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Aquatic Weeds in Africa and their Control

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Introduction

The invasion of rivers, dams and lakes throughout Africa by introduced aquatic vegetation represents one of the largest threats to the socioeconomic development of the continent. Currently there are five aquatic weeds that are especially problematic in Africa: water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (*Pontederiaceae*); red water fern, *Azolla filiculoides* Lam. (Azollaceae); parrot's feather, *Myriophyllum aquaticum* (Vell.) Verdc. (*Haloragaceae*); water lettuce, *Pistia stratiotes* L. (*Araceae*); and salvinia, *Salvinia molesta* Mitchell (*Salviniaceae*). All are native to South America and, except for the rooted *M. aquaticum*, are free-floating macrophytes. The exact date and mode of introduction of these plants in some countries is obscure, but water hyacinth has been present in Africa since the late 1800s, while water lettuce was used as a medicinal plant in ancient Egypt (Holm *et al.*, 1977). These plants were sought after ornamentals, which would have aided their dispersal to new areas. In the absence of natural enemies and, invariably, the presence of nutrient-enriched waters, these aquatic weeds have proliferated and become problematic. Water hyacinth is the most damaging of these weeds and has increased in importance since the late 1980s.

The status of the distribution and impact of aquatic weeds in Africa and their control has been well reviewed in the proceedings of two workshops, one held in Zimbabwe in 1991 (Greathead and de Groot, 1993) and the other held in Nairobi in 1997 (Navarro and Phiri, 2000). Here, we review the status of aquatic weeds in Africa, focusing on recent research into the biological control of these plants.

Water Hyacinth

Water hyacinth is the most widespread and damaging aquatic weed throughout the world and it impacts many of the aquatic ecosystems in Africa. Dense mats of this weed degrade rivers, lakes, wetlands and dams, and limit their utilization.

Mechanical and chemical control

Manual removal of the weed is invariably the first control option practised in most countries where water hyacinth occurs. Barriers in the form of booms or cables have been effectively used in Côte d'Ivoire, Zambia and South Africa to protect hydropower water intake pumps and water extraction pumps. Although often tried, the use of harvesters has not been highly successful in Africa, as the extent and the reproductive rate of the weed and the shallow waters, in which it often occurs, make this technique impractical. Herbicides have been used for the control of water hyacinth in Ghana, Nigeria, South Africa, Zambia and Zimbabwe. The herbicides used include those with glyphosate, diquat and terbutryn and 2,4-D amine, as active ingredients. Creating barriers where water hyacinth can accumulate makes costly herbicidal control more effective as a whole block can thus be sprayed, and saves time and energy following small or individual plants targeted for spraying. Herbicidal control can relieve congestion of areas where access is obstructed (Cilliers *et al.*, 1996a).

Biological control

Biological control is considered the only sustainable control option for water hyacinth and several natural enemy species have been released in Africa (Table 11.1). The first successful biological control programme on the continent was in the Sudan (Beshir and Bennett, 1985) and the most recent and dramatic has been on Lake Victoria where expansive mats of the plant have collapsed (Cock *et al.*, 2000).

Regional summaries

East Africa

Water hyacinth in Tanzania dates back to 1955, when it was recorded on the Sigi and Pangani rivers, which empty into the Indian Ocean. The weed was reported from the Ugandan inland Lake Kyoga in 1987. However, water hyacinth gained importance as an aquatic weed in 1989 when it was first noticed on Lake Victoria. Initial infestations in Kenya were limited to a few bays but they later increased to cover most of the fishing beaches (Mailu *et al.*, 1999), stretching into Uganda. By 1990, the weed had covered most of the

Table 11.1. The natural enemy species established on water hyacinth in Africa.

Country	Natural enemy species established					
	Neochetina eichhorniae Warner Coleoptera: Curculionidae	*Neochetina bruchi* Hustache Coleoptera: Curculionidae	*Eccritotarsus catarinensis* (Carvalho) Heteroptera: Miridae (Plates 35, 36)	*Niphograpta albigutallis* Warren Lepidoptera: Pyralidae (Plates 33a, 33b)	*Othogalumna terebrantis* Wallwork Acarina: Galumnidae (Plate 34)	*Cercospora piaropi* Tharp. *Hyphomycetes*
Bénin	X	X				
Burkina Faso	X	X				
Congo	X	X				
Côte d'Ivoire	X	X				
Egypt	X	X				X
Ghana	X	X				X
Kenya	X	X				X
Malawi	X	X	X	X	X	
Mali	X	X				
Mozambique	X	X			X	
Niger Rep.	X					
Nigeria	X	X				X
Rwanda	X	X				
South Africa	X	X	X	X	X	X
Sudan	X	X		X		
Tanzania	X	X				
Togo	X	X				
Uganda	X	X				
Zambia	X	X			X	
Zimbabwe	X	X			X	

southern, Tanzanian, shoreline of Lake Victoria, with dense infestations occurring on the sheltered bays of Mwanza, Bauman, Emin Pasha, Mara and Rubafu (Mallya, 1999). Upstream, in Rwanda, water hyacinth thrived in a number of small lakes that feed into the Kagera River, which flows into the lake.

At the peak of infestation, water hyacinth covered an estimated 15,000 ha along Lake Victoria's shoreline in Kenya, Tanzania and Uganda, thus creating socio-economic and health problems for the lakeside residents (Mailu, 2001). Problems associated with this massive infestation, among others, included obstruction of both urban, rural and industrial water intake points, reduced fishing and hence fish exports, increase in human diseases and a reduced industrial output due to frequent interference with hydropower generation.

Biological control was considered the only viable method for reducing the impact of water hyacinth on the lake, and the two weevils, *Neochetina eichhorniae* Warner and *Neochetina bruchi* Hustache (Coleoptera, Curculionidae) (Plates 31a, 31b, 32) were released there in 1995. Numerous weevil-rearing stations were erected around the lake and, with the aid of the local fishing communities, several million weevils were released.

In a combined effort of both mechanical and mainly biological control, the water hyacinth biomass was reduced by an estimated 80% within a period of 4 years on the Ugandan part of the lake (Cock *et al.*, 2000). On the Kenyan shores of the lake, some 4 years after introduction, adult weevil numbers varied from 0 to 32 per plant with an average of six adults per plant and the weed coverage had been reduced by up to 80% (Ochiel *et al.*, 2001). In Tanzania, an integrated control approach, which included manual removal of the weed from fishing beaches and the introduction of the two weevils, resulted in a 70% reduction of water hyacinth within 3 years (Mallya *et al.*, 2001). The source of the water hyacinth coming into the lake has also been targeted with the construction of three weevil-rearing stations along the Kagera River in Rwanda (Moorehouse *et al.*, 2001), ensuring that biological control agents have been released at the source of the water hyacinth infestation.

Since the second half of 2000, there have been reports of a resurgence of water hyacinth in the Ugandan waters of Lake Victoria (Ogwang, 2001). This has been attributed to germination of seeds in the sediment stimulated by light penetration following the decline of the water hyacinth mat. The weevils have dispersed on to these new mats and it is envisaged that these will also be brought under control.

Elsewhere in this region, the weevils reduced the water hyacinth coverage by 80% on Lake Kyoga in Uganda (Ogwang and Molo, 1999) and the release of the weevils on the Sigi and Pangani rivers in Tanzania in 1995 reduced the amount of manual removal required to keep the river channels open (Mallya, 1999).

West Africa

Water hyacinth was observed in Bénin in 1977 (van Thielen *et al.*, 1994) and in Ghana and Nigeria in 1984 (Akinyemiju, 1987; De Graft Johnson, 1988). In Bénin, of the four species released, only the two weevil species have established, which is similar to most of the other countries within the region (Table 11.1). *N. eichhorniae* is the dominant species, having dispersed widely, while *N. bruchi* is confined to the release localities. At Tévèdji, Lihu and Kafedji on the Ouémé river, water hyacinth cover was reduced from 100% to 5% within 8 years, while the same level of control was achieved in just 5 years on Lake Azili, where the weevils had dispersed from the nearest release site 15 km away (Ajuonu *et al.*, 2003). When waterways at Tévèdji and Lake Azili became free, the communities celebrated the return of fishing activities, during which there was lots of dancing, wining and eating that was witnessed by government officials. Overall, water hyacinth in Bénin has been reduced from a serious to a moderate pest and the economic return of this project was 149:1 for southern Bénin alone (De Groote *et al.*, 2003).

However, at some sites like Savalou and Kpokissa, the weevils have not been as effective because the host plants were stranded in shallow mud banks when water receded, thus affecting the root-dwelling weevil pupae (Ajuonu *et al.*, 2003).

Nigeria receives an annual influx of water hyacinth from the Niger River, which threatens hydroelectric power generation. The weevil *N. eichhorniae* was released in Nigeria in 1994, while *N. bruchi* was released in 1995. In addition, a series of booms were used to collect the weed for manual removal and by 2001, water hyacinth infestation was visibly reduced compared with 1995 (Femi Daddy, 2002, New Bussa, personal communication).

In Niger, *N. eichhorniae* spread from the releases on the Niger River in Nigeria about 700 km upstream to the capital Niamey, where the weevils have had a visible impact on water hyacinth infestations. Reports from Ghana indicate that there has been a decline in water hyacinth populations following the release of the weevils in 1994 (de Graft Johnson, 2001, Accra, personal communication). A similar decline has been reported from Côte d'Ivoire (G. Mesmer Zebeyou, 2001, Abidjan, personal communication). Biological control projects on water hyacinth have also been initiated in Burkina Faso, Togo and Mali.

As part of the International Mycoherbicide Programme for *E. crassipes* Control in Africa (IMPECCA) field surveys and laboratory experiments have identified those fungal pathogens across the continent that are specific to water hyacinth and cause the greatest levels of disease (A. den Breeÿen, 2002, Stellenbosch, personal communication).

Southern Africa

Since the late 1970s, the Plant Protection Research Institute of South Africa has released five arthropods and one pathogen as natural enemies against the weed in that country (Table 11.1) (Cilliers, 1991a; Hill and Cilliers, 1999). In some areas of South Africa, good control has been achieved, while in other areas, low temperates in high-altitude climatic areas and interference from other control options have retarded biological control. It has been shown that under a rigorous, successful herbicide programme, biological control agents are suppressed. Once continuous spraying stops, agents can build up and control water hyacinth.

In South Africa, active research on pathogens on water hyacinth is ongoing. The rusts *Cercospora piaropi* Tharp. (Hyphomycetes), *Alternaria eichhorniae* Nag Raj & Ponnappa (*Ascomycotina*) and *Acremonium zonatum* (Sawada) W. Gams (*Ascomycotina*) are present in the field and *Cercospora rodmanii* Conway (*Hyphomycetes*) (= *C. piaropi*) has been released (Table 11.1). Elsewhere in the region, Malawi has had a successful water hyacinth biological control programme on the Shire River (Phiri *et al.*, 2001), the weed is under good control on Lake Kariba (Chikwenhere *et al.*, 1999), but there are still sporadic outbreaks on Lake Chivero, in Zimbabwe, which are attributed to high pollution levels (Chikwenhere and Phiri, 1999). The weevils, although present in some areas, have recently been further released in Mozambique (T. Chiconela, 2000, Maputo, personal communication; G. Phiri, 1997, Nairobi, personal communication).

Unfortunately, due to political unrest, little is known of the situation in Angola. In northern Egypt, *N. eichhorniae* and *N. bruchi* were released in August 2000 on two lakes. By July 2002, water hyacinth on Lake Edko was reduced by 90%. On Lake Mariout, reduction was slower due to water pollution (Y. Fayad, 2002. Giza, personal communication). The pathogen *Alternaria alternata* (Fr.) Keisser (Ascomycotina) has been utilized (Fayad, 1999).

Red Water Fern

The genus *Azolla* incorporates heterosporous aquatic fern species, which have a symbiotic association with the heterocystous cyanobacterium (blue–green alga) *Anabaena azollae* Strasburger, which grows within the dorsal leaf lobe cavities (Peters and Calvert, 1987). The alga can fix atmospheric nitrogen and is able to fulfil the nitrogen requirements of the plants, making them successful in nitrogen-deficient waters (Ashton, 1992). Various *Azolla* spp. have therefore been distributed as biological fertilizers in many developing countries, which has increased the distribution of this genus to many parts of the world (Lumpkin and Plucknett, 1982).

Origin and distribution

A. filiculoides is native to South America (Lumpkin and Plucknett, 1982) and has become a weed of small dams and slow-moving rivers in a number of countries around the world. It was first recorded in South Africa in 1948 (Oosthuizen and Walters, 1961). The fern was confined to small streams and farm dams in the centre of the country for many years. However, phosphate-enriched waters, the lack of natural enemies, and dispersal between water bodies by man and waterfowl facilitated an increase in its distribution and abundance. It is also know to be invasive in Zimbabwe, Zambia, Malawi, Mozambique and Uganda (Hill, 1999).

Impact

Red water fern is able to undergo rapid vegetative reproduction throughout the year by elongation and fragmentation of small fronds. Under ideal conditions, the daily rate of increase can exceed 15%. This translates to a doubling time for the fern of 5–7 days (Lumpkin and Plucknett, 1982). The fern can also reproduce sexually via the production of spores, especially when the plant is stressed. Spores can overwinter and are resistant to desiccation, allowing re-establishment of the fern after drought.

The increasing abundance of *A. filiculoides* in conservation, agricultural, recreational and suburban areas over the last 20 years has aroused concern. Among the major consequences of the dense mats (5–30 cm thick) of the weed on still and slow-moving water bodies in South Africa are: reduced quality of drinking water caused by bad odour, colour and turbidity; increased water-borne, water-based and water-related diseases; increased siltation of rivers and dams; reduced water surface area for recreation (fishing, swimming and water-skiing) and water transport; deterioration of aquatic biological diversity (Gratwicke and Marshall, 2001); clogging of irrigation pumps; drowning of livestock; and reduced water flow in irrigation canals.

Mechanical and herbicidal control

Mechanical and herbicidal control options have been suggested for red water fern. However, mechanical control is labour intensive. Small infestations of the weed in accessible areas can be removed with rakes and fine meshed nets, and the plants used as cattle and pig fodder, or compost. The disadvantages of this method are that the rate of increase of the plant is such that a concerted effort is required to keep up with the daily production of even a small infestation, and if eradication was achieved, re-establishment of the weed from spores resistant in substrate of the water body is inevitable. Glyphosate, paraquat and diquat-based herbicides have been used in the control of red water fern (Steÿn *et al.*, 1979; Axelsen and Julien, 1988; Ashton, 1992). The disadvantages of herbicidal control for *A. filiculoides* are that it is expensive, especially in view of the extensive follow-up programme required to eradicate the plants that continually germinate from spores. Also, there is a danger of spray drift on to non-target vegetation and a need for well-trained personnel. As mechanical control was impractical and herbicide use undesirable in the aquatic environment, the need for a biological control programme against *A. filiculoides* was elevated.

Biological control

The pre-introductory survey of the insect fauna associated with *A. filiculoides* (Hill, 1998a), and host records from elsewhere in the world, indicated that the genus *Azolla* is mostly attacked by generalist herbivorous insects and that very few specialist insect species have evolved on this genus (Lumpkin and Plucknett, 1982). Despite this, the weevil *Stenopelmus rufinasus* Gyllenhal (Curculionidae) and the flea beetles *Pseudolampsis guttata* (LeConte) and *Pseudolampsis darwini* (Scherer) (Coleoptera, Chrysomelidae, Alticinae) appear to have specialized on the genus *Azolla* (Habeck, 1979; Buckingham and Buckingham, 1981; Casari and Duckett, 1997) and were thus prioritized as potential biological control agents for red water fern. All three species were introduced into quarantine in South Africa between 1995 and 1998; *S. rufinasus* and *P. guttata* were subjected to host-specificity testing, and the culture of *P. darwini* was terminated as there was concern that its populations might become mixed with those of *P. guttata*, a species similar in morphology. The laboratory host range of *P. guttata* proved to be too wide to consider it for release in Africa (Hill and Oberholzer, 2002), while the host range of the frond-feeding weevil, *S. rufinasus* was far more restricted and it was cleared for release in late 1997 (Hill, 1998b). The second flea beetle, *P. darwini*, has not been re-imported as it was decided first to fully evaluate the impact of the weevil and determine if an additional agent was required to bring the weed under control.

Impact of Stenopelmus rufinasus

The first release was made on a 1-ha dam at a bird sanctuary in Pretoria in December 1997. Nine hundred weevils were released on the dam, which was 100% covered by a 5-cm-thick mat of the weed. Within 2 months, the mat had collapsed and from a 2-m^2 sample of decaying material in excess of 30,000 weevils were reared (Hill, 1999).

By late 2001 the weevils had been released (usually in batches of 100 adults) at some 110 sites throughout South Africa. The information available on these sites was that the weevil had been responsible for completely clearing 72 of them in less than 1 year (Plates 37, 38). For the remaining 38 sites, either the weed had been washed away during flooding, they had not been revisited or it was too early to tell. In addition to this, the weevil had migrated to other sites, up to 300 km away from the release sites. At 7% of the sites, the weed returned up to 2 years after the initial clearing, but the weevil located 90% of these and brought the weed under control again (A.J. McConnachie, 2001, Johannesburg, unpublished data). Five years after the first release of *S. rufinasus* in South Africa, the weed no longer poses a threat to aquatic ecosystems. An economic analysis on the biological control of red water fern in South Africa revealed a benefit to cost ratio of around 70:1 (A.J. McConnachie, 2001, Johannesburg, unpublished data). Unfortunately there was no attempt to quantify monetarily the benefit to biodiversity, but this has no doubt been substantial.

The weevil has been exported to Zimbabwe, where it has been responsible for clearing a number of farm dams (Table 11.2) (G. Chikwenhere, 1998, Harare, personal communication). It has also dispersed to Mozambique from South Africa. This project has been extremely successful in a short period of time and there is no need for an additional agent and no reason why *A. filiculoides* should pose a threat to any aquatic ecosystem in Africa any more.

Table 11.2. Natural enemy species released and established on water lettuce, red water fern, parrot's feather and salvinia in countries of Africa.[a]

Country	Natural enemy species released						
	Neohydronomus affinis[b]	*Stenopelmus rufinasus*[c]	*Lysathia* sp.[d]	*Cyrtobagous salviniae*[e]	*Cyrtobagous singularis*[e]	*Paulinia acuminata*[e]	*Samea multiplicalis*[e]
Bénin	X						
Botswana	X				X	X	X
Burkina Faso							
Congo	X			X			
Cotê d'Ivoire	X			X			
Egypt							
Ghana	X			X			
Kenya				X		X	
Malawi							
Mali							
Mozambique		X					
Namibia				X			
Niger Rep.							
Nigeria	X						
Rwanda							
South Africa	X	X	X	X			
Senegal	X						
Sudan							
Tanzania							
Togo	X						
Uganda							
Zambia	X			X	X	X	X
Zimbabwe	X	X		X		X	

[a]Data taken from Julien and Griffiths (1998).
[b]Agent for water lettuce.
[c]Agent for red water fern.
[d]Agent for parrot's feather.
[e]Agent for salvinia.

Parrot's Feather

There are two species of *Myriophyllum*, *M. aquaticum* (parrot's feather) and *M. spicatum* L. (spiked water-milfoil), that are weeds in southern Africa, but only *M. aquaticum* is troublesome. Parrot's feather roots in sediments up to a depth of 1.5 m below the water surface. In South Africa, propagation is entirely vegetative because there are no male plants in the country and no seeds are produced (Henderson, 2001). The plants grow throughout the year in subtropical regions, but at high altitudes the extremities of the aerial shoots are killed by winter frost. The dead parts provide shelter for new shoots, which sprout from the nodes during the following spring. Problems caused by dense mats of *M. aquaticum* are similar to those caused by other aquatic weeds. In South Africa, the threat posed by *M. aquaticum* was already noted in the 1960s, when the weed was considered to be of greater importance than water hyacinth.

Origin and distribution

The plant originates in South America and has been recorded in a number of countries, including Australia (Sainty and Jacobs, 1994). A small yet troublesome infestation was recorded from Lesotho, and it is known as a problem in Zimbabwe (Chikwenhere and Phiri, 1999). This plant has not become a major weed in other African countries.

Mechanical and chemical control

No herbicides have been registered for use against *M. aquaticum* in South Africa. Two glyphosate-based herbicides were used experimentally and brought temporary control, but these herbicides did not affect the root zone of the plants. Mechanical control is not practical, because any plant fragment not removed is capable of growing.

Biological control

A biological control programme was initiated against the weed in South Africa in 1991, which resulted in the release of the flea beetle *Lysathia* n. sp. (Coleoptera, Chrysomelidae) (Table 11.2). The release sites were located in a range of climatic zones, including Mediterranean, subtropical, temperate and cool temperate regions. Releases were made by introducing allotments of 50 adults on to infestations of the weed or by placing out plants with unknown numbers of larvae and pupae among *M. aquaticum* plants in the field. In most cases, establishment was confirmed following single introductions of the beetles in an area, but in a few cases, especially in the Mediterranean climatic region, the initial introductions failed and additional releases were needed before establishment was achieved (Cilliers, 1999a).

Lysathia n. sp. completes some seven to nine generations during summer and has survived through winter throughout South Africa, even in areas where there is frequent frost (e.g. in the Vaal River catchment). Emergent stems of *M. aquaticum* are killed by frost, but the beetles shelter on the undamaged leaves and shoots that are surrounded and protected by the outer layers of dead plant material. The beetle populations decline during winter, but survive in sufficient numbers to rebound rapidly in spring and summer. This induces a cyclical sequence of defoliation followed by partial recovery of the plants. Feeding by adults and larvae of *Lysathia* n. sp. has a cumulative effect on the growth of *M. aquaticum* and as beetle populations and feeding frequencies increase, the time taken for the plants to recover increases. Evaluations at one site indicated that the surface area covered by *M. aquaticum* declined slowly from 50% to 20% over 3 years. Continual resurgence of *M. aquaticum* infestations may necessitate the release of additional biological control agents. The stem-boring weevil, *Listronotus marginicollis* (Hustache), is a promising candidate to supplement the damage caused by *Lysathia* n. sp. The fact that *M. aquaticum* does not produce viable seeds in South Africa should restrict its ability to recover from prolonged periods of damage caused by introduced agents and the prospects for bringing *M. aquaticum* under biological control are very favourable (Cilliers, 1999b).

Water Lettuce

Water lettuce is a free-floating macrophyte. The perennial plants consist of rosettes of leaves with a tuft of long fibrous roots and resemble floating heads of lettuce. The flowers are pale and inconspicuous, and mainly present in mid summer, but can be found throughout the year. Seeds are viable and are borne underneath the older leaves and released into the water. They survive in the dry mud and germinate in the next wet season (Cilliers, 1991b).

Origin and distribution

Water lettuce originates in South America, and has been known in Africa since the time of Pliny (Holm *et al.*, 1977). It is recorded as a weed in a number of countries around the world, including Australia and the USA, and several countries throughout Africa (Julien and Griffiths, 1998).

Mechanical and chemical control

Mechanical control is impractical due to the plant's rapid growth rate. The only known registered herbicide is terbutryn in South Africa, although glyphosate has been used successfully. In small impoundments which are regularly subjected to alternate wet and dry regimes, herbicide control was used to deplete the seed bank as soon as seedlings reappeared after a dry spell (Cilliers *et al.*, 1996b). This proved impractical, as water lettuce infestations often escaped detection until after the plants had set seed.

Biological control

Biological control of water lettuce using the weevil *Neohydronomus affinis* (Hustache) (Coleoptera, Curculionidae) was first attempted in South Africa with positive results within 9 months on a seasonal pool, but control took longer (up to 3 years) on a fast-flowing river (Cilliers, 1991b; Cilliers *et al.*, 1996b). In northern Zimbabwe, control was achieved within 8 months (Chikwenhere, 1994) (Table 11.2).

Where a large seed reserve occurred at a man-made impoundment in the Kruger National Park in South Africa, *N. affinis* successfully controlled resurgence from dormant seeds each year. Subsequently, biological control has succeeded in Ghana, Côte d'Ivoire, Senegal and Kenya (A. Pieterse, 1998, Amsterdam; O. Diop, 2000, Dakar; A. Mailu, 1999, Nairobi, personal communications). In Bénin, the impact of *N. affinis* was monitored for 7 years and the total collapse of the water lettuce biomass was documented at two ponds (Fig. 11.1). The weevil spread on its own across most of the country (Ajuonu and Neuenschwander, 2002).

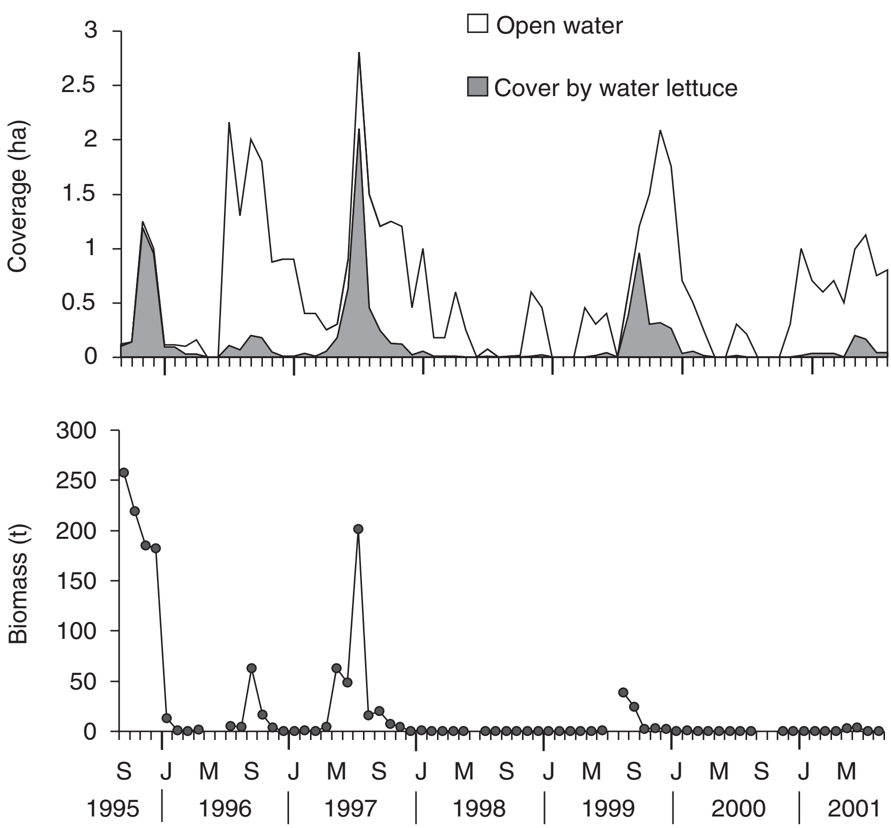

Fig. 11.1. Impact of *Neohydronomus affinis* on coverage (ha) and biomass (t ha^{-1}) of water lettuce, *Pistia stratiotes*, at Sé, in Bénin.

Salvinia

Salvinia is a free-floating aquatic fern species. It is sterile, producing sporocarps without viable spores, and thus only reproduces vegetatively.

Origin and distribution

This weed is of South American origin and has spread to many countries in Africa. In South Africa it was only surpassed by water hyacinth as an aquatic weed and was particularly troublesome in regions with a subtropical climate. It has also been recorded as a weed in a number of African countries. Salvinia was a major problem on Lake Kariba. As the dam was filling up in the early 1960s, the water was enriched due to organic-rich runoff and decay of plant material. By 1963, salvinia covered some 22% of the lake surface and threatened the infrastructure of the hydropower generation plant at the Kariba dam (Mitchell, 1972).

Mechanical and chemical control

Herbicide applications (diquat, terbutryn and glyphosate) were used to control this weed. Manual removal has been used, but the weed invariably outgrows all efforts.

Biological control

A number of species have been introduced for the control of salvinia in Africa (Table 11.2). Initially the plant was misidentified as *Salvinia auriculata* Aublet and the weevil *Cyrtobagous singularis* Hustache was introduced to Botswana and Zambia, but had little impacts on the weed populations (Julien and Griffiths, 1998). Following success in Australia, the weevil *Cyrtobagous salviniae* Calder and Sands (Coleoptera, Curculionidae) was introduced to a number of African countries (Table 11.2) where it has controlled this weed (Cilliers, 1991c). In addition, the grasshopper *Paulinia acuminata* (Degeer) (Orthoptera, Paulinidae) was introduced to Botswana, Kenya, Zimbabwe and Zambia. It did not establish in Kenya and had little impact on the weed in the other three countries (Julien and Griffiths, 1998). The pyralid moth *Samea multiplicalis* (Guenée) was also introduced to Botswana and Zambia, but failed to establish.

In subtropical areas, control of salvinia using *C. salviniae* was obtained within 18 months, regardless of the extent of the infestation, provided the tissue nitrogen content of salvinia was above 1% (dry weight). If the plants had a nitrogen concentration of lower than 1%, the weevils failed to establish (Room and Thomas, 1985). In the cooler areas, control took longer, but usually no more than 3 years. When infestations occurred on rivers, it usually took longer to achieve control. On closed systems, populations of both the weed and the biological control agent often collapsed to the point that neither the plant nor

C. salviniae could be found for years. One to 2 years after flooding, these impoundments could again be infested from nearby rivers or other infestations and the resultant unhindered growth of the weed necessitated reintroduction of the biological control agent. On rivers, a balance was achieved with some host plants remaining to sustain a population of the biological control agent. Equilibrium was reached and thus permanent control was attained on rivers, but not on smaller man-made impoundments.

Discussion and Conclusion

The biological control of aquatic weeds has been highly successful in Africa. Most of these weeds no longer pose as much of a problem as they did 10 years ago, before the introduction of biological control agents. Recently, new agents on water hyacinth and parrot's feather were found in South America and finally released in South Africa, and have proved useful additions to the already existing control agents on these weeds.

Several factors have contributed to the success of these programmes, including the tropical climate of some regions, which allowed rapid increases in biological control agent populations. In more temperate and cooler high altitude regions it has taken longer to attain biological control. There are simple techniques available for the mass-rearing of these agents for waterweeds, which allows for the release of large populations, facilitating their establishment. Biological control has been most successful on large water bodies where wind and wave action have aided in the break up of the waterweed mats already stressed by biological control agents, as was demonstrated on Lake Victoria. Also, the lack of herbicide application, which has been shown to interfere with biological control efforts in the USA and South Africa (Center *et al.*, 1999; Hill and Olckers, 2000) but which has not been used in most of Africa, has also contributed to these successes. However, eutrophication of freshwater ecosystems does contribute to the problem by promoting the luxurious growth of these weeds and this may extend the time it takes to control the weed.

Most of these weed biological control programmes have relied on technology that has been developed in other countries, notably Australia and the USA. However, as institutes throughout the continent become more experienced in this line of research, the reliance on developed countries will diminish and local technology will be able to solve local problems.

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