Management of salvinia (*Salvinia molesta*) in Australia

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Summary

Since its introduction into Australia in 1952 the aquatic fern salvinia has caused serious problems. Despite considerable effort at control and eradication, no single satisfactory solution has emerged. This paper reviews the control methods that have been attempted in Australia. Of the chemical methods used, spraying with paraquat, diuron or AF 101 have been the most successful. The construction of floating booms or nets has also shown a potential to restrict infestations and make eventual control easier. Damming of estuaries usually increases the problem of salvinia control through restricting the inflow of salt water and preventing the plants from being washed out to sea, whilst floods can further spread existing infestations. The importance of developing an efficient and integrated control programme before the infestation becomes well established is of paramount importance. As part of this approach, alternatives to chemical control should be actively pursued.

Introduction

Salvinia (*Salvinia molesta* Mitchell) is an aquatic fern of South American origin (Mitchell, 1973; Mitchell and Thomas, 1972) that has spread throughout the tropics and subtropics (Mitchell, 1978). Since its recorded introduction into Australia at Luddenham, NSW, in 1952 (Harley and Mitchell, 1981) salvinia has spread throughout the country; particularly along the eastern seaboard (Figure 1). It has caused problems in recreation areas, impoundments, irrigation systems and other inland waters (Farrell, 1978; Julian, 1978; Finlayson and Mitchell, 1981) and has the potential to spread further and interfere with proposed developments such as the Burdekin scheme (Finlayson and Mitchell, 1981).

Much effort has been directed towards the control of salvinia both in other countries (Cook and Gut, 1971; Kam-wing and Furtado, 1977; Mitchell, 1979) and in Australia (Farrell, 1978; Mitchell, 1978; Diatloff *et al.*, 1979; Finlayson, 1981) but no single satisfactory approach has yet emerged.

A major factor in the spread and distribution of salvinia throughout Australia is its rapid rate of growth under suitable conditions. Growth rates of 51% day^{-1} (1.36 days doubling time) in a sewage lagoon and 26% day^{-1} (2.67 days doubling time) in a lake were recorded by Finlayson (1981) in north-western Queensland while Cary and Weerts (1981) recorded rates of 32% day^{-1} (2.2 days doubling time) under culture conditions. The proven capacity of salvinia to grow rapidly under Australian conditions raises special problems in relation to its control. This paper outlines the results of a number of control techniques that have been applied at various locations within Australia (Figure 1). For a more general account of the control of salvinia the reader should consult Harley and Mitchell (1981).

Tinaroo Falls Dam, Queensland

The Tinaroo Falls Dam stores water to generate electricity and to supply irrigation water to the Atherton Tablelands (Figure 1). The history and control of the salvinia infestation at the dam has been recorded by Julian (1978). An estimated 18 ha of salvinia was present in 1977, spread over 40 km of shoreline. Much of this occurred in inlets and partly timbered areas where the plants were difficult to reach and therefore difficult to control. Initial control attempts by the Queensland Water Resources Commission using paraquat, diuron and 2,4-D (Table 1) were not successful. Further details of the herbicides used in these unsuccessful attempts were not given.

These earlier attempts were followed by aerial spraying with AF 101 (kerosene, surfactant and diuron mixture) at 110 L ha^{-1} to control the loosely distributed salvinia. Such aerial sprays (at concentrations of 220 L ha^{-1}) were not, however, successful against the more tightly packed mats. Similar lack of success with AF 101 on tightly packed mats has been reported elsewhere in Australia (Farrell, 1978; Finlayson, 1981), since for effective control this herbicide has to spread across the water surface from the point of application and make contact with the plants (Diatloff *et al.*, 1979; Finlayson, 1981). When the mat formations were broken up with motor boats before spraying with 250 L ha^{-1} AF 101 the density of salvinia was reduced by 80 to 85%, though a second spraying was necessary to control the regrowth from unaffected growing tips. Such regrowth

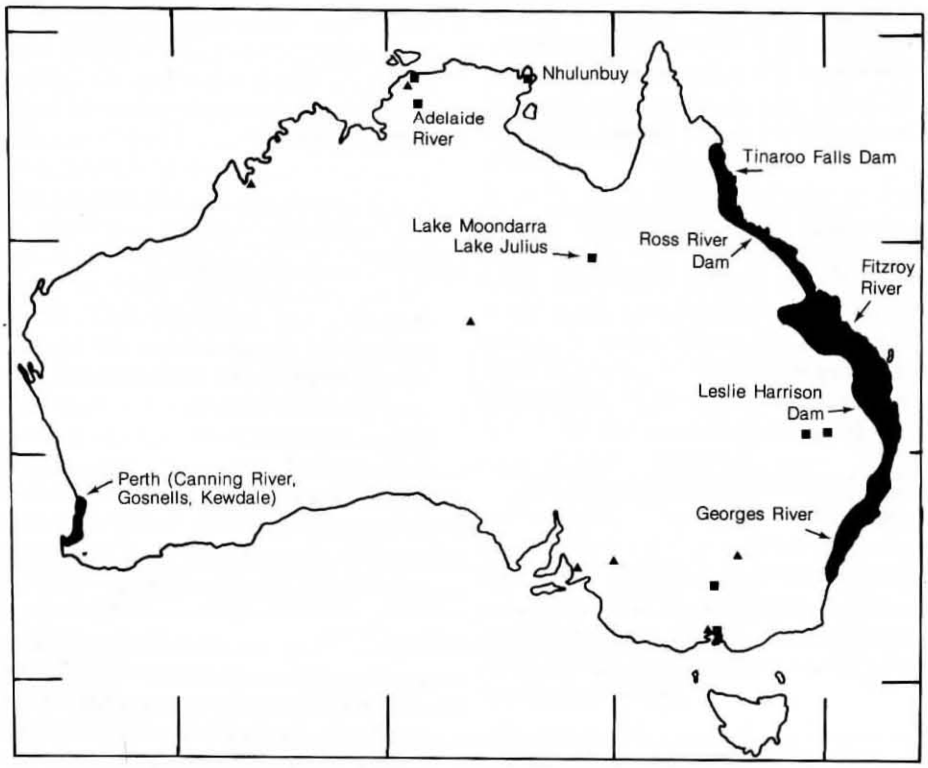

Figure 1 Distribution of salvinia in Australia (adapted from Harley and Mitchell, 1981). Areas of general occurrence are shaded while isolated occurrences are indicated by triangles (garden ponds or aquaria) or squares (field sightings or herbarium specimens).

has been reported on a number of occasions when this herbicide has been used and has been partly overcome by adding 0.5 kg ha^{-1} diuron to the mixture (Farrell, 1978; Diatloff *et al.*, 1979; Finlayson, 1981).

Aerial applications were successful over open water but boats and a hovercraft were necessary to spray other areas, and the overall result of the spraying was to reduce the salvinia infestation to less than 1 ha. Although the dam is not completely clear of salvinia, the managing authorities consider the problem is controllable (A. C. Julian, pers. comm.). Occasional outbreaks still occur from material washed in from farm dams but these are controlled when noticed. Since the initial control programme in 1977 no large outbreaks have occurred and the AF 101 application has been considered a success.

Lake Moondarra, Mount Isa, Queensland

Lake Moondarra is the principal source of water for the mining and domestic needs of Mount Isa. Salvinia was first observed in the lake in October 1975, and its spread since that time has been described by Farrell (1978) and Finlayson (1981). Since manual removal failed to limit the spread of salvinia a spraying programme using 11 L paraquat in 5000 L of water ha^{-1} was started in January 1976 (Table 1). Despite the expenditure of $88 000 this programme did not contain the salvinia and was eventually stopped in November 1976. In conjunction with the paraquat spraying, a series of floating booms was used to restrict the spread of salvinia throughout the lake and, except for times of high river flow, these were a success.

Throughout the remainder of 1977 very little was done to control the salvinia and it built up to an estimated 141 t (fresh weight) ha^{-1} covering an area of about 200 ha (Finlayson, 1981). In December 1977 spraying with AF 101 from a hovercraft commenced and reduced the fresh weight biomass to 35 t ha^{-1} spread over 204 ha by February 1978 (Farrell, 1978). The addition of diuron to the spray mixture did not prevent the growth of new shoots from the kerosene-affected plants although experimental evidence had previously pointed to the effectiveness of such treatment (Diatloff *et al.*, 1979; Finlayson, 1981). Despite an initial reduction in biomass the hovercraft treatment did not deliver enough herbicide to contain or prevent regrowth of the salvinia. To overcome this problem a helicopter was used to deliver 51 000 L of the herbicide AF 100 (i.e. AF 101 minus the diuron) during October 1978. This approach was more successful and the biomass was reduced from 142 t ha^{-1} to 41 t ha^{-1} over 275 ha at a cost of $18 000 compared to $50 000 for the hovercraft programme (Finlayson, 1981).

Spraying by helicopter was successful when used against large areas of salvinia, but was not effective against smaller, isolated areas of weed. A temporary management strategy of helicopter spraying with AF 100 at periodic intervals was therefore adop-

Table 1 Summary of chemical control programmes used against salvinia

Herbicide Common name	Trade name	Active ingredients	Rate of product	Locality
AF 101	—	1.25 kg diuron in 20 L 3:2:55 acetone:Caldec:kerosene	110–250 L ha^{-1}	Tinaroo Falls Dam
			—	Ross River
			—	Adelaide River
			112 L ha^{-1}	Lake Moondarra
AF 100	—	1:45 Caldec:kerosene	112 L ha^{-1}	Lake Moondarra
diquat	Reglone	200 g L^{-1} diquat dibromide monohydrate	5.5 L ha^{-1}	Western Australia
diuron	Diurex 80	800 g kg^{-1} diuron	4.9 kg ha^{-1}	Fitzroy River
			$1/100^{c}$	Tinaroo Falls Dam
hexazinone	Velpar	900 g kg^{-1} hexazinone	–	Georges River
			2 kg ha^{-1}	Western Australia
			3 kg ha^{-1}	Lake Julius
glyphosate	Roundup	360 g L^{-1} glyphosate	–	Georges River
paraquat	Gramoxone	200 g L^{-1} paraquat dichloride	–	Ross River
			5 L ha^{-1}	Fitzroy River
			a	Leslie Harrison Dam
			–	Georges River
			3 mL $L^{-1\,b}$	Nhulunbuy
			11 L ha^{-1}	Lake Moondarra
			$1/400^{c}$	Tinaroo Falls Dam
			3 mL $L^{-1\,b}$	Adelaide River
—	Monotox	378 g kg^{-1} DSMA, 240 g kg^{-1} diuron, 64 g kg^{-1} 2,4–D sodium salt	—	Ross River
—	Duotox	480 g kg^{-1} diuron, 30 g kg^{-1} DSMA	—	Ross River
2,4–D	Lane 2,4–D	500 g kg^{-1} 2, 4–D	$1/200^{c}$	Tinaroo Falls Dam
—	Tryquat	100 g L^{-1} paraquat dichloride 50 g L^{-1} diquat dibromide monohydrate	3 mL $L^{-1\,b}$	Nhulunbuy

— information not available
[a] high volume spraying with 225 mL Gramoxone in 136 L water (approx.)
[b] rate calculated per water volume not area
[c] dilution rate only given

ted while alternative strategies were considered. The latter included testing different herbicides either alone or in combination with AF 100. The more effective of these (hexazinone and diuron) are not registered for use in potable water and could not therefore be considered seriously for large scale application.

A second approach was to offer support to the CSIRO Division of Entomology's biological research programme. As part of this programme, the weevil *Cyrtobagous singularis* was introduced into the lake (Room *et al.*, 1981). It attacked the mats and smaller fragments became washed to the edge of the lake where, because of the drastic fall in water level which followed, they became stranded and died. Salvinia has now virtually disappeared (as also has the weevil) though efforts are under way to maintain both at low population densities. A moth *Samea multiplicalis* has also been introduced to the lake as part of the control programme.

Lake Julius, Mount Isa, Queensland

This lake is located 80 km downstream of Lake Moondarra on the Leichhardt River and is an important supplementary water supply to Mount Isa. Salvinia was first discovered in this lake during March 1977, but it is not known if this infestation floated downstream from Lake Moondarra or was directly introduced into the lake. The initial infestation was heavily sprayed with hexazinone (Table 1), though over the following years some plants have been regularly found around the edge of the lake. These plants are usually removed manually. More recently (January 1981) attempts have been made to control these small infestations by the introduction of the moth *Samea multiplicalis* (P. J. Room, pers. comm.).

Ross River, Townsville, Queensland

The presence of salvinia in weirs along the Ross River (Figure 1) has been of concern to the Townsville City Council since 1966 (C. J. Lee, pers. comm.). Until the construction of the Ross River Dam further upstream, these weirs were an important source of water for Townsville and are still an important auxiliary supply. Paraquat with the surfactant Agral 60 (Table 1) was successfully applied from knapsack sprayers to contain the main outbreaks in 1966–67. In June 1970 further spraying was recommended but no action was taken. The majority of this growth was flushed out of the river in 1971 by rain associated with cyclone Althea. By 1974 the weirs were again severely infested and in April 1975 spraying trials were carried out with paraquat and a mixture of 240 g kg^{-1} diuron, 378 g kg^{-1} DSMA and 64 g kg^{-1} 2,4-D sodium salt (Monotox) and with diuron (with the addition of colloidal sulphur). One weir was completely sprayed with Monotox and a 90% kill achieved. Immature plants that were re-infesting the weir were sprayed with paraquat in December 1975. Between December and the following February heavy rain flushed the weirs of salvinia.

In April 1976 spraying with Monotox and Duotox (480 g kg^{-1} diuron and 30 g kg^{-1} DSMA) was carried out and continued until November when equipment failure stopped the programme. The summer rains of 1976–77 and 1977–78 flushed the weirs and removed large quantities of accumulated salvinia. During 1978 AF 101 sprayed from a hovercraft was successfully used in some areas, and in 1979 the weirs were partially drained which stranded much of the plant material.

The chemical control programmes conducted by the Townsville City Council in conjunction with the flushing of the river have successfully contained salvinia in the Ross River. The accumulation of salvinia between the weirs in the dry season could serve as a source of infestation (as could several other occurrences of this weed in the area) for the Ross River Dam.

Fitzroy River, Rockhampton, Queensland

The history of the salvinia infestation in the Fitzroy River is closely related to that of water hyacinth (*Eichhornia crassipes* (Mart.) Solms). The latter has been present in the region since early this century but was not considered to be a serious problem until the construction of a barrage on the Fitzroy River in 1970 (Springell and Blake, 1975). This decreased the effectiveness of the annual floods in flushing material out to sea and stopped the incursion of salt water that normally prevents growth of water hyacinth in the tidal reaches of rivers. Salvinia was first reported in 1972 and by 1975 was common above the barrage and in areas that had been cleared of water hyacinth by spraying with 2,4-D (Mitchell, 1978).

The combination of salvinia and water hyacinth in the Fitzroy River system causes interference with recreation activities, deoxygenates the water and clogs irrigation and water supply facilities (Mitchell, 1978). The potential for these infestations to spread and cause more serious problems is immense and chemical control programmes have been directed against both species. It is extremely difficult, however, to control effectively the numerous small infestations that occur in billabongs and amongst inundated trees.

Since the first major outbreak of salvinia in 1978 in an area cleared of water hyacinth, paraquat (Table 1) has been used in a spraying programme (R. J. Ciesiolka, pers. comm.). Being a contact herbicide, paraquat was not entirely successful and was replaced with diuron mixed with Citowett and BS 100 as wetting agents, using enough to produce a frothy spray mixture. This mixture stayed afloat under calm conditions for about 1 hour and was clearly effective in penetrating the thick mats of salvinia amongst the logs and trees.

The infestations of salvinia and water hyacinth in the Fitzroy River are such as to require continuous programmes to prevent their spread. Complete eradication is not possible in this situation without an extensive and expensive control programme, perhaps supplemented by an effective biological control programme.

Leslie Harrison Dam, Capalaba, Queensland

The Leslie Harrison Dam was constructed in 1968 to supply water to the Redland Shire near Brisbane (Figure 1). Salvinia was first noticed there during 1971–72 after heavy rain had overflowed several farm dams that contained small infestations. During 1974 spraying with paraquat and Agral 60 surfactant (Table 1) was carried out in several small creeks and amongst fringing reeds around the edge of the lake. It was necessary to spray the thicker mats several times and also to spray the banks at least to the high water mark as stranded plants could survive for some time on the moist soil. After two years of regular spraying all infestations were controlled and no new outbreaks have been recorded (D. Morton, pers. comm.).

The control programme in the Leslie Harrison Dam was initiated before the weed became too widespread and was vigorously sustained until full control was achieved. This programme is noteworthy as full control was achieved several years ago and no re-infestation has been observed.

Georges River, Liverpool, New South Wales

A major factor in the growth of aquatic

plants in this section of the Georges River is the discharge of effluent from the Glenfield Sewage Treatment Works. During periods of low flow the nutrient rich effluent forms a substantial proportion of the inflow into the system and provides ideal conditions for plant growth (Mitchell, 1978). Alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.), an aggressive aquatic plant from South America, occurred at one time in heavy infestations in this part of the river but has now been effectively controlled by an imported biological control agent (Julien *et al.*, 1979). However, duckweed (*Lemna* sp.) and salvinia later became established in the river (C. Heath and I. C. Smalls, pers. comm.).

By December 1980 salvinia had replaced duckweed as the major weed species. Spraying with hexazinone, paraquat and glyphosate (Table 1) started in January 1981. About 25% of the infested areas (mainly those with aesthetic appeal) were sprayed and re-infestation prevented by floating booms. Storms in April 1981 carried both the booms and salvinia further downstream into the estuarine parts of the river but no serious problems have developed there, probably due to the low salt tolerance of salvinia (Harley and Mitchell, 1981). The infestation of salvinia continues to be extensive in the freshwater reaches of river below the Glenfield Sewage Works and is a source of concern to local residents and the Liverpool City Council. The problems are likely to continue as long as the effluent from the sewage treatment plant is allowed to discharge into the river.

Western Australia

Salvinia infestations in Western Australia have been reported from Bunbury in the south to Kununurra in the north, but none are as extensive as those reported elsewhere in Australia. The largest infestations have occurred in the Perth metropolitan area (Figure 1) where about 3 km of the Canning River was heavily infested, and Tomato Swamp at Kewdale and Eudoria Swamp at Gosnells each contained about 2 ha of salvinia (A. J. Tapley, pers. comm.). The Agriculture Protection Board of Western Australia has adopted two approaches to controlling salvinia, one for still water such as lakes and swamps and the other for running water such as rivers and drains (A. J. Tapley, pers. comm.). Lakes and swamps were treated with one application of hexazinone (Table 1) applied in November at a rate of 2 kg ha^{-1} for an average water depth of 0.5 m, the rate being increased proportionally for each 0.5 m increase in water depth. It took three weeks after spray application to achieve complete control of the salvinia in the swamps. In running water diquat at a rate of 5.5 L ha^{-1} is used.

In 1975 the main channel of the Canning River was clear of salvinia as a result of a saltwater incursion induced to control infestations of the submerged weed, hydrilla (*Hydrilla verticillata* (L.f.) Royle), but a number of swamps and billabongs that drain into the river were still covered (Mitchell, 1978). Attempts to eradicate these smaller infestations by pumping in salt water were not entirely successful, as inflows of less dense fresh water enabled the floating plants to survive. Regular incursions of salt water into the main channel of the river are prevented by a weir that was built to limit this inflow during the dry summer months. Planned saltwater incursions may help control the salvinia in the river but this procedure would have an adverse effect on other components of the ecosystem.

Tomato Swamp in the Perth suburb of Kewdale contained about 2 ha of salvinia in 1974 (A. J. Tapley, pers. comm.). Attempts to clear the swamp started in February 1974 when about 100 people spent a day dragging the thick mats and entangled rushes (*Scirpus* sp.) from the water. When it was found that the problem was much greater than expected, mechanical equipment was used to remove the salvinia from one-half of the swamp (Wilson, 1977). This half was maintained free of salvinia and eventually the other half was cleared using hexazinone (A. J. Tapley, pers. comm.).

The Agricultural Protection Board considers that salvinia is controllable in Western Australia with methods currently in use. The Board is aware of possible re-infestation from backyard ponds and these are cleared whenever salvinia is detected. Salvinia has not caused problems in the Ord River irrigation development in the north of the State, though one small infestation was reported from Kununurra (A. J. Tapley, pers. comm.).

Nhulunbuy, Northern Territory

Salvinia was first recorded from the Nhulunbuy town lagoon (Figure 1) during 1976 (I. L. Miller, pers. comm.). The lagoon is used as a receptacle for storm water drainage and is virtually a swamp sustaining a large crop of aquatic vegetation including salvinia. Outflow from the lagoon is to the sea so there is no risk of infestations occurring further downsteam. The initial infestation of salvinia covered 1.5 to 2 ha of the 65 ha lagoon (I. L. Miller, pers. comm.).

Control measures have been undertaken since 1977 by the Nhulunbuy Corporation and the Northern Territory Department of Primary Production. Initial irregular spraying with paraquat (Table 1) was not successful. Further spraying was carried out in 1978 and by mid-1980 some success had been achieved with a 2:1 paraquat:diquat mixture (Tryquat). Control in some areas was difficult because of the presence of fringing vegetation, very thick mats and lack of water. The last inspection in July 1981 found salvinia to be confined to the edges of the lagoon but more dense than during 1980.

The costs incurred by the Northern Territory Government on this programme are in excess of $20 000 (I. L. Miller, pers. comm.) whilst the costs of the Nhulunbuy Corporation are not known. It is planned to continue spraying after the 1981–82 wet season when some of the salvinia is washed out to sea and the higher water level makes boat access easier.

Adelaide River, Northern Territory

Salvinia was recorded in a series of pools in the Adelaide River at the Daly River Road crossing (Figure 1) during January 1977 (I. L. Miller, pers. comm.). Spraying with a 2:1 paraquat:diquat mixture (Tryquat) and later 2,4-D amine (Table 1) began almost immediately and by the end of February the main pool was virtually clear. Nets were erected across several pools to prevent salvinia from spreading further downstream. Floods in March broke the nets and some plants were found in two pools downstream. These infestations were either removed by hand or sprayed with Tryquat and the banks scorched with a flame thrower to remove excess vegetation and make surveying of the area easier. AF 101 has been used in these ponds since early 1979 and no salvinia plants have been seen since May of that year. This herbicide is still used each year to penetrate under the overhanging vegetation to prevent re-infestations.

Since 1977 regular surveys downstream of infested pools have revealed no further infestations. Access to the river course from the road is difficult and the channels and pools must be surveyed on foot. The source of infestation is considered to be a small area of rainforest upstream of the road crossing, but the thick overhanging vegetation seriously impedes survey of this area. The total cost of the control measures from January 1977 to mid-1978 was $6330 (I. L. Miller, pers. comm.).

Discussion

Salvinia infestations occur widely in Australia, mainly along the east coast but with several major occurrences in the south west and northern inland regions. The weed has been difficult to control even though some notable successes have been achieved.

Management strategies for salvinia must take account of its rapid vegetative reproductive capacity and other factors that have enabled it to become a successful weed throughout Australia. Cary and Weerts (1981) have shown, under experimental conditions, that water temperature is one important factor. They found very little growth below 20°C and optimum growth at 26° to 28°C. This is supported by evidence from Lake Moondarra where only very low growth rates were recorded at 13°C as compared with those obtained at 30°C (Finlayson, 1981). These higher temperatures are typical of those recorded in many Australian water bodies during summer (e.g. Finlayson *et al.*, 1980; Gordon *et al.*, 1981).

The relationships of salvinia growth to nutrient availability is also important and needs further investigation. Cary and Weerts (1981) suggest that many water bodies in Australia do not contain sufficient nutrients to sustain active growth of salvinia, but where nutrient addition occurs (either by diffuse or point sources), the situation is clearly very different. The nitrogen and phosphorus half saturation values (amount required to support half the maximum growth rate) calculated from experimental data are relatively low (D. Toerien, pers. comm.) and this raises the possibility that diffuse nutrient sources or nutrient recycling could support large salvinia populations. It is interesting to note that of the cases considered in this report only two were in water bodies receiving a point source of nutrients.

The impact of changing water levels, flood flows and saltwater incursions are other important factors. Salvinia is favoured by rising water levels and flood flows in inland areas can spread it further. However, in localities near the coast (e.g. Ross River, Townsville and Nhulunbuy) floods can alleviate problems by flushing large quantities of the weed out to sea. Falling water levels generally have an adverse affect, as can saltwater incursions (e.g. Canning River, Perth and Fitzroy River, Rockhampton). It is often found, however, that dams and weirs built to conserve fresh water or to prevent saltwater incursions negate the effect of floods and salt water on salvinia. An understanding of the effects that these factors can have on salvinia infestations may enable them to be manipulated to reduce severe problems and contribute significantly to management procedures.

Salvinia has been successfully controlled by herbicides in Australia as this paper has shown. The use of paraquat on Leslie Harrison Dam in Queensland was the first of several cases where herbicides have been used successfully to the point of eradication. In nearly every case success has resulted from the thoroughness of the spray programme, the persistence with which it was sustained and, in the case of large water bodies, because it was implemented before the infestation had reached an exponential growth phase. Experience on Lake Moondarra, Mount Isa has shown that even with the use of a hovercraft it is difficult to spray at a rate that keeps pace with regrowth from unsprayed areas. Allowing salvinia to develop thick mats not only prevents access and reduces the effectiveness of spraying but also provides numerous propagules for reinfestation of cleared areas. It is absolutely imperative that, once the extent of an infestation has been determined, control measures be carried out as soon as possible. Undue delays could greatly reduce the chances of eradication or gr^eatly increase the costs of limiting the extent of weed in the waterbody to a manageable amount.

A number of chemicals have been used to control salvinia successfully in Australia. Besides paraquat, diquat and paraquat/diquat mixtures (Tryquat) have been used, but less frequently. Diuron has been used to control infestations on the Fitzroy River, Rockhampton (R. J. Ciesiolka, pers. comm.) and to eradicate smaller infestations in New South Wales (State Pollution Control Commission, 1977) but cannot be used in potable water. Diuron also causes problems if residues remain in water that is drawn off for irrigation purposes (Bowmer and Adeney, 1978). It may, however, be possible to combine small amounts of diuron with the kerosene:surfactant mixture AF 100 (to make AF 101) and thus circumvent the need for registration of the larger quantity that would otherwise be necessary (Finlayson, 1981). Another very effective herbicide that has been used with success in non-potable water is hexazinone (Toth and Campion, 1979; D. Morton and I. C. Smalls, pers. comm.). This is expensive to purchase when compared to the alternatives (Finlayson, 1981) but its effectiveness in still water and on thick mats, where it can kill the plants by direct contact and by absorption through the roots, can help allay this cost (A. J. Tapley, pers. comm.).

The availability of AF 101 has allowed some spectacular successes to be achieved in controlling large areas of salvinia (Farrell, 1978; Julian, 1978) without any apparent detrimental effect on the ecosystem. Perhaps the most spectacular short-term success with this mixture was achieved in Lake Moondarra, Mount Isa. After the failure of a paraquat spraying programme to contain the initial small infestation, several spraying programmes with AF 101 were carried out. Large amounts of salvinia were killed but the programmes were costly and were not carried out regularly enough to reduce the problem. The situation in Lake Moondarra was a prime example of an infestation reaching a level where expensive chemical control methods could contain, but not reduce it.

Eradication of salvinia was also claimed for the biological control agent *Cyrtobagous singularis* on Lake Moondarra (Room *et al.*, 1981), though plants were subsequently found on the lake. The morphology of these plants indicates that they were possibly a re-infestation from a population upstream or in a backwater. Eradication by a biological control agent is most unusual and indeed can be counter productive, as in this case, since the control organisms are also eradicated and must be re-introduced to contend with any re-infestations.

For a biological control agent to succeed it is often necessary for the reproductive capacity of the pest to be impaired by some form of environmental stress, providing that the growth and reproduction of the control agent is not adversely affected. In the case of salvinia, which is incapable of sexual reproduction, any factor that decreases plant growth or restricts the availability of suitable habitats would promote effective control. Falling water levels, poor nutrient status, and competition from other plants would all contribute (Mitchell and Rose, 1979; Room *et al.*, 1981). Once biological control agents have become available, as for salvinia in Australia they should be used to control infestations wherever possible, especially as they are likely to promote the most cost-effective method in the long term.

Chemical and biological methods of control need not, however, be mutually exclusive. Both have been used successfully in Australia on salvinia, even on the same infestations. So far, however, they have been used as alternatives and it is now important that the two approaches be combined into one programme. The integration of the two methods must be based on an understanding of the ecological responses of the weed to different environmental conditions as well as on the mode of action and effectiveness of the herbicides and the ecological requirements and mode of attack of the biological control agent. In general, the biological control agent should serve to keep the weed population at low levels. When the growth of the weed outstrips the capacity of the existing population of control agents to control it, a herbicide can be used judiciously to reduce the size of the infestation to allow the control agents to reassert control.

While it is possible to control salvinia in Australia by both chemical and biological methods, every effort should be made to prevent infestations occurring in the first place. Salvinia is now proclaimed as a noxious weed in all States of Australia and this should assist in restricting its distribution, but only if the legislation is rigorously enforced. Where an infestation does occur, prompt action should be taken to ensure that it does not reach an unmanageable size as so often occurs in Australia. While it may not be possible to eradicate every plant (e.g. those amongst dead trees or swamp vegetation), it is easier to contain small outbreaks with floating booms, herbicides and biological control agents than it is to control large outbreaks. More effort should also be directed towards reducing the suitability for the growth of salvinia of water bodies susceptible to infestation. This includes the diversion or further treatment of nutrient rich effluents that aggravate problems already present because of the high temperatures and still conditions existing in the virtually unoccupied water surface habitat of many Australian fresh waters.

If successful control measures are to be implemented, it is necessary to understand fully the environmental conditions that have promoted the growth of salvinia in Australia. This requires further research into the growth habit of the plant and its response in infested areas to key environmental factors such as temperature and nutrient levels.

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