much less expensive to utilize and are readily accepted by the public and governmental agencies. Unfortunately, biocontrols take a long time to develop and effective control agents are sometimes not available for the most serious weed problems. Biological agents used in Thailand include the insects *Episammia pectinicornis* (Hampson) formerly *Namangana pectinicornis* (Hampson) for control of *Pistia stratiotes* L.; *Neochetina eichhorniae* Warner. for control of *Eichhornia*; and *Acanthascelides quadidentus* and *A. puniceus* for *Mimosa* control. Fishes that are used include *Ctenopharyngodon idella* Val.; *Oriochromis niloticus* L. formerly *Tilapia nilotica*; and *Puntius gonionotus*.

Research and control operations on mechanical, chemical and biological control methods is constantly underway in Thailand. Practically, the most effective long term management of aquatic weeds in Thailand is the integration of all of the range of methods into properly executed control programs.

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Management of Salvinia in the Northern Territory

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ABSTRACT

Aquatic weeds are spreading into new areas of the world. *Salvinia molesta* was first reported in Australia's Northern Territory in 1976. Ten more field infestations have since been reported. Chemical, physical and biological methods are being integrated on a regional basis for their control. Five infestations have now been eradicated and two substantially reduced by chemical and physical control methods. Biological control with the weevil *Cyrtobagous salviniae* is proving to be successful but cyclical in nature. In shallow water its success is limited, probably by high temperatures which affect the weevil's reproduction.

Key words: Salvinia molesta, physical control, chemical control, biological control, *Cyrtobagous salviniae*, exotic plants, spread.

INTRODUCTION

Ennis and Vandiver (1979) reported that two of the principal trends in aquatic weed management were the increasing spread and proliferation of exotic weeds into new areas of the world, and the likelihood of greater attention being given to the integration of chemical, physical and biological methods for their control. These trends have certainly shown to be true in Australia's Northern Territory, where no alien aquatic weeds were known to occur until the mid 1970s.

The Northern Territory covers an area of 1,346,200 kms, one sixth of the area of Australia. Its population is 155,800, representing only 0.93% of the country's total. This does not, however, mean that weed problems are any less than in more populous areas, but it does mean that there are fewer people to detect and control weeds.

The climate, vegetation and landforms vary considerably from the arid interior to the coast. It is in the higher rainfall and consistently warm areas that introduced tropical aquatic weeds pose the biggest threat, but they do also have the potential to cause localized problems in water storages in the arid zone.

The asexually reproducing free floating aquatic fern, salvinia (*Salvinia molesta* D. S. Mitchell) is believed to have been introduced into Australia as an ornamental plant, having first been collected in the south-eastern part of the continent in 1952 (Harley and Mitchell 1981). It was apparently spread around the country by man through the aquarium and horticultural trade, and by personal exchanges of plant material (Mitchell 1978). It was first found in the Northern Territory in a pool at a Darwin plant nursery in August 1976. In September 1976, the first field infestation was recorded in a lagoon in the remote town of Nhulunbuy. Between 1977 and 1988, ten more field infestations were recorded. These infestations represent the most northerly field occurrences of salvinia in Australia (Finlayson and Mitchell 1982).

Mean temperatures at Darwin in the hottest month (November) are 33.4 C maximum, 25.9 C minimum, and in the coolest month (July) are 29.8 C maximum, 20.2 C minimum, with an annual rainfall of 1600 mm which falls mainly in the November-March period (Anon. 1975). Many perennial waterways occur, so conditions are ideal for the growth and spread of salvinia (Mitchell and Tur 1975).

The detrimental effects of salvinia have been well documented, being similar to those caused by other aquatic weeds (Harley and Mitchell 1981). Therefore, when salvinia was first reported in Darwin, the Government commenced a public awareness and control program. At that time biological control agents were not available for salvinia in Australia, so chemical and physical methods were used. Despite the statement by Thomas and Room (1986)

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that "attempts to control salvinia chemically have, without exception, failed to provide a long term solution", chemical control has been very successful in the Northern Territory and, when combined with physical methods, has resulted in complete eradication of a number of infestations (Miller and Pickering 1988). Biological control has now also been introduced. This paper describes the occurrence and present status of salvinia infestations in the Northern Territory, and the methods used for its successful management.

OCCURRENCE AND SPREAD

Locations of salvinia in the Northern Territory are shown in Figure 1. Since the first report in 1976 a large number of other occurrences have been found in aquariums and garden ponds in Darwin. One occurrence was reported in Alice Springs. Plants were found in Darwin aquarium shops which had obtained stocks of aquatic plants and fish from southern Australia, confirming that salvinia was being spread by the aquarium trade.

After the first field infestation was recorded at Nhulunbuy, a small infestation was found in a storm water drain which flowed into Rapid Creek in a Darwin suburb (September 1976). Salvinia was subsequently recorded on the Adelaide River (January 1977), Mission Hole (July 1981), Mary River (August 1981), Howard River (June 1982), Lily Pond Creek (July 1982), Finniss River (January 1983), Billabong Creek (February 1983), Magela Creek (September 1983) and Holmes' Jungle (June 1988) (Figure 1).

We believe that salvinia has been spread from Darwin to these sites by man, through the release of aquarium fish into natural waterways, by fishermen transporting the weed with live bait between rivers or attached to boats which are transferred by road to other sites within a short enough period to allow the plants to remain alive. One instance has been observed where a feral water buffalo

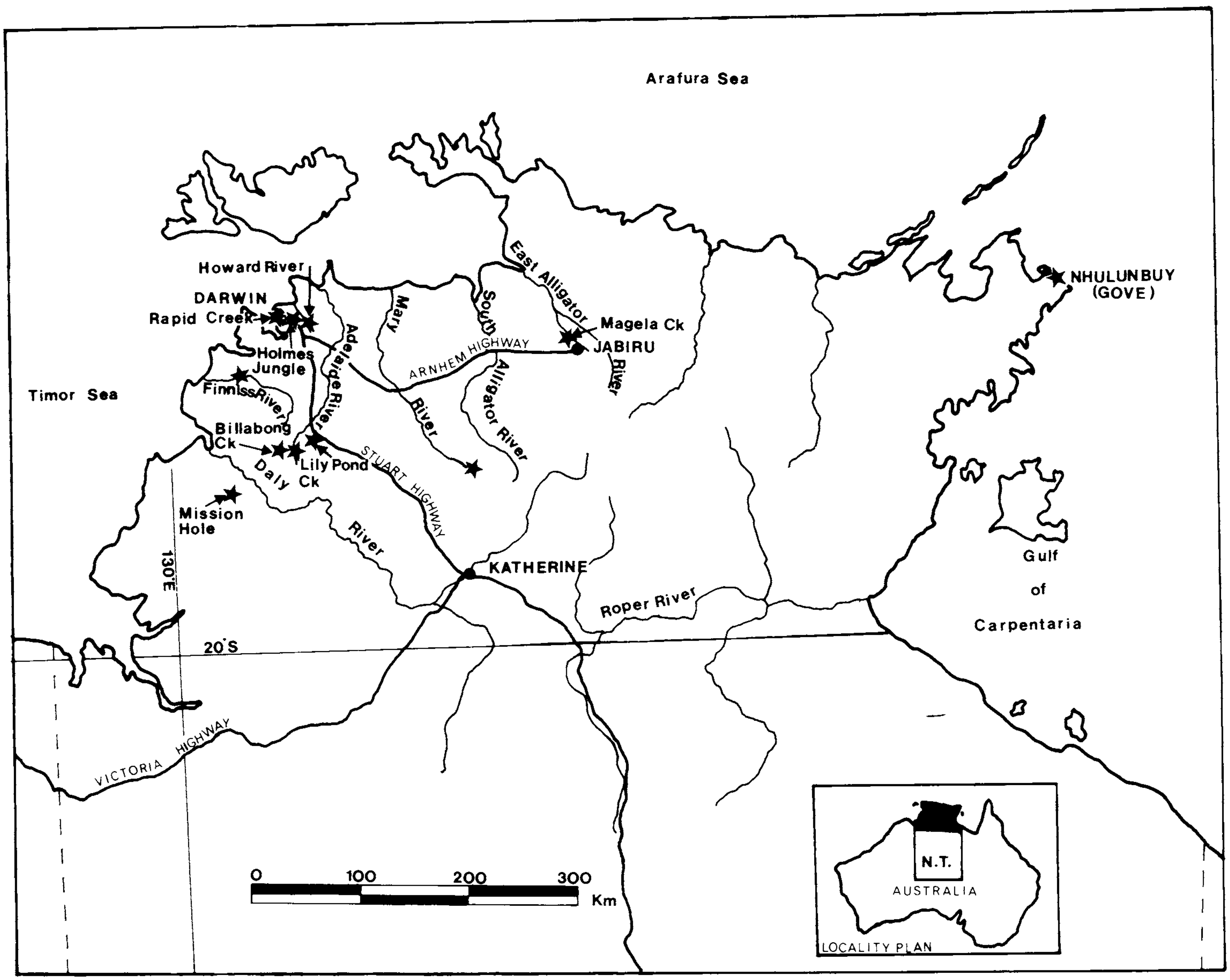

Figure 1. Locations of salvinia infestations in the Northern Territory.

(*Bubalus bubalis* L.) emerged from a lagoon with salvinia on its back. It is possible, that at a walking pace, the salvinia could have been carried to a nearby water body.

PUBLICITY

Since 1977 a continuing publicity campaign has increased public awareness of the danger of salvinia and encouraged the public to report new infestations.

Publicity methods have included television advertisements and interviews, news items, radio interviews, newspaper and magazine articles, show exhibits, pamphlets, posters and lectures to interest groups. The publicity was aimed at the aquarium trade and the general public, firstly to prevent outbreaks at their source in aquariums and ponds, secondly to encourage reports of field infestations to the Government and thirdly to emphasize the importance of cleaning boats prior to moving them from one waterway to another.

As a direct result of this publicity, reports were made of salvinia in aquariums and in the field before infestations became too large to manage. This allowed for quick control action and, in many cases, led to its successful eradication.

CONTROL

Due to the low population density, few resources are available for weed control in the Northern Territory compared with the rest of Australia. As floating aquatic weeds have general public nuisance value all control of field infestations of salvinia has been carried out by the Government.

The methods used are physical barriers, manual removal, herbicides and biological control.

Physical barriers. If there is danger of downstream movement when an infestation is first found, a net is erected if the terrain allows for its construction (Figure 2). In some cases a series of nets has been constructed as insurance against breakage of one or more during floods. As salvinia reproduces only by vegetative means, downsteam spread will not occur if the plants can be confined. The 'primary-invading-form' of salvinia (Mitchell and Tur 1975) can, however, easily break into small parts which are capable of reproducing. Therefore the nets have a fine mesh.

Manual removal. Small areas of salvinia are removed either by hand or by using small nets. This method is primarily used in home aquariums and ponds, or after a

Figure 2. A net constructed to prevent downstream movement of salvinia.

large infestation has been initially reduced by herbicides. Following removal, the plants are killed by desiccation and burnt.

Herbicides. Early control work was carried out using 0.04% paraquat (1,1′-dimethyl-4,4′-bipyridylium dichloride), 0.04% paraquat + 0.02% diquat (9,10-dihydro-8a,10a-diazoniaphenanthrene dibromide), 0.04% paraquat + 0.12% 2,4-D (2,4-dichlorophenoxy acetic acid), 0.06% paraquat + 0.1% 2,4-D, and 0.04% paraquat + 0.02% diquat + 0.12% 2,4-D. All these mixes contained 1.2 g/l of non-ionic surfactant.

Being contact herbicides (Fryer and Evans 1968), paraquat and diquat desiccate the surface layers of salvinia leaves. However, in salvinia mats the leaves are compressed and deeply folded, the inner parts of the plant being protected from herbicides. Therefore repeat sprayings are necessary. Combining the translocated herbicide 2,4-D with paraquat and diquat allows for control of the protected buds. Mixtures of paraquat and diquat have also been used to desiccate overhanging vegetation which protects salvinia plants from herbicides. It is then removed by burning.

Since 1979 AF101 has been used. This is a mixture of 20 g/l diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea and 150 g/l surfactant (calcium dodecylbenzene sulphonate) with acetone and kerosene as co-solvents (Diatloff *et al.* 1979). For application it is diluted 1 in 10 with kerosene. The kerosene and surfactant in this mixture cause it to spread out over the water in a thin layer, spreading through the surface hairs of salvinia. This destroys its buoyancy and causes the plant to sink. The translocated herbicide, diuron, ensures control of submerged axillary and terminal buds which escape contact with the surface treatment.

The floating capability of AF101 has been used to advantage where waterways are surrounded by dense overhanging terrestrial vegetation. When AF101 spreads over the water surface, it moves through spaces in this vegetation to control salvinia which may be missed by other control measures. Equipment used to apply it has been either a high-volume sprayer or a low-volume sprinkler-sprayer. The latter was developed specifically for applying AF101 (Diatloff and Anderson 1980). It delivers large drops of the herbicide which immediately spread over the water surface. Volumes as low as 10 l/ha are possible which reduce wastage and pollution.

Hexazinone (3 cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5,-triazine-2,4 (1H,3H)-dione) is known to control a number of aquatic weeds including salvinia (Toth and Campion 1979; Anderson 1981). It was highly effective in controlling large salvinia mats on Billabong Creek after a single aerial spray. Hexazinone, as the water miscible liquid, was applied by helicopter through D6/45 nozzles at a rate of 3 kg a.i./ha in a total spray volume of 60 l/ha. There was no long term deleterious effect on non-target species on the banks which consisted principally of pandanus (*Pandanus aquaticus* F. Muell.). This plant appears to be resistant to the effects of hexazinone at that rate of application.

Difficulties experienced in the control of salvinia by physical and chemical methods relate mainly to problems of access and environmental factors. There are few roads, and vehicle access around all infestations is poor except at Rapid Creek. Foot access is also difficult due to the density of vegetation and plant debris. In many cases salvinia exists in densely vegetated channels where small plants can remain hidden. At Nhulunbuy, in particular, there was a high risk of attack by salt water crocodiles (*Crocodilus porosus* Schneider). To eradicate salvinia, every single plant fragment must either be removed or sprayed. During the wet season, rivers are prone to flash flooding which will rapidly move infestations downstream. Environmental conditions are conducive to rapid growth of salvinia throughout the year, so regular follow up control is necessary.

TABLE 1. CONTROL METHODS AND STATUS OF FIELD INFESTATIONS OF SALVINIA IN THE NORTHERN TERRITORY.

Location	Date reported	Control method	Result
Nhulunbuy	Sep 1976	1977-81: physical/chemical 1981: biological control agent released	Reduced area, but not eradicated. 1982: weevil established. successful control.
Rapid Creek	Sep 1976	1976: physical	Last seen Dec 1976. Eradicated.
Adelaide River	Jan 1977	1977-82: physical/chemical	Last seen Dec 1982. Eradicated.
Mission Hole	Jul 1981	1981-84: physical/chemical 1983-86: biological control agent released into swamp downstream of main water-hole.	Last seen main water hole Jun 1983. Eradicated. 1988: Establishment not confirmed.
Mary River	Aug 1981	1981: physical/chemical	Last seen Oct 1981. Eradicated.
Howard River	Jun 1982	1982: biological control agent released	1982: Weevil established. Successful control.
Lily Pond Creek	Jul 1982	1982-83: physical/chemical	Last seen 1983. Eradicated.
Finniss River	Jan 1983	1983: biological control agent released.	1983: Weevil established. Successful control.
Billabong Creek	Feb 1983	1983: physical/chemical	Last seen Jun 1983. Eradicated.
Magela Creek	Sep 1983	1983: physical/chemical 1983-84: biological control agent released	Not eradicated. 1986: Established in all waterholes. control variable.
Holmes' Jungle	Jun 1988	1988: physical/chemical	1988: Controlled but not eradicated.

Physical and chemical control methods have been most successful where surveys and control were carried out regularly. However, these methods require a high input of manpower and other resources so, as the number of infestations increased, it became increasingly difficult to adequately service each infestation.

Biological control. Salvinia occurs naturally in southern Brazil (Forno and Harley 1979) where it is contained by three phytophagous insects (Forno and Bourne 1984), a weevil (*Cyrtobagous salviniae* Calder and Sands), a pyralid moth (*Samea multiplicalis* Guenee) and a grasshopper (*Paulinia acuminata* De Geer). In 1980, *C. salviniae* was released onto what was Australia's largest salvinia infestation on Lake Moondarra, Queensland, achieving almost total control (Room *et al.* 1981). Adults of this weevil feed externally upon leaf buds, but the main damage inflicted upon salvinia is the tunnelling by larvae within the rhizomes (Sands *et al.* 1983). The rhizomes then become brittle, the salvinia mats are easily broken up, the leaves become brown and lose their buoyancy and the plants sink.

S. multiplicalis was also introduced into, and has become established in Queensland (Sands and Kassulke 1984), but Forno (1985) considers that it has not been an effective control agent in tropical Australia, possibly due to its ina bility to tolerate high summer temperatures.

In November 1981 a colony of 850 adults of *C. salvinia* was obtained from Queensland for release in the Northern Territory. It was released on the largest infestation at th time, at Nhulunbuy where difficulties were being experi enced with chemical control. Initially, released adults wer contained within floating cages to prevent premature dis persal, but this technique was discontinued when it wa found to be unnecessary. Adult weevils disperse by walkin unless there is a shortage of undamaged host plants (Roon *et al.* 1984). Typically this dispersal rate is of the order o a few metres per month. Room *et al.* (1984) found tha establishment of *C. salviniae* at a site could be effected b releasing as few as 200 adults and that extensive damag could become apparent after four months.

In order to enhance the spread of *C. salviniae*, they ca be collected manually from areas where they are abundan and transferred to new sites. Adults can be easily separate from the salvinia on which they occur by holding the plant underwater beneath a coarse mesh, for 24 hours. Th weevils float to the surface and can be collected and place into a container of fresh salvinia for transport.

Figure 3. a. Salvinia completely covering the Howard River prior to the spread of the weevil, *Cyrtobagous salviniae*, to this site (above) and 3b. The same location, 10 months later (on opposite page).

It is not proposed to introduce *S. multiplicalis* into the the Northern Territory. Three native pyralid moths, *Nymphula tenebralis* Lower, *N. responsalis* (Walker) and *N. turbata* (Butler) are very common as larvae feeding upon expanded leaves of salvinia in the Northern Territory and the damage they cause is very similar to that caused by *S. multiplicalis*. With the high temperatures experienced during summer inhibiting its population growth, *S. multiplicalis* would not be expected to significantly improve the degree of control exerted by *C. salviniae* in concert with the native moths.

At some sites, control by *C. salviniae* has been unsuccessful, particularly in shallow water. This may be due to high temperatures as, during the hottest months, the temperature at the surface of salvinia frequently exceeds 40 C. The optimum temperature for development of *C. salviniae* is near 32 C, and above 37 C eggs fail to hatch (Forno *et al.* 1983).

STATUS OF INFESTATIONS

The current status of each infestation is shown in Table 1. Their size and nature vary between sites from a small mat in a drainage line at Rapid Creek to mats and scattered plants over approximately 35 km of the Magela Creek system.

Miller and Pickering (1988) described the Adelaide River infestation and detailed a 10 year physical and chemical eradication program. Recently the trend has been towards biological control. Physical and chemical methods are, however, still used where rapid control is required, and where it is deemed feasible to achieve eradication.

The most successfully controlled infestations using *C. salviniae* are at the Howard and Finniss Rivers. Here, control is cyclical. Salvinia now typically occurs as a fringe of primary-form plants (Mitchell and Tur 1975) along the edges through the cooler dry season. Then it begins to expand rapidly as temperature and humidity increase in September and October, followed by an equally rapid decline as populations of *C. salviniae* build up (Figure 3). The rivers are then flushed by annual floods during February and March, and the cycle begins again.

Salvinia management has been achieved in the Northern Territory by the integration of publicity with chemical, physical and biological control. This illustrates that swift action on an aquatic weed can halt its spread in a new geographical area.

Five infestations have now been eradicated and two

Figure 3b.

substantially reduced by chemical or physical control methods. Biological control with *C. salviniae* is proving to be successful, but in shallow, open waterholes its success is probably limited by high temperatures which affect the weevil's reproduction.

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