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Response of Sago Pondweed to Combinations of Low Doses of Diquat, Cutting, and Shade

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ABSTRACT

Sago pondweed (*Potamogeton pectinatus* L.) is a problem submersed weed of rivers, irrigation and drainage channels throughout temperate and subtropical regions of the world. Responses of this weed to low doses of diquat and cutting in the presence and absence of shade are described. Diquat at conditions concentrations ranging from 0.2 to 0.5 mg/l for 24 to 168 hours provided good control of sago pondweed under glasshouse conditions. Diquat at low doses of 0.1 and 0.2 mg/l and cutting alone, were not sufficient to provide acceptable control for normal management purposes, but low doses of diquat or cutting combined with 50 to 75% shade provided good control.

Key words: herbicides, light availability, UK, rivers, submersed weeds.

INTRODUCTION

Sago pondweed (*Potamogeton pectinatus* L.) is a major temperate to sub-tropical submersed weed, primarily in rivers, irrigation networks and drainage channels (Caffrey 1990, Sabbatini and Murphy 1996, Spencer 1986, van Wijk 1988, Kantrud 1990). Control methods are usually based on physical removal or herbicides (Wade 1993, Murphy and Barrett 1993). Diquat is widely used to control this weed, and is typically applied at 1.0 mg/l active ingredient, with a minimum exposure period of 24 hours (Barrett and Murphy 1982), to provide control for up to 1.0 year (Fox et al. 1986, Van and Conant 1988, Caffrey 1990). Increasing concern about use of herbicides in aquatic systems has produced pressure to reduce the loadings of herbicides used for aquatic weed management. One possible approach is to combine reduced concentrations of herbicide treatments with other control techniques in integrated management programs. Shading was suggested by Dawson (1978, 1981, 1989) as an ecologically sound method of complementing the impacts of mechanical and chemical control on aquatic weeds in channel systems. van Vierssen and Hootsmans (1990) suggested manipulation of underwater light regime, i.e., using turbidity-promoting benthic-feeding fish coupled with a low dose of herbicide to cause chronic stress to the target weeds, and followed, where necessary, by mechanical removal. This approach was used in channel systems in Argentina (Hootsmans et al. 1996, Sabbatini et al. 1998, Sidorkewicj et al. 1998), with good results. In this study we evaluated the effectiveness of low doses of diquat, combined with shading and cutting, to control sago pondweed.

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MATERIALS AND METHODS

Experiment 1: Effects of diquat concentration and exposure time

Sago pondweed tubers were collected from the River Kelvin, Glasgow, Scotland and planted (30 tubers per tank) approximately 6 weeks prior to herbicide treatments, in 32 plastic tanks with a volume of 30 l at a depth of 3 cm into sediment obtained from the same river. The sediment was presieved to remove any potential propagules. The tanks were filled with water from the Glasgow public water supply (calcium 4.6 mg/l; pH 8.26; nitrate 0.63 mg/l; reactive phosphate 0.53 mg/l; chlorine 0.31 mg/l: West of Scotland Water plc), aerated, and replaced every 72 hours. Tanks were set up in a heated glasshouse (20C) with supplementary lighting (16 hours light: 8 hours dark regime: Navilux 400W sodium floodlights). Approximately 90% germination success occurred. The experiment consisted of 32 treatment combinations of diquat concentrations (0, 0.1, 0.2 and 0.5 mg/l diquat) and exposure time (0, 1, 2, 12, 24, 48, 96, and 168 hours), arranged in a random-block design with three replicates (Lane et al. 1982). The use of a dual-control design (with zero treatments allocated for both exposure period and herbicide concentration factors) was intended to provide sufficient untreated replicates (n = 33) to permit meaningful comparison with treated means, on a concentration-by-concentration basis. Eleven control tanks were allocated, at random, across the three blocks as controls for one each of the three herbicide concentration factor-levels. Null hypotheses were "no effect of herbicide exposure period or concentration, or the interaction of these factors, on growth variable measured; plus no effect of blocks (i.e. location on glasshouse bench)". At the end of the assigned exposure time, each tank was emptied and refilled with tapwater at least three times to remove diquat residues. Plants were allowed to grow for an additional 8 weeks after treatment. Response variables measured (per plant) were whole plant dry weight (g), shoot length (cm), tuber production, and tuber dry weight (g).

Experiment 2: Effects of shade, cutting, and low-dose diquat

Tubers and sediment used in this study were collected as for the previous experiment. Tubers were allowed to germinate in 36 plastic tanks with a volume of 2.8 l of tap water for

1.0 week in the glasshouse. After germination, 30 tubers were planted in each 30-l tank, and grown on for 8 weeks after germination (with similar levels of germination success as in Experiment 1). The effects on sago pondweed of diquat (0, 0.1, 0.2, and 0.5 mg/l) with cutting (uncut, cut once, cut twice: using a sharp knife), and shading (no shade, low shade, high shade) were examined in a split-plot design (Lane et al. 1982), with three blocks, where the cutting treatment was split: Each tank was considered as a plot, within which one third of plants were uncut, cut once, or cut twice. This design economized on space and number of tanks required to accommodate the experiment, without compromising statistical requirements. When plant height reached an average of 40 cm, tanks were shaded with a layer of white (50% light reduction) or black (75% light reduction) shade material, or left unshaded. Herbicide applications were made 1.0 week after shading commenced. Treatments cut once were applied 60 days after start of shading. Treatments cut twice had cuts applied 60 and 90 days after shading was applied. Cutting treatments uniformly reduced the plant length to 2 cm after each treatment. All plants were allowed to grow for an additional 8 weeks after the date of the second cut. Response variables measured (per plant) were shoot length (cm) and dry weight biomass (g). Null hypotheses were: “no effects on response variables of the treatment factors imposed, alone or in combination, plus no effect of blocks”.

In both experiments data were analyzed for treatment effects by standard ANOVA procedures with subsequent use of Tukey’s Least Significant Difference test (Little and Hills 1978) to separate means.

RESULTS

Experiment 1: Effects of diquat concentration and exposure time

Injury to sago pondweed plants occurred at most concentrations and exposure times tested. Block effects were not significant. Exposure to 0.5 mg/l diquat resulted in 100% inhibition of plant growth and tuber production (Figure 1). The 0.1 and 0.2 mg/l treatments also significantly ($p < 0.001$) reduced biomass at all exposure times (Figure 1). Most shoots in the 0.1 and 0.2 mg/l diquat concentrations at 48-, 96-, and 168-hour exposure times were brown, necrotic and appeared dead.

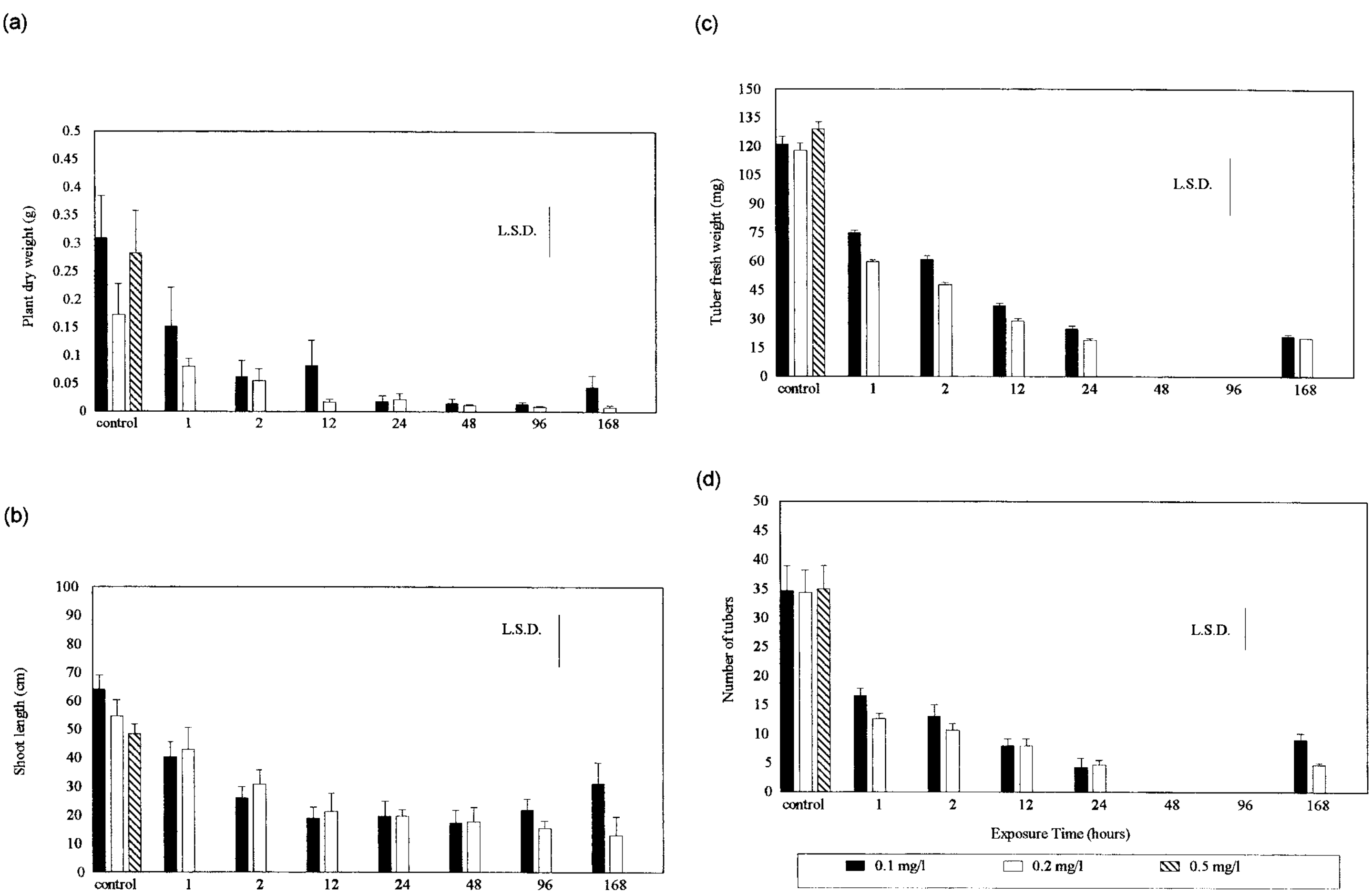

Figure 1. Effects of diquat concentration and exposure time on (a) plant dry weight (g), (b) shoot length (cm), (c) tuber weight (g), and (d) tubers per plant in sago pondweed. Error bars represent ±1 standard error (s.e.); separate bars represent least significant difference: L.S.D. ($p < 0.05$). Control values represent means of sets of untreated plant response data, *a priori* divided at random into three sets (n = 11 per set), each corresponding to one of the three herbicide concentrations.

The inhibition of tuber production persisted long after the plants had recovered from initial herbicidal effects. The duration of tuber suppression increased with increasing dose. The 0.1 and 0.2 mg/l treatments (12, 24, 48, 96, and 168 hours exposure) reduced tuber production by 58 to 100%. The tubers produced in the 0.1 and 0.2 mg/l treatments at all exposure times were also much smaller than those of untreated plants (Figure 1).

Experiment 2: Effects of shade, cutting, and low-dose diquat

ANOVA on data collected 120 days from the start of experiment showed significant effects of diquat and shading on sago pondweed growth variables. Block effects were not significant. There was a significant reduction in plant dry weight at low and high shade (51 and 81% respectively) compared with unshaded plants (Figure 2). Cutting alone was ineffective as a control measure. Compared with uncut plants, there was a 23% increase in biomass after one cut (Figure 2). Although a 53% reduction of biomass was observed after two cuts compared with control plants (Figure 2), this was not significant ($p > 0.05$). Diquat significantly reduced plant biomass compared with untreated controls (Figure 2).

Combinations of cutting, shading and diquat resulted in better control of sago pondweed than any single method alone. A significant decrease of plant biomass was observed after one cut under both low and high shading. Doubling the cutting frequency produced even better results: 67 and 96% biomass reductions for the cut twice treatment, with low and high shade respectively (Figures 2 and 3).

Plant length was significantly reduced by high shade. Despite a 22% reduction in plant length compared with untreated plants, there were no significant differences between treatments after cutting (Figure 3). Greater reductions of plant length were observed at the low doses of 0.1 and 0.2 mg/l of diquat under shaded conditions (Figure 3).

DISCUSSION

Increasing effects on plants were observed, as expected, with increasing diquat concentration and exposure times (i.e., increasing herbicide availance: Murphy and Barrett 1990). However, rapid regrowth occurred at low availances: treatments with 0.1 and 0.2 mg/l for 1, 2, and 12 hours of exposure were inefficient in significantly reducing sago pondweed biomass. New growth of treated plants remained bleached and necrotic while in contact with diquat. When diquat was removed, plants began to regrow from tubers. Regrowth from tubers suggests a lack of herbicide transport to tubers (Van and Stewart 1985), in keeping with the well-known poor ability of diquat for translocation within the plant (Murphy and Barrett 1993).

Regrowth depended on the exposure time. The results suggest that low doses of diquat can control sago pondweed, but must be in contact for >24 hours. However these results were obtained in softwater (low Ca^{++}) systems under artificial conditions, which may not necessarily reflect conditions occurring in all natural systems. Long exposure periods are difficult to achieve for diquat in ambient conditions, even using

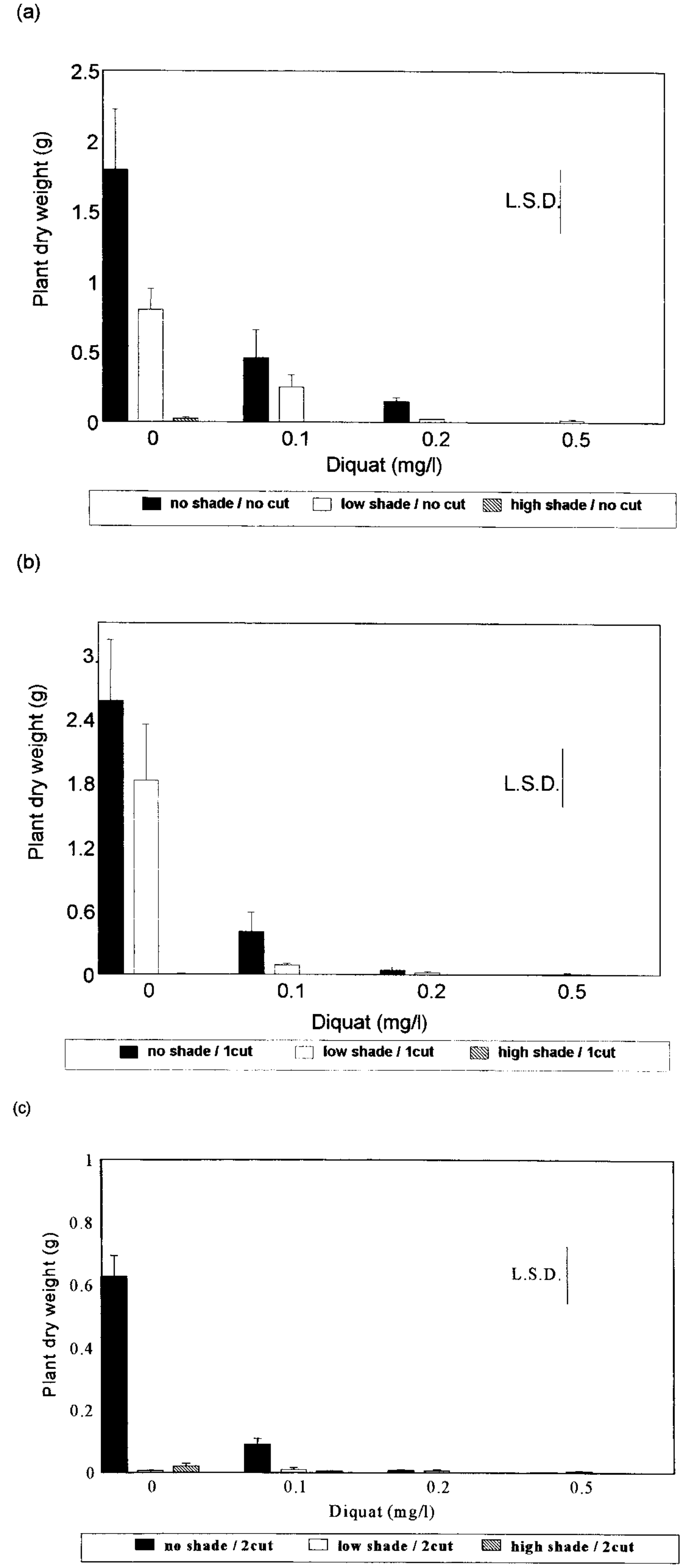

Figure 2. Effects of diquat concentration, cutting and shading on plant dry weight (g) in sago pondweed: (a) no cut, (b) cut once (1cut), (c) cut twice (2cut) treatments. Error bars represent ±1 s.e.; separate bars represent L.S.D. ($p < 0.05$).

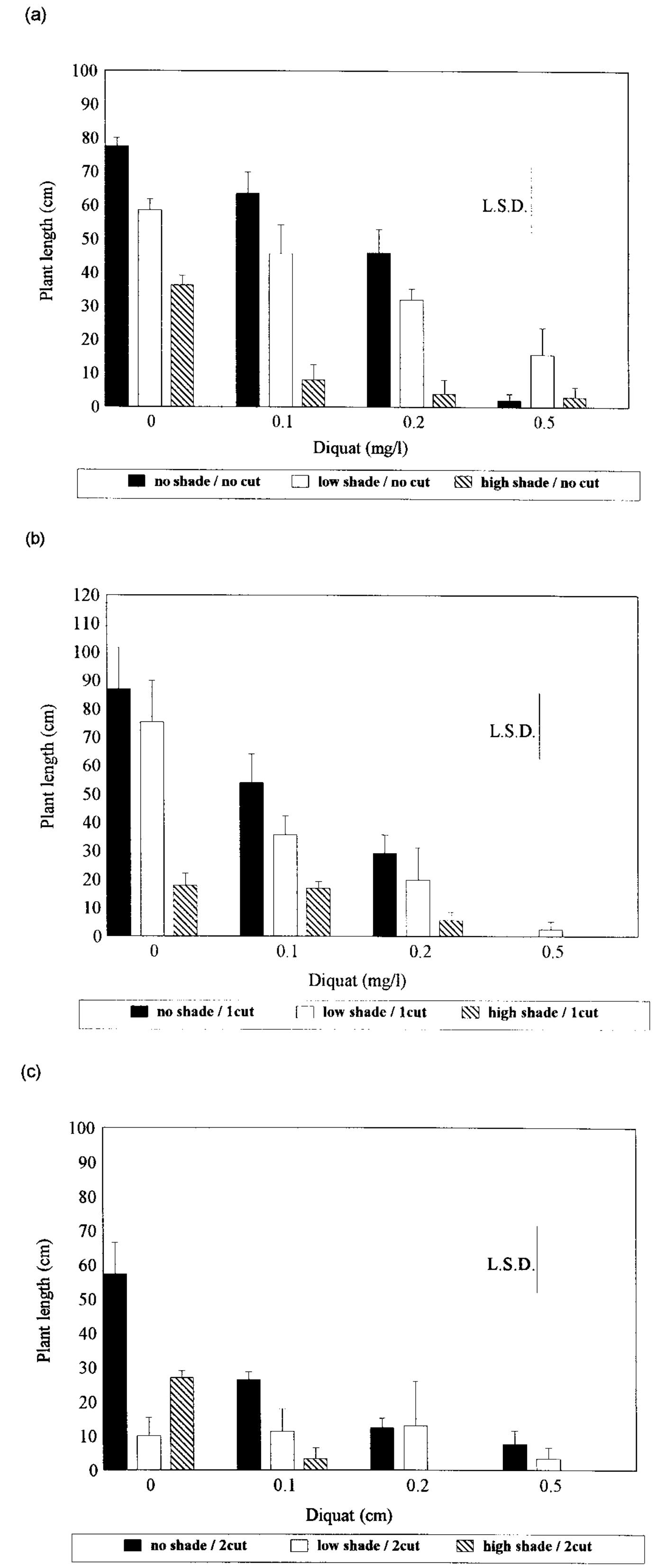

Figure 3. Effects of diquat concentration, cutting and shading on plant length (cm) in sago pondweed: (a) no cut, (b) cut once (1cut), (c) cut twice (2cut) treatments. Error bars represent ±1 s.e.; separate bars represent L.S.D. ($p < 0.05$).

formulations with slow-release properties (Murphy and Barrett 1993). Residue loss in flowing water, herbicide adsorption to organic and clay particles in water and sediment, and antagonistic action from Ca^{++} ions in water are all known problems affecting diquat availance (Murphy and Barrett 1993).

Consequently, the use of supplementary management procedures to increase the effectiveness of low doses of diquat is attractive. Our results show a significant improvement in sago pondweed response to diquat (measured as reduction in plant biomass) in the low-availance treatments when shade stress was also affecting the plants. Sago pondweed proved unable to survive the combination of different stress and disturbance-based control methods (low doses of herbicide, cutting, and shading). Possible means of increasing shade include planting trees or other tall plants along watercourse margins, use of dyes, or increasing turbidity by manipulating benthivorous fish populations to increase sediment disturbance. Our results suggest that the possibilities for using such methods, in combination with low-dose diquat-treatment regimes are worth further investigation in order to evaluate the practical implications of integrated weed control regimes (e.g., Murphy and Pieterse 1990) for sago pondweed management, based on the combined use of low doses of diquat or cutting with high-shade conditions.

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LITERATURE CITED

Alvey, N., N. Galway and P. Lane. An introduction to GENSTAT. Academic Press, London.

Barrett, P. R. F. and K. J. Murphy 1982. The use of diquat-alginate for weed control in flowing waters. Proc. EWRS 6th Int. Symp. on Aquatic Weeds 1982, European Weed Research Society, Wageningen, The Netherlands. pp. 200-208.

Caffrey, J. M. 1990. Problems relating to the management of *Potamogeton pectinatus* L. in Irish rivers. Proc. EWRS 8th Int. Symp. on Aquatic Weeds European Weed Research Society, Wageningen, The Netherlands. pp. 61-68.

Dawson, F. H. 1978. Aquatic plant management in semi-natural streams: the role of marginal vegetation. J. Environ. Manage. 6: 213-221.

Dawson, F. H. 1981. The reduction of light as a technique for the control of aquatic plants—an assessment. Proc. Aquatic Weeds and their Control, Association of Applied Biologists, Warwick, UK. pp. 157-163.

Dawson, F. H. 1989. Ecology and management of water plants in lowland streams. Freshwat. Biol. 57: 43-60.

Fox, A. M., K. J. Murphy and D. Westlake 1986. Effects of diquat alginate and cutting on the submerged macrophyte community of a *Ranunculus* stream in Northern England. Proc. EWRS 7th Int. Symp. on Aquatic Weeds 1986, European Weed Research Society, Wageningen, The Netherlands. pp. 105-111.

Hootsmans, M. J. M., A. A. Drovandi, N. Soto Perez and F. Wiegman 1996. Photosynthetic plasticity in *Potamogeton pectinatus* L. from Argentina: strategies to survive adverse light conditions. Hydrobiologia 340: 1-5.

Kantrud, H. A. 1990. Sago pondweed (*Potamogeton pectinatus* L.): a literature review. U.S. Fish Wildl. Serv., Resourc. Publ. 176. 89 pp.

Little, T. M. and F. J. Hills 1978. Agricultural experimentation: design and analysis. Wiley, Chichester.

Murphy, K. J. and A. H. Pieterse 1990. Present status and prospects of integrated control of aquatic weeds. *In:* A. H. Pieterse and K. J. Murphy, eds. Aquatic Weeds: 2nd Ed., Oxford University Press, Oxford. pp. 222-227.

Murphy, K. J. and P. R. F. Barrett 1990. Controlled-release aquatic herbicides. *In:* R. M. Wilkins, ed. Controlled Delivery of Crop Protection Agents. Taylor and Francis, London. pp. 193-211.

Murphy, K. J. and P. R. F. Barrett 1993. Chemical control of aquatic weeds. *In:* A. H. Pieterse and K. J. Murphy, eds. Aquatic Weeds: 2nd Ed., Oxford University Press, Oxford. pp. 136-173.

Sabbatini, M. R. and K. J. Murphy 1996. Submerged plant survival strategy in relation to management and environmental pressures in drainage channel habitats. Hydrobiologia 340: 191-195

Sabbatini M. R., K. J. Murphy and J. H. Irigoyen 1998. Vegetation—environment relationships in irrigation channel systems of Southern Argentina. Aquat. Bot. 60: 119-133

Sidorkewicj, N. S., A. C. López Cazorla, K. J. Murphy, M. R. Sabbatini, O. A. Fernández and J. C. J. Domaniewski. 1998. Interaction of common carp with aquatic weeds in Argentine drainage channels. J. Aquatic Plant Manage. 36: 5-10.

Spencer, D. F. 1986. Early growth of *Potamogeton pectinatus* L. in response to temperature and irradiance: morphology and pigment composition. Aquat. Bot. 26: 1-8.

Van, T. K. and R. D. Conant. 1988. Chemical control of hydrilla in flowing water: Herbicide uptake characteristics and concentration versus exposure. Tech. Rep. A-88-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 33 pp.

Van, T. K. and K. K. Stewart. 1985. The use of controlled-release fluridone fibers for control of hydrilla (*Hydrilla verticillata*). Weed Sci. 34: 70-76.

van Vierssen, W. and M. J. M. Hootsmans. 1990. Weed control strategies for *Potamogeton pectinatus* L. based on computer simulations. Proc. EWRS 8th Int. Symp. on Aquatic Weeds 1990, European Weed Research Society, Wageningen, The Netherlands. pp. 231-236.

van Wijk, R. J. 1988. Ecological studies on *Potamogeton pectinatus* L. I. General characteristics, biomass production and life cycles under field conditions. Aquat. Bot. 31: 211-258.

Wade, P. M. 1993. Physical control of aquatic weeds. *In:* A. H. Pieterse and K. J. Murphy, eds. Aquatic Weeds: 2nd ed. Oxford University Press, Oxford. pp. 93-135.