetland to nutrient enrichment by monitoring the relative saturation with nutrients of the sediment exchange complex, it is an expensive undertaking and is unlikely to be conducted in routine monitoring programs.

Management Implication 8.
The switch from a macrophyte dominated state to a phytoplankton dominated state can occur rapidly.

Management Implication 9.
There is a distinct limit to the potential for use of wetlands to treat nutrient-enriched waters, such as storm water, arising from saturation of sediment-binding capacity.

Management Implication 10.
Rooted, submerged macrophytes greatly promote the loss of nitrogen from wetlands by facilitating nitrification/denitrification processes in the sediments, and by generating high pH values in the water column which promote the volatilization of ammonium. Removal of significant amounts of these plants is likely to reduced the rates of such processes, and lead to the appearance of inorganic nutrients in the water column.

Communication Strategy

In view of the relevance of the research findings for the improved management of aquatic resources in Australia, we made the commitment to an effective communication strategy a key feature of the Project. In order to circulate widely the research findings and their management implications, a wide range of communication approaches was developed, and these are described below.

Workshops

The Research Team was involved in six workshops during the Project, three of which were general in their coverage and the other three specifically tailored as avenues to communicate specific research results and management implications.

We presented a paper at the workshop "Wetlands in a Dry Land: Understanding for Management" held in Albury in September 1997. A chapter entitled "The implications of nutrient enrichment for wetland management" was written for the workshop, and subsequently published in the book *Wetlands in a Dry Land: Understanding for Management* edited by W.D. Williams. Associate Professor Boon also held a 2-day Environmental Industry Training Workshop for Greening Australia on "Ecology and Management of Wetlands" in April 1998, at Victoria University. A second workshop, again sponsored by Greening Australia, on "Wetland Ecology and Management" was held at Dunkeld (the Grampians, western Victoria) in November 2000, with presentations on wetland ecology, assessment of wetland health, and quantification of wetland water quality.

In addition to participating in these three general wetland workshops, the Research Team organised three information workshops specific to the Project in 2000:

- Maffra (eastern Victoria), 29 May 2000;
- Tatura (central Victoria, near the field sites), 14 June 2000; and
- Sale (eastern Victoria), 3 August 2000.

Agendas for the workshops are attached in Appendix B. These show the aims of the workshops were to facilitate transfer and application of the research findings. An indication of the value placed on these workshops by stakeholders and industry groups is that the Tatura workshop was largely sponsored financially by Goulburn-Murray Water, and the Maffra and Sale workshops attracted partial financial sponsorship from the Victorian Department of Natural Resources and Environment and Waterwatch.

Each of these three focussed workshops attracted 20-60 participants, from a wide range of institutions. The organisations represented included the following:

- Community groups, such as Field and Game Victoria, Waterwatch, the Field Naturalists Club, Victorian Wetlands Trust, and the Australian Landscape Trust;
- Landcare groups;
- Consulting firms, such as Nolan ITU, EDAW, CMM Fisher Stewart, Sinclair Knight Merz, and Water EcoScience;
- Research organisations, including CSIRO and the CRC for Freshwater Ecology;
- Government departments, including the Department of Natural Resources & Environment, Department of Infrastructure, Parks Victoria, Victorian EPA and Agriculture Victoria; Environment Australia and Land and Water Australia
- Rural Water Authorities, such as Goulburn-Murray Water, and East Gippsland Water;
- Educational organisations, including Deakin, Monash and Adelaide Universities, and various TAFEs;
- Local Councils;
- Catchment Management Authorities, including North Central CMA, Goulburn-Broken CMA and East Gippsland CMA ;
- RAAF;
- Gippsland Coastal Board;
- Wellington Salinity Group; and
- Gippsland Water Monitoring Partnership.

At the Tatura and Sale workshop, an evaluation sheet was circulated to gauge the workshops' effectiveness. Summaries of workshop evaluation responses are given in Table 3, below.

Table 3. Evaluation of workshops' effectiveness.

	Percentage of responses			
Workshop	Excellent or Very useful	Good or Useful	Satisfactory or Some use	Poor or Not useful
Tatura Workshop, 14 June 2000 (*n* = 30 responses)				
Presentation quality	27	70	3	0
Content of research	37	50	13	0
Group discussion	17	64	13	6
Sale Workshop, 3 August 2000 (*n* = 30 responses)				
Presentation quality	47	53	0	0
Content of research	67	30	3	0
Group discussion	38	42	17	3

Note that the participants overwhelmingly found (81 – 97 % of participants) the workshops to be at well run and the research useful or excellent in quality and potential application to the management problems that they faced. None of the 60 participants who returned their assessment forms found the research to be of no use to them.

Information brochures

Two information brochures were produced, and 1000 copies of each distributed widely across government departments and agencies, non-government organisations, scientific societies, and conservation groups. The first brochure was produced at the commencement of the Project, to advertise its aims. The second was produced at the beginning of 2000, when most field experiments had been finalised, and aimed to provide a summary of key findings to wetland managers.

Copies of the two brochures are attached in Appendix C.

Newsletter articles

Articles on the Project were published in the following newsletters and newspapers:

- "Visiting wetland scientists". *Gippsland Times and Maffra Spectator*, 28 August 1998;
- "Effects of nutrient enrichment on wetlands". *Wetland Link* 2: 2 (2000);

- “Research hopes for damaged wetlands”. *Monash News* (2000);
- “So long and thanks for all the fish”. *Nexus* 10 (1): 5 (2000); and
- “Some unexpected results: the consequences of nutrient enrichment of wetlands”. *Wetlands Alive* 4 (2): 10 (2000).

Links with other programs

Formal links were established during a visit to Canberra in December 1997 with Dr Richard Davis, Program Co-ordinator of the National Eutrophication Management Program (NEMP. A summary of the research undertaken in the current Project was placed on the NEMP’s internet Home Page in May 1998.

Technology Transfer

The Research Team has been involved in the following studies linked with the Project:

- “Lake Mokoan Biomanipulation Workshop”, November 1998;
- “Revegetation Plan for Jones Park Lake, Brunswick”, December 1998;
- “Review of NRE Wetland Monitoring Program”, December 1998;
- “Clay Particles and Water Quality of Karkarook Lake and Wetlands, Moorabin”, February 1999;
- “Wetland management plans for Lakes Cullulleraine, Iraak, Powell and Carpul”, February 2000; and
- “Development of a Lakes Management Plan for the Kialla Lakes”, August 2000

Requests for information

In February 2000, the two Principal Investigators were selected as Specialist Advisors for Wetland Care Australia.

Other requests for information on nutrient inputs to wetlands were received throughout the period of research from the following wetland managers, and advice provided to:

- Urban Initiatives, Melbourne;
- Water EcoScience, Melbourne,Victoria;
- Natural Resources and Environment, Maffra, Victoria;
- Sinclair Knight Merz, Melbourne, Victoria;
- Woodward-Clyde, Melbourne;
- City of Greater Shepparton Council, Shepparton, Victoria;
- Royal Botanic Gardens Melbourne, Victoria;
- Glossop High School, South Australia;
- Inland Fisheries Service, Tasmania; and
- Tweed Shire Council, New South Wales

Conference papers

Results from the research have been progressively aired to audiences at a number of conferences and workshops addressing the ecology and management of aquatic resources, including:

- Boon, P.I., Bailey PC, Morris K & Hughes LS (2001). Nutrient enrichment and the loss of submerged aquatic plants from wetlands and shallow lakes: an experimental approach. Societas Internationalis Limnologiae.XXVIII Congress, Melbourne: 4-10 February 2001;

- Boon PI (2000). Loss and degradation of wetlands in south-east Australia. Australian Wetlands Forum - Australian Society for Limnology Annual Scientific Congress. Darwin: 7-10 July 2000;

- Boon PI, Bailey PC, Morris K & Hughes LS (2000). Multiple stable states in wetlands: I: A background to experimental studies. Australian Society for Limnology Annual Scientific Congress. Darwin: 7-10 July 2000;

- Morris K, Bailey PC, Boon PI & Hughes LS (2000). Multiple stable states in wetlands: II: Nutrient enrichment and the loss of submerged plants. Australian Society for Limnology Annual Scientific Congress. Darwin: 7-10 July 2000;

- Hughes LS, Morris K, Bailey PC & Boon PI (2000). Multiple stable states in wetlands: III: Where do the nutrients go? Australian Society for Limnology Annual Scientific Congress. Darwin: 7-10 July 2000;

- Bailey PC, Boon PI, Morris K & Hughes LS (2000). Multiple stable states in wetlands: IV: Management implications of research findings. Australian Society for Limnology Annual Scientific Congress. Darwin: 7-10 July 2000;

- Boon PI (2000). Ecological impact of freshwater inflows to the Coorong. South Australian Department of Environment and Heritage, Adelaide 19 May 2000;

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- Morris K, Boon PI, Bailey PC and Hughes LS (1999). Effects of nutrient enrichment and plant harvesting on primary producers in a shallow urban lake densely vegetated by the submerged macrophyte *Vallisneria americana*. New Zealand Limnological Society and Australian Society for Limnology Joint Annual Conference. Wairakei (New Zealand): 29 Novermber - 2 December 1999; and

- Boon PI (1998). Carbon cycling in Australian wetlands. Lakeside seminar series Australian Society for Microbiology, Tasmanian Branch. Bronte Park, 1-3 May 1998.

Peer-reviewed publications

One paper has been published in the scientific literature: the chapter "The implications of nutrient enrichment for wetland management" published in the book edited by W.D. Williams (1998) *Wetlands in a Dry Land: Understanding for Management*.

Two manuscripts are currently in preparation for submission to the peer-reviewed journal, *Freshwater Biology*:

- "Stable states in the vegetation of wetlands and shallow lakes. The effect of nutrient enrichment and plant harvesting"; and
- "Stable states in the vegetation of wetlands and shallow lakes. A novel mechanism for the loss of macrophytes".

We anticipate that both manuscripts will be submitted by April 2001. The publication of research findings in the peer-reviewed literature will ensure that they are readily accessible to a wide range of researchers and managers, and will be archived for future reference. Publication in the peer-reviewed press is a key feature of scientific research, and the research cannot be considered to be complete until such publication has taken place.