AQUATIC WEEDS AND THEIR MANAGEMENT IN SOUTHERN AFRICA: BIOLOGICAL CONTROL OF SALVINIA MOLESTA IN THE EASTERN CAPRIVI.

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SUMMARY

Salvinia molesta Mitchell or Kariba Weed, has been a problem in the Eastern Caprivi wetlands since the early 1970's. Following studies on the extent of the problem, local growth rates of the plant and different control methods, a biological control programme was initiated by the Department of Water Affairs. Host-specific natural enemies were sought and in 1983, 500 snout weevils, *Cyrtobagous salviniae* Calder and Sands, native to South America, were imported from Australia. These bred successfully in Katima Mulilo and by March 1985 over 10 000 had been released at 14 selected sites in the Eastern Caprivi. Within 14 months 97% of the weed at the Ngoma site on the Chobe River had disappeared. The present low weed intensities indicate that the *Salvinia molesta* infestation is being successfully controlled by *Cyrtobagous salviniae*.

In Press: Paper presented at the SADCC Wetland Conservation Conference held in Gaborone, Botswana 3 - 5 June 1991. To be published in the Conference Proceedings.

INTRODUCTION

Aquatic invasive alien plants have caused problems in southern Africa since the 1960's. They include Salvinia molesta Mitchell (Kariba weed), Eichhornia crassipes (Mart.) Solms (water hyacinth), Myriophyllum aquaticum (Vell.) Verdc. (parrot's feather), Azolla filiculoides Lam. (water fern), and Pistia stratiotes L. (Nile cabbage or water lettuce).

Whereas indigenous plants are in equilibrium with their habitat, alien macrophytes can grow excessively. Absence of their natural enemies and new nutrient-rich habitats tend to contribute to rapid, uncontrolled plant growth. For instance Salvinia molesta took full advantage of the enriched waters of the impounded Zambezi River and within a year covered 21% of the water surface of Lake Kariba (Mitchell 1969). Floating plants are easily spread to new areas by water currents and wind. Many can reproduce vegetatively from small fragments that are carried inadvertently by man or animals to new areas.

Excessive growth of aquatic plants interferes with navigation, hydro-electric schemes, irrigation, disease control, fish production and harvesting, water quality, aquatic crops, recreation and may increase water loss due to evapotranspiration. These problems are intensified in a tropical climate where luxuriant plant growth continues throughout the year, complicating eradication measures.

Salvinia molesta is one of the most troublesome aquatic weeds in the world. In 1960, with the construction of the Kariba Dam, this weed underwent explosive growth in the newly impounded nutrient-rich waters. A year later littoral Salvinia molesta colonies covered 200 - 400 km2 (Mitchell, 1972). It was hoped that the invasion would be transient, induced by temporary high nutrient concentrations. Indeed a fluctuating, decreasing trend occurred, by 1966 only 10% of the lake's surface was covered (Mitchell 1969). It subsequently appears to have stabilized at 6% with values as low as 3% reported in 1973 (Jacot Guillarmod 1979). Due to continual re-infestation by viable fragments, thought to originate in the Chobe River, the problem persists, but the plants are mainly restricted to sheltered bays and river inflows.

At present the heaviest infestations of Salvinia molesta in southern Africa occur along the Zambezi and its tributaries. Progressive encroachment threatened the Caprivi wetlands in Namibia but this infestation is now under control. This was achieved by a successful biological control programme using the snout weevil Cyrtobagous salviniae Calder and Sands and is the main subject of this paper.

In Botswana a rigid "cordon sanitaire" is maintained to protect the delicately balanced Okavango Swamp environment from invasion by Salvinia molesta, using a combination of chemical and biological methods. A recent occurrence of the weed at Xini Lagoon in the Moremi National Park was eradicated by a combination of mechanical, chemical and biological methods. More than 3 000 adult Cyrtobagous salviniae were released onto the mat to reduce the risk of infested plants being dispersed (Schlettwein 1986 b).

In Zimbabwe the Sabi river is infested. In South Africa it has been reported from the Kruger National Park, Natal and in the Wilderness lake area in the Cape (Jacot Guillarmod 1979). There are no records of Salvinia molesta problems in Lesotho nor Swaziland, it occurs in both Angola and Mozambique and although present, it is not considered a problem in Tanzania. It is however a serious problem in Kenya (G Howard pers. comm.).

Salvinia molesta is a free-floating aquatic fern which occurs naturally in southwest Brazil (Forno and Harley 1979). It is an extremely reduced pteridophyte, with a horizontally floating stem. Each node bears a pair of buoyant aerial leaves and a submerged leaf which functions as a root. Buoyancy is maintained by a layer of air-trapping water repellent hairs on the upper surface of the aerial leaves (Sculthorpe, 1967). Being a sterile hybrid, Salvinia molesta depends entirely on vegetative means of propagation. Attempts at germinating spores have been unsuccessful (Jacot Guillarmod, 1979).

Salvinia molesta has two distinct growth forms. The pioneer, invasive form found in open waters has flat, open leaves, whilst the plants found in mature mats are characterized by large, folded, V-shaped leaves. Mats form when plants blown together in sheltered areas intertwine as they grow. These can be as thick as O,5m, support secondary colonization and eventually form permanent "Sudd" islands which can block waterways, particularly in the more sheltered floodplain areas.

The first specimens of Salvinia molesta in southern Africa were collected in 1948 at Katombara, fifty-five kilometres upstream of the Victoria Falls (Mitchell 1967). It is spread by natural extension, water currents, wind, human activities (boats and fishing) and birds.

The only other alien floating macrophyte found in Eastern Caprivi is Pistia stratiotes, commonly known as water lettuce or Nile cabbage. It occurs in the Chobe river and the Linyanti swamps near Nkasa Island in Namibia and in northern Botswana (Hines et al. 1988, Schlettwein et al., in press, Smith 1989). In Zimbabwe Pistia stratiotes is a serious problem in dams and rivers near Harare, particularly in Lake McIllwaine. It is being successfully controlled by the weevil Neohydonous affinis Hustache in the Manyame River (Chikwenhere and Forno, in press).

DESCRIPTION OF THE AREA

As shown in figure 1, the Eastern Caprivi in the North-east of Namibia is practically surrounded by perennial rivers, the Zambezi River in the North and the Kwando, Linyanti, Chobe system in the West, South and East. The Eastern Caprivi covers an area of 11 600 km^2 of which 30% consists of floodplains. The entire area is very flat and the average elevation is 930m above sea level. Until Lake Liambezi dried up in 1985 (Grobler and Ferreira 1990, Schlettwein et al., in press), the Kwando River acted as a tributary to the Zambezi, flowing through the Linyanti swamps to the Lake which in turn fed the Chobe River which joins the Zambezi near Kasangula. Due to the lack of topography in the Eastern Caprivi, exceptionally high floodwaters from the Zambezi River can move up the Chobe River reversing its flow. Under these conditions floodwaters from the Zambezi can flow directly into Lake Liambezi via the Bukalo channel. The hydrology of the region has been studied (Schlettwein et al.,in press).

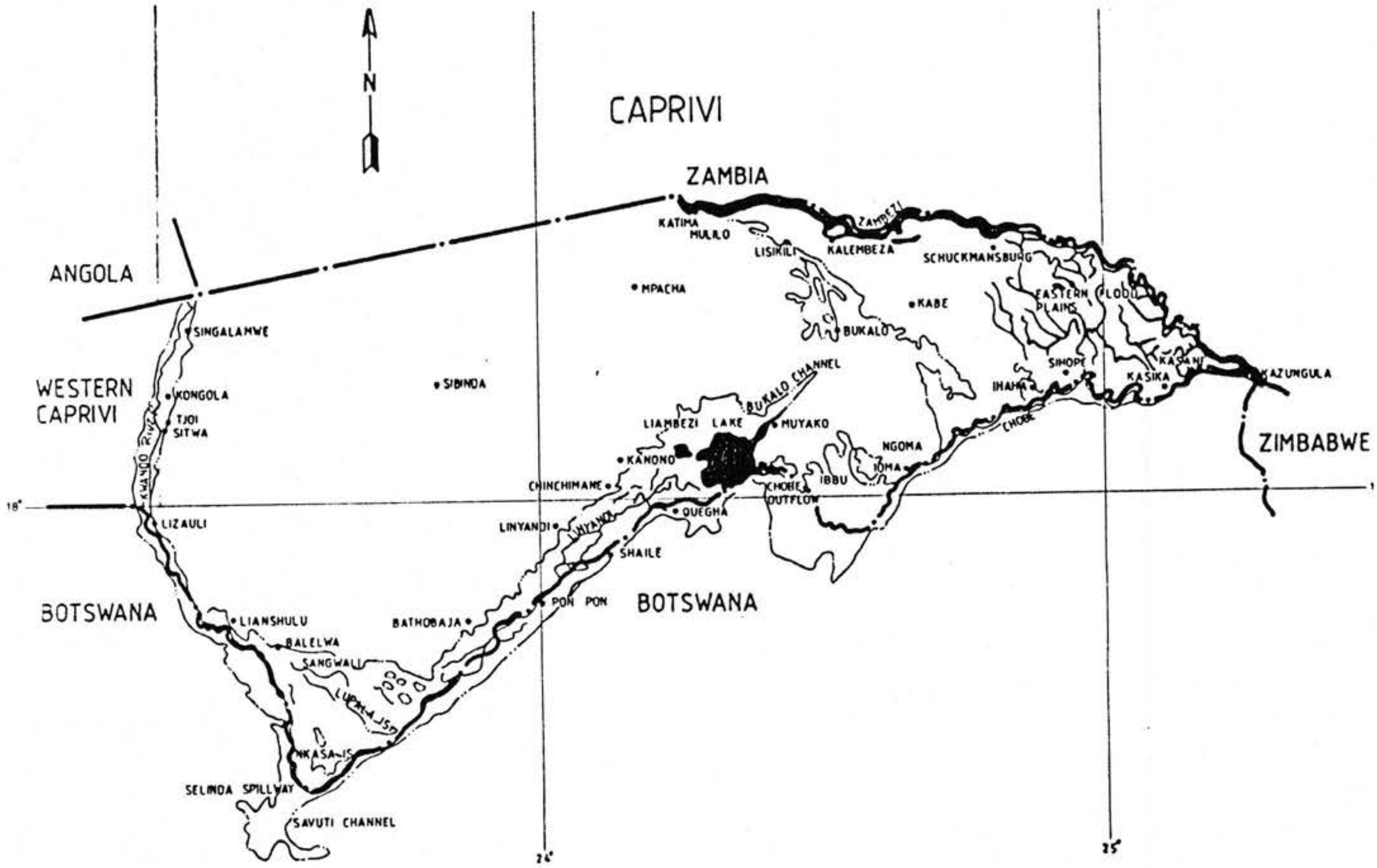

Figure 1. Map of the Eastern Caprivi showing places mentioned in the text.

<u>The Salvinia molesta problem.</u>

The quiet sheltered waters and slow flowing rivers of Eastern Caprivi are ideal for <u>Salvinia</u> <u>molesta</u>. Kariba weed spread to the Eastern Caprivi in the 1950's and by 1972 was found throughout the region (Edwards et al. 1972). The infestation peaked in 1975 when an estimated 26% of the surface area of Lake Liambezi was covered (Seaman et al. 1978). The history of the infestation in Namibia is well documented (Edwards and Thomas 1977, Smith 1969, Seaman et al. 1978, Van der Waal 1978, 1979, Malan and Koch 1985, Hines et al. 1985, Schlettwein and Hamman 1984, Schlettwein et al., in press).

The Eastern Caprivi wetlands which support a rich variety of plants and animals (Schlettwein et al., in press) were threatened by the progressive encroachment of Salvinia molesta. During the 1970's, drifting mats and permanent "Sudd" islands blocked waterways, local fish catches declined and low oxygen levels beneath the Salvinia mats impaired water quality and were unfavourable for zooplankton and fish (Seaman et al. 1978).

Biological control of Salvinia in the Eastern Caprivi

To protect the wetlands in Eastern Caprivi and those in neighbouring Botswana it was essential to check the growth and spread of Salvinia molesta. Between 1969 and 1979 several attempts were made by Namibian and Botswanan authorities at both chemical and biological control of Salvinia molesta in these wetlands (Smith 1969, Edwards and Thomas 1977, Hines et al. 1985). These were did not achieve long-term success.

In its natural habitat in South America, Salvinia molesta growth is kept in check by several species of insects which feed on it. Early attempts at finding a suitable control agent for Salvinia concentrated on the natural enemies of Salvinia auriculata Aubl.. Bennet (1976) collected insects feeding on Salvinia species in South America and tested them for host specificity using crops likely to be grown near Lake Kariba.

The aquatic grasshopper, Paulinia acuminata De Geer was subsequently released on both the Zambian and Zimbabwean sides of Lake Kariba. Between 1972 and 1974, 2700 Paulinia acuminata grasshoppers, and 1300 Cyrtobagous singularis weevils, field collected in Trinidad, were released onto Salvinia molesta in the Linyanti and Chobe rivers (Bennet 1976, Edwards and Thomas 1977). In Mozambique, Paulinia acuminata released on the Cabora Bassa Dam control the early invasion stages but have little effect on mature plants (Jacot Guillarmod, 1979). Paulinia is common Zambia in the Kafue floodplain area (G Howard pers. comm.).

In 1975 a further 250 Cyrotobagous singularis were released at Pon Pon. Attempts at recapture were unsuccessful (Edwards and Thomas 1977), until 1981 when Cyrtobagous singularis was found on Salvinia molesta in Lake Liambezi. An investigation was conducted to establish the distribution, densities and effectiveness of Cyrtobagous singularis as control organisms in the Eastern Caprivi (Schlettwein 1985 b). Low densities of Cyrtobagous singularis weevils were found throughout the Eastern Caprivi wetlands with the exception of the Kwando River north of Balelwa. The low densities were attributed to the fact that this particular weevil species prefers Salvinia auriculata to Salvinia molesta. Although established, Cyrtobagous singularis did not prove to be an effective control agent for Salvinia molesta in the Eastern Caprivi (Schlettwein 1985 b).

Australian scientists returned to South America to search for more specific natural control organisms for Salvinia molesta. Likely control organisms were collected and taken to Australia for stringent testing. Results showed that the weevil Cyrtobagous salvinae (Figure 2) is an effective and highly specific control agent, feeding and breeding exclusively on Salvinia molesta (Forno 1987, Forno and Harley 1978, Forno et al. 1983, Room et al. 1981, 1984, Sands et al. 1983). They also found a suitable moth species, Samea multiplicalis (Sands and Kassulke 1984).

The Department of Water Affairs research project.

In 1980 the control of Salvinia molesta in the Eastern Caprivi was taken over by the Namibian Department of Water Affairs. The objectives of the Water Affairs research project were to assess the extent of the problem (Malan and Koch 1985), determine the growth potential and ecological requirements of the weed, evaluate different control techniques and finally to apply and monitor the most suitable form of control (Koch and Schlettwein 1983, Schlettwein and Hamman 1984, Schlettwein 1986 a, Water Quality Division 1985, Giliomee 1986). The effects of pesticides and herbicides on the control organisms were also investigated (Schlettwein and Giliomee 1990, Schlettwein 1985 a). Other important aspects of the programme were to create public awareness, encourage international co-operation and lobby for legislation prohibiting the sale and transport of aquatic weeds.

Early in the project it became evident that biological control using a suitable host specific control agent was the best control option for Salvinia molesta in the Eastern Caprivi.

Biological control agents must meet three criteria, they must show a definite preference for the target plant, they must inflict damage severe enough to significantly retard growth and they must pose no threat to the local ecology. Cyrtobagous salviniae, a close relative of Cyrtobagous singularis, met all the requirements. Further, these weevils had been successfully reared in Australian laboratories, stringently screened, and had been used successfully to control Salvinia molesta on Lake Moondarra (Room et al. 1981, Forno et al. 1983, Finlayson 1984).

All four life stages of the weevil are dependent on the host plant. The eggs and pupae are inactive and harmless whilst the larval and adult stages can cause severe damage to the plant. The larvae tunnel into the floating stem and so cause the plant to disintegrate whilst the adults feed on the leaves and apical buds, often destroying them (Sands et al. 1983).

METHODS AND MATERIALS

The preliminary control assessments

A literature survey was done and some preliminary investigations were carried out to assess the various control options.
Chemical control: Six herbicides (Roundup, Paraquat, Diquat, 2-4 D, Diuron and Gramaxzone) were tested for their suitability to control Salvinia molesta. These tests were conducted in experimental ponds at the laboratory in Katima Mulilo. One field test was conducted in an isolated backwater at Balelwa on the Kwando River. An area of approximately 1000m^2 was hand sprayed during 1983 using Roundup (H.W.R. Koch pers.comm.).

Mechanical control: A physical barrier was erected across the the Kwando River at Kongola Bridge to trap any Salvinia drifting downstream from Angola, as this was thought to be a possible source of infestation into the Eastern Caprivi. Chicken mesh wire 1 m wide was suspended vertically across the River. It was held by a nylon rope across the top and a steel cable underneath, about 40 cm protruded above the water surface. The barrier was checked and cleared weekly and remained in place for a year during the 1982/83 season (H.W.R. Koch pers.comm.).

Biological control: From the literature is was evident that biological control was a viable option. While negotiations were underway to secure the most suitable control organisms, the seasonal growth and habitat requirements of Salvinia molesta in the Eastern Caprivi were examined in relation to nutrient levels in the water.

The growth rate studies.

During the 1982/83 season field observations were carried out at an open water site, an existing Salvinia molesta mat and a reed bed in Lake Liambezi, in flowing water in the Chobe River and at the end of the Bukalo Channel. At two monthly intervals five plants each with five pairs of leaves were collected at each site and placed in floating squares (0,75 x 0,75m) which were fitted with wire mesh bases to prevent intrusion by nearby plants. The total wet biomass, total number of leaf pairs and the number of dead leaves per square as well as water temperatures were recorded regularly. Monthly water analyses were done to determine nutrient concentrations and general water quality.

Growth rates were calculated using the formula:

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$ (Mitchell and Tur 1975)

Where RGR is the Relative Growth Rate and W_1 and W_2 are plant weights at times t_1 and t_2. The same formula was used to calculate the growth rates by means of the number of leaf pairs. RGR x 100 = % Growth per time interval. Netto growth rates were derived by subtracting mortality rate from growth rate.

During the 1983/1984 season field trials were conducted to compare growth rates in natural waters and artificially enriched water at six different localities: the Bukalo channel and Chobe outflow in Lake Liambezi, Lisikili, Kalembeza, Sitwa and Balelwa. Square floating boxes were divided into three sections, two of which were lined with plastic bags each filled with 80 litres of water, the third section served as a control. Four boxes were placed in the Bukalo channel and two at each of the other sites. Each week the bags were filled with nutrient enriched water and three plants each with five pairs of leaves were collected nearby and placed in each section. In the Bukalo channel seven nutrient concentrations were used (0,16g/80ℓ, 0,32g/80ℓ, 0,64g/80ℓ, 1,28g/80ℓ, 2,56g/80ℓ, 5,08g/80ℓ and 10,16g/80ℓ of 11% N, 22% P fertilizer), and at the other sites three concentrations were used (0,64g/80ℓ, 1,28g/80ℓ and 5,08g/80ℓ). Relative growth rates were calculated and monthly water analyses continued.

During the 1984/1985 season growth rates were measured under both natural field and controlled laboratory conditions. Two floating quadrants were placed in a permanent pool at Ngoma bridge from August 1984 to January 1985 to determine natural field rates.

A simultaneous laboratory experiment was conducted in 44 open plastic containers (0,4m x 0,4m x 0,7m). Four contained natural river water from the Zambezi, twenty contained nutrient enriched water (2g 46% N/100 litre) and twenty contained a balanced nutrient solution (1,5g $Ca(NO_3)_2$, 2gKNO_3, 10g $MgSO_4$, 0,75g $NH_4H_2PO_4$, 0,75g $(NH_4)_2$ HPO_4, 0,076g $FeSO_4$ $7H_2O$ and 0,1g Na EDTA per 1001).

Five plants each with five pairs of leaves were placed into each quadrant and container, each week the leaf pairs were counted and the fresh mass of each plant recorded. The plants and culture solutions were replaced every three weeks.

Nutrient analysis

As nutrients play an important part in the growth rate of Salvinia molesta (Mitchell and Tur 1975), chemical analysis of the water and plant material was done to correlate nutrient levels to growth rates. Water samples from Katima Mulilo, Kongola, Sitwa, Ngoma, and Muyako were analyzed each month.

During April and May 1982 plant material collected from Sitwa, Balelwa, Muyako, Ngoma and Lisikili were analyzed for nitrogen. Three plants each with five healthy pairs of leaves were collected from each site, dried at 100°C, milled and analyzed using the Kjeldahl method (Toerien et al. 1974).

Biological control.

The Breeding Programme: Two consignments of adult Cyrtobagous salviniae beetles were obtained from the Entomology Division of the C.S.I.R.O. in Australia. The first 144 insects imported in 1982 failed to breed. A second batch of 500 arrived in September 1983 and bred successfully. Of the 473 which survived transport, 150 were released into each of 3 ponds (3 x 1 x 0,35m) containing Salvinia molesta plants with approximately 600 buds. The plants were grown in nutrient solution to ensure maximum growth rates and optimal food quality for the weevils. Each week the adults, larvae and pupae on each of 40 plants were counted and the ratio of damaged to undamaged buds determined. Early in November, 397 beetles were harvested and used to start four new colonies.

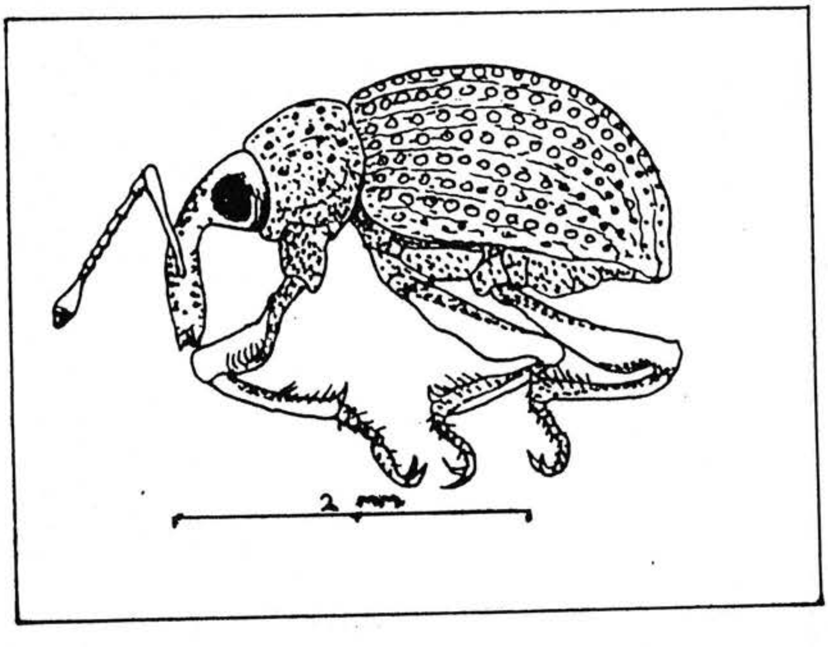

Figure 2. Cyrtobagous salviniae Calder and Sands, the biological control organism used on Salvinia molesta Mitchell in the Eastern Caprivi wetlands in Namibia.

The release and monitoring programme: As soon as the Cyrtobagous salviniae reached a density of 35 adults per 20 plants and bud damage was as high as 75%, half of the infested plant material was removed for use at the release sites and the ponds were restocked with uninfested plants. In December the first 450 adult Cyrtobagous salviniae beetles were harvested and released at Sitwa in a side channel of the Kwando River, a site chosen because of the absence of the closely related, Cyrtobagous singularis weevils (Schlettwein 1985 b). By March 1985 over 10 000 insects had been released at 14 selected sites: Sitwa, Bukalo channel, Ngoma bridge, Lisikili, two sites at Ihaha, Lianshulu, Balelwa, Nkasa island, Kasaya channel, Kasika, two sites in the Mutwalwizi channel, and at the first blockage on the Kwando).

Four of the sites, Ngoma, Muyako, Lisikili and Ihaha were photographed regularly to obtain a visual record of the progressive deterioration of the mats. At each site 2 - 5 kg wet mass Salvinia molesta was collected each month and weighed. The insects extracted using a Berlese funnel (Boland and Room 1983), then counted to determine insect densities and the percentage of damaged buds was calculated.

Since 1976, millions of insects have been successfully bred and released. Releases are made wherever infestations are found and these are regularly monitored. To maintain a wide distribution of control organisms, fresh Salvinia molesta with Cyrotobagous salviniae weevils is re-introduced where Salvinia mats and the insects on them have sunk.

Pesticide and Herbicide tests.

The effects of the insecticides used for tsetsefly (Glossina moritans centralis Machado) and mosquito control on the biological control agents of Salvinia molesta were investigated. In preliminary tests, the same concentrations of DDT and Dieldrin and the herbicide Paraquat that are routinely used in field control programmes were used. Five repetitions were done for each poison. These were applied to isolated Salvinia molesta cultures each with 30 beetles. A detailed investigation into the effect of Endosulfan and alphamethrin, used to control tsetse fly in the Okavango Delta, was carried out in 1987 at Mpacha airport (Schlettwein and Giliomee 1990).

RESULTS AND DISCUSSION

Control assessment.

Chemical control: Herbicide tests showed that a selective dipyridyl herbicide could be used to combat Salvinia molesta effectively in the short-term. Because herbicide treatments are expensive and detrimental to the environment in the long-term they are not considered suitable for the Eastern Caprivi.

Mechanical control: Weed removal by means of barriers, rakes, nets or mechanised harvesters are labour-intensive, time-consuming and must be repeated regularly. It was considered impractical in the extensive wetlands of Eastern Caprivi due to access problems.

The barrier at Kongola bridge caught all floating debris coming downstream but not a single Salvinia molesta plant, indicating that the Kwando River was not a source of new infestations.

Growth rates.

Growth rates measured during the 1982/83 season under natural conditions ranged from 0,3% per day in the open water in Lake Liambezi to 8,5% per day at Ngoma in the Chobe River. Strong seasonal fluctuations were evident in Lake Liambezi where growth rates increased with increasing water temperatures, growth rates were highest in autumn at water temperatures of 27°C and lowest in July at temperatures of 15°C. In Kariba, growth is best in the autumn (Sculthorpe 1967).

No seasonal pattern was detected in the Chobe River, perhaps because the river had stopped flowing and the resultant increase in nutrient concentrations enhanced growth rates. Compared to relative growth rates measured on Lake Kariba which ranged from 4,85% per day to 8,61% per day (Mitchell and Tur 1974), Salvinia molesta growth rates on Lake Liambezi of 0,3% per day to 5,9% per day were low, whilst those measured at Ngoma in the Chobe River of 4,4% per day - 8,5% per day were similar.

The 1983/84 comparison of field growth rates in natural and enriched waters showed that in summer, growth rates varied from 3,8% to 6,1 % per day on Lake Liambezi and from 14% - 15% per day on enriched water.

The 1984/85 results showed that field growth rates at Ngoma (4,3 - 8,5% per day) remained similar to those determined in 1982/83 i.e. similar to Lake Kariba rates but were far lower than the maximum relative growth rate of 19% measured in Lake Moondara in Australia (Finlayson 1984). Salvinia molesta grown in the laboratory on natural water from the Zambezi River were lower at 3,1% to 5.3% per day. Much higher growth rates of 16% to 24% per day were observed in plants grown on artificially enriched water in the laboratory. These rates are similar to other laboratory determined optimal growth rates of 15% to 30% per day (Gaudet 1973).

The growth experiments showed that growth rates of Salvinia molesta in the Eastern Caprivi were low compared to rates recorded in Lake Kariba and Lake Moondara, the only exception was in the Chobe River where rates were comparable to Kariba Lake. Under natural conditions in the Eastern Caprivi the plants could double their mass in 8 to 20 days, whilst under optimum laboratory conditions the plants could double their mass in 3 days. Chemical analysis of Salvinia molesta plant material collected in the Eastern Caprivi confirmed that low nitrogen or phosphorus levels could be limiting growth (Toerien et al. 1984).

Biological control

The breeding programme: The first eggs were noted six days after the insects were released into the breeding ponds. After a month the first larvae appeared and within two weeks pupae were found. A week later an increase in the number of adult weevils was recorded. Breeding continued throughout the year but slowed down in autumn and winter when the water surface temperatures dropped below 20°C. Experiments conducted in Australia showed that no eggs were laid at temperatures below 21°C and that most eggs failed to hatch at temperatures below 19°C (Forno *et al*. 1983). In summer temperatures above 39°C retarded breeding but this problem was overcome by covering the ponds with 40% shade cloth. Temperatures decreased to 33°C and breeding rates recovered. Since 1983 *Cyrtobagous salviniae* have been reared successfully at the laboratory in Katima Mulilo.

The release and monitoring programme: The earliest success was achieved in the Chobe River at Ngoma bridge. A total of 1500 insects were released at Ngoma Bridge. Releases were made in February, October and November 1984. Once established, population densities of the weevil increased steadily and peaked in January 1985 at 2,26 ±0,48 adults per plant. Bud damage decreased in autumn and winter and again slightly just before peaking in January. The mat started to sink in December 1984 when bud damage was 73,8%, by the end of February 1985, 50% of the mat had sunk and 15 months after the insects had first been released on the mat, the area was clear with only a few plants visible at the edges. These were all in the primary invading form.

Similar trends were observed at the other release sites. Insect numbers gradually increased on the mats with a slight decrease in winter when surface water temperatures were below 20°C and a mid-summer peak when water temperatures were above 30°C. Low population densities and resultant low bud damage can also be correlated to low nitrogen concentrations in the host plants (Schlettwein 1986 a). The periods between releases and visible damage ranged from 8 - 12 months, and the time taken for a mat to sink varied from 15 months to just over three years. Laboratory experiments showed that an estimated population density of 300 adults and 900 larvae of *Cyrtobagous salviniae* per m^2 are needed to control *Salvinia molesta* effectively (Room 1988), at Ngoma densities of 89 adults per kg wet mass were sufficient to cause the mat to deteriorate and eventually sink. Soon after a maximum density of 750 adults per kg was recorded on the few remaining plants.

On the Kwando River the plant is now limited to a fringe along the bank and the remaining mats in the Linyanti swamp area support high densities of control organisms and should sink soon. Lake Liambezi dried up in 1985. The Chobe is almost weed-free and in the Zambezi floodplains many dense mats have disappeared and only a fringe of *Salvinia* remains along the river banks, but mats in the Masida backwater have yet to sink and a new infestation was found in Chinchimane channel in 1989 (Schlettwein *et al*., in press).

The pesticide and herbicide tests:

In the preliminary tests using DDT and Dieldrin, all the insects died within 48 hours of being exposed to these poisons at the concentrations used in disease control programmes. In the herbicide test all the insects died within 3 days but it is not clear if this was on account of the poison or starvation after their food source had been eradicated.

In the aerial spraying simulations, adult Cyrtobagous salviniae beetles were susceptible even at low dosages of 6g/ha endosulfan, whilst the weevils exposed to 6 - 12g/ha showed a remarkable recovery after 3 weeks but were killed at the higher dosages (Schlettwein and Giliomee 1990). Recommendations based on these results are that aerial spraying of endosulfan to control tsetsefly be applied when water temperatures are above 21°C and that 21 days or more be allowed between repetitions to give the weevils a chance to recover.

CONCLUSION

Salvinia molesta growth rates in the Eastern Caprivi are relatively low and can be correlated to low nutrient concentrations. Laboratory and field studies using artificially enriched water prove that Salvinia molesta has the potential to grow much faster, it could double its mass every 3 days. Finlayson (1984) warns that even where Salvinia molesta growth is controlled, any increase in nutrient levels will cause an increase in growth rates in which case the control agent may not be able to successfully control the plant. This is a very real threat in the Eastern Caprivi where ever increasing agricultural activity is expected to increase the nutrient load in the waters. It is important that nutrient concentrations in the wetlands of Caprivi continue to be monitored.

Although controlled herbicide applications have been used in the Okavango Swamps to check Salvinia molesta encroachment at a cost of approximately 100 000 rands annually (Jacot Guillarmod, 1979), this is not considered a suitable long-term solution to the problem in Namibia. Mechanical control was also ruled out as Salvinia molesta exploitation is not commercially profitable and carries the serious risk of re- infestation. Biological control using the weevil Cyrtobagous salviniae was chosen as the best long-term solution to the Salvinia molesta problem in the Eastern Caprivi.

The insect rearing and breeding programme was successful. The beetles adapted well and have become firmly established in Namibia.

The first success in the biological control programme was achieved in 1985, five years after the start of the research project, when the mat at Ngoma bridge sank within 15 months. Under local conditions it takes from 15 months to 3 years for Salvinia molesta mats to sink after treatment.

Care must be taken when applying herbicides or pesticides in areas where the control organism is active.

Currently, Salvinia molesta is under control in Namibia. The intensity of the infestation has decreased drastically since Cyrtobagous salviniae was introduced.

Insects are still being bred and released in the Caprivi and the results continue to be monitored. Insects from Namibia have been exported to South Africa and Botswana to combat Salvinia molesta problems there.

Acknowledgements

The following people are acknowledged for their help: Mr A Da Silva of the Geohydrology Division for translating the summary into Portuguese, Mr K Rostami of the drawing office for drawing the map of Eastern Caprivi, Mr K.S. Roberts and Ms B.A. Curtis for critically reading the manuscript and the Secretary for Water Affairs, Namibia for permission to publish this paper. The organizors and sponsors of the SADCC Wetlands Conservation Conference are thanked for the invitation and finances to attend.

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