Potential for the restoration of aquatic macrophytes in billabongs

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ABSTRACT: *Aquatic macrophytes greatly enhance the conservation value of billabongs (floodplain lakes), but many billabongs are devoid of macrophytes. Evidence from the fossil record and a limnological survey suggests a regional decline in macrophytes since the mid 1800's, and supports a hypothesis of 'switching' in the dominance of aquatic macrophytes and phytoplankton. It may be possible (and practical) to switch the plant dominance back to the macrophytes. To do so would involve improving the light conditions for macrophytes by temporarily lowering water levels. Once macrophyte dominated, the billabongs should remain so unless further unnatural perturbations occur.*

1. INTRODUCTION

Aquatic macrophytes are an important component of shallow lakes. They provide substrate for a variety of organisms, contribute enormous amounts of organic matter to food chains, and create diverse physicochemical conditions that often differ markedly from adjacent open-water regions (Carpenter and Lodge 1986; Carignan and Neiff 1992). Besides harbouring large invertebrate communities (Timms and Moss 1984; Cyr and Downing 1988), macrophytes provide protection for small fish, including fish fry (Zaret 1984; Timms and Moss 1984; Nichols 1991), and increase the waterfowl carrying capacity of a lake (Bellrose et al. 1979; Scheffer et al. 1993).

Thousands of shallow floodplain lakes, known as billabongs, fringe the lowland rivers of the south east Murray Basin (Pressey 1986). Most of these are abandoned former river courses or related depressions formed as rivers migrate across their floodplains. Billabongs along river tracts are practically the only natural freshwater lakes found over vast areas of inland Australia, so that their ecology is of special importance.

Aquatic macrophyte cover is highly variable between billabongs; some are choked with vegetation and others are almost entirely devoid of higher plant life. It is noteworthy, though, that most of the large, abandoned channels have little submersed macrophyte cover, in spite of having extensive shallow water regions that seem suitable for the development of beds of submersed plants. Many of these billabongs are fringed by emergent plants such as sedges and rushes, but these provide less structural diversity for aquatic biota than some of the common submersed plants such as *Myriophyllum*, and submersed and emergent plants differ in their effects on billabong limnology (Boon et al. 1990).

The ecological importance of aquatic macrophytes makes factors underlying variation in plant cover of considerable interest, and in particular whether plant cover is affected by land use or other factors that offer management opportunities.

The landscape surrounding the Murray River and its tributaries has changed vastly since settlement in the mid 1800's (Buxton 1974). Farming, mainly the grazing of cattle and sheep, is practised throughout the south east Murray Basin. The Murray River and several of its tributaries have been dammed well up their tracts. Carp are widespread in the river-flood plain system (Shearer and Mulley 1978).

The aim of this paper is to demonstrate the relationship of land use or other human-related impacts (e.g. fish introductions) to regional patterns of aquatic macrophytes. The results are discussed with reference to potential management avenues for the enhancement of submersed aquatic macrophyte cover.

2. STUDY SITES

The study region encompasses the eastern Murray River and the lower Ovens River (figure 1). This region includes stretches of unregulated river (Murray River above the Hume Dam, Ovens River) and regulated river (Murray below the Hume Dam). Farming intensity on the floodplain is variable but generally decreases downstream for both rivers.

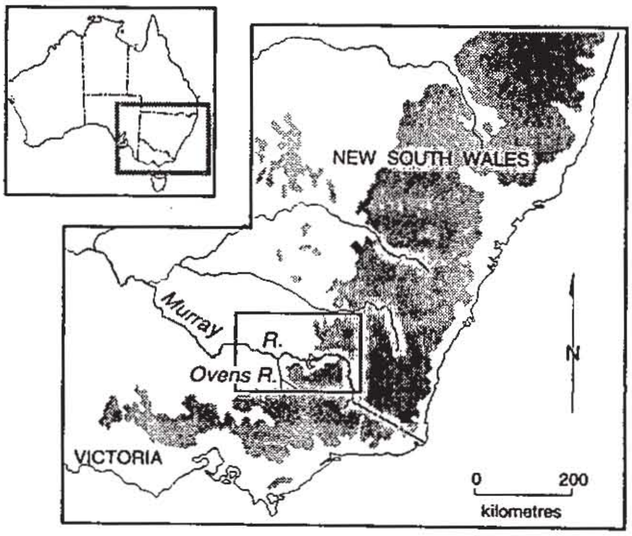

Figure 1. The study region. Stippled area is above 600 m.

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site	location	area (ha)	max depth (m)
9	U Murray	3.6	1.5
Hogan's	M Murray	5.4	4
21	Ovens	3.4	1.9
23	Ovens	1.6	2.0
25	Ovens	1.3	1.5
32	L Murray	4.8	3.6
38	L Murray	5.4	3.1

Table 1. General features of billabongs from which sediment cores were obtained. All are either sublinear abandoned channels or cutoff meanders. U, M, and L refer to upper, middle and lower sections of the Murray in the study area.

Forty two billabongs were surveyed for their limnology. Billabongs were selected using a stratified sampling method so that unregulated sites and sites with low farm exposure are adequately represented (Ogden 1996). A strictly random sampling in the study region would be biased towards intensely farmed and regulated billabongs, reflecting the predominance of land use practices in the region. Thirty one billabongs were randomly selected within farming and regulation strata and a further 11 billabongs were added to the survey to bolster the representation of billabongs that are less intensely farmed. Farming intensity was gauged by the density of trees and saplings, and observations of stock, dung, stock trails and billabong bank collapse.

The number of billabongs surveyed on each river reach is 11 on the Murray above the Hume Dam, 8 on the Murray between the Hume and the confluence with the Ovens River, 14 on the Murray below Lake Mulwala, and 9 on the Ovens River.

Sediment from 6 billabongs in the limnological survey and one other billabong were examined for their fossil record (table 1).

3. METHODS

This section provides an outline of the methods used in this study. A more detailed description of the methods is found in Ogden (1996).

3.1 Present day patterns

A 15 month sampling program was undertaken to the correlate physicochemical and plant cover data from each of the 42 billabongs in the survey. Sampling trips were carried out every 2 months starting in January 1992 and finishing in March 1993. Billabongs were not sampled if they were dry or were experiencing a substantial flood.

Macrophyte abundance was visually estimated and a score was recorded corresponding to < 5%, 5-25%, 25-50%, 50-75% or 75-100% plant cover. Maximum depth was recorded and physicochemistry was measured from the deepest point in the billabong, preferably in open water. pH was measured at 1 m depth and 3 integrated samples of the top 2 m of the water column were pooled for chemical analyses. Bicarbonate was measured on site by titration and the remaining measurements (turbidity, major ions, total nitrogen, total phosphorus) were made on stored samples by standard methods.

3.2 Historic patterns

It is possible that pristine control billabongs no longer exist for gauging the impact of land use on macrophytes since farming occurs throughout the region (Walker and Hillman 1977). The relative amount of fossil remains of two families of Cladocera with contrasting habitat preference, Bosminidae which prefers open water, and Chydoridae which are mainly littoral species, is used to estimate the past extent of the littoral zone in the billabongs (cf. Korhola 1992). The percentage of Chydorids in billabong surface sediments has been shown to be positively related to aquatic macrophyte cover estimated as outlined above (Ogden 1996).

A single sediment core recovered from the deepest point in each of seven billabongs was sampled every 20 cm. Three surface sediment samples (top 1 cm) from the profundal zone were also pooled for analysis. The silt fraction, including cladoceran remains, was isolated from dispersed sediments by sieving and the fossils separated from inorganics by running the sample through a water column. The sample was dewatered, put in silicon, and slides prepared. Fossils were counted at 100x magnification. Estimates of percent chydorids are based on 200 - 300 remains.

Billabong sediments deposited after ca. 1870 are differentiated on the basis of the presence of pollen from the introduced tree genus *Pinus*, which has been confirmed as a valid post settlement marker by ^{210}Pb dating in two cores (Ogden 1996). The *Pinus* pollen was isolated in the same manner as Cladoceran remains, and counted using a dissecting microscope.

4. RESULTS AND DISCUSSION

4.1 Historic macrophyte levels

There is a sharp decline in the percentage of chydorids around the first appearance of *Pinus* pollen, in 6 of the 7 sediment cores examined (figure 2; table 2). The timing of the decline is interpreted as ca. 1870 (see above), just after settlement of the region by Europeans.

About half the decrease is due to taphonomic processes; the percentage of chydorid remains in surface sediments is higher than sediments immediately below this in a number of billabongs, including several with very low aquatic macrophyte

site	present day submersed macrophyte cover	depth in profile of first *Pinus* pollen	depth of 'step' decrease in % chydorids	nature of pre settlement record
9	nil	75	between 65 and 45 cm	poorly preserved in parts but macrophyte cover appears to be variable
Hogan's	nil though few observations	95	between 105 and 85 cm	macrophyte cover high throughout
21	some seasonal cover at margins	35	between 45 and 25 cm	poorly preserved
23	extensive cover	25	none: possible decrease at 35 cm not sustained	few sections examined; poor preservation in most of the sections
25	some seasonal cover at margins	55	between 85 and 65 cm	not extensively examined
32	nil	62	between 65 and 55 cm	macrophyte cover high throughout

Table 2. Present-day and historic levels of aquatic macrophytes in 6 billabongs. The 'step decrease' in chydorids corresponds to decreasing macrophyte cover, and the appearance of *Pinus* pollen to European settlement (see text).

cover. Therefore, higher percent chydorid remains do not reflect a recent expansion of macrophyte beds, but relatively less preservation of chydorid than bosminid remains in samples below the surface zone of accumulation.

In spite of historic changes in preservation potential, the fossil cladoceran profiles still indicate a decrease in aquatic macrophyte cover since settlement. Taphonomic processes consistently account for less than 50 % of the decline in percentage chydorids. The remaining decrease is interpreted as indicating a contraction in the extent of aquatic macrophyte beds.

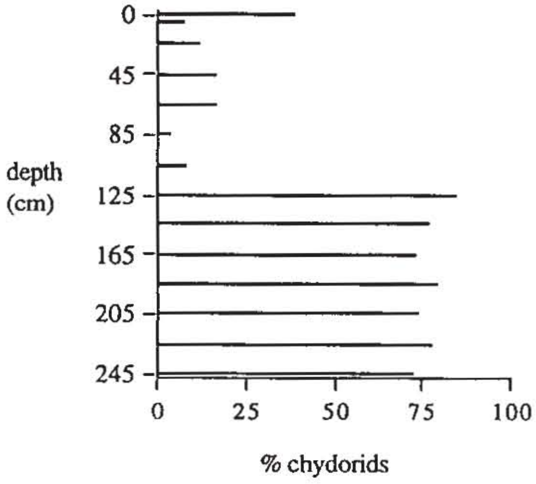

Figure 2. The profile of percent chydorids in a sediment core from site 38. The first appearance of *Pinus* pollen is at 115 cm. Present day macrophyte cover in site 38 is nil. See caption to table 2 and text for explanation.

Supporting this, the one billabong with extensive, persistent macrophyte beds (site 23; table 2) does not show a marked decrease in percentage chydorids. Lower organic inputs to sediments from macrophytes since settlement have increased the oxidation of sediments (Ogden 1996), which has also affected the percentage of chydorid remains preserved.

The historic contraction of macrophyte beds is likely to be related to submersed rather than emergent macrophytes. Present-day billabongs often have a fringe of emergent vegetation but lack submersed macrophyte beds. Much less commonly, both emergent and submersed macrophytes occur. The emergent macrophytes appear to colonised to the same depth in both instances, suggesting that they would not have colonised a greater area in the past. Furthermore, the historic decrease in macrophytes is as apparent in billabongs with fringing emergent macrophytes as ones with more limited development of emergent plants.

It is noteworthy that in cores with continuous preservation of Cladocera, for example cores from sites 32, 38 (figure 2) and Hogan's Billabong, the levels of percent chydorids vary little within either the pre settlement or post settlement period.

The patterns and timing of macrophyte decline are at odds with several theories for explaining macrophyte abundance. The decrease in macrophytes is not gradual enough to invoke succession as the mechanism, and in any case is the opposite pattern to what is expected from succession (Korhola 1992). Carp are clearly not the agent underlying this variation. The major period of carp expansion is in the 1960's (Shearer and Mulley 1978), nearly a century after the decline in macrophytes. Tench (*Tinca tinca*) and Redfin (*Perca fluviatilis*) were introduced during the time period corresponding to the decline in aquatic plants (Weatherly and Lake 1967). However, the comparative effects of these species and native fish on billabong macrophytes are unknown.

River regulation is not responsible since regulation began in the 1930's, which post dates the decline in macrophytes, and the decline also occurs on unregulated sections of floodplain.

Early farming, mainly grazing, was concentrated on the floodplain since alternate water sources did not exist (Williams 1962). Cattle and sheep may have eaten macrophytes or increased turbidity levels in billabongs. Extensive tree clearance in the early days was carried out to provide fuel for riverboats (State Pollution Control Commission 1987). This may have affected billabongs via litter inputs, protection of banks and wind exposure. However, since the grazing and tree clearance on the floodplain have decreased this century (Ogden 1996), why have aquatic macrophytes not recovered to their pre settlement levels of abundance?

The 'step' decrease in chydorids suggests that two alternative stable states (Scheffer et al. 1993) exist for macrophyte cover in billabongs and that the billabongs have 'switched' to phytoplankton dominance in the post settlement period. Rapid switching of shallow lakes between macrophyte dominated, clear water phases and turbid phytoplankton dominated phases has been documented in other parts of the world (Scheffer et al. 1993). In Australia, Douglas-Hill (1995) recently suggested that these two stable states are found in New South Wales farm dams.

Scheffer (1990) and Scheffer et al. (1993) have developed a theory to explain the phenomenon of switching in the dominance of macrophytes and phytoplankton with a number of assumptions and predictions that can be examined in the context of south east Murray Basin billabongs.

4.2 Alternative stable states?

Scheffer (1990) and Scheffer et al. (1993) have proposed that in certain situations it is possible for alternative equilibria between macrophytes and phytoplankton to exist from the same initial lake conditions. The alternative states are stable due to a number of feedback mechanisms. A variety of disturbances may lead to a switch from one stable state to another, but the proximal reason for switching is turbidity (see below).

It appears that the same set of initial conditions has lead to different endpoints of macrophyte cover in the region's billabongs. Conditions in billabongs dominated by macrophytes are only consistently different from phytoplankton dominated sites with respect to water clarity (Ogden 1996). Mean nutrient levels are lower in macrophyte dominated billabongs but medians are not appreciably lower (table 3), suggesting that general levels of nutrient loading are the same but phytoplankton dominated sites have occasional periods of high nutrients. pH is circumneutral in all sites, waters are fresh at all times, and patterns of macrophyte dominance are not correlated with maximum site area (Ogden 1996). However, this conclusion must be tempered by the fact that a number of potentially important factors (e.g. trace elements) were not measured.

The theory of alternative stable states is only applicable to lakes where nutrient limitation of macrophytes is not a primary factor (Scheffer 1990). Nitrogen and phosphorus often limit plant growth but this is almost certainly not the case in the regions billabongs. Average annual levels of nitrogen and phosphorus in the billabongs surveyed are eutrophic by OECD standards (table 3 and Ogden 1996; Rast et al. 1989).

Another assumption is that sections of the water column in the shallow lakes are at or near a critical light level for photosynthesis to take place (Scheffer et al. 1993). The euphotic depth of the regions billabongs was not measured in the limnological survey but can be roughly estimated from the levels of turbidity and secchi depths observed (table 4). The precision of such estimates is poor (Kirk 1994) but adequate enough to indicate that the regions billabongs have euphotic depths near to maximum site depth, as was found for Ryans 1 billabong in the centre of the field area (Oliver 1990, table 4).

Alternate equilibria should only be found in shallow, relatively even-bottomed lakes (Scheffer 1990). In such lakes, normal fluctuations in turbidity will prevent photosynthesis in a relatively large section of the water column since turbidity levels are already near critical levels for photosynthesis. At some point, as turbidity levels increase, a catastrophic decline in macrophytes will occur since nearly all of

site	total N mg/l med	mean	max	total P mg/l med	mean	max
1	.42	.52	1.11	.05	.11	.42
5	1.40	1.28	1.60	.14	.14	.25
6	1.15	1.17	1.48	.09	.13	.42
7a	.45	.61	1.40	.09	.19	.62
22	1.20	1.41	2.80	.13	.14	.23
23	.97	.99	1.40	.09	.13	.32
all 42 sites:	1.36	2.05	19.6	.16	.30	5.2

Table 3. Levels of total nitrogen and total phosphorus in well vegetated sites and all sites in the limnological survey.

	mean depth (m)	turbid. (NTU)	mean secchi depth (m)	Z_{eu} (m)	Z_{col} (m)
this study:					
42 sites	1.6	34 (mean)	.44		1.1 (T) 1.3 (S)
Oliver 1990:					
Ryans1		5 - 12		.9-2.3	1 - 2
Ryans2		7 - 90			.2 - 2

Table 4. The light environment in the regions billabongs. Z_{eu} is euphotic depth and Z_{col} is potential depth of colonisation by macrophytes (Kirk 1994). (T) and (S) are estimates based on turbidity and secchi depth, respectively.

the macrophytes occupy the same position in the water column. Once the majority of the water column is only habitable by phytoplankton, feedback mechanisms help stabilise this state. In deeper lakes with gradually sloping basins, the relative area that can be colonised by macrophytes does not change as drastically as turbidity levels increase, and the decline in macrophytes is more linear with increasing turbidity levels.

The billabongs with the clearest evidence of switching (sites 32, 38, Hogan's Billabong) are the deepest billabongs examined for their historic plant cover, but are also the largest sites and probably have the most gently sloping bottoms. The billabongs in the survey that are macrophyte dominated mainly seem to fall into two groups: shallow sites and deep sites that have fairly steeply sloping basins, which supports Scheffer's hypothesis.

The patterns of aquatic macrophytes in the region are consistent with the theory of alternative stable states. Such evidence cannot be construed as proof that switching is the dominant mechanism in billabongs, but stands as a useful starting point for management initiatives and a hypothesis for further research.

4.3 Restoration of macrophytes

The restoration of aquatic macrophytes in billabongs is desirable because of their ecological importance. Very shallow billabongs tend to be macrophyte dominated, but are generally ephemeral and poor habitat for longer lived species such as fish (cf. Bonetto et al. 1969). This discussion is therefore restricted to consideration of deep water billabongs.

Attempts at the restoration of aquatic macrophytes in billabongs previously dominated by phytoplankton has been successful in a number of instances (Moss 1990; Hosper and Jagtman 1990). A variety of methods have been employed, but several general trends are apparent that have differing applicability to billabongs.

A reduction of nutrient loadings is, depending on nutrient levels, necessary or helpful if macrophytes are to be restored (Jeppesen et al. 1990; Moss 1990; Scheffer 1990). However, a reduction in nutrient loadings is probably not required in this situation since there are deep billabongs in the region that are macrophyte dominated which are about as nutrient rich as phytoplankton dominated billabongs (table 3). Jeppesen et al. (1990) also found lakes the size of billabongs remained macrophyte dominated at phosphorus levels encountered in this study. In any case, nutrient reduction is probably not feasible in the shorter term due to the extensive use of fertilisers in the region and the diffuse source of nutrients carried by floods.

Food web manipulations have successfully restored macrophytes by encouraging the growth of large bodied Cladocera (e.g. *Daphnia*) which effectively keep phytoplankton populations in check (Moss 1990). These often involve introducing a piscovore, which puts pressure on planktivorous fish, releasing the populations of *Daphnia* from predator control. However, piscovores undoubtedly gain access to billabongs during floods and if they have not reduced the populations of planktivorous fish already there is no reason to believe artificial introductions will have any more success. Nevertheless, the emplacement of artificial shelters for *Daphnia* is one possible way that their populations may be encouraged (Moss 1990; but see Irvine et al. 1990).

With respect to restoration by food web manipulations, it is noteworthy that the only human related impact other than farming and tree clearance that corresponds to the timing of the decline in macrophytes is the introduction of Tench and Redfin. It would be interesting to know if these fish directly or indirectly affect *Daphnia* abundance differently than native planktivores. If so, the abundance of these exotic fish may have to be taken into account in the restoration of aquatic macrophytes.

Perhaps the most promising method involves directly improving the light environment for macrophytes. This can be achieved by temporarily lowering water levels (Scheffer et al. 1993). Currently, low water in billabongs corresponds to the late summer and winter during macrophyte senescence, and high water to the spring when maximum growth of macrophytes occurs, which is the opposite of what is desired to restore macrophytes (Ogden 1996). Water could be pumped out during the spring so that macrophytes receive maximum sunlight during their growth phase. Once restored, the macrophyte beds should be stable unless another unusual disturbance occurs, so that ongoing water level manipulations are not required.

The billabongs chosen for restoration should be as remote from farm activities as possible and have a good cover of trees to faithfully recreate the pre-settlement conditions. They should be isolated from large-scale water level fluctuations that characterise billabongs with connections to the Murray River during irrigation flows (Pressey 1986; Ogden 1996). Seeding with plant propagules is desirable, and the abundance of carp may have to be taken into account.

5. CONCLUSION

The evidence presented above lends support to the hypothesis by Scheffer et al. (1993) that two alternative stable states exist in the billabongs; one that is macrophyte dominated, and one that is phytoplankton dominated. Phytoplankton currently dominate most of the large, deep billabongs in the study region. The restoration of aquatic macrophytes is desirable in light of their ecological importance, and it may be possible to switch billabongs from phytoplankton dominance back to macrophyte dominance. Projects that aim to restore aquatic macrophytes in the regions deeper billabongs offer a good opportunity to meld management and science. The process of the restoration of macrophytes can be used as an experiment to test the general hypothesis of alternate stable states and uncover the mechanisms involved.

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6. REFERENCES

Bellrose, F.C., Paveglio, F.L. & Steffeck, D.W. (1979) Waterfowl populations and the changing environment of the Illinois River Valley. Illinois Natural History Survey Bulletin 32: 1-53.

Bonetto, A., Dioni, W. & Pignalberi, C. (1969) Limnological investigations on biotic communities in the Middle Paraná River Valley. Verh. Internat. Verien. Limnol. 17: 1035-1050.

Boon, P., Frankenberg, J., Hillman, T., Oliver, R., Shiel, R. (1990) Billabongs. In The Murray , Eds. N. Mackay and D. Eastburn, pp. 167-181. Murray-Darling Basin Commission, Canberra.

Buxton, G. L. (1974) The middle reaches in the 19th century. In The Murray Waters, Man, nature and a river system Ed. H. J. Firth and G. Sawer, pp. 109-123. Angus and Robertson, Sydney.

Carignan, R. & Neiff, J.J. (1992) Nutrient dynamics in the floodplain ponds of the Paraná River (Argentina) dominated by the water hyacinth *Eichhornia crassipes*. Biogeochemistry 17: 85-121.

Carpenter, S.R. & Lodge, D.M. (1986) Effects of submersed macrophytes on ecosystem processes. Aquatic Botany 26: 341-370.

Cyr, H & Downing, J.A. (1988) The abundance of phytophilous invertebrates on different species of submerged macrophytes. Freshwater Biology 20: 365-374.

Douglas-Hill, A. (1995) Factors affecting either macrophyte or cyanobacterial dominance in farm dams. Poster presented at the 34th Congress of the Australian Society for Limnology.

Hosper, S.H. & Jagtman, E. (1990) Biomanipulation additional to nutrient control for restoration of shallow lakes in the Netherlands. Hydrobiologia 200/201: 523-534.

Irvine, K, Moss, B, & Stansfiled, J. (1990) The potential of artificial refugia for maintaining a community of large-bodied cladocera against fish predation in a shallow eutrophic lake. Hydrobiologia 200/201: 379-389.

Jeppesen, E. Jensen, J.P., Kristensen, P., Søndergaard, M., Mortensen, E., Sortkjær O. & Olrik, K. (1990) Fish manipulation as a lake restoration tool in shallow, eutrophic, temperate lakes 2: threshold levels, long term stability and conclusions. Hydrobiologia 200/201: 219-227.

Kirk, J.T.O. (1994) Light and photosynthesis in aquatic ecosystems. Cambridge Univ. Press, Camb.

Korhola, A. (1992) The Early Holocene hydrosere in a small acid hill-top basin studied using crustacean sedimentary remains. J. of Paleolimnology 7: 1-22.

Moss, B. (1990) Engineering and biological approaches to the restoration from eutrophication of shallow lakes in which aquatic plant communities are important components. Hydrobiologia 200/201: 367-377.

Nichols, S.A. (1991) The interaction between biology and the management of aquatic macrophytes. Aquatic Botany 41: 225-252.

Ogden, R.W. (1996) The effects of farming and river regulation on billabongs of the eastern Murray River and lower Ovens River. Unpublished PhD thesis.

Pressey, R.L. (1986) Wetlands of the River Murray below Lake Hume. River Murray Comm. Environmental Report 86/1.

Scheffer, M. (1990) Multiplicity of stable states in freshwater systems. Hydrobiol. 200/201: 475-486.

Scheffer, M., Hosper, S.H., Meijer, M-L., Moss, B. and Jeppesen, E. (1993) Alternative equilibria in shallow lakes. Trends in Ecology and Evolution 8: 275-279.

Shearer, K.D. & Mulley, J.C. (1978) The introduction and distribution of the Carp, *Cyprinus carpio* Linnaeus, in Australia. Australian Journal of Marine and Freshwater Research 29: 551-563.

State Pollution Control Commission (1987) Murray-Darling Basin environmental resources study. Murray-Darling Basin Comm., Canberra.

Timms, R.M. and Moss, B. (1984) Prevention of gropwth of potentially dense phytoplankton populatins by zooplankton grazing, in the presence of zooplanktivorous fish, in a shallow wetland ecosystem. Limnology and Oceanog. 29: 472-486.

Weatherley, A.H. and Lake, J.S. (1967) Introduced fish species in Australian inland warters. In Australian inland waters and their fauna ed. A.H. Weatherley. ANU Press, Canberra.

Williams, O. B. (1962) The Riverina and its pastoral industry, 1860-1869. In The simple fleece. Studies in the Australian Wool Industry Ed. A. Barnard pp. 411-434. Melbourne University Press, Parkville, Victoria.

Zaret, T.M. (1984) Fish/zooplankton interactions in Amazon floodplain lakes. Verh. Internat. Verien. Limnol. 22: 1305-1309.

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.