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The integrated control of water hyacinth, *Eichhornia crassipes*, in Africa based on Roundup® herbicide treatments

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Abstract. Water hyacinth, *Eichhornia crassipes*, infestations throughout Africa have resulted in population migrations due to the inhibition of fishing, an increase in various diseases such as malaria as well as the reduced utilization of waterways for transport and recreation. This weed is currently on the increase in Africa. Roundup® (360 g glyphosate per l) has been extensively researched regarding its favourable environmental-impact characteristics and this has resulted in this product being widely used for the control of water hyacinth. Successful control programmes have been based on a Roundup® spray followed by regular spot-spraying, mechanical or hand removal and, more recently, the utilization of biological control agents such as insects, mites and diseases. Initially, herbicide is applied from aircraft, but follow-up treatments are applied by spray teams from boats and from the shoreline. It is critical for a control programme to be implemented which will also allow for biological control agents to remain established in the area. Detailed analyses on the impact of herbicide use on this water weed have been conducted in South Africa, Nigeria and Zimbabwe, with the conclusion that there is very little or no adverse effect on water quality.

Introduction

Distribution in Africa

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laub., originated in Brazil, where it was described from the San Fransisco river in 1824 (Bock 1966). Its spread in Africa seems to have started when it was recorded in Egypt between 1879 and 1893 (Tackholm and Drar 1950). It was first recorded in South Africa in 1908 (Stent 1913); in Réunion and Madagascar in 1920 (Decary 1965); in Zimbabwe (Southern Rhodesia) in 1937 (Brain 1937); in Zaire (Belgian Congo) in 1952 (Evans 1963); the Sudan in 1957 (Gay 1958); Senegal in 1964 (Little 1965). It was first recorded in Nigeria in 1983 and has now spread to all coastal waterways, including the Benin and Escravos Rivers (Akinemiju 1987). It was first recorded in Uganda in Lake Kyoga in 1987 and by 1990 it was recorded in Lake Victoria (Orach-Meza 1995) with a continual infestation from the Kagera River, indicating it to be present in eastern Zaire, Rwanda and Burundi. Apart from these documented cases, water hyacinth is known to occur in Ghana, Kenya, Malawi, Mozambique, Tanzania and Zambia and it is probably present throughout sub-Sahara Africa. It would appear that the Okavango delta system in Botswana is free of water hyacinth as well as Lesotho and Swaziland (C.J. Cilliers personal communication) and this status should be maintained at all costs. The occurrence of water hyacinth in Botswana and in any river systems feeding this aquatic delta environment should attract immediate international action to prevent an infestation.

The occurrence of water hyacinth is generally associated with polluted water and thus it is a symptom of other environmental issues that need to be rectified before any control measures can have a significant and permanent effect on this problem weed.

Problems associated with water hyacinth

By allowing water hyacinth to spread unchecked in an aquatic system, one or more of the following problems will arise and demand that control action be taken: (i) the fishing potential can be greatly reduced or nullified due to fishermen not being able to penetrate the thick mat and fish being forced to relocate; (ii) in many parts of Africa, people who were dependant on fishing have themselves been forced to relocate and find other employment due to water hyacinth invasion of fishing waters which in turn creates additional social probems and pressures apart from the problem weed; (iii) the disruption or total prevention of water transport and the use of water bodies for recreational purposes;

(iv) the weed creates an ideal environment for disease vectors such as mosquitoes for malaria transmission, fresh water snails that carry bilharzia; (v) in certain areas, water hyacinth has proven to be an ideal environment for snakes (Uganda) and crocodiles, which prey on humans and animals at watering points; (vi) by forming large mats, entire aquatic environments have changed above and below the water surface, with a greatly-reduced biological diversity; (vii) a major repercussion of having a dense water hyacinth infestation, is the effect on, or the total obliteration of, spawning areas for fish species, some of which can be commercially important, as well as the effects on other organisims throughout the entire food chain; (viii) the suppression or disappearance of indigenous aquatic plant species; (ix) the vast quantities of plant material have been known to block the inlets to hydroelectric turbines and the inlets to pumps for domestic or agricultural use; (x) the plants will form an excellent barrier which will dam water and greatly increase damage in a flood situation; (xi) by forming a blanket on the water surface, wave action is prevented and oxygenation of the water is greatly reduced; (xii) the evapotranspiration of a water body covered by water hyacinth is up to 3.5 times more than that of a clear water body (H.H. Bosman personal communication), creating additional water loss in a continent that suffers from too little water; and (xiii) water from water hyacinth infested sources requires additional flocculant treatment to remove the high organic carbon concentration, which imparts the 'taste' of the hyacinth, before the water is made available for human consumption, and this can require further treatment to adjust the water pH.

Control measures

Due to the capacity for water hyacinth to reproduce vegetatively at the rate of up to five percent per day, the equivalent of doubling its numbers every 15-18 days, it is a rapid invader of open water (H.H. Bosman personal communication). In addition, it is a prolific seed-producer with the seeds being released in the water where they are distributed widely. Seeds can remain viable for up to 15 years in the substrate and soil (Matthews 1967). These characteristics necessitate that a control programme must: (i) remove plants considerably faster than they can reproduce; (ii) be able to contain a population to a very small area; and (iii) prevent large-scale reinfestation. This is also dependant on the source of any water pollution being rectified.

Manual control

Removal of water hyacinth by hand, or with rakes or forks, is suitable for small areas in dams or along river shorelines and is dependant on the number of labourers available. The removed plants must be placed on the bank, away from the possibility of flood waters reaching them, and allowed to dry or be utilized for another purpose. This becomes an ongoing practice as seed germination will pose a continual threat, as well as reinfestation from adjacent areas. Plants are known to grow in soil away from free water and can survive extreme drought conditions, which emphasizes the necessity for thorough and permanent control measures. Manual control is an important follow-up measure for chemical control.

Mechanical control

To justify their use, mechanical harvesters must be able to remove an amount of water hyacinth that is considerably greater than the reproduction capacity, on a daily basis. For example, a 100-ha infestation (which is largely determined by the prevailing wind) can grow by 5 ha per day and thus a mechanical harvester would be required to remove at least 8-10 ha per day for significant progress to be made. This enormous volume of material must be transported to a suitable location where it can be processed to ensure that it does not become an ecological problem on land. When the mass of water hyacinth is taken at the equivalent of 25 kg per m^2 (Scott *et al.* 1979), 100 ha of water hyacinth represents 25000 tons or a dry biomass of 1250 tons. This will require the desiccation of 250 tons of fresh material and disposal of 12.5 tons of dry matter for every ha harvested.

There are a number of harvesters that have been built either to float on water or to operate from the shore using a drag basket. Few, if any, have solved the water hyacinth problem and, when functional, the mass of rotting vegetation awaiting disposal can create an environmental problem. Mechanical harvesters are expensive to build and have a poor track record. The terrain and nature of African rivers can also preclude the use of harvesters.

Chemical control

Herbicides are generally acknowledged as the only control method that will rapidly and significantly

reduce and contain large water hyacinth infestations. Consideration must be given to the choice of herbicide and its environmental impact characteristics as well as acceptable application methods.

Glyphosate, the active ingredient in Roundup®, is one herbicide that is highly specific in controlling plants but has little or no effect on other living organisms such as man, birds, fish and micro-organisms and this enables it to be used with safety in environmentally-sensitive aquatic areas. It has proven to be rapidly degraded into naturally-occurring products in aquatic systems with degradation complete in three days (Zaranyika and Nyandoro 1993; Yei-Shung Wang *et al.* 1994). Roundup® gives excellent water hyacinth control at rates of 4-6 l per ha, preferably in spray volumes of 100-200 l per ha for ground equipment or in 20-50 l per ha for aerial application or in a 3-4% solution for spot spraying. Lower rates should only be used on small plants in relatively low densities. Kill of the water hyacinth is gradual and takes up to four weeks, which avoids a rapid release of dead and decaying plant material into the system. In all cases, an even spray-droplet distribution on the foliage is essential for good results (Basson 1991; Akinyemiju 1993, 1994; Monsanto 1995).

Another herbicide that has been used is 2,4-D amine but due to its toxicity to animal life, a relatively long and persistant residual action (Yei-Shung Wang *et al.* 1994) and volatilization which can cause severe off-target damage, regulatory authorities have either restricted or prohibited its use on aquatic environments for water hyacinth control. South Africa and Zimbabwe have prohibited its use for water hyacinth and other aquatic-plant control. Certain 2,4-D formulations, such as the esters, are known to be very toxic to fish (Tomlin 1994).

Diquat is a non-selective contact herbicide that has been used for water hyacinth control and results in a very rapid kill which can cause severe deoxygenation of the water, especially where algae are also present. Use in stationary water bodies is not recommended. Degradation in water is rapid but metabolic breakdown does not occur in plants. Its use is appropriate for the control of submerged water weeds in moving water systems (L. du Toit personal communication; Tomlin 1994).

Terbutryn is another herbicide that was used for water hyacinth control but due to rapid kill and the resulting deoxygenation of water which resulted in fish mortalities, as well as the accepted policy of not applying triazine herbicides to an aquatic environment, this product can not be considered for water hyacinth control (J.J. van Biljon personal communication).

A wide variety of spray equipment can be used to apply the herbicide to the target plants. Aerial application is the quickest and is used extensively on open water-bodies such as lakes, dams and rivers. Fixed-wing aircraft are used for the larger areas due to their capacity for heavier payloads, and helicopters and micro-light aircraft are being used on rivers and shorelines where manoeuvrability is required. Accessability to the target and the danger of spray drift to non-target areas must always be considered.

Boat-mounted application equipment should be used on shoreline infestations as well as on floating islands that do not warrant aerial spraying. Motorized pumps with spray booms or high-pressure hand guns or hand-operated knapsack sprayers are generally used.

Vehicle-mounted and knapsack sprayers are used for shoreline clean-up and maintenance spot-spraying of water hyacinth. Motorized-equipment mounted in a vehicle allows for a high-pressure system with long hoses for easier accessability and a spray swath of up to 7 m. Once major infestations have been cleared up, hand-held spray bottles can be used.

A technique to concentrate water hyacinth on rivers and canals, is to place cables with reinforced mesh across the water flow. This concentration of plants can easily be sprayed with Roundup® by aircraft and the decomposing matter is gradually released into flowing water where it is diluted. This technique is currently used on 12 locations on the Vaal River, South Africa (W. Liebenberg personal communication). A weir for water storage and off-take can serve the same purpose. Wind also plays a role in concentrating these plants. However, when plants are compacted and sprayed, the spray deposit is unlikely to reach each and every plant and a follow-up spray after about four to six weeks is required in these situations.

Biological control

The Plant Protection Research Institute (PPRI) in Pretoria, has conducted an extensive programme to release biological control agents of water hyacinth and to evaluate their effects in South Africa. The following species are established in South Africa: two weevil species, *Neochetina eichhorniae* Warner and *N. bruchi* Hustache; a moth, *Sameodes albiguttalis* Warren; a mite, *Orthogalumna terebrantis* Wallwork; and two

pathogens, *Alternaria eichhorniae* Nagaraj and Ponappa and *Cercospora piaropi* Tharp.. Additional species are under evaluation, namely: a moth, *Bellura densa* (Walker); a bug, *Eccritotarsus catarinensis* Carvalho; and a pathogen, *Cercospora rodmanii* Conway (Cilliers 1990, 1991a and personal communication).

The *Neochetina* species have become established in Sudan (Beshir and Bennett 1985), in Benin (Van Thielen *et al.* 1994), in Lake Kyoga in Uganda (via Benin) and in Lake Naivasha in Kenya (Orach-Meza 1995; T. Twongo personal communication). It can be expected that the Nile River system will be colonized by these weevils. *Neochetina eichhorniae*, obtained from PPRI, Pretoria, was released in the Lilongwe River, Malawi, during November 1995 and in the Shire River during January 1996, where water hyacinth is a problem (these releases were undertaken by the author and G. Phiri, CABI). Extensive evaluation of pathogens has been done in Egypt with the conclusion that *Alternaria alternata* (Fr.) Kiessler is the most promising for the control of water hyacinth (Elwakil *et al.* 1988).

Encouragement for the development of a successful biological- or integrated-control programme against water hyacinth can be gained from the effective control of water lettuce, *Pistia stratiotes* L., by a weevil, *Neohydronomus affinus* (Hustache), in South Africa (Cilliers *et al.* 1994). Another aquatic weed that has been controlled successfully in South Africa is Kariba weed, *Salvinia molesta* D.S. Mitchell, by *Cyrtobagous salviniae* Calder and Sands (Cilliers 1990, 1991b). This success followed those achieved in Australia (Room *et al.* 1981) and in Sri Lanka (Room *et al.* 1988; Julien 1992).

Integrated control

An effective long-term control programme should make use of Roundup® herbicide for the reduction of large-scale water hyacinth infestations combined with a regular follow-up spray programme at two to three month intervals. Biological control agents should be released in designated reserve areas that will not be sprayed. The initial spray should be timed to coincide with the mobile stage, usually the adult, of the insect's life-cycle to allow for migration from treated plants. In cool areas there are population peaks of the insect agents, but in the tropical and subtropical areas, the peaks are less pronounced and mobile stages of the agents are present throughout the year. The unsprayed reserve areas can be in reedbeds, tributaries or bays. Continual monitoring and spot-spraying of the water hyacinth are essential. Roundup® will not have a direct effect on the adult insects, mites or pathogens in such an integrated programme but can indirectly effect the life-stages within the plant. The success of an integrated control programme is largely dependant on detailed planning, good administration and management, coupled with adequate financial support and long-term committment.

In South Africa, diligent monitoring and spot-spraying by the Department of Water Affairs and Forestry has resulted in the Wilge and the upper reaches of the Olifants Rivers being virtually free of water hyacinth for many years. This programme is now being implemented on other rivers such as the Vaal and Crocodile that are infested with this weed. The success of the water hyacinth control programme on Hartebeestpoort Dam in South Africa, which was sprayed by air with terbutryn in 1977 and 1978 with shoreline spraying with diquat in 1979 and since then with Roundup®, is well known. However, this success entails continued effective mangement with diligent monitoring (Scott *et al.* 1979; G.T. Willemse personal communication).

The affect of spraying on water quality

The two major concerns when spraying water hyacinth with a herbicide such as Roundup® are: (i) the presence of herbicide residues in the water; and (ii) the effect of the large mass of decaying plant material on the water quality and the aquatic environment.

Chemical residues

In many studies world-wide, Roundup® has been shown to degrade rapidly and, apart from the herbicidal activity, no adverse effects have been recorded on aquatic organisms. One day after spraying Roundup®, only 6.2% is detectable in the water and after two days none is detectable (Yei-Shung Wang *et al.* 1994). The herbicide is metabolized within 24 h of penetrating a plant and very little herbicide is actually available to contaminate the water. Glyphosate does have an affinity for clay particles that can be suspended in water or in the sediment and can be bound up in them, but this glyphosate is not biologically available and will degrade (Reynolds 1989; Akinyemiju 1993, 1994; Zaranayika and Nyandoro 1993; Yei-Shung Wang *et al.* 1994).

Due to the characteristics of other herbicides such as 2,4-D and diquat, that are relatively stable and more toxic, restrictions have been placed on their use in aquatic environments. In many countries, water intended for humans, animals or agriculture cannot be used within seven days of spraying. This is totally impractical in the vast majority of African areas and because of residues in the water, 2,4-D is not recommended in countries such as South Africa and Zimbabwe.

Decaying plant material and water quality

When 1200 ha of water hyacinth was sprayed on Hartebeestpoort Dam, South Africa, with two follow-up sprays on 320 and 240 ha, extensive and detailed measurements on water quality were done (Scott *et al.* 1979). The parameters studied included water transparency, temperature and dissolved oxygen *in situ*. The water samples were analysed for sodium, potassium, fluoride, chloride, sulphate, total alkalinity, pH, silica, nitrate, ammonium, orthophosphate, total phosphorous, Kjeldahl nitrogen, electrical conductance, calcium, magnesium, iron, manganese, cobalt, chromium, zinc, copper, nickel, cadmium, lead, total and organic nitrogen, chemical oxygen demand and suspended solids. Samples were also taken for bacteria, algae, zooplankton and zoobenthos counts, as well as chemical residues in water, fish and plants. The relatively slow decomposition of plant material contributed to the minimal effect of spraying on the water quality. Apart from very slight oxygen-level reductions in surface water at weeks four and five after spraying, no ill effects were measured in fish and other biota, and other changes that were measured were slight and appeared to be of little consequence in the aquatic environment.

In a detailed study done on water hyacinth control with Roundup® on the Ere channel in Nigeria, the presence of water hyacinth reduced water quality to such an extent that fish of economic importance were absent. There was a reduction of dissolved oxygen in the water at weeks three and four after spraying but by week six the oxygen level was back to normal; fish populations were restored and no mortalities were recorded.

Bacterial and fungal populations and other micro-organisms showed no adverse effects from the spraying of Roundup®. Glyphosate residues were only recorded from open-water samples, with a peak at four hours after spraying followed by rapid degradation. Water samples taken from under the water hyacinth mat reached a residue peak of less than 1% after five days, which was of little significance. Laboratory studies on fish species concluded that glyphosate has no intrinsic toxic effect on fish and other aquatic organisms (Akinyemiju 1993).

In Canada, a detailed study on the effects of Roundup® sprayed in a forestry situation and an analysis done on an aquatic system, Carnation Creek, Forestry Canada and the British Columbia Ministry of Forestry concluded that the use of Roundup® in a forestry situation resulted in an absolute minimal effect on the aquatic system (Reynolds 1989).

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