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Managing Submersed Aquatic Plants in the Sydney International Regatta Centre, Australia

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ABSTRACT

The Sydney International Regatta Centre is a $A40 million dollar facility located at Penrith NSW, Australia. It consists of two interconnected shallow lakes, with a capacity of around 3,000 megalitres. The competition lake is 2.3 km long and 170 m wide with an average depth of 5 m, while the warm-up lake has an average depth of 4 m and a convoluted shoreline. The two lakes are used for training, rowing, and canoeing events up to and during the Sydney 2000 Olympic games and form the rowing heart of Sydney. Adjoining these two lakes and drawing its water from them is the white water slalom course for the Olympics. When the rowing course was originally constructed, the lakes were planted with ribbonweed (*Vallisneria americana* var. *americana* Michaux), with the intent to establish a basis for a healthy aquatic plant assemblage, which was capable of "out-competing" invasive macrophyte species and nuisance blue-green algae. Over the past few years, the aquatic plant assemblages have flourished, with six additional native species colonizing the lakes. In March 1997, ribbonweed began to break away at its base and float to the surface. This defoliation caused major problems for management of the lakes and its primary users, as floating leaves interfered with rowing and swimming events. To alleviate the problem, ribbonweed was physically removed, and mechanical harvesting has been the primary management tool used to keep the plants under control. A program of monitoring was established in 1997, where spatial and temporal patterns in the distribution and abundance of submersed aquatic macrophytes were measured over two years. This program found that harvesting was ineffective, in terms of keeping plant biomass to a manageable level. In this paper we report the results of the monitoring program and present some preliminary data on a management experiment, which used the herbicide fluridone to help reduce plant growth in conjunction with physical and mechanical removal.

Key Words: macrophyte, artificial lake, *Potamogeton* spp., *Vallisneria americana, Hydrilla verticillata*, harvesting, herbicide, fluridone.

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INTRODUCTION

Submersed and emergent plants are essential components of aquatic ecosystems and play vital structural and functional roles within these habitats (Westlake 1975). Eutrophication of waterways and invasion by exotic species can lead to excessive growth of macrophytes (Roberts et al. 1999). Major problems associated with the growth of nuisance aquatic weeds have occurred to lakes and rivers throughout the world and are generally related to conflicts over the intended use or perceived function of a body of water (Clayton 1996). To be able to manage aquatic plants effectively within any body of water, a fundamental understanding of the nature of scale and the patterns and processes operating within the system are essential (Farmer and Adams 1991).

The Sydney International Regatta Centre (SIRC) near Penrith, Australia (Figure 1) was constructed as part of the Penrith Lakes Scheme (Carter et al. 1994). The competition lake is 2.3 km long and 170 m wide with an average depth of 5 m. The substratum at the edge of the rowing lake consists of a 5-10 cm diameter gravel bed overlaying clay, while the deeper parts of the lake are shale with a silt covering. The warm-up lake has an average depth of 4 m and a convoluted shoreline. The two lakes are used for water sports and will be used during the Sydney 2000 games. When the SIRC was originally constructed, the lakes were planted with ribbonweed (*Vallisneria americana* var. *americana* Michaux) (Jacobs and Frank 1997) in an effort to alleviate the potential problems caused by algae and exotic macrophytes[5], and to establish a "balanced aquatic ecosystem" with a healthy aquatic plant assemblage, capable of out-competing nuisance algae and "exotic" macrophytes (McCreary 1991).

Over the past few years, the aquatic plant assemblages in the lakes have flourished, which is not surprising given the shallow depth and clear water. In March 1997, ribbonweed began to break away at its base and float to the surface[5]. The actual cause of the defoliation was never established but was probably due to rising water levels, increased turbidity, stratification and low dissolved oxygen levels[6]. Further investigations indicated that blue-green algae (*Oscillatoria* sp.) growing at the base of the ribbonweed could be associated with the detachment[6]. This defoliation caused major problems for management of the lakes and its primary users, as

[5]AWT. 1997. An assessment of the current status of Penrith Lakes macrophytes. AWT EnSight report No. 97/099 for Penrith Lakes Development Corporation Ltd.

[6]Sainty, G. R. 1997. Sydney International Regatta Centre: submerged plants—rowing and warm-up lake. Report to the Olympic Co-ordination Authority. Sainty and Associates, Sydney.

floating leaves interfered with all types of water sports. To alleviate the problem, floating ribbonweed was physically removed from the lakes using aquatic weed harvesters.

A monitoring program was instigated in October 1997, where spatial and temporal patterns in the distribution and abundance of submersed aquatic macrophytes were measured[7], so that predictions in plant growth could be used to assist with the management of the lakes (Madsen 1993). The monitoring ceased after June 1999, and no further quantitative sampling was done until June 2000. Qualitative assessments of plant growth continued and the lake's managers were advised that the mechanical harvesting was not controlling the plant growth.

As the Sydney 2000 Olympic games approached, the managers of the SIRC became concerned about the potential disruption of the games. The objective of this study was to therefore determine whether herbicides, such as fluridone, in conjunction with ongoing physical removal could assist in managing the aquatic macrophytes within the SIRC. A pilot experiment was therefore planned to establish the efficacy of using fluridone in controlling the growth of aquatic plants. The experiment was to begin in August 1999 however government approval to use fluridone was not given until January 2000. Here we report on the results of the macrophyte monitoring program and present the results of the fluridone trial.

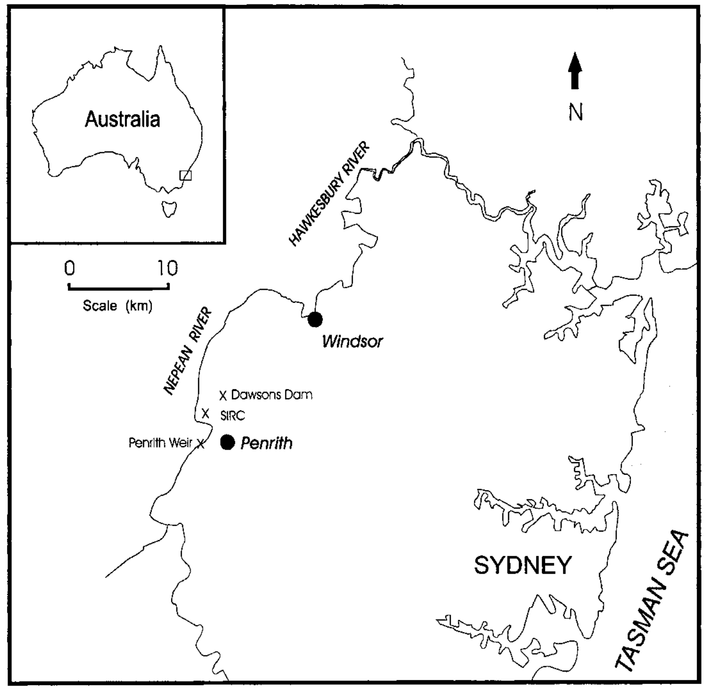

Figure 1. Location of the Sydney International Regatta Centre at Penrith NSW. Australia.

MATERIALS AND METHODS

Spatial and Temporal Patterns

The SIRC lakes are located to the north west of Penrith (within the Penrith Lakes Scheme), adjacent to the Hawkesbury-Nepean River (Figure 1). The SIRC consists of two lakes (competition lake and warm-up lake) connected by narrow channels at either end. To be able to generalize about the distribution and abundance of aquatic macrophytes through time, the competition rowing lake was divided into 40 potential sites. Six of these sites were randomly selected at each of ten random times between October 1997 and June 1999. The competition lake was divided into three depth zones, and within each zone SCUBA divers randomly harvested five $0.04m^2$ quadrats of all aquatic macrophytes (see Roberts et al. 1999). Within each of the three depths, SCUBA divers also randomly collected ten individual ribbonweed plants for leaf length measurements. Each replicate sample was placed in pre-labelled plastic bags on the support boat, and appropriate field notes at each site were recorded. The contents of each quadrat were field sorted to species level. The samples were air dried for two hours to remove excess moisture, and the fresh weight (to the nearest gram) of each species determined using a Sartorius (5,000 g) field balance. The epiphytic algae from each plant were scraped into a plastic container and weighed separately.

Analysis of variance (ANOVA) was used to examine spatial and temporal differences in macrophyte richness and abundance. Where time was considered a random factor, sites were nested within time and depths were fixed. Prior to analysis of variance, the data were examined for homogeneity of variances using Cochran's test. Where variances were found to be heterogeneous, the raw data were transformed using a log $(x + 0.5)$ function (Underwood 1981). A further Cochran's test was done to ascertain whether the transformation was successful. If the transformation was unsuccessful, the analyses were done on the untransformed data. Where significant differences were found in the analysis of variance, Student-Newman-Keuls (SNK) tests were used to establish where these differences were (Winer 1971).

THE EFFECTS OF FLURIDONE ON PLANT GROWTH

In May 1999, trials were undertaken of alternative plant removal techniques including the use of pneumatic chainsaws, weed-control mats, and airlift dredging. Management strategies to control plants within the SIRC also included the use of a variety of harvesting techniques and a drawdown of the lake by approximately 2m. In addition, an experiment was done to assess the potential use of fluridone in controlling pondweeds and to assist in slowing the growth rate of ribbonweed in the SIRC competition lake. Fluridone was initially added to the SIRC competition lake along a 500 m section (Impact Close) on the 6th January 2000, and again on the 18th January and 9th February 2000. At each of seven sites within the SIRC, a single water sample was collected from both surface and bottom waters over the next 12 weeks. The concentration of fluridone was determined, using the FasTest procedure, at each of the seven sites and the data were pooled for each site to establish the mean concentration of fluridone at various places within the SIRC. One location at the far end of the competition lake (Impact Far) and two locations within the warm-up lake (Control Close and Control Far) were also

[7]Sainty, G. R., D. E. Roberts, S. P. Cummins and G. J. Hunter. 1998. The management of aquatic macrophyte assemblages in the Olympic Rowing Lake, Penrith NSW. Sainty and Associates, Sydney.

selected to act as controls to the treatment area. Two independent reference locations (outside the SIRC) were also sampled at the same spatial and temporal scales, to independently assess the effects of fluridone on the aquatic plants. These locations were at Penrith Weir and Dawson's Dam (see Figure 1). Within all locations, three random sites were sampled by harvesting biomass from three replicate 0.04 m^2 quadrats, with two sampling times before and two times after treatment. It should be noted that the first sampling time did not include the independent reference locations. To assess the dispersal and concentration of fluridone throughout the SIRC lakes, single water samples were collected in the surface and bottom waters at seven sites beginning on the 6th of January through to the 11th of February 2000. These samples were sent to SePRO Indiana for determination of the fluridone concentration using the FasTest.

In March 2000, it was noted that ribbonweed was dislodging from the bottom of the lakes and rising to the surface. An assessment of the "percentage plants loose" was done at the same spatial scale as the fluridone experiment to assess the extent of potential plant dislodgment over the entire SIRC. SCUBA divers randomly placed five 0.5 m^2 quadrats within each of 3 sites at each of the locations. Within each quadrat, individual ribbonweed plants were counted and recorded as either attached or loose. The variable "percentage plant looseness" was then calculated and ANOVA used to examine differences between locations.

RESULTS

Spatial and Temporal Patterns

Seven species of aquatic macrophytes were recorded from within the SIRC rowing lake, which included ribbonweed, hydrilla (*Hydrilla verticillata* (L.f.) Royle.), clasped pondweed (*Potamogeton perfoliatus* L.), blunt pondweed (*Potamogeton ochreatus* Raoul), curly pondweed (*Potamogeton crispus* L.), floating pondweed (*Potamogeton tricarinatus* A. Benn. & F. Muell.) and red watermilfoil (*Myriophyllum verrucosum* Lindl.). As well as aquatic plants, five algal taxa were identified; *Chara* sp., *Nitella* sp., *Cladophora* sp., *Oscillatoria* sp., *Spirogyra* spp., and the epiphytes termed "aufwuchs" (diatoms, bacteria, detritus and silt). Significant Depth × Site (Time) interactions were found for all derived variables analyzed, which indicated small-scale patchiness at different depths at each site through time. Up until June 1999, species richness fluctuated through time, however no significant differences were found in the Time × Depth interaction (Figure 2a). Generally, the shallow fringes of the lake (0-2 m depth) had greater species richness than the deeper sections (>4 m depth). Total macrophyte abundance fluctuated significantly through time depending on which depths were examined (Figure 2b). The total abundance of macrophytes generally fluctuated between 100-200 g FW/0.04 m^2 in the shallow sections of the lake. In general the patterns observed in the total abundance reflected growth and decline of ribbonweed, the most abundant submersed species (Figure 2c). In the deeper parts of the rowing lake, total abundance increased significantly between February and May 1998 due to increased algal epiphytes on the leaves of the ribbonweed. Total abundance declined over the next few months, after which it steadily increased due to ribbonweed growth within the deeper sections of the lake. There were significantly greater fresh weights of ribbonweed at depths greater than 2 m. Although the abundance of ribbonweed fluctuated through time, its leaf length generally increased in the deeper sections of the lake and declined at times in the shallower sections, probably because of continued mechanical harvesting. A significant difference was found in the Time × Depth interaction for hydrilla (Figure 2d) where its biomass increased in the depth range 0-2 m from September 1998 through to June 1999. Within the shallow sections of the lake, the biomass of clasped pondweed fluctuated through time with increased growth beginning in October 1998. In depths over 4 m, blunt pondweed had peaks in its growth in December 1997 and October 1998. Epiphytes such as filamentous algae and Aufwuchs were generally more abundant in the deeper sections of the lake, and were attached to the leaves of ribbonweed and pondweeds. The greatest epiphyte abundance occurred in the last two sample periods of 1999, in April and June and was associated with the leaves of ribbonweed.

The Effects of Fluridone on Plant Growth

The theoretical dose rate for fluridone in the SIRC was 20 ppb. Fluridone mixed throughout the lakes, with the single highest measurement (prior to full mixing) recorded within the treatment area (35 ppb) on the 18th January 2000. The greatest mean (±SE) concentration of fluridone was found at and close to the treatment area (10.2 ± 2.3 ppb). The data suggested that fluridone was highly mobile and well mixed within the SIRC, with concentrations of around 3 ppb recorded at sites, located in the warm-up lake.

The effect of fluridone on the growth of aquatic plants was examined in two analyses because there were no before data at time 1 for the independent reference locations. The first analysis tested the hypothesis that there would be no differences in derived macrophyte variables at treatment and control locations within the SIRC, from before to after the application of fluridone. Apart from significant Location and Time (Period) main effects, there was no evidence for fluridone treatment on total species richness and the abundance of hydrilla. Generally, there were no significant differences in the Period × Location interaction, which indicated that there were no effects of fluridone on plant growth from before to after its treatment. There were however significant differences in the Location × Time (Period) interaction for total (Figure 2e) and ribbonweed biomass (Figure 2f). Significant Site (Period × Time × Location) interactions indicated small-scale patchiness at sites through time for these two variables.

In the second analysis, a significant Time × Location interaction was found for all variables except for hydrilla biomass. After 3 months there was no evidence of fluridone causing a reduction in plant biomass at the treatment location, however hydrilla was observed to have lost its green pigment, pondweeds were translucent and ribbonweed exhibited patches of translucence. In March 2000, ribbonweed began to break away from the sediment and rise to the surface causing problems for rowing events[4]. It was implied that the fluridone

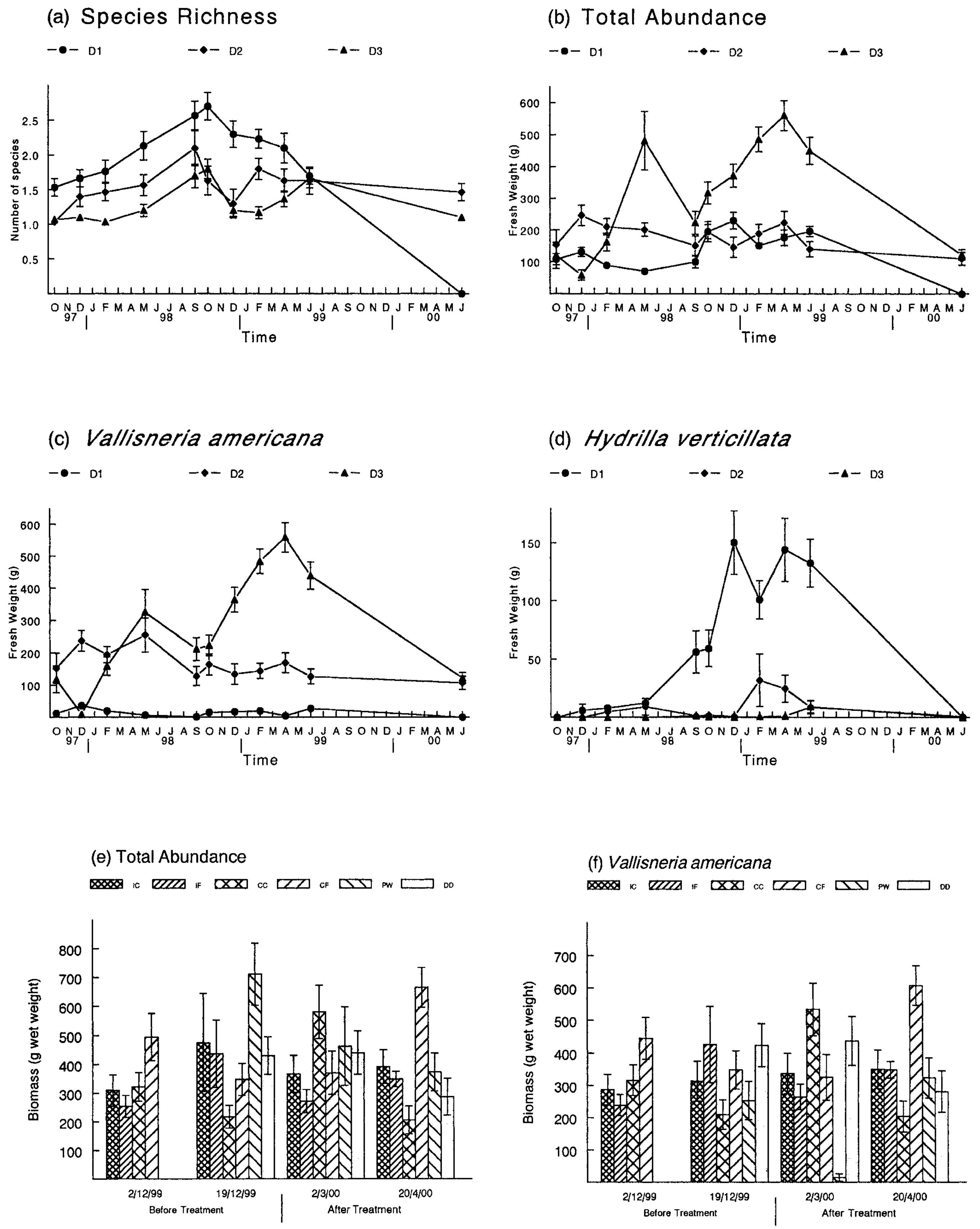

Figure 2. Mean (± standard error) (a) richness and (b) total, (c) vallisneria and (d) hydrilla abundance estimates (fresh weight in g 0.04 m^2; n = 30) from within the competition lake in the Sydney International Regatta Centre and (e) total and (f) vallisneria abundance both before and after application of fluridone (fresh weight in g 0.04 m^2; n = 9).

treatment had caused the large-scale detachment of ribbonweed across the SIRC, which would continue to cause serious problems for competitors up to and during the Sydney 2000 games. Assessment of the plant attachment over the entire SIRC and in the reference locations indicated that there were significantly greater numbers of plants loosely (approximately 80%) attached in the vicinity of the fluridone treatment zone compared with all other locations.

A final quantitative assessment was done in June 2000, at the same spatial scale as the monitoring program. This sampling followed observations that the general health of the aquatic plants within the SIRC had declined due to fluridone application, extensive air suction dredging and a drawdown of the lake by approximately 2 m. The result has been a total loss of aquatic macrophytes within the depth range 0-2 m (Figures 2a-d) and significant declines in species richness and biomass in depths over 4 m (Figures 2a-d). The leaves of ribbonweed were generally observed to be turning yellow, necrotic in places and exhibiting very poor root structure at sites where fluridone was applied. These symptoms declined the further we moved away from the fluridone application area.

DISCUSSION

Seven native flowering submersed plants were recorded in the SIRC lakes, with the most troublesome species for lake managers and users being ribbonweed and the pondweeds. The abundance of hydrilla had increased in some of the deeper sections of the lake, from June 1999 up until the application of fluridone in January 2000. Red milfoil was not abundant in the deeper waters of the lake, however it has been observed at these depths (Sainty and Jacobs 1984). The species in the SIRC included most of the native submersed species that can be found in the nearby Hawkesbury-Nepean River system (Cummins et al. 1995).

Aquatic plant species richness generally increased through time until October 1998, after which it declined. The SIRC lakes are relatively new and it could be expected that changes in species richness would occur as plants are recruited and spread throughout the system. There are few published accounts of succession in macrophyte assemblages in artificial lakes in Australia, however Royle and King (1991) described significant colonization of submersed plants within three years in Lake Liddell, NSW. Species richness in the SIRC was also found to decrease with depth, which was to be expected as the distribution and zonation of freshwater macrophytes is generally related to available light (Spence 1967).

There were no exotic submersed species found within the SIRC lakes. Two aquatic "weeds" grow in the nearby Hawkesbury-Nepean River; egeria (*Egeria densa* (Planch.) Casp.) and elodea (*Elodea canadensis* Michx.) (Cummins et al. 1995), and given enough time they will probably establish within the SIRC. The mechanisms by which these aquatic plants can potentially disperse into the SIRC are important in terms of the final suite of species that will be found. Many aquatic macrophytes produce specialized structures to aid in reproduction and dispersal. An example of successful dispersal by fragmentation has been observed in Hawkesbury-Nepean River (Roberts et al. 1999) where egeria was effectively spread by flooding.

In the past 3 years we have observed the continued growth and spread of macrophytes to non-vegetated areas of the lake. Total plant and ribbonweed biomass fluctuated through time with the greatest fresh weights measured in the deeper parts of the SIRC. While the lakes are considered to be nutrient poor, i.e. oligotrophic (Carter et al. 1994), the water quality is ideal for growing submersed aquatic plants. The catchments are being developed, and enrichment of the system may occur in the future, with the potential for increased plant growth. The submersed macrophytes within the lake do not appear to be limited by nutrients in either the water column or the sediments. Nutrition may be considered of secondary importance to growth with light and temperature the main limiting factors (Barko and Smart 1981). Ribbonweed generally requires water temperatures above 20C for vegetative growth (Barko et al. 1981) while maximum growth and photosynthetic activity occurs at about 32C (Catling et al. 1994). The maximum temperature recorded within the SIRC was 28C during February 1998 with water temperatures considered most favorable for the growth of ribbonweed occurring for at least 7 months of the year.

While it initially appeared that using fluridone to control macrophyte growth was not working, in recent months we have noted a reduction in ribbonweed "health". The final quantitative assessment in June 2000 indicated a reduction in the number of species and a significant reduction in the fresh weight of ribbonweed within the SIRC. The ambient fluridone concentration within the entire SIRC after 5 months was approximately 3 ppb, and at this concentration is probably still affecting plant growth.

The airlift dredger has proved successful in helping to remove the biomass of all plant species within the SIRC. The lake drawdown has also reduced the plant biomass within the shallow sections and once the lake level is restored these shallows should re-colonize. The dredging and laying of weed mats are now becoming effective on the aquatic plants within the SIRC, however the risk of blooms of blue-green algae has increased with the significant disturbance occurring to the system.

Problems associated with the presence or proliferation of aquatic plants are generally associated with conflict over the intended use or perceived function of a water body (Clayton 1996). In this case, the intended use of the lakes is recreational, and management needs to be focused on keeping macrophyte growth to levels where the lakes are useable. Given the increased richness and abundance of plants within the system, it is predicted that they will continue to cause serious concerns for managers and users. The proliferation of aquatic plants in lakes, reservoirs, rivers and estuaries has caused major ecological imbalances to aquatic systems. In many cases, this has led to significant financial burdens for managers of these systems (Clayton 1996). Aquatic plants require sufficient water, light and nutrients as well as a suitable temperature range and appropriate substratum in which to grow. Manipulating these factors can result in some level of control of aquatic plant growth. The four control techniques of habitat modification, physical removal, chemical and biological control may all need to be used to successfully manage the SIRC. The "leave alone strategy", which has become popular in recent years, is not an option as the lakes will be in continual use up to and following the Sydney 2000 Olympic games.

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