Chapter 6 Farm dam rehabilitation: Results

6.1 Introduction

This chapter records the results from the farm dam seed bank glasshouse germination experiment (Chapter 6.2) and changes in the water quality variables (Chapter 6.3) and biological components (Chapter 6.4) in the treated and control groups of farm dams

6.2 Glasshouse farm dam sediment trials

After the BACI experiment the community composition of the seed bank of the farm dams was different from before the treatments were imposed although that difference was not statistically significant. The species which germinated from the submerged trays at 5 and 20 cm depth from the farm dam sediments before (in the Spring) and after treatment (in the Autumn) are given in Table 6.1. The number of submerged species that germinated pre-treatment was between 0 and 4 per dam sediment and water plants germinated from all but two of the twelve dams. Some species germinated in both seasons. Most dams had an increase of one or two species after treatment (mean increase 0.7) and the number of submerged species that germinated increased in the control, seed bank and lime treatments (Figure 6.1(a)).

From the average percentage cover of established plants in the trays from the dam sediments taken before the experiment, five of the farm dams had the potential to develop cover of nil to 1%, four dams had the potential to develop between 10 and 38% cover and 3 dams had the potential to develop between 45 and 58% cover (Figure 6.1(b)). These calculated potentials did not take the depth tolerance of the species into account, and were based on the average percentage cover of trays obtained to a depth of 20 cm. There was litle difference in cover between trays placed at 5 and 20 cm so the results were pooled for both depths. Sterilised sand in control trays showed no seed transfer.

The percentage cover of submerged plants was higher in sediment samples taken after the treatments were imposed, for all treatments except the seed bank treatment (Figure 6.1(b)). Even though the control and lime treatments had no seed bank added, sediment samples from these dams had the greatest increase in percentage cover in the glasshouse, possibly due to a seasonal effect on growth. The greatest percentage cover was from *Glossostigma diandrum and Elatine gratioloides* that germinated in both spring and autumn trials.

Table 6 1 Species which germinated in the submerged trays (pooled 5 and 20 cm depth) of farm dam sediments before (spring) and after (autumn) treatment. Treatments: Ctrl = control, Sb = seed bank, L = lime, Sb-L = seed bank-lime. *B* = before treatment, *A* = after treatment See Chapter 2.6.3 for list of 'functional species' (Brock and Casanova 1997). Whether species acted as a submerged (S) or an emergent (E) sp. in flooded conditions is indicated in bold.

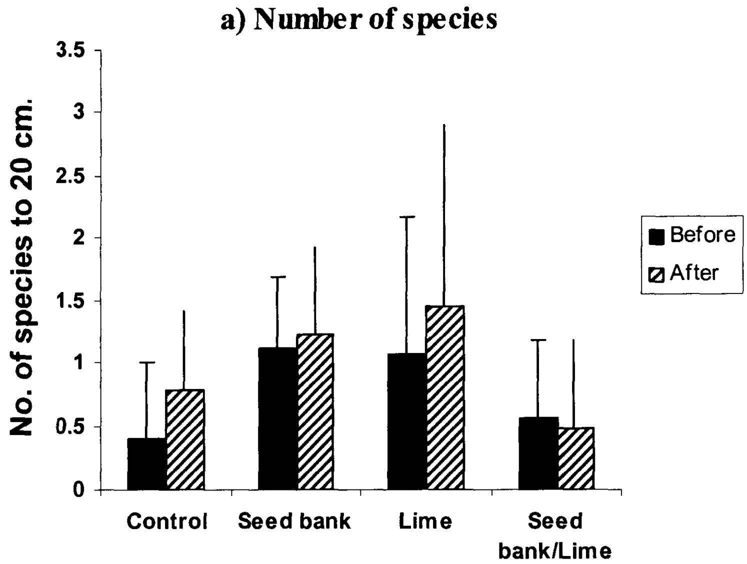
Species	**Ctrl** *B*	**Ctrl** *A*	**Sb** *B*	**Sb** *A*	**L** *B*	**L** *A*	**Sb-L** *B*	**Sb-L** *A*
Elatine gratioloides Arp **(S)**	✓	✓	✓	✓	✓	✓	✓	✓
Glossostigma diandrum Arp **(S)**	✓	✓	✓	✓	✓	✓	-	-
Chara sp. S **(S)**	-	✓	✓	✓	✓	✓	-	✓
M. variifolium Arp **(S)**	-	-	-	✓	✓	✓	-	-
M. verrucosum ARp **(S)**	-	-	-	-	✓	✓	-	-
Limnosella australis Arp **(S)**	-	-	✓	✓	✓	-	✓	✓
Isoetes sp. S **(S)**	-	✓	-	-	-	-	-	-
Gratiola peruviana Tda **(E)**	-	-	✓	-	✓	-		-
Cyperus difformis Ate **(E)**	✓	-	✓	✓	✓	-	-	✓
Eleocharis sp. Arp **(E)**	✓	-	✓	✓	✓	-	✓	✓
Eleocharis pusilla Ate **(E)**	✓	✓	✓	✓	✓	✓	✓	✓
Grasslike-sp. Tda **(E)**		✓		✓		✓		-
Typha orientalis ATe **(E)**	-	-	✓	✓	✓	-	-	-
Lilaeopsis polyantha Arp **(E)**	-	-	-	-	-	✓	-	-
Juncus sp. ATe **(E)**	✓	✓	✓	✓	✓	✓	✓	-
Number of species	6	7	10	11	12	9	5	6

In the spring trials, the species that germinated most often was *Gratiola peruviana* (known as an emergent terrestrial damp species, Tda that behaved in permanently flooded conditions as an emergent). In the autumn trials the species which germinated most frequently was the *Chara* sp. (a submerged species) and a grass-like species (an emergent Ate or Tda). *Chara* sp. accounted for the small increase in percentage cover in the seed bank treatment although it was present in all treatments.

A film of blue-green algae formed on several of the trays in which there was no seed or oospore germination. *Eleocharis pusilla, Cyperus difformis, Typha orientalis, Gratiola peruviana and Juncus* sp. germinated but these were not included in Figure 6.1 (a) or (b) because they were Ate or Tda species and because of their upright form and sparseness they did not contribute greatly to the percentage cover. This does not mean they were unimportant components of the seed bank germination but their upright form makes it difficult to measure these species against species that spread laterally and cover the sediments. Air and water temperatures in the glasshouse and the tanks holding the trays of sediment were similar for the spring and autumn trials. Light intensity in the glasshouse would have been much lower than the out door light intensity obtained in the previous pond experiment. and this could have affected the quality of the stimuli for seed germination (Britton and Brock 1994).

Species germination and percentage cover appeared to be influenced by the locality of the dams in the catchment rather by the experimental treatment. Even before treatment the dams were observed to cluster into three main groups determined by the germination of the dominant species having the highest percentage cover in the trays. This was not statistically tested and was not acknowledged as likely having an influence on seed bank distribution until later. Two groups were situated east (Harnham) and west (Uralla) of the New England Highway and one group was made up of dams from three widespread locations (Dumaresq, Walcha and Rockvale) (Figure 5.2). The three species-dominant groupings of the dams before treatment were (1) *Glossostigma diandrum* coexisting with *Elatine gratioloides* (Uralla); (2) *Eleocharis pusilla* (not counted as a submerged plant) with *Elatine gratioloides* (Harnham) and (3) *Elatine gratioloides* (Dumaresq, Walcha and Rockvale). Occasional submerged and emergents germinated (*Chara* sp., *Limosella australis, Myriophyllum variifolium* and *M. verrucosum*), with dams showing their individuality through the species that germinated from their sediments. One dam (Dam 12) had few individuals germinate in all samples, so was not grouped.

After treatment, the germination from the sediments did not change these initial groupings but the seed bank treatments could have introduced new species to the dams. *Chara* sp. germinated in 4 out of of the 6 dams seeded with seed bank or seed bank-lime (Dams 1, 4, 11, 7) and *Myriophyllum variifolium* germinated in 3 out of 6 dam sediments where previously it had not germinated. The charophytes were sometimes difficult to identify due to the lack of oospores and mature stem and tip characteristics but four species were identified; *Chara globularis, C. muelleri, Nitella cristata* and an unknown *Nitella* species. In the trays from the seed bank treated dams one to five plants of *Chara* sp. germinated per tray and each plant covered 25-50% of the tray. In a few trays from dams not treated with seed bank (Dam 6, 10) *Chara* sp. also germinated. It appears there are both seed bank and seasonal effects working in unison and confusing the study. Only two dams, dams 5 and 10 (both lime treated) had *Myriophyllum variifolium* and *M. verrucosum* respectively, pre-treatment and post treatment.



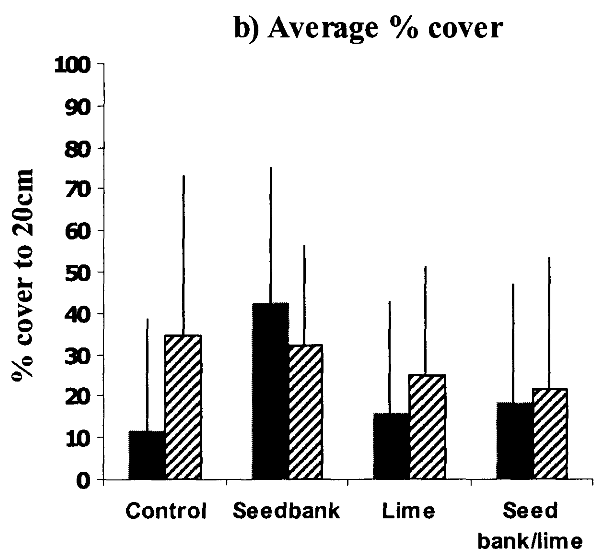


Figure 6-1 Glasshouse trials on farm dam sediment seed bank germination in relation to experimental treatment: (a) Average number of submerged water plant species that germinated from each dam sediment and (b) average percentage cover of trays. Results for (a) and (b) are for pooled depths 5 and 20 cm after 3 months. Error bars represent one standard deviation. See Table 6.1 for identity of submerged plants marked in bold.

6.3 Comparison of water variables (averages) of treatment groups before and after treatments

Data from the eight water quality variables that were measured in farm dams are given in Appendix VI. Depth variation was excluded from the analyses as it was measured after the treatments started. Means for the treatment group variables for the 4-before and 4-after samplings and their standard deviations are shown in Table 6.2. The secchi disc transparency depth, turbidity and chlorophyll-$_a$ variables showed a difference between the averages of the control dams and the averages of the treatment dams in the 4-before and 4-after measures (Table 6.2). The results of t-tests and confidence intervals on both within and between treatment group means before and after the treatment (impact) are given in Table 6.3 and the results of this BACI analysis will be discussed in Chapter 7.2.2

Secchi depth increased in all groups but the largest increase was in the seed bank-lime treatment group followed by the lime and then the seed bank treatment groups (Table 6.2 and Figure 6.2). Turbidity was increased in the control group, slightly increased in the seed bank group but decreased in the lime and seed bank-lime groups (Table 6.2). Soluble reactive phosphate decreased in all but the lime group and showed the greatest decrease in the seed bank group (Table 6.2 and Figure 6.5a). Total phosphate decreased in all groups but was highest in the seed bank-lime group (Table 6.2 and Figure 6.5b). Conductivity and pH rose in all treatment groups and chlorophyll-$_a$ was reduced in the seed bank-lime and seed bank treatments, increased very slightly in the lime treatment but increased much more in the control group (Table 6.2). Although these results indicate trends in response to the experimental treatments, none of these changes, apart from secchi depth in the seed bank-lime treatment were significantly different (See Chapter 6.3.1)

If the points on the graph at the A9 or 9th sampling, taken 20 months after treatment, are included in the graph of 'secchi vs time' (Figure 6.3), there is a change in ranking of the points for the treatment groups. Due to stock introduction to two of the dams in two groups (seed bank and seed bank-lime), it was not possible to include this last data point (Figure 6.4). However it is worth noting the change in ranking even though the disturbance was not applied to all groups. The clarity of the lime treated group after 20 months had dropped to below its before-treatment and post-treatment average while the control group remained the same (Figure 6.3). A marked increase in clarity was discernible in the seed bank treated group even though one dam in this group had been disturbed by stock. This increased clarity coincided with the establishment of charophytes in one dam (Dam 11) (Figure 6.4). The submerged vegetation changes are described in Chapter 6.5.1.

6.3.1 Secchi disc transparency

Results of changes in the secchi disc depth transparency are shown in Figure 6.2 and Table 6.2. Water clarity increased immediately after treatment in the seed bank-lime treatment dams. In the seed bank treated dams water clarity stayed the same for 2 months before clearing to a level greater than the seed bank-lime or any other group. In the lime treated group the clarity increased sharply 3 months after treatment and by the 8th sampling (April

1998) showed the highest clarity of all groups even though in this group the average SRP rose by 0.06 mg L^{-1} and the chlorophyll-$_a$ was slightly increased. By the 8th sampling (April 1998) the clearest water was in the lime and the seed bank-lime treated groups, followed by the seed bank treated and control groups. In the lime treated group there was a larger significant difference in clarity between it and the control after treatment ($p < 0.005$) than between it and the control before treatment ($p < 0.05$). In the seed bank-lime treatment the difference from the control before treatment was not significant ($p < 0.1$) but the difference from the control after treatment was significant ($p < 0.005$). The clarity in the seed bank treatment group also increased, but it was not significantly different to the control group either before or after treatment. Levene's test for homogeneity of group variances using $\log_{10}$ transformed secchi disc depth showed the variances of the seed bank and lime treated groups were homogenous ($p > 0.5$ and $p > 0.2$ respectively). However, for the seed bank-lime treatment Levene's test of group variances was heterogeneous and $p < 0.05$. When the dams were surveyed twenty months after treatment (Figure 6.3), there was a visible change and the seed bank treated dams had the clearest water followed by the seed bank-lime and control groups with the lime treatment was the least clear. Over the longer term the difference between the average clarity of the seed bank treated dams and the average clarity of the control dams doubled after treatment but the other groups reverted to their former poor levels of water clarity.

After the 8th (April 1998) sampling but before the 9th sampling (June 1999-20th months after-treatment), there was an introduction of stock into the fenced areas of two dams, one in the seed bank and one in the seed bank-lime treatment groups (Dams 1 and 2). This was due to the experiement having finished and drought making the edge vegetation susceptible to grazing. The impact of stock on the edges of the dams is likely to have increased the turbidity and modified the edge vegetation. This effect is more visible when dams are treated as individuals (Figure 6.4).

The impact at these two sites had an impact on the group averages for the seed bank and seed bank-lime treated groups in the 9th sampling (as demonstrated by the large differences in standard deviation seen in Figure 6.3). The control group shows no change from its Before or After condition

Table 6 2 Averages of water quality variables for four groups of dams in a BACIP experiment in which parameters were measured for 4 months before and 4 months after impact (various treatments) and their difference. n =12 for both before and after, except for chlorophyll-$_a$ where n = 6 Before and n = 12 After. Impacts (treatments) were: control (no treatment), seed bank, lime and seedbank-lime. A positive sign indicates an increase in the parameter, a negative sign indicates a decrease. Secchi depth (Secchi) in m., turbidity in NTU, conductivity in µS cm^{-1}, chlorophyll-$_a$ in µg L^{-1}, SRP and TP in mg L^{-1}, temperature (Temp) as degrees centigrade, °C.

Treatment Group	Before	After	Difference	Before	After	Difference
	Secchi Depth			**SRP**		
Control	0.23 ± 4.3	0.25 ± 5.4	+ 0.01	0.14 ± 0.06	0.1 ±.01	- 0.04
Seed bank	0.23 ± 7.6	0.32 ± 11.5	+ 0.09	0.19 ± 0.09	0.14 ± 0.05	- 0.05
Lime	0.34 ± 17.3	0.45 ± 8	+ 0.10	0.13 ± 0.08	0.19 ± 0.15	+ 0.06
Seedbank-lime	0.32 ± 4.5	0.51 ± 13.1	+ 0.18	0.16 ± 0.08	0.14 ± 0.07	- 0.03
	Turbidity			**TP**		
Control	57.7 ± 25	63.1 ± 28	+5.4	0.27 ± 0.06	0.25 ± 0.1	- 0.02
Seed bank	52.7 ± 45	56.5 ± 34	+3.8	0.32 ± 0.06	0.31 ± 0.1	- 0.02
Lime	46.5 ± 36	31.2 ± 18	-15.3	0.29 ± 0.24	0.28 ± 0.2	- 0.02
Seedbank-lime	39.2 ± 27	25.1 ± 18	-14.1	0.26 ± 0.07	0.20 ± 0.1	- 0.06
	Conductivity			**pH**		
Control	79 ± 52	141 ± 63	+ 62	7.2 ± 0.4	8.4 ± 0.7	+ 1.2
Seed bank	52 ± 12	100 ± 31	+ 48	6.8 ± 0.2	7.5 ± 0.5	+ 0.6
Lime	71 ± 30	153 ± 58	+ 82	7.5 ± 0.3	8.1 ± 0.4	+ 0.6
Seedbank-lime	80 ± 40	171 ± 87	+ 86	7.5 ± 0.1	7.9 ± 0.4	+ 0.3
	Chlorophyll-*a*			**Temp.**		
Control	12.7 ± 3.8	54.4 ± 45.3	+ 42	12.9 ± 4.4	25.9 ± 2.4	+ 13
Seed bank	45.9 ± 33.1	37.7 ± 29.1	- 9	14.7 ± 4.8	24.5 ± 3.1	+ 9.8
Lime	30.6 ± 54.7	31.68 ± 29.9	+ 1	13.3 ± 5.2	26.1 ± 1.9	+ 12.8
Seedbank-lime	27.6 ± 19.3	15.3 ± 7.9	- 12	14.1±4.8	27.4±3.2	+13.3

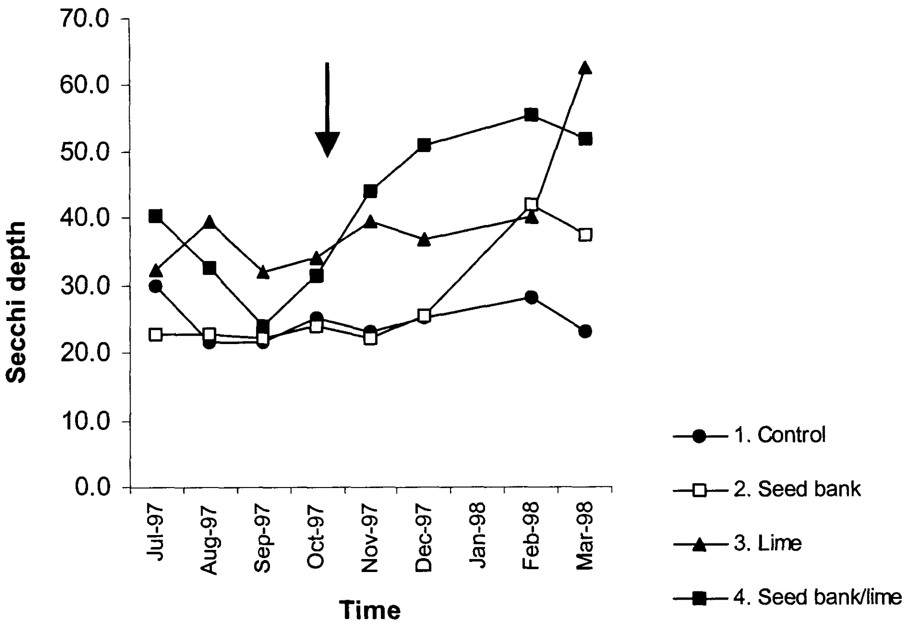


Figure 6-2 Results from a Before-After-Control-Impact-pairs (BACIP) experiment to see if the secchi disc transparency depth changed over time after treatment (impact) with either seed bank, lime or seed bank-lime. For each point n = 3. Control group was not treated. Treatment (shown by arrow) was done directly after 4th sampling in October 1997. Standard deviations from group means are not shown on this graph for simplicity; for standard deviations see Figure 6.3.

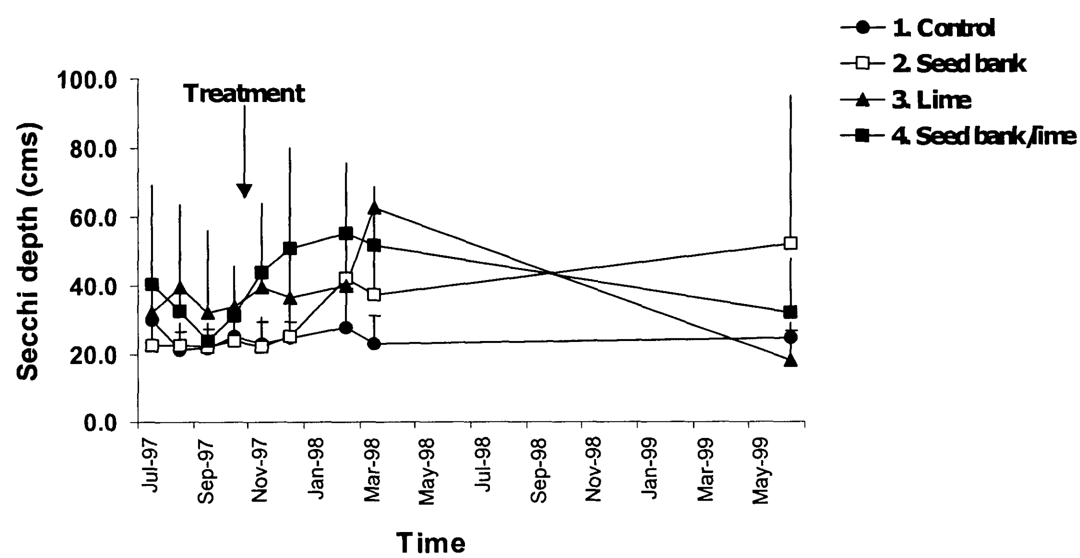


Figure 6-3 Results from a BACIP experiment to see if the secchi disc transparency depth (secchi depth) changed over time after treatment (impact) with either seed bank, lime or seed bank-lime. Treatment was after October 1997 (4th sampling). Note difference from Figure 6.2 20 months after treatment (9th sampling) (June 1999) and standard deviations in seed bank treatments due to introduction of stock to one of the three replicated dams. Arrow shows time of treatment. Error bars represent one standard deviation.

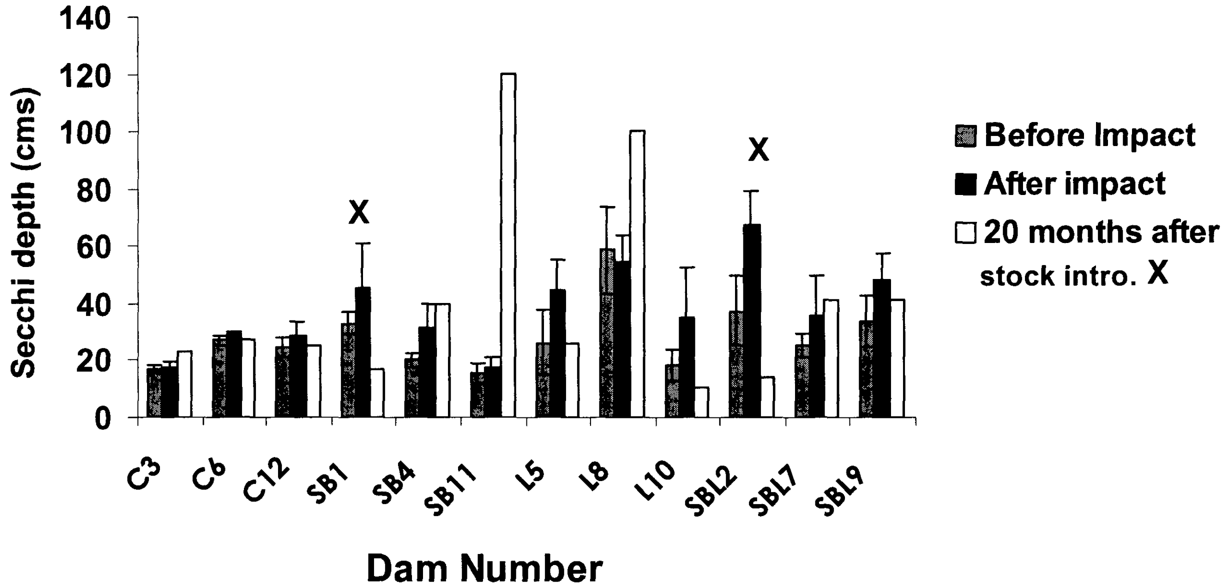


Figure 6-4 Secchi depth in individual dams before and after treatment and 20 months after treatment. C = control, SB = seed bank, L = lime, SBL = seed bank-lime treatment. Numbers represent dam number. 'X' over columns represents dams that were impacted by stock introduction. Error bars represent one standard deviation for the average secchi depth in each dam. No standard deviation is given for the column '20 months after' or the 9th sampling, as it was a 'one-off' sampling.

6.3.2 pH, Temperature, SRP and TP

The pH of the water in all dams started to rise in the spring as algal activity increased with the temperature increase and this happened in all dams. The pH was lower in the controls, lime and seed bank groups one month after treatment but remained high for 2 months in the seed bank-lime group. By the 7th (February 1998) sampling, the pH in the control group started to increase again and increased more than any of the treated groups to a mean of pH 8.4 (maximum pH = 9.9). At the end of four months the pH was still highest in the controls followed by lime, seed bank and seed bank-lime. The smallest difference in the mean pH before and after treatment was in the seed bank-lime treated dams (Table 6.2).

SRP peaked before treatment at the 4th measure (spring) in the seed bank and the control groups but not in the other two groups. After treatment in late October 1997, the SRP dropped in all dams to rise again till mid-summer (January-February 1998) in all dams. SRP was 0.3 mg L^{-1} (300 $\mu g\ L^{-1}$) in the lime treatment by the 8th sampling in April 1998 (Figure 6.5(a)). The lime treatment group had the highest SRP of all groups at the A8 (April 1998) sampling (but still had a low chlorophyll-$_a$ concentration) but the differences were not significant.

Total phosphate was high in winter (July 1997) dropped and then showed a similar rise in Spring in all groups before treatment, and was highest in the seed bank group. Levels were within the range (0.2 – 0.5 mg L^{-1}) (Figure 6.5 (b)). The control group had the highest TP of all groups at the A8 sampling (April 1998) but this difference was not significant between groups and all groups were very close in their TP concentrations.

Overall, the average SRP decreased after treatment in all groups except in the lime treatment group, and TP decreased slightly in all groups (Table 6.2). Localised rainfall and inflows affected the turbidity at different times in some dams and not others, and the input of suspensoids and the resuspension of clay particles probably impacted on the TP readings.

20 months after treatment, in mid winter (June 1999), the 9th sampling showed that the cold temperatures had reduced such variables as SRP, TP, conductivity and chlorophyll-$_a$. At this sampling the pH and conductivity in all groups was similar. The lime and seed bank-lime treatment groups had returned to their pre-treatment turbidity and secchi depth levels, but these treatments had the lowest concentration of SRP and TP (0.02 and 0.087 mg L^{-1}) respectively) but this was not much less than in July the previous year.

6.3.3 Depth variation

Water levels dropped by an average of 6 to 7 cms from the baseline level in all dams in the first two months after treatment due to the increasing warmth and the dry Spring. Some inflow (mean rise + 7.2 cm from baseline) occurred in five of the dams before the 7th sampling in February 1998, due to localised thunderstorms but a drop was experienced in the balance of the dams (mean drop -21 cm from baseline) due to ongoing dry weather. In some large dams where slope was low, and inflow was adequate, the observation that made that the edge vegetation was ensured sufficient water for high germination and establishment (Plate 4 a). The water loss through evaporation and seepage was highest by the A8 measure in April 1998 because of higher temperatures that left water levels an average of 24 cms below those found at the start of the treatment. Emergent plants from the introduced seed bank germinated in large numbers below the original water level at the start of the treatments. Due to this change in water level, seeds were observed to germinate even on bare clay (Plate 4 b) but these plants had disappeared by the A8 sampling in April 1998, and were replaced with more hardy terrestrial species

6.4 BACI Analysis: Results of t-tests on water variables of treatment groups.

The results of the t-tests *between* treatment groups, both before and after, and *within* groups are given in Table 6.3 to 6.10.

Table 6 3 Comparisons of **Secchi Disc Depth** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 17 T = 0.04 P = 0.97	DF = 12 T = -1.77 P = 0.01	DF = 15 T = -2.63 P = 0.019

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 20 T = -0.71 P = 0.49			
Seedbank (2)		DF = 16 T= -1.66 P = 0.12		
Lime (3)			DF = 20 T = -1.31 P = 0.20	
Seedbank + Lime (4)				DF = 17 T = -2.99 P = 0.0083

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 15 T = -1.35 P = 0.20	DF = 15 T = -3.91 P = 0.0014	DF = 14 T = -4.51 P = 0.0005

Table 6 4 Comparisons of **turbidity** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 17 T = 0.33 P = 0.74	DF = 19 T = 0.89 P = 0.38	DF = 21 T = 1.73 P = 0.098

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 21 T = -0.50 P = 0.63			
Seedbank (2)		DF = 20 T= -0.23 P = 0.82		
Lime (3)			DF = 16 T = 1.32 P = 0.20	
Seedbank + Lime (4)				DF = 18 T = 1.51 P = 0.15

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 21 T = 0.52 P = 0.61	DF = 18 T = 3.27 P = 0.0042	DF = 18 T = 3.95 P = 0.0009

Table 6 5 Comparisons of **conductivity** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 12 T = 1.87 P = 0.087	DF = 18 T = 0.51 P = 0.62	DF = 20 T = -0.07 P = 0.95

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 21 T = -2.82 P = 0.01			
Seedbank (2)		DF = 13 T= -4.43 P=0.0007		
Lime (3)			DF = 17 T = -4.53 P = 0.0003	
Seedbank + Lime (4)				DF = 15 T = -3.51 P = 0.0032

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 17 T = 2.08 P = 0.053	DF = 21 T = -0.51 P = 0.62	DF = 20 T = -1.03 P = 0.32

Table 6 6 Comparisons of **pH** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 21 T = 2.12 P = 0.046	DF = 17 T = -1.32 P = 0.20	DF = 19 T = -1.19 P = 0.25

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 14 T = -3.85 P = 0.0018			
Seedbank (2)		DF = 16 T = -2.52 P = 0.023		
Lime (3)			DF = 19 T = -2.54 P = 0.02	
Seedbank + Lime (4)				DF = 21 T = -1.83 P = 0.081

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 20 T = 2.58 P = 0.018	DF = 15 T = 0.89 P = 0.39	DF = 18 T = 1.56 P = 0.14

Table 6 7 Comparisons of **temperature** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 21 T = -0.93 P = 0.36	DF = 21 T = -0.21 P = 0.83	DF = 21 T = -0.64 P = 0.53

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 16 T = -8.99 P = 0.0000			
Seedbank (2)		DF = 18 T= -7.20 P=0.0000		
Lime (3)			DF = 13 T = -8.00 P = 0.0000	
Seedbank + Lime (4)				DF = 19 T = -7.94 P = 0.0000

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 20 T = -0.56 P = 0.58	DF = 20 T = -0.28 P = 0.79	DF = 20 T = -1.29 P = 0.21

Table 6 8 Comparisons of **soluble reactive phosphate (SRP)** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 20 T = -0.78 P = 0.44	DF = 21 T = 0.22 P = 0.83	DF = 21 T = -0.48 P = 0.64

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 15 T = 0.97 P = 0.35			
Seedbank (2)		DF = 14 T = 0.84 P = 0.41		
Lime (3)			DF = 19 T = -1.01 P = 0.32	
Seedbank + Lime (4)				DF = 20 T = 0.65 P = 0.52

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 21 T = -1.63 P = 0.12	DF = 13 T = -1.70 P = 0.11	DF = 19 T = -1.24 P = 0.23

Table 6 9 Comparisons of **total phosphate(TP)** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 18 T = -0.85 P = 0.41	DF = 14 T = -0.10 P = 0.93	DF = 21 T = 0.34 P = 0.74

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 21 T = 0.57 P = 0.57			
Seedbank (2)		DF = 21 T = 0.27 P = 0.79		
Lime (3)			DF = 21 T = -0.01 P = 0.99	
Seedbank + Lime (4)				DF = 21 T = 1.13 P = 0.27

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 20 T = -1.14 P = 0.27	DF = 15 T = -0.44 P = 0.66	DF = 21 T = 0.99 P = 0.33

Table 6 10 Comparisons of **chlorophyll-$_a$** among four treatment groups before and after treatment with seedbank (2), lime (3) and seedbank and lime (4). A fourth group was a control (1). The significance of differences was tested using a two sample t-tests. Degrees of Freedom (DF), T and level of significance (P) are shown for each comparison.

Comparison of treatment groups with control **before** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 5 T = -2.45 P = 0.058	DF = 5 T = -0.80 P = 0.46	DF = 5 T = -1.86 P = 0.12

Comparison of before and after values **within** treatment groups

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)	DF = 11 T = -3.17 P = 0.0089			
Seedbank (2)		DF = 9 T = 0.52 P = 0.62		
Lime (3)			DF = 6 T = -0.04 P = 0.97	
Seedbank + Lime (4)				DF = 5 T = 1.51 P = 0.19

Comparison of treatment groups with control **after** treatment

	Control (1)	Seedbank (2)	Lime (3)	Seedbank + Lime (4)
Control (1)		DF = 18 T = 1.08 P = 0.30	DF = 19 T = 1.45 P = 0.16	DF = 11 T = 2.95 P = 0.013

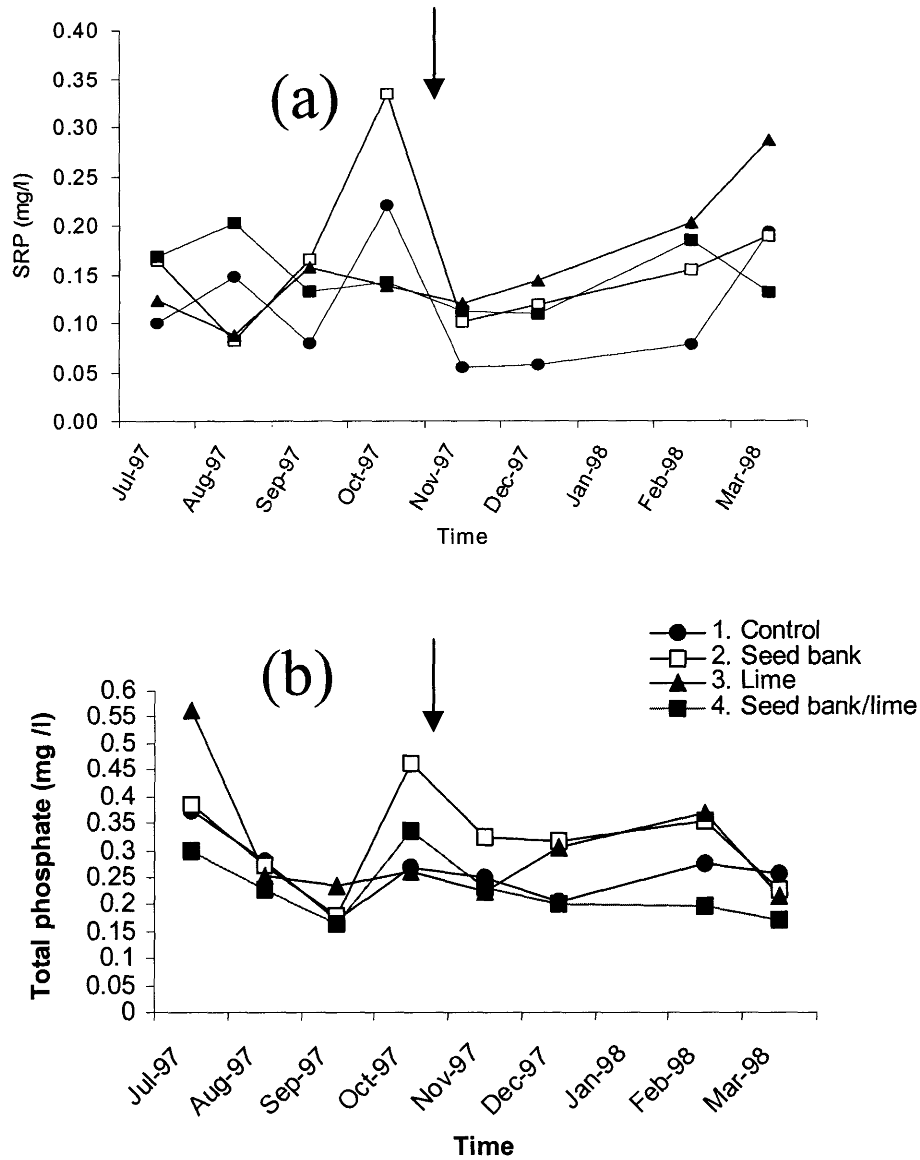


Figure 6-5 Results from a BACIP experiment to see whether (a) soluble reactive phosphate (SRP) and (b) total phosphate (TP) both in mg L^{-1} of four treatment groups: control, seed bank, lime and seed-bank-lime changed after treatment. Treatment time (shown by arrow) was after the 4^{th} sampling in mid-October 1997.

6.5 Biological changes

6.5.1 Plant germination in farm dams

Submerged vegetation

Submerged vegetation, usually of *Limnosella australis* or *Elatine gratioloides* sometimes germinated in large numbers but did not persist past one month. The reason for this was grazing by ducks or early desiccation (Plate 4 c shows the edge of one dam in which *Limnosella australis* which had established one month previously was eaten by ducks). *Myriophyllum variifolium* and *Chara* sp. occasionally germinated in shallows on slopes with a low angle but also disappeared within a month of being tagged and identified with a stake. The submerged water plant germination and biomass obtained in the glasshouse and pond trials could not be reproduced in any equivalent amount in farm dams and so data was not collected and analysed.

Even though this is not part of the BACIP of 4-before and 4-after samplings, it is of interest to note that twenty months after treatment (June 1999,A9 sampling), in one of the six dams to which seed bank had been introduced, a dramatic change was observed. A 100% cover of *Nitella sonderi* had established to 54cm depth and large numbers of zooplankton were present. This development of charophyte vegetation was associated with a drop in turbidity from 57.8 NTU (average) of the dam before treatment to 15.4 NTU after treatment. This reduction in turbidity corresponded to an increase of secchi disc transparency of 100 cm. Soluble reactive phosphate and total phosphate had been reduced in this dam by 50% and 40% four months after treatment (April 1998), and 20 months after treatment (June 1999) SRP and TP were reduced by 94% and 77% respectively.

6.5.2 Algal abundance as determined by chlorophyll-$_a$ concentration

Two months of analyses for chlorophyll-$_a$ were done before treatment and 4 were done after treatment. The results of the BACIP experiment on chlorophyll-$_a$ are in Figure 6.6. Adding lime to the dams visually removed green algae and although the pH rose with liming it reverted back to neutral within a week. The overall effect was to increase water clarity in both lime and seed bank-lime treatments (Figure 6.3) and by suppressing algal biomass at a time when algal numbers would have risen naturally with increasing warmth, this may have reduced the algal induced high pH which blue-green algae species tolerated. The seed bank-lime treatment group never increased its average chlorophyll-$_a$ concentration over the 5 months after treatment. After treatment with lime alone there was an increase in the chlorophyll-$_a$ concentration but then a decline to below the before-treatment concentration but the level was always below the average for the control group. In all groups except the control group, the chlorophyll-$_a$ concentration dropped by the 7th sampling date (February 1998) and was found at its lowest concentration by the 8th sampling (April 1998) in late summer. In the three treatments a low chlorophyll-$_a$ (< 20 μgL^{-1}) concentration was detected compared to the control group. In the control group the chlorophyll-$_a$ concentration rose after the December 1997, 6th sampling to greater than 40 μgL^{-1} with a high standard deviation around the mean. Algal abundance did not reach high levels over the summer. Dam 5 (one of the group treated with lime) had a permanent blue-green algal bloom but had a low algal concentration at this time.

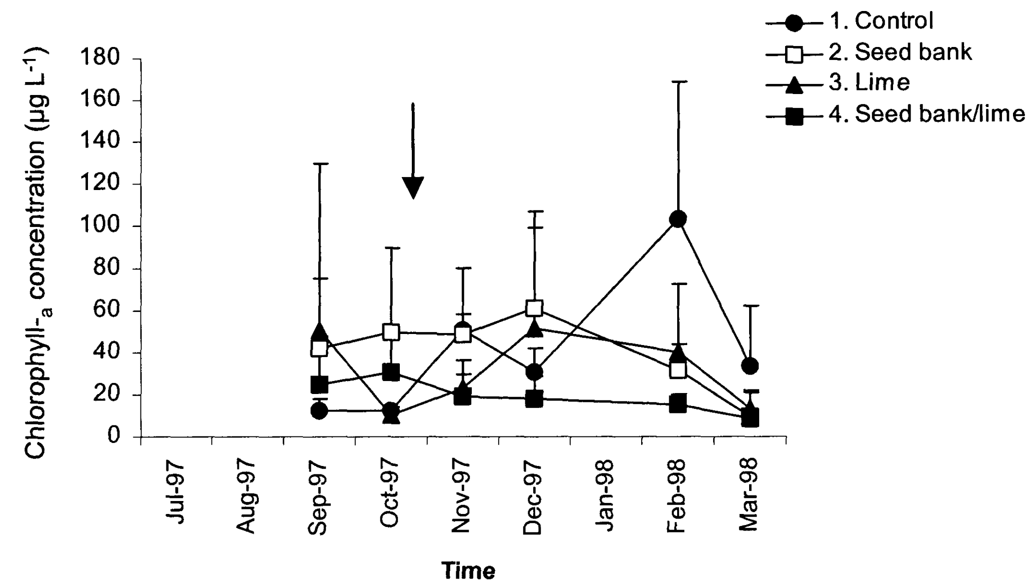


Figure 6-6 Results from a BACIP experiment to see if the chlorophyll-$_a$ concentration in four treatment groups: control, seed bank, lime and seed bank-lime changed after treatment. Treatment time (shown by arrow) was after the 4th sampling in mid-October 1997. Two samplings for chlorophyll-$_a$ (July and August) were not taken. Error bars represent one standard deviation from the mean.

6.5.3 Zooplankton and Phytoplankton.

Zooplankton and phytoplankton samples were identified for three times before- and four times after-treatment and the taxa data is in Appendix VII. No PATN analyses were made on this data as sampling was done to observe if any major changes occurred with treatment. Total numbers of zooplankton and phytoplankton taxa were lower in the winter and spring and higher in late spring, summer and autumn. An increase in the number of total taxa occurred in all groups after treatment with the warmer months. The highest increase was in the lime treatment group and the smallest increase in the control group (Table 6.11).

Of the zooplankton, protozoan ciliates were usually dominant when found, and *Cladocera* and *Copepods* were well represented in both before and after samples. No evidence of pH shock was seen in the zooplankton as exhibited by their increased numbers and diversity after treatment.

Dinoflagellate species were not found in the control group from the 5th to the 8th samplings while turbidity was the highest in this group. They were only found in four dams out of a total of 12 over this sampling period. Euglenophytes, green colonial algae (*Sphaerocystis, Botryococcus*) and large green flagellated algae (*Eudorina, Volvox* and *Gonium*) were well represented in all groups including in the control groups over the same period. Over the length of the experiment most dams showed algal species changes determined by seasonal succession, with *Volvox* the most common algae in spring and Euglenophytes and blue-greens the most common algae in summer.

In the phytoplankton study *Anabaena circinalis* was found in one sample out of the thirty-six (12 dams x 3) samples taken before-treatments (2.7%). In the four samplings after-treatment *Anabaena circinalis* was found in thirteen samples from a total of forty-eight (12 dams x 4) (27%). In these thirteen samples *A. circinalis* was dominant in seven. This increase in blue-green algae over summer was found in all groups except the seed bank-lime group. A brief *A. circinalis* bloom was observed once between sampling times in one dam in this group.

Phytoplankton species presence and dominance was influenced more by the locality of the dams than by the experimental treatment. Dams in the 'Uralla grouping' from the seed bank sediment trials consisted of green filamentous algae (*Spirogyra* and/or *Cladophora,* or blue-green algae *Anabaena* and/or *Microcystis*) in spring which changed to dominant filamentous algae (any of above) with Euglenophytes in summer.

Table 6 11 Average number of zooplankton and phytoplankton taxa and their standard deviation in groups of farm dams in a BACIP experiment before and after treatment and the change in species richness. Treatments: Control, seed bank, lime and seed bank-lime.

Treatment Group	Zooplankton Before (±s.d)	Zooplankton After (±s.d)	Difference	Phytoplankton Before (±s.d)	Phytoplankton After (±s.d)	Difference
Control	1.3 ± 0.9	1.3 ±1.0	Nil	3.1 ± 1.9	3.6 ± 2.1	+ 0.5
Seed bank	1.1 ± 1.6	1.3 ± 1.3	+ 0.2	2.2 ± 2.6	4.5 ± 2.8	+ 2.3
Lime	1.1 ± 1.7	1.2 ± 0.9	+ 0.1	1.4 ± 1.4	4.2 ± 4.0	+ 2.8
Seed bank-lime	1.2 ± 1.4	2.1 ± 1.4	+ 0.9	2.2 ± 2.1	4.3 ± 3.0	+ 2.1

Chapter 7 Farm dam rehabilitation: Discussion

This chapter focuses on the aims and results presented in Chapters 5 and 6. Discussion of the germination from the farm dam sediments in the glasshouse and their potential cover is presented in Chapter 7.1. The results of the impact of the three treatments on the water variables are discussed in Chapter 7.2. Germination of water plants in farm dams is discussed in Chapter 7.3. Changes in zooplankton and phytoplankton are briefly discussed in Chapter 7.4. Limitations of the experiment and possible variations that could be made to the experimental design are discussed in Chapter 7.5.

7.1 Glasshouse germination of water plants from farm dam sediments:

In general, farm dams had few seeds or oospores of submerged water plants germinating from their sediments in the glasshouse either before or after treatment. The lack of germination in the sterilised sand trays indicates there was no transfer of seed or oospores from one dam sediment to another. Because the sediments were subjected to permanently flooded conditions the germination of emergent water plants was restricted. The geographical location from which the samples were taken exerted an effect on germination.

Submerged conditions in natural lakes and rivers in Europe and the USA are known to be difficult for water plant seed germination and establishment (Haag 1983, Hartleb *et al.* 1993, Kimber *et al.* 1995). In Australia, terrestrial and amphibious edge species will commonly germinate from farm dam and wetland sediments in the glasshouse when subjected to damp conditions but lower biomass and species richness develops under permanent flooding (Casanova and Brock 2000). There are explanations for the poor germination of submerged water plants from farm dam sediments both before and after treatment. Low numbers of germinations may be due to low numbers of seeds in the farm dam sediments, the low viability of seeds, the constitution of sediments or even the effect of the blue-green algal film (possibly *Microcystis* or some other blue-green alga). This film formed on some of the sediments in the trays and could have limited the light or intensity of light on the seeds. Toxins from the algae were not expected to have repressed germination, as *Microcystis aeruginosa* toxins were not found to affect aquatic plant establishment (Casanova *et al.* 1999). The presence of this blue-green algal film could indicate either a nitrogen deficiency or an anoxic condition of the sediments favourable to this algal biofilm development but not to seed germination. The time between treatment and sampling the dam sediments the second time was probably too short to determine if there was an increase in the seed bank from water plant reproduction and seed set. This was because there was little establishment and reproduction of water plants in the farm dams over the summer-autumn months compared to that in the artificial ponds. The differences in the number of species which germinated in the before and after-treatment trays implies that seasonal germination of submerged plants in the glasshouse is higher in the autumn than the spring, despite comparable air and water temperatures. Some plants germinated in spring and not autumn, others germinated in autumn and not spring, and still others germinated in both seasons. There were not enough plant germinations to do a statistical analysis, but this finding agrees with the germination results of Britton and Brock (1994) from the seed banks of natural wetlands.

Time is also an important factor in germination of water plant seeds. Autumn germination is in the normal range for many charophyte species, but if trays had been kept underwater for longer any dormant oospores of *Nitella sonderi* and *N. subtilissima* would probably have germinated in the following spring (Casanova 1993). It remains speculative as to whether the higher numbers of *Myriophyllum variifolium* and charophytes that germinated in the trays of the dams seeded with introduced seed bank were a result of seeding or of season, as they also germinated in trays from the other treatments.

The influence of location on the physiochemical variables in farm dams was seen in the grouping and dominance of germinations from the sediment, so it is probable that the locality was exerting its effect on the biological components of ecosystems as well. Limnologists have debated the effect of geology (a local effect) on chemical processes in inland waters (Hart and McKelvie 1986, Banens 1989, Bowling 1989). Catchment lithology can affect the chemical composition of river water and groundwater (Hart and Mc Kelvie 1986) so it would not be surprising for farm dams to reflect catchment conditions. However, rather than the treatments drastically changing the germination of water plants from the sediments, the locality effect was still stronger and was probably exerting a buffering effect on the results.

Previous PATN analyses of farm dam variables (Douglas-Hill 1995, Casanova *et al.* 1997) grouped farm dams depending on their soil type, chemical and biological components in much the same way that terrestrial plants are grouped by PATN analysis. Whether the addition of lime or seed bank can exert a change over the long term on the chemical and biological components in these dams and rearrange their original biological groupings is still inconclusive.

7.2 BACI analysis: interpretation of the means, t-tests and significance of the changes in water variables of the treatment groups.

Physiochemical and biological changes as the result of treatment were made mainly to water clarity and a reduction in algal biomass rather than an increase in submerged water plant biomass. A difference (positive or negative) represents a change within each treatment group before and after treatment, but the assessment of change is not focused on changes in means of a variable and does *not* necessarily indicate a change caused by the treatment (impact) (Table 6.2). The change must be significant both *within* the treatment group and *between* the control group and the treatment group for the change to be considered to be the result of the treatment (impact) which was applied (Tables 6.3 to 6.10).

Secchi disc depth

Over the short term the impact of the lime and seed bank-lime treatments (Figure 6.2) could be said to have been positive with respect to clarity. There appears to be a stabilizing influence of lime on clarity as seen in the higher clarity in the seed bank-lime group and the increase in secchi depth in the lime treatment group, an effect that has lasted for 4 months. This may have been due to the fine particles of lime remaining in the water column or being resuspended by internal currents which could have continued flocculating suspended clays in the inflows. Over the long term (Figure 6.3) it could be assumed that seed bank addition alone gave the highest long-term water clarity, but it is not clear if the relationship between the treatment and the change is a real one or caused by a temporal variability in water quality.

Before treatment, secchi disc depths were similar in all groups. Adding seedbank-lime showed a significant increase in secchi disc depth *between* the control and *within* this treatment group - so this is considered a significant change as the result of imposing this treatment. The control and lime treatment group of dams showed a significant difference in means after treatment but as this was not also observed *within* this group, lime alone is not considered to have had a significant impact.

Turbidity

Within groups the mean turbidity did not change significantly over the sampling period although there was a decrease in turbidity in the lime and seed bank-lime groups (Table 6.4). *Between* treatment groups all groups were similar before treatment but there was a significant change between the control group and the lime and seed bank-lime groups after treatment. As the changes are not significant both within and between groups they are not seen as significant.

SRP and TP

Within groups the mean SRP and TP showed no change in any of the treatment groups before and treatment. Comparison *between* control and treatment groups showed no significant differences between the means before or after treatment. It is interesting that SRP was reduced in all groups except the lime treated group over the experimental period in which the SRP was high, but not unusual for a farm dam. At the 8th sampling TP was at the level of between 0.2 - 0.3 mg L^{-1} (200-300 μg L^{-1}) in all the treatment groups with the lowest concentration found in the seed bank-lime group. The drop in SRP and TP could be due to the lack of inflow and less resuspension around the 8th sampling and the flocculation of clay particles. This flocculation and sedimentation of algae and clay particles to which phosphorus is attached was the primary cause of the improved clarity in all the treatment groups. Algal biomass (chlorophyll-$_a$ concentration) and TP were highest in the control group, which suggests that any treatment that causes flocculation of suspended clay could be also useful in reducing TP.

Lime treatment can be used to give a short-term fix in reducing suspended algae and clay but efficient SRP removal needs a pH greater than pH 10.5 that would kill the biota (Murphy *et al.* 1988). Yearly applications of lime have been shown to cause the fixation of phosphorus and calcium as apatite (Mandaville 1996). A combination of lime-seed bank or seed bank treatment in this experiment gave the same or better short-term reduction in SRP, TP and chlorophyll-$_a$.

Over the long-term (20 months) the lime and seed bank-lime treatment groups returned to similar levels of turbidity and secchi depth as before treatment (Figure 6.3) but these groups had the lowest concentration of SRP and TP at the 9th sampling (Appendix VI). This suggests that even though lime addition did not appear to have a long-term effect on clarity there may have been some effect on binding the phosphates that are usually very high concentrations in farm dams. The sampling data of May 1999 is limited by being a one-off in the winter and research needs to be done on the actual role of lime in binding phosphate and as to whether phosphate is the culprit in eutrophication (Biebrick 1996, 1998).

Temperature

Within groups the mean temperature increased significantly in all treatment groups after treatment, including in the control. This change is due to natural increase over the summer-autumn months. Comparison *between* control and treatment groups shows no sigificant differences between the means before or after treatment.

pH and conductivity

Within groups the change in pH was only significant in the control group due to a natural increase in chlorophyll-$_a$ between the winter-spring and the summer-autumn sampling events. In none of the treatment groups was there a large change in mean pH *between* any of the treatments. Any small increases in pH in the treated dams were the result of seasonal changes. The pH rose as a result of the influence of increasing water temperatures on algal activity. When the pH rose during the lime applications, the rise was monitored and restricted to pH < 9.0. Because the lime treatment never exceeded 25 kg per megalitre, dams were not overlimed and their ability to buffer themselves was not compromised. Monitoring of the pH and algae after treatment showed that the pH returned to pre-liming levels within a week but the algal blooms had disappeared, leaving the water with a high clarity. A pH decline after lime treatment is considered to be due to reduced rates of algal primary production and increased rates of algal decay (Prepas *et al.* 1990, Murphy *et al.* 1988). If left unlimed, pH and chlorophyll-$_a$ concentrations may have continued to rise as algal succession progressed, as occurred in the control group.

Within groups the mean conductivity increased significantly in summer and autumn in all the treatments including the control so this change was due to natural seasonal increases. Before treatment all groups were similar and there is also no difference in means *between* the control and treatment groups after the treatment.

Chlorophyll-$_a$

Within groups the mean chlorophyll-$_a$ increased significantly in the control group over the summer-autumn months. This change is due to a common seasonal increase in algae but which only appeared to occur in the control group. A small significant difference is observed in the mean chlorophyll-$_a$ concentrations *between* the control and the seedbank/lime group after treatment ($P = 0.013$). However, this difference is not the result of the seed bank-lime treatment because there is no corresponding significant change *within* that group before and after treatment (See 7.4). *Chlorophyll-$_a$* concentrations in this experiment were never as high as found in previous surveys (Douglas-Hill 1995, Casanova *et al.* 1997) when ranges were found between 4.0 and 772 $\mu g\ L^{-1}$.

Depth variation

Depth variation over the experimental period after treatment was predominantly negative with little physical disturbance to the water column in the dams, but brief summer storms and turbid inflows (Chapter 6.3.3) were responsible for the slight reduction in secchi depth at the 8th sampling.

7.3 Germination and establishment of water plants in farm dams

Submerged vegetation

The germination of edge vegetation was sometimes dramatic but establishment of both submerged and emergent vegetation was either short or long-lived depending on various factors. In Part 1, high plant biomass and germination under conditions of low to medium turbidity supported the hypothesis that the establishment of submerged water plants in artificial ponds was not restricted by turbidity. In contrast, in farm dams there was great difficulty with submerged water plant germination and establishment. In many farm dams, even with stock excluded, the edge sediments were continually disturbed as a result of the lapping and movement of waves caused by wind, which slightly increased the turbidity. At several sites migrating ducks left their webprints and faeces at the water's edge. On steep slopes there was a downward flux of fine sediment that could have buried water plant seeds. After treatment, all the treatment groups except the control group showed an improvement in their light climate that was sustained for four months until the 8^{th} sampling in April 1998. This period was long enough for some water plant germination to have occurred. Secchi depth was high enough in all treatment groups for the euphotic depth, Z_{eu}, of water plants to be in the range of 60 to120 cms. Lack of light or water turbidity was not the factor preventing the germination and establishment of water plants in farm dams.

The seed of *Myriophyllum variifolium* introduced in the Racecourse Lagoon seed bank to two of the treatment groups was expected to germinate in large numbers as had transpired in the artificial ponds. A few germinations of this species occurred but the plants did not persist. Because *M. variifolium* germinates all year round in the glasshouse and in open but protected conditions (Britton and Brock 1994), and as an amphibious fluctuation responder species, it can adapt to changes in water depth by putting out roots at nodes when stranded (Brock and Casanova 1997). The lack of germination and establishment was unexpected considering the variety of slope present at treatment sites, but this may be due to factors such as grazing, wave disturbance or sediment anoxia.

Elatine gratiolodes and *Limosella australis* had established on the drying sediments in one dam, which had a low slope. These plants have small flowers and seeds and could have reproduced between sampling dates and before ducks grazed them. Low growing edge plants such as these and *Glossostigma diandrum* and *Crassula helmsii* which are also amphibious fluctuation responders, can germinate and set seed in a few weeks (Crosslé 1998). However an increase in these species in the seed bank was not supported by the glasshouse germination trials in the autumn post-treatment.

Four months after treatment few water plants had been observed to establish in the field for a period long enough to reproduce and set seed. In contrast to the pots of wetland seed bank in the experimental ponds that showed a robust submerged biomass after 6 weeks and which contained reproductive plants, farm dam sediments did not establish any significant submerged water plant biomass over the 16 weeks after treatment. Several factors could account for this such as duck and invertebrate grazing, the unnatural water regime, the condition and consistuency of the sediment, seed burial and sediment nutrients. In charophytes, the density of charophyte oospores has been found to decrease markedly at the edge of the charophyte meadow and amass by the millions in the charophyte vegetation (RIZA 1999).

Some support for the hypothesis that seed bank addition could improve water clarity in farm dams is seen by the seed bank group averages at 20 months after treatment (Figure 6.3). The observations could not be continued past 20 months for the usual reasons that arise in all research - lack of time, equipment and money. In this study charophytes germinated in only one of the 6 dams treated with seed bank but not treated with lime. This shows that charophyte establishment can occur in farm dams even if by chance, and that when it does it is associated with highly desirable water quality outcomes such as a reduction in turbidity and a reduction in SRP and TP. These charophyte beds also provided refuges for numerous zooplankton (pers. obs.). Similar results of the effects of charophytes on water quality have been reported in the recent works of Scheffer (1998) and Van den Berg *et al.* (1999).

Factors other than turbidity and the availability of propagules are likely to affect water plant abundance, they could be the same factors that affect phytoplankton abundance or they may be different. High phosphate and low nitrate-nitrogen ratios may be negatively affecting submerged plant establishment - a reversal of the conditions that make *Anabaena circinalis* common to farm dams. The Australian wood duck (*Chenonetta jubata*) is associated with farm dams and stock water and appears to have benefited from the more available water in farm dams (Brock and Jarman 2000). Herbivory could be having a significant effect on establishment as individual charophytes, *Myriophyllum variifolium* and hundreds of *Limosella australis* and *Elatine gratioloides* plants disappeared between monitoring events due likely to flocks of ducks that move from dam to dam (pers. obs.) Herbivory was given as a factor preventing vegetation colonisation or recovery in lakes (Scheffer 1998, Perrow *et al.* 1997b, Moss *et al.* 1996) but this was not supported by later experiments with coot (*Fulica atra*) (Perrow et.al. 1997b). Long-necked turtles (*Chelodina longicollis*) could also be grazing water plants as they are commonly found in New England farm dams and use them as refuges during dry seasons (Brock and Jarman 2000). The common freshwater crayfish (*Cherax destructor*) found in farm dams and called 'yabbies' in Australia were seen feeding on organic matter just below the surface of the water where they burrow into crevices in the dam wall (pers. obs.). The effects of animal, bird and invertebrate disturbance on submerged plant establishment should be investigated as well as sediment conditions on seed and oospore germination.

7.4 Zooplankton, Phytoplankton and relationship to chlorophyll-$_a$ concentration

A smaller influence of geophysical location on water plant species distribution was observed on the dominant phytoplankton but this was not analysed with PATN. The reduced chlorophyll-$_a$ concentrations in the treated groups compared to the control group were not found to be significant (Figure 6.6). A similar reduction over summer in algal biomass with lime treatment was found in three different hard-water lakes, but without control lakes (Murphy *et al.* 1988, Prepas *et al.* 1990, Babin *et al.* 1994). Chlorophyll-$_a$ concentration (as a measure of algal biomass) was slightly reduced in the seed bank-lime and seed bank treatment groups. The very slight increase in the average chlorophyll-$_a$ concentration in the lime treated group is due to the persistent blue-green algal bloom in dam 5, which increased the group chlorophyll-$_a$ average. From the phytoplankton data this reduction appears to be due to the absence and lower abundance of blue-green algae in the seed bank-lime and seed bank treatment groups respectively. This is not conclusive even with randomised sampling as quantitative sampling of phytoplankton needs to be performed over several seasons and years. In two of the three control dams chlorophyll-$_a$ was higher due to the dominance of blue-green algae (*Anabaena circinalis*) in the summer to the autumn samplings.

Even though all dams would be anticipated to have shown a similar increase in chlorophyll-$_a$ with the warmer months, the trend towards a reduction in chlorophyll-$_a$ concentration with an increase in species richness of zooplankton and phytoplankton was interesting. The lime treatment, which had a very small increase in chlorophyll-$_a$, had the highest increase in taxa richness. Zooplankton species increase in the warmer months is common probably due to the increase in the numbers of bacterioplankton and algae which are their food supply (Boulton and Brock 1999). Lime treatment did not reduce their numbers or diversity as would have been expected with the reduction in algae. The use of lime in a Canadian lake initially recorded almost unchanged numbers of *Daphnia,* but after two weeks the numbers of *Daphnia* increased their density (Murphy *et al.* 1988). This is considered to be a natural response due to the high tolerance to extremes in pH that these invertebrates exhibit.

In the seed bank-lime treated group the slightly higher increase in zooplankton diversity and grazing may have had some influence on the low concentrations of blue-green algae. Lime is recorded as shifting the dominant algal taxa from blue-green to green flagellated forms and diatoms (Prepas *et al.* 1990). In the lime treated Canadian lake discussed above, the first lime treatment had no effect on chlorophyll-$_a$ concentrations but a second treatment resulted in the rapid sedimentation of the blue-green alga, *Aphanizomenon flos-aquae* (Murphy *et al.* 1988). This study can't really be compared, in that a second treatment of lime was not applied to the farm dams so the effect of a second treatment of lime on *Anabaena circinalis* through a further reduction in phosphate (or nitrogen–phosphate ratios) is uncertain).

7.5 Limitations of experiment

7.5.1 Sampling errors

Sampling errors could have occurred when taking seed bank cores from the shallow waters around dams and the proportion of variation could have been less if more samples had been taken from all depths. Seed banks are known to be notoriously patchy (Brock *et al.* 1994b) and where seeds are rare, as when water plants reproduce by vegetative means rather than by sexual reproduction, fewer seeds would be sampled.

Changes to zooplankton and phytoplankton are difficult to interpret without qualitative counts over four seasons and over at least two years. Phytoplankton would ideally be sampled every week so that the trends in successional changes could be recorded for farm dams with different catchment inputs but this was not done for this experiment due to distance considerations and time limitations. The minimum number of 3 replicates per treatment group meant that individual variations in dam variables had a large effect on the averages and increased the standard deviations. This was obvious from the data at the 9th sampling (June 1999) when one dam in the group of three was interfered with after the BACI experiment was officially finished in April 1998. Ideally 5 to 6 replicates would have been more satisfactory but this would be limited by the time and labour needed to collect and sieve the seed bank, to treat the dams with lime and seed bank, sample for all the variables and analyse the water samples.

7.5.2 Limitations to the interpretation of results

Ideally seed bank germination trials in the glasshouse should be done at the same time of year and in successive years, to detect an increase in sediment seed bank. If the after-treatment germinations of sediments had been done in the following spring a different result may have occurred with both seasonal and dormant seed bank germination. The seasonal germination patterns of species and the dormancy and viability of seeds play an important part in wetland plant survival (Brock and Britton 1995).

Glasshouse trials are not good predictors of establishment in the field since it is difficult to replicate field conditions such as temperature fluctuations, water turbulence and light intensity in a glasshouse, but they are still useful indicators of the 'potential' of a seed bank. With submerged water plants the percentage 'potential cover' needs caution in interpretation, as the species that dominated and covered the sediments in the glasshouse were generally shallow water species. Since the water in the tanks was clear they were able to colonise to a depth of 20 cm but physiological factors could have prevented them colonising at greater depths. Placing trays at a greater depth could have helped initiate the germination of deeper water species and given a better estimate of percentage potential cover of the sediments.

One year was insufficient for field research as the time for observing the changes in the field is limited by the order in which pond and glasshouse experiments need to be completed and the time frame of a Masters project.

Part 3

Synthesis

Chapter 8: Synthesis, Management recommendations and future research

Chapter 8 Synthesis, Management Recommendations and Future Research

The first two parts of this thesis included the Literature review in Chapter 1, Chapters 2 to 4 on research into the turbidity tolerance of water plants in the artificial ponds, and Chapters 5 to 7 on research into establishing water plants in turbid farm dams. These make up the research section of this thesis. The final and third part is a synthesis of the results of the first two parts. It discusses how conservation and water quality managers could come to a suitable agreement with landowners. A description of the extension work undertaken and the extension material used with the landowners on whose properties the research was done is in Appendix VIII.

8.1 Synthesis

The results of the pond experiment were limited to those species found in two wetlands in the Northern Tablelands, but otherwise supported the hypothesis that some submerged species of water plants could germinate and establish under low to high turbidity. Germination of some species was actually increased under increased turbidity. Only two submerged angiosperms, *Vallisneria gigantea* and *Potomageton ochreatus,* were found to be tolerant of turbidity and known to grow in deep water. Both these species grow to the surface to reproduce sexually but can also reproduce asexually underwater. Several species of the genera *Chara* and *Nitella* were tolerant of low light, developed a high biomass and were low growing. Other species in these three genera (*Chara, Potamogeton* and *Vallisneria*) have low light compensation points (Kirk 1994, Blanch 1997) so we can assume that at least some other species in these genera found in other areas would be turbidity tolerant. All the species that were found tolerant of turbidity were native species and would be suitable for rehabilitation of many wetlands and farm dams in the Northern Tablelands.

While emergent, submerged and floating plants all have a part to play in supporting a healthy ecology in a lake or waterbody, the focus in this thesis was on the percentage of the sediments covered with water plants. Conclusions and recommendations are therefore focused on those species that need complete submersion. Some submerged species may not be welcome in dams used for homestead water supplies as their upward growth can block pumps and pipes. Charophyte species (stonewarts) because of their low growing habits could provide an ideal tool for the improvement of aquatic habitat and water quality in farm dams. Some species of charophytes may have a strong smell when crushed and should be avoided. Further plantings or seeding of low growing, emergent and floating species could be introduced for habitat heterogeneity in shallower areas of dams where these did not interfere with the provision of a water supply. Charophytes can colonize sediments at different depths depending on the water clarity (Scheffer *et al.* 1994, Schwarz *et al.* 1997, 1999). This implies that the deeper sediments of farm dams could probably be colonized using a variety of charophyte species if the conditions for successful charophyte germination and establishment were known. Unfortunately the success of the pond experiment in establishing submerged germination using seed bank from a temporary wetland could not be replicated in the highly variable field situation.

Using secchi depth as a measure of euphotic depth simplifies the extension of aquatic ecology into the broader community because equipment and methods are cheap, simple and robust. It does not require the use of degradable standards to calibrate turbidity equipment to read water samples, or run on a battery - failures of either which can affect results. The concept of measuring water clarity and the calculations for the euphotic depth using secchi depth measures are straightforward and this underpins the control and management of soil erosion through directly measuring the effects of run-off on water clarity in farm dams, rivers and wetlands. Once water has been cleared and higher standards of water quality have been experienced it becomes normal for landowners to anticipate this as the usual condition in farm dams (pers. obs.)

Seed bank studies are important to establish the presence of seed bank in dams or wetlands in which rehabilitation is planned. Seeds may be present but rarely establish due to grazing by aquatic animals or other factors. Knowing the seed bank status of the wetland could hasten any rehabilitation project because if seed banks are found to be non-viable, alternative sources of propagules through plantings or introduced seed could be investigated. If seeds are found to be present and viable then some temporary protection might be all that is required in establishing water plants. It is better to establish local provenances that are adapted to the area and encourage retaining a broader genetic base, especially where populations of wetland plants are fragmented. Most of the farm dams used in the rehabilitation experiment had few submerged water plant seeds in their sediments so with man-made wetlands and dams the choice lies between introducing seed bank or encouraging the establishment and reproduction of those species already present. To support wetland rehabilitation efforts, information on seed bank germination, water plants and water regime are available from the University of New England and DLWC as a series of three wetland booklets (Brock 1997, Brock and Casanova 2000, Brock, Casanova and Berridge 2000).

The addition of seed bank was inconclusive for the establishment of a cover of submerged vegetation, but it showed great promise for the establishment of emergent vegetation where slope angle was low (Sansom 1997). Although edge vegetation was not measured in this research it was observed to be successful at establishing in dams with a low slope angle (pers.obs.) (Plate 4 a). Edge vegetation offers wildlife habitat and refuge (Brock and Jarman 2000), and can be used as biological filters through nutrient accumulation (Chambers and Mc Comb 1992, Scheffer 1998) and act as physical barriers where they reduce edge disturbance (Chambers *et al.* 1995).

The use of lime or seed bank or a combination of seed bank and lime increased the average secchi disc depth and indicated that high phytoplankton biomass could be temporarily reduced through this approach. The clearing of water did not lead to blue-green algal blooms even when phosphate concentrations were high. Lime did not cause a long-term change in pH or cause toxic death in zooplankton provided the amount of lime was calculated against volume of the dam and the pH was not allowed to go above 9.0 during addition. Blue-green algal blooms were not observed during sampling in the seed bank-lime treatment group, and there was a reduction of their presence in the seed bank and the lime treated groups compared to the control group. It could be informative to conduct an experiment to test the hypothesis that addition of lime or organic matter reduces the dominance of blue-green algae such as *Anabaena circinalis* as lime has previously been found to encourage species of blue-green algae. This research did not result in a permanent change or successful 'switch' in any of the treated groups from a turbid phytoplankton dominant state to a clear, water plant dominant state. Despite this, the growth of charophytes in one seed bank treated dam after 20 months was seen as a singular achievement. This change could have been due to chance alone but it supports the hypothesis that a 'switch' is possible, although the specific conditions for a 'switch' are still unknown.

8.2 Management recommendations

The results of this project are summarised here:

- Water plants can establish under turbid conditions in experimental ponds.

- Germination of some underwater species was actually increased under increased turbidity.

- Similar establishment of underwater plants from seed bank is rarely achieved in the field and the factors preventing establishment need to be identified.

- The use of secchi disc depth is likely to be more practical for novice water managers than other measures of turbidity.

- Light limitation is not the main factor preventing germination and establishment of water plants in farm dams.

- There was no evidence that turbid water needs to be cleared to enable water plants to establish.

- The addition of lime and seed bank or combinations of lime and seed bank to farm dams can increase water clarity and temporarily disrupt algal succession.

- Farm dams usually have poor water plant seed banks.

- The ideal sediment conditions for the germination of water plants are not known.

- Charophytes are particularly tolerant of flooded and turbid water conditions and because they reproduce underwater, are low growing and cover the sediments, they would be ideal for improving aquatic habitat in farm dams as they are known to improve water quality.

Man has always modified landscapes and their biological components for agriculture and domesticated stock and since white man's arrival in Australia the wetlands in the Northern Tablelands have undergone large changes over the past 200 years (Haworth 1994, Brock *et al.* 1999). Farm dams are the result of the necessity to provide permanent water for stock and human use on fenced and subdivided lands and even though this has meant the draining and damming of smaller wetlands it has probably reduced the destructive impact on larger wetlands. Recent changing perceptions of wetlands has come too late to prevent most wetlands from being drained and dammed. The rehabilitation of farm dams will not restore everything that has been lost, but as our principal water resource we need to protect them from pollution and degradation. By removing stock from waterways and dams, establishing edge vegetation, controlling algal blooms where appropriate and establishing submerged water plants for zooplankton refuges, we can partly achieve that aim. Landowners interested in improving water quality on their farms can use the measurement of secchi disc depth to monitor their farm dams and wetlands and record changes in turbidity over time and to manage catchment erosion. Many of the present farm dams are filling with sediment and as such could be redesigned to fit the best model for water plant establishment and as functioning wetlands, not just for water storage and stock use. Many of the changes in land management that are necessary to sustain water quality will not always be immediately acceptable to all landowners but the role of wetland processes in sustaining water resources can be discussed at Landcare group meetings and the principles expounded on from there.

The 'water weed' mentality from the 1970's still influences the use of water plants as useful and welcome additions to farm dams and ponds. Few native plants with highly visible, fragrant and colorful flowers have been presented to the public as an environmentally desirable alternative. Ironically, one of the worst waterweeds, the introduced South American species, *Echinornia crassipes*, has showy lilac flowers and this species is a declared environmental weed of Australian wetlands (Sainty and Jacobs 1981). An outcome that could be acceptable to many landowners would be the use of charophytes in farm dams, as they are low growing and would not block water pumps, and the use of edge vegetation to protect dam walls and provide habitat. As serious water quality issues will continue to affect the landowners of the Northern Tablelands and elsewhere until blue-green algal blooms can be managed, an option to control algae in the short-term would be the use of small amounts of lime to disrupt algal succession as is done in Canada. Lime does not have the toxicity of alum (aluminium sulphate) or copper sulphate (an algaecide) to aquatic animals and invertebrates

8.3 Future research

As above, the hypothesis that addition of lime or organic matter (either as seed bank or other substances such as barley straw) reduces the dominance of species such as *Anabaena circinalis* is worth further study as the problem with blue-green algae in water impoundments increases. There is some concern among scientists that lime may aggravate blue-green algae due to their tolerance of alkaline pH and that lime is now obsolete as a treatment and this needs investigation. The characteristics of the sediments for water plant species germination and establishment is an area for future research. Dam sediments could be anoxic and limiting germination (Perrow *et al.* 1997a) or increasing germination of specific water plants (Van den Berg pers. comm.). The effect of redox reactions through light induced oxygen production by benthic algae is another area that is neglected. We do not know what kind of sediments are most suitable for water plant germination and if the farm dams need to be treated a certain way before they will support water plants. Drying of the farm dam sediments did not appear to increase germination in trays in the glasshouse although drying has been shown to be important in the recovery of natural wetlands. Some water plants germinated in both glasshouse and field so not all farm dam sediments are incompatible with water plant survival. Farm dams must have more structural complexity, including the right angle of slope to support submerged water plant germination and establishment (Sansom 1997). Emergent vegetation establishment was highly successful at several farm dam sites but its action on sediment conditions, phosphate release and organic matter production in the field of water ecology is not fully understood.

Previous surveys of dams with established water plants and good water quality need to be reassessed with the angle of slope and bathymetry as two new input variables. The multivariate analysis of a large data set of farm dam characteristics that has already been collected could pinpoint the common characteristics of farm dams in which water plants, including charophytes, have naturally established. Dams for rehabilitation could then be chosen with the physical and chemical attributes that are most suitable for plant establishment

The disappearance of young plants observed in the field suggests the hypothesis that grazing is having a large effect on submerged plant establishment. Protection from grazing animals during field establishment would have helped narrow down the reasons for the poor establishment of submerged water plants but this was expensive, time consuming and it was difficult to construct efficient protection in dams with different bank slope, bathymetry and water regimes. Part of the problem with designing efficient protection lay in the uncertainty surrounding the identity of the grazers whether zooplankton, small water animals, yabbies or ducks. Plant establishment cages that could be staked to the sediments and opened from the top for observation and identification of water plants could be useful in future experiments.

Charophytes are easily grown in shallow water and can form fertile oospores within a few weeks (Casanova 1993). The density of oospores increases inside the mass of rhizomes and can remain germinative for decades (Riza 1999). Their commercialization as a seed source to improve water quality, supply food for invertebrates in aquaculture and improve aquatic habitat would be an economically useful proposition. Charophytes were agreeable to cultivation in the glasshouse in shallow tanks of turbid water and reproduced within a few weeks (pers. obs.). RIZA Institute for Inland Water Management and Waste Water Treatment in the Netherlands and a University in Perth, Western Australia, are researching the use of charophytes for water quality improvement in lakes and mining ponds (John and Ward 1996, Riza 1999). It must be taken into account during wetland rehabilitation projects that the use of non-provenance charophytes in rehabilitation may be just as problematic as when using terrestrial plants.

One important factor in the experimental design would be to have more control over the experimental units, with perhaps a contract with the landowner to keep stock out of farm dams for a longer period of time as the time for establishment and observation needs to be extended.