Eradication of salvinia (*Salvinia molesta*) from the Adelaide River, Northern Territory

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Summary

In January 1977 the aquatic weed *Salvinia molesta* was found growing in the upper reaches of the Adelaide River, N.T., and threatened to infest the entire river system. The nature of the river, the infestation and a successful 10-year eradication program are described.

Herbicides used were paraquat, diquat, 2,4-D and AF 101. Nets were erected to prevent downstream movement of the weed and surveys were carried out on foot, by boat, canoe and helicopter. Small areas of salvinia were removed by hand and overhanging vegetation along the edges of the river was burnt to expose hidden plants.

The last sighting of salvinia on the river was on 14 December 1982 but regular surveys continued until 1986 to ensure that no re-infestation occurred.

Introduction

The Adelaide River varies considerably along its length from its headwaters on Tipperary Station in the Northern Territory to its mouth in Van Diemen Gulf (Figure 1). In its upper reaches the river consists of a series of pools and narrow channels for most of the dry season (April–September), but is prone to flash flooding during the monsoonal wet season due to the nature of the land systems surrounding it. These were described by Christian and Stewart (1952). They vary from low hills covered with mixed open forest to sharp, steep, rocky ridges and hills with some gorges and scarps sparsely covered with *Eucalyptus* spp. The pools are generally closely surrounded with pandanus (*Pandanus aquaticus* and *P. spiralis*), various grasses and ferns, or bamboo (*Bambusa arnhemica*). The channels support areas of monsoon forest or mixed forest and bamboo and are often surrounded by paper bark (*Melaleuca leucodendron*) swamps.

The central part of the river below Adelaide River township flows through the Marrakai land system. It consists of slightly elevated river levees covered with open forest, interspersed with mixed open forest on gravelly hills and grassed alluvial plains which are prone to shallow flooding. Below Marrakai crossing the river is under tidal influences, meandering through the subcoastal floodplains with their dark, cracking clays covered with open grassland, sedges, other herbaceous species and the introduced woody weed *Mimosa pigra*. The plain blends into a littoral zone of salt and mangrove mud flats, sand dunes and lateritic capped cliffs at the sea.

The area drained by the river covers 7640 km^2 and has an estimated average annual flow of 1980 m$^3 \times 10^6$ (Anon. 1985). The river is used for irrigation of horticultural crops, as a water supply for livestock and domestic use, for recreation and tourism. A potential dam site (Warrai Dam) has been investigated in its upper reaches to supplement the water supply to Adelaide River town and Darwin, and for irrigation development.

In January 1977 an infestation of the aquatic weed salvinia (*Salvinia molesta* D. S. Mitchell) was reported in the upper reaches of the river (Figure 1). Salvinia is an asexually reproducing free-floating fern, buoyancy being assisted by uniseriate hairs on the top of papillae on the upper sufaces of the floating leaves (Harley and Mitchell 1981). Problems of blocking and pollution of the waterways by salvinia elsewhere in Australia, Asia, the Pacific and Africa have been documented previously (Williams 1956; Hattingh 1961; Mitchell 1973, 1978 *a,b*; Farrel 1978; Sundaresan and Reddy 1979; Mitchell *et al.* 1980; Harley and Mitchell 1981; Finlayson and Mitchell 1982). This was the third report of a field infestation of salvinia in the Northern Territory but the first of an infestation which threatened an entire river system. Its presence on the Adelaide River posed a significant threat to the river's actual and potential uses, to the ecology of the river

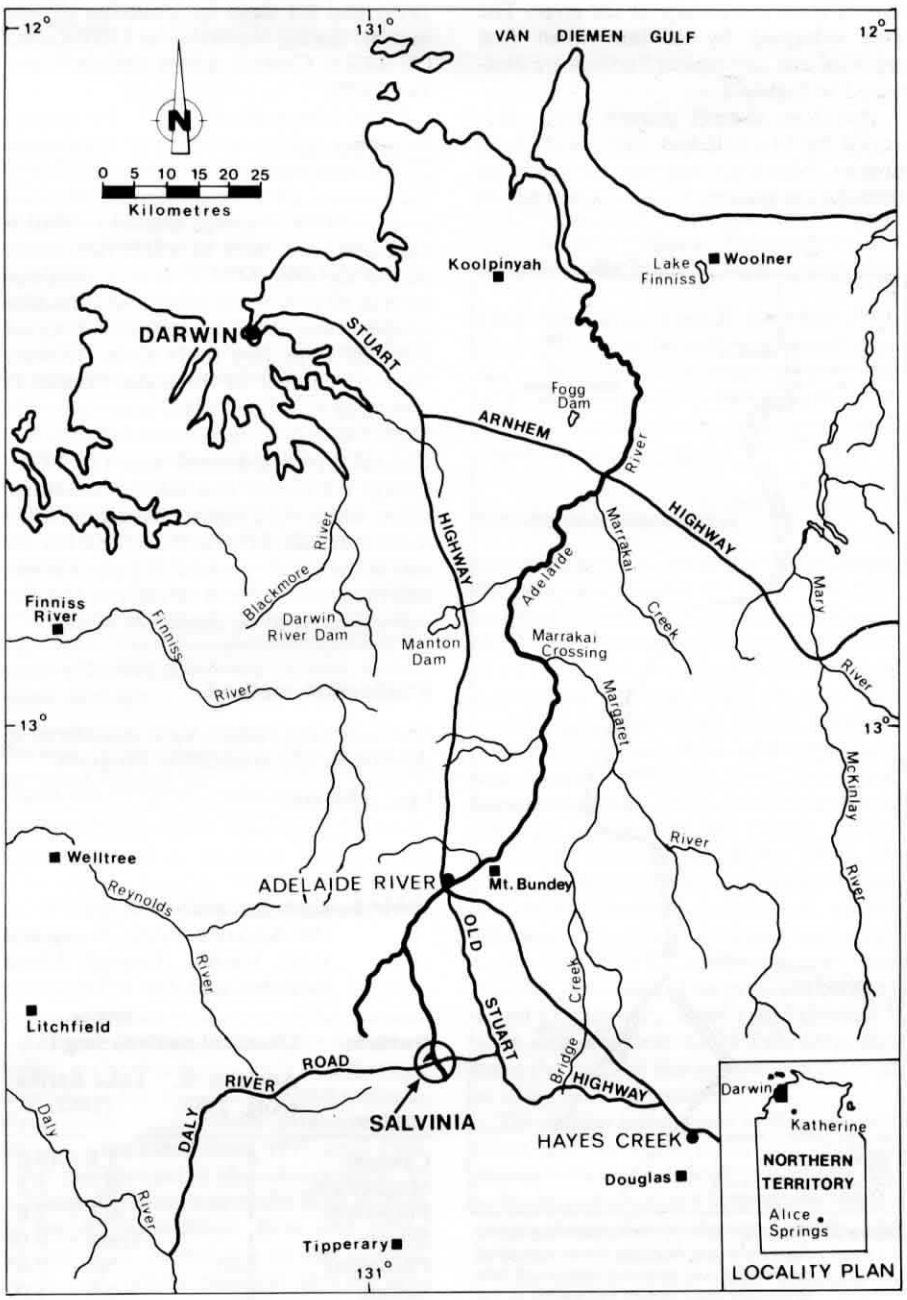

Figure 1 Map of the Adelaide River system showing location of the salvinia infestation.

system and provided a source of infestation for other waterways in northern Australia.

At the time of discovery of the infestation, chemical and physical methods were the only techniques available to control salvinia in Australia (Farrel 1978, 1979; Julian 1978), though since that time biological control agents have become available (Room *et al.* 1981; Sands and Kassulke 1984). Currently, both biological and chemical control methods are employed in the Northern Territory depending on the location, size and accessibility of the infestation. In the 10-year eradication program reported in this paper, chemical and physical techniques were used.

Description of the infestation

The infestation was first located on the Adelaide River on 10 January 1977, beside a road bridge 120 km S.S.E. of Darwin at latitude 13°29'S., longitude 131°06'W. (Figure 1). This is approximately 240 km upstream from the mouth of the river. The area occupied by salvinia when first reported and subsequent findings are illustrated in Figure 2.

The three distinct growth forms described by Mitchell and Tur (1975) were present. 'Mat-form' salvinia was scattered through the monsoon forest upstream of the main infestation, completely covered 0.4 ha of pool 1 and was scattered through channel 1 (Figure 2). The 'primary-invading-form' and the 'open-water-colonizing-form' were found in parts of the monsoon forest, through the channels and in pools 2, 3 and 4. The total length of river infested was 1.8 km.

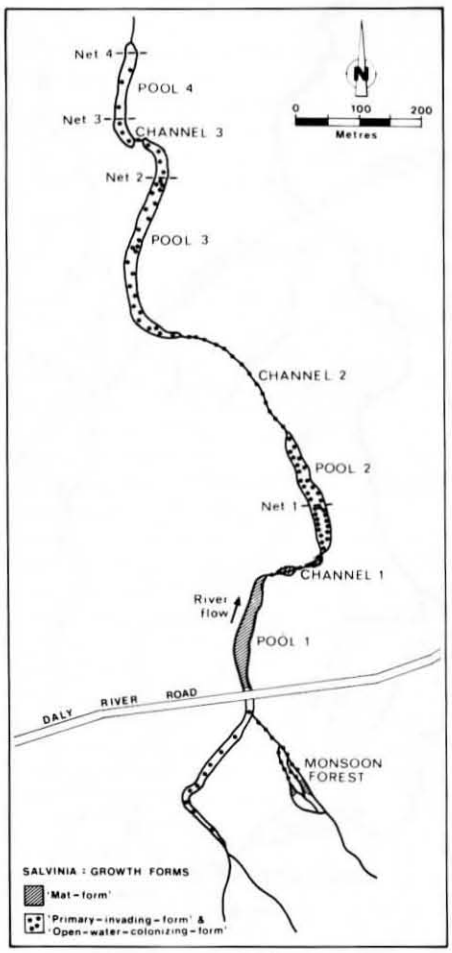

Figure 2 Map of the salvinia infestation in the upper reaches of the Adelaide River indicating direction of river flow and positions of nets to prevent downstream movement of the weed.

Growth rates of salvinia are known to vary with temperature, light intensity, nutrient content of the water, pH and growth form (Cary and Weerts 1983 *a,b*, 1984; Mitchell and Tur 1975; Sale *et al.* 1985). Optimum growth occurs under uncrowded conditions in open water, at water temperatures of 30°C, and under conditions of high nutrient availability (Mitchell and Tur 1975). Recorded doubling times under field conditions elsewhere in the tropics have been as short as 1.3 days for doubling of percentage cover in a sewage lagoon near Lake Moondarra (20°34'S.), Mt Isa (Finlayson 1984), 2.2 days for doubling of leaf number during December in Lake Moondarra (Farrel 1979) and 8.1 days for doubling of leaf number during November in Lake Kariba (16°44'S.), Central Africa (Mitchell and Tur 1975).

Mean temperatures from the nearest recording station are 36.1°C maximum, 22.7°C minimum in November and 31.4°C maximum, 12.3°C minimum in July (Anon. 1975). Average annual rainfall is 1492 mm, over 90% of which falls in the period October–March. Water temperatures at 10 mm depth, measured at midday in open water at the infestation site, varied from 28°C in July to 33°C in October. Nutrient content of the water in pool 1, measured in August 1980, is compared in Table 1 with that measured in Lake Kariba, Central Africa (Mitchell and Tur 1975). Except for nitrate and sulfate concentrations, which were higher, nutrient content in the Adelaide River at the infestation site was in the range recorded in Lake Kariba, and the growth rate of salvinia in January was expected to be similar or higher.

Eradication method

The following factors were considered in developing the eradication program.

(i) The infestation, being in the headwaters of the river, could spread throughout the entire system—at least down to where it became too saline.

(ii) The infestation was discovered in the middle of the wet season. Consequently, *(a)* the river might flash flood and carry the salvinia further downstream, *(b)* environmental conditions were conducive to rapid growth of the weed, and *(c)* vehicle access along the banks and foot access into channels was difficult.

(iii) The source of infestation was in an area of monsoon forest and paperbark swamp upstream of pool 1. The density of the vegetation and plant debris made surveying difficult. Similar vegetation in the channels between pools meant that boat and foot access was impeded.

(iv) The banks of the pools were lined with thickly overhanging pandanus and other vegetation which impeded access and protected the salvinia from herbicides.

(v) The river banks downstream of the infestation were inaccessible to vehicles except at selected points even in the dry season due to the nature of the terrain, entry of creeks into the river and the river-bank vegetation.

Table 1 Chemical analysis of water from the Adelaide River, N.T., and Lake Kariba, Central Africa (Mitchell and Tur 1975)

Nutrient	Chemical analysis (mg l^{-1})	
	Adelaide R. (Aug. 1980)	Lake Kariba (1962)
Calcium	8	3.8 – 16.0
Magnesium	3	0 – 5.8
Potassium	1	0.1 – 2.0
Nitrate	1	Trace – 0.06
Phosphate	0.05	Nil – 0.05
Sulfate	6	0.5 – 1.0

For successful eradication the infestation had to be attacked immediately. The program commenced on 12 January 1977, two days after the infestation was reported, using the methods outlined below. Locations and number of times each method was used are given in Table 2.

Herbicides used were Gramoxone (200 g l^{-1} paraquat dichloride), Reglone (200 g l^{-1} diquat dibromide monohydrate), Lane 2,4-D Amine 50 (500 g l^{-1} 2,4-D amine as the dimethylamine salt) and AF 101 (20 g l^{-1} diuron + 150 g l^{-1} calcium dodecylbenzene sulfonate with acetone and kerosene as co-solvents). The purpose of using paraquat, diquat and 2,4-D was to obtain a rapid kill and collapse of mats before flooding would carry the salvinia downstream. Both paraquat and diquat act quickly on foliage, the principle mode of action being by contact, while 2,4-D is readily translocated (Fryer and Evans 1968).

For application, AF 101 was diluted 1 in 10 with kerosene. The kerosene and surfactant in AF 101 cause it to float on top of the water, spreading over the surfaces of the plant, destroying its buoyancy and submerging it, while the translocated herbicide (diuron) in AF 101 ensures complete control of axillary and terminal buds which are normally submerged and escape contact with the surface treatment (Diatloff *et al.* 1979). The role of AF 101 on the Adelaide River was to spread through the overhanging vegetation to control salvinia which may have been missed during survey and hand-removal operations from January 1979. Its use was continued as a precautionary measure until 1984 to prevent reinfestation even when no salvinia was detected.

Table 2 Summary of methods used to eradicate salvinia from the Adelaide River, 1977–1986

Method	Location[A]	No. of times method used				
		1977			1978–86	Total
		Jan.–Feb.	Mar.–Sep.	Nov.–Dec.		
1. Herbicides						
paraquat + diquat	Mf	1	–	1	1	3
paraquat + diquat + 2,4-D;	P1, Ch1	7	–	–	–	7
paraquat + 2,4-D; or	P2	3	–	4	–	7
paraquat alone	P3	1	–	4	–	5
	P4	–	–	–	–	0
AF 101	P1–4	–	–	–	4	4
	Mf	–	–	–	7	7
2. Net erection	P2–4	2	–	1	1	4
3. Edge burning	P2–4	–	–	–	2	2
4. Surveys						
Foot/boat/canoe	Mf, P1–4, Ch1–3	9	5	4	26	44
(including manual removal where appropriate)	To Marrakai crossing, Adelaide R. Town, or west branch	–	1	–	10	11
Helicopter	To Arnhem Hwy or Adelaide R. Town	–	1	–	2	3

[A] Mf, monsoon forest; P, pool; Ch, channel.

The herbicide mixes used at various times were as follows:

January–February 1977: 0.04% paraquat + 0.02% diquat; 0.04% paraquat + 0.02% diquat + 0.12% 2,4-D; 0.04% paraquat + 0.12% 2,4-D; 0.06% paraquat + 0.1% 2,4-D; 0.04% paraquat.

November 1977 and 1978–79: 0.04% paraquat + 0.02% diquat, on salvinia and for desiccation of edge vegetation prior to burning.

1979–1984: 0.2% diuron + 1.5% calcium dodecylbenzene sulfonate in kerosene.

All paraquat/diquat/2,4-D mixes contained 2 ml l^{-1} of Agral 60 spray activator wetting and spreading agent (600 g l^{-1} non-ionic surfactant).

For the first spraying the paraquat/diquat mixture was applied through a blower mister from a boat. Subsequent sprayings of this mixture and the paraquat/diquat/2,4-D mixes were applied through an 'FMC Bean' spray gun connected to a trailer-mounted pump and tank by 100 m of high pressure hose. This enabled the unit to be stationed on the bank and the spray gun operated either from a boat, from the bank or by dragging the hose through the channels. Knapsack sprayers were used for spraying edges from the bank and for small isolated mats of plants from a boat. The AF 101 was applied to the free water surface using a sprinkler-sprayer (Diatloff and Anderson 1980).

Nets were erected in series (Figure 2) to prevent the downstream movement of the weed. The fact that salvinia is sterile and reproduces vegetatively (Harley and Mitchell 1981) meant that if plants could be satisfactorily confined, downstream spread would not occur. The nets were 2 m high, of which 30 cm was below the water surface, and consisted of wire netting (12.5-mm mesh) covered with aluminium gauze flyscreen. They were suspended on plain fencing wire connected to 'star' steel fence posts driven into the bank. Short wings (4–7 m long) were extended onto the bank in case of flooding. The gauze mesh was necessary as salvinia is very fragile especially when in the 'primary-invading-form' and can easily break up into small segments capable of passing through wire netting.

The nets were erected in a series as insurance against breakage of one or more during floods. They were checked regularly to remove floating debris and salvinia, and to repair damage.

Burning of the edges after desiccation by paraquat/diquat was carried out to assist in removing overhanging vegetation that was protecting small salvinia plants from herbicides and to facilitate detection of plants during surveys. This was carried out using a 'Rega Junior Flame Thrower' with kerosene fuel.

Surveys were carried out on foot, by boat or canoe and by helicopter. Foot surveys were carried out regularly in the monsoon forest, on both sides of pools and through channels in the infested area and immediately downstream. More extensive foot surveys were made from 1977 until 1986 either downstream to Marrakai crossing, to Adelaide River town or to the West Branch of the Adelaide River. Boat and canoe surveys were carried out in the infested pools and, where possible, downstream from the infestation. Helicopter surveys were conducted along the length of the river down to the Arnhem Highway or to Adelaide River town.

Hand removal of weed from small areas either directly or by means of small nets was carried out from boats or from the bank in association with spraying and surveys. These plants were dried and destroyed by burning.

Results and discussion

There was an intensive control effort during the first two months of 1977. The first spraying in pool 1 with paraquat and diquat on 12 January caused chlorosis and necrosis of exposed leaf surfaces within 1 week but was not sufficient to kill the mat. This result was similar to the impact made on Tinaroo Falls Dam, Qld, where paraquat and diquat produced only superficial browning (Julian 1978). Salvinia leaves in mats are compressed and deeply folded; hence the inner parts of the plant are protected from contact herbicides. It was not until after four sprayings at weekly intervals with paraquat/diquat and paraquat/diquat/2,4-D, that the mat lost bouyancy and sank. This occurred between 4 and 11 February. Pool 1 and channel 1 were virtually clear by 24 February, this being the last date that salvinia was detected in those areas (Figure 3).

The smaller infestations in the monsoon forest and the other pools and channels proved to be more difficult to eradicate due to floods and problems in detecting hidden plants. Flash floods during January and February moved salvinia through channel 1 into pool 2. Water levels returned to normal within 24 hours and some salvinia

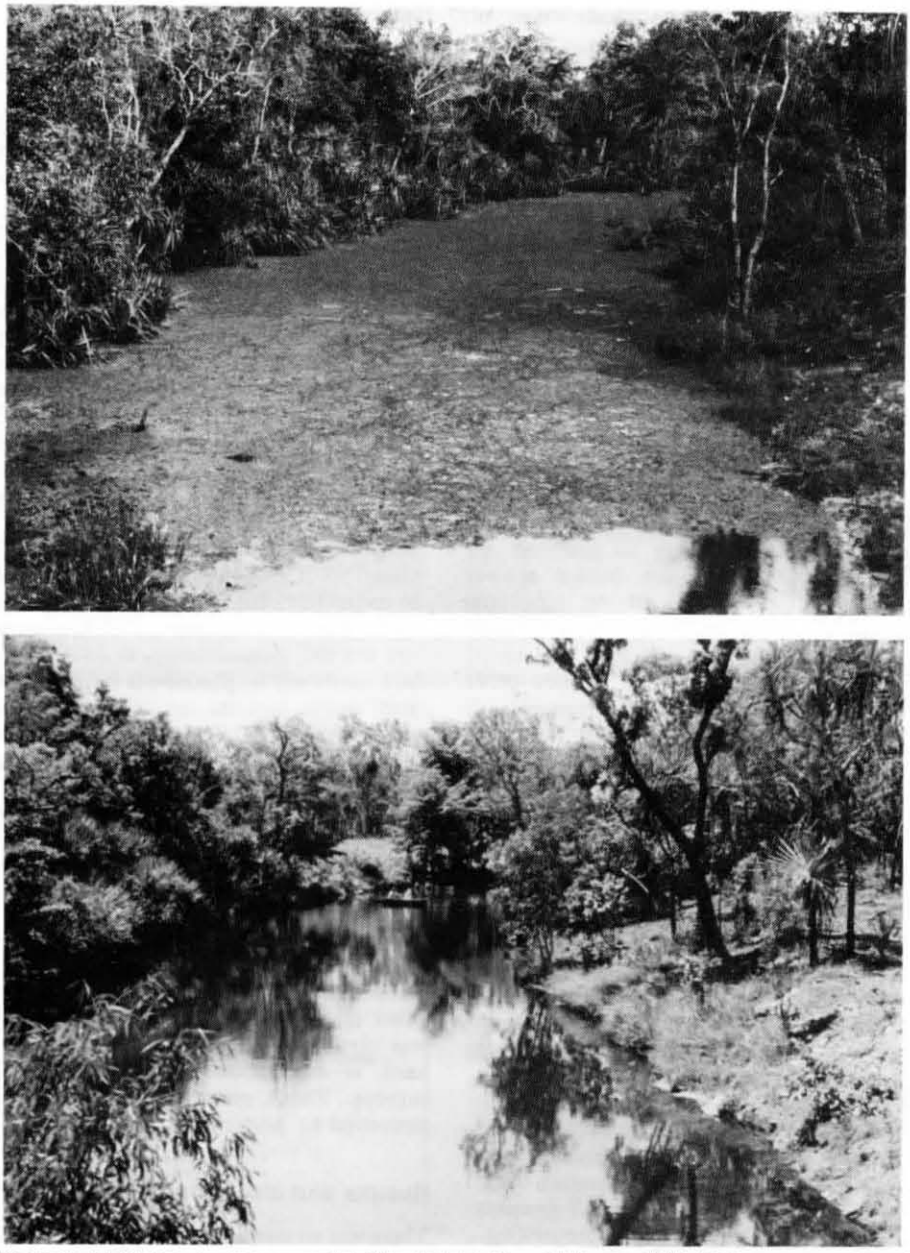

Figure 3 (*a*) 'Mat-form' salvinia on pool 1 of the Adelaide River, 10 January 1977. (*b*) The same area free of salvinia, 25 September 1980.

plants which were caught in vegetation above the normal level subsequently died from dehydration. In March only a few plants were present in pool 2 but on the evening of 21 March prolonged rainfall (245 mm at Adelaide River town) caused the river to flood breaking nets 1 and 2. Nets 3 and 4 had not been erected at that stage but, because of the intensive control effort, very little salvinia was present, and so the chance of spread was reduced. Plants remained in the monsoon forest, pools 2, 3 and 4 and in channels 2 and 3 after floodwaters receded. They were eradicated from all pools and channels by the end of May 1979, the last sighting of salvinia being on 15 August 1978 in channels 2 and 3, 29 December 1978 in pool 2, 2 March 1979 in pool 3 and 28 May 1979 in pool 4.

After May 1979 no further sightings were made anywhere on the river until the end of 1982. During the intervening period it was believed to have been eradicated but regular surveys continued. On 7 December 1982 a small mat (4 m^2) and plants in the 'primary-invading-form', were found scattered over 20 m of channel in the monsoon forest. These were removed by hand and the area sprayed with AF 101 on 8 December. No plants have been detected the monsoon forest since 14 December 1982. At no stage was salvinia detected below net 4.

Regular surveys have continued since 1982 but no reinfestation has occurred. As salvinia has not been detected for 4 years we are now confident that it has been eradicated.

The control techniques described here were successful in achieving eradication. The same techniques, with some variation in herbicide treatments have been applied to six other field infestations of salvinia in the Northern Territory, four of which have been eradicated and two substantially reduced. The essence of success in all these programs was early detection of infestations, brought about by public awareness of the dangers of this weed, followed by swift action, regular follow-up and a long-term commitment to the task.

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