Faculteit Wetenschappen
Departement Biologie
Afdeling Ecologie en Systematiek der Dieren
Laboratorium voor Aquatische Ecologie

KATHOLIEKE
UNIVERSITEIT
LEUVEN

# The control of waterhyacinth infestation needs an integrated multi-strategy approach

Promotor:

Prof. Dr. F. Ollevier

Bijgevoegde stelling aangeboden
tot het bekomen van de graad van
Doctor in de Wetenschappen
door

Heidi Coene

2000

# Introduction

Aquatic weeds occupy an ambivalent position in freshwaters. In small amounts they play a number of important roles in the ecosystem. They provide shelter, breeding place and food for many aquatic organisms, and their detritus is a starting point in the aquatic food chain. Moreover, macrophytes help in stabilising shores by protecting them against erosion, and in the nutrient dynamics of the waterbody (Gopal 1987, Fox 1996). However, outside their natural range of occurrence, they can exhibit excessive growth creating nuisance in various ways.

The waterhyacinth *Eichhornia crassipes* Martius Solms-Laubach is a flowering aquatic plant (Liliales, Pontederiaceae). In its native range in the Amazonian river basin (Brazil, South America), waterhyacinths are harmless and typically occur in seasonally inundated natural environments rather than in irrigation canals and large permanent lakes as is the case in the introduced range of Asia and Africa. Admirers of its beautiful flower have translocated the waterhyacinth worldwide, and in the tropical and sub-tropical freshwater environments, the weed multiplies prolifically and spreads rapidly to become one of the most noxious waterweeds known (Twongo 1998). The lack of natural enemies (which keep it under control in its native habitat) and the environmental degradation of waterbodies are the major factors contributing to its rapid spread. Waterhyacinth has been reported to directly obstruct navigation, to change the waterflow in irrigation channels, to degrade water quality for domestic use, to cause serious oxygen depletion, to interfere with the existing flora and fauna, and to destroy habitats for waterbirds and fish (Gopal 1987, Harley 1990). The waterhyacinth also increases the dispersal of several deadly diseases like malaria, schistosomiasis and filariasis (Lee 1995, Bos 1997). Around lakes, it can have serious socio-economical impact on the local fishermen communities by obstructing access to fishing grounds and landing sites, loss of gear, reduction in fish stocks and the disruption of fish breeding (Mailu 1997). In rivers, it can greatly interfere with water use, fishing and transport, sometimes cutting off entire villages from access to markets, health care centres, etc. (Olaleye *et al.* 1993, Van Thielen *et al.* 1994). Finally, it has been shown to have a deleterious effect upon biodiversity and biomass of fish species in shoreline habitats (Willoughby *et al.* 1993).

Waterhyacinth control has received great attention. While the initial control mechanism was largely chemical, during recent years both biological and integrated control approaches have been promoted. In the present paper, we will give an overview of some biological characteristics of the waterhyacinth with emphasis on factors responsible for its weedy potential. We will resume the major control mechanisms, with some notes on their theoretical background and specific advantages. We will further suggest a more integrated approach to control the waterhyacinth and make some concluding remarks.

## The biology of waterhyacinth

The free-floating part of the waterhyacinth comprises a shoot with a rosette of petiolate leaves, a terminal inflorescence and numerous roots hanging in the water. The plants exhibit a high degree of morphological plasticity. The leaves can vary greatly in shape and size, from long-petioled leaves to bulbous floaters; but all intermediate forms can be observed in the same stand as a result of different microhabitat factors. The bulbous petioles are dominating in the colonising form of the plant (Wright and Bourne 1986). The flowers are lilac and occur mostly in groups of 8 to 15. Three floral morphs have been distinguished, differing in style length and stamen height. However, these forms are seldom observed together in nature. Roots are generally short in nutrient-rich water and long in nutrient-poor water. Roots can also be anchored in the mud in case of reduced waterlevels (Gopal 1987, Harley 1990).

Although waterhyacinth reproduces both vegetatively and sexually, vegetative propagation is more important for its rapid spread and colonisation of new water bodies. Vegetative reproduction implies the production of stolons from the base of the rosette. The vegetative growth is generally very rapid under favourable conditions of higher temperature and nutrient availability. A 50% increase in terms of biomass produced has been reported within two weeks. The high vegetative multiplication rates suggest that high density and competition for space may soon affect plant growth, if not, nutrients would restrict growth. However, the great morphological plasticity coupled with the wide ecological amplitude allows high growth rates over long periods. As density increases, the plant starts vertical growth (elongation of petioles) together with increase in leaf surface area. The plant also produces vast quantities of seeds, which sink to the bottom and remain there until favourable conditions are met for germination. Seed dormancy can take up to 20 years. This explains the observation of recolonisation after chemical or physical eradication. Surely, the high reproductive capacity and the strategy allowing switching between sexual and vegetative reproduction under different environmental conditions promote the weedy potential of waterhyacinth.

Waterhyacinths can occur as static mats fringing inlets and bays, but can also form large mobile mats, which are constantly moved by the wind and the water currents. This mobility of the weed might highly constraint effectiveness of control and monitoring strategies. Waterhyacinth grows in a variety of freshwater habitats, representing a broad spectrum of physico-chemical conditions. It has a high tolerance to environmental fluctuations. Growth of waterhyacinth is greatly enhanced by the level of nutrients in the water, particularly the levels of nitrogen, phosphorous and potassium (Reddy *et al.* 1989, 1990). Growth is most affected by low (nearly frost) temperatures. Drought conditions and consequent lowered waterlevel do not influence waterhyacinth populations. However, drought conditions may alter mineral availability by reduced runoff. Water hyacinth can not tolerate brackish water.

The weed is very resistant to water pollution, and has often been proposed as potential biological filter in wastewater treatment (Jamil *et al.* 1987). It is able to uptake and store high amounts of heavy metals (Kay and Haller 1986, Panda *et* *al.* 1988). Waterhyacinth also removes organic compounds (including some pesticides) from polluted waters (Harley 1990).

## The control of waterhyacinth

### Manual and mechanical control

Manual removal is typically done with simple mechanical devices and handtools like rakes and forked hoes. In several developing countries, this method has proven to be successful on a local scale by mobilisation of the local communities through short-term campaigns (Twongo 1998). Manual control is labour expensive, time consuming and unsatisfactory, particularly in large and heavily infested areas. However, it involves little environmental hazard and is a useful method for reducing small infestations or for maintenance of critical points (Harley 1990).

Mechanical cutters or harvesters have been designed to float on the water surface or to operate from the shoreline with the objective of destructing the waterhyacinth (by fragmentation) or removing it from the waterbody (Gopal 1987). The logistics of removal requires that the weed must be transported and processed (Cooke *et al.* 1993). It might however be advantageous to remove biomass, because otherwise plants will release nutrients at senescence, and will contribute to oxygen depletion (Gopal 1987). However, the high costs involved in the development, operation and maintenance of machines and the processing of harvested biomass is a significant factor restricting their wide application.

### Chemical control

Chemical control might imply small-scale applications in areas accessible by land or boat or the use of helicopters and small planes for large-scale controls. Important considerations before using chemicals should be the specificity of the effect, its environmental toxicity and persistence. While it might be appropriate in lakes or reservoirs where water is not used as potable supply or in agriculture, the use of chemicals is highly controversial in densely populated areas where water is used for domestic purposes. Although this method might be effective in short-terms, successful control often implies a long-term commitment including repeated applications of herbicides, as infestation will often regenerate from scattered plants and seeds. This makes it very costly, especially in developing countries where equipment, chemicals and finances are scarce. Moreover, the unknown environmental impact makes this method highly controversial in many countries (Gopal 1987, Cooke *et al.* 1993).

A large number of herbicides have been tested for their efficacy in controlling the weed. The chemicals 2,4-D, Glyphosate (Roundup) and Diquat are most commonly used. Several local studies have shown the safety of these chemicals through acute toxicity tests (Gutierrez *et al.* 1996, Anonymous 1997). Worldwide, huge sums of money and enormous efforts have been expended to control waterhyacinth by herbicide application (Chikwenhere 1994). However, experience has shown that chemical control (together with mechanical removal) has seldom led to successful long-term control (Harley 1990).

### Biological control

The rapid growth of exotic plants outside their native range is often explained by the lack of natural enemies. Biological control aims at finding suitable organisms, preferably associated with the weed in the native range, which can stress the weed either individually, or in combination with other organisms, to the extend of controlling its population. Biological control is thus an induced population regulation, in which the population of one species lowers the numbers of another species by mechanisms such as predation, parasitism, pathogenicity, or competition. This results in a new dynamic equilibrium between the biocontrol agent and the target plant at a lower acceptable level of plant biomass (Samways 1981, Cooke *et al.* 1993).

An efficient and safe introduction of natural enemies needs an elaborated and complex procedure. It involves the search for host-specific organisms with biocontrol potential, their evaluation and release in the field. The steps involved in the development of the program and their respective objectives are summarised in Table 1.

Table 1: Summary of steps involved in introduction programs of natural enemies (adapted from Van Driesche and Bellows 1996)

| Step | Objectives |
|---|---|
| 1. Target selection and assessment | Identify target pest, evaluate the extent of the problem, establish objectives for introduction program |
| 2. Preliminary taxonomic and survey work | Determine current state of taxonomic knowledge of pest and natural enemies, conduct literature review on natural enemies of target species and relatives, survey in target area for any existing natural enemies |
| 3. Selecting favourable search locations | Define native home of target pest and other possible areas of search for natural enemies |
| 4. Selecting natural enemies for collection | Choose which candidate enemies may be appropriate to collect for further study in quarantine |
| 5. Exploration, collection and shipment of candidate natural enemies | Obtain and introduce candidate natural enemies into quarantine |
| 6. Quarantine and exclusion | Process shipped material to destroy any parasite, disease or other inclusions |
| 7. Rearing and safety testing | Conduct research in quarantine on natural enemies to define host range and specificity |
| 8. Field colonisation and evaluation of effectiveness | Release natural enemies in the field and monitor establishment and efficacy |
| 9. Agent efficiency and program evaluation | Evaluate degree of achievement of overall program goal and objectives |

For phytophagous arthropods or plant pathogens, a number of tests on specificity and safety are required. These tests are aimed at determining the potential host range to prevent unintended damage on nontarget plants. Host-specific feeding habits are determined by multiple choice tests (offering several food plants at the same time) and starvation tests (starving the organism before providing a selected food plant).

Several organisms have been found suitable for the biological control of waterhyacinth. The most important ones are two weevils (*Neochetina eichhorniae* and *N. bruchi*), the waterhyacinth mite (*Orthogalumna terebrantis*), a pyralid moth (*Sameodes albiguttalis*) and the phytopathogen *Cercospora rodmanii* (Gopal 1987). Recently, also the leaf-sucking mirid *Eccritotarsus catarinensis* has been reported as promising bioagent (Hill *et al.* 1999, Stanley and Julien 1999).

*Neochetina eichhorniae* and *N. bruchi* are weevils from the Curculionidae family, and are currently reported as the most successful biocontrol agents (Harley 1990, Hill and Cilliers 1999). Basic information on their biology and host-specificity is now available. The adults of both species are nocturnal and feed on leafs and petioles of the waterhyacinth. This feeding produces typical feeding scars on the plant, which can be used easily for the estimation of adult weevil populations (Wright and Center 1984). The species have differing oviposition preferences (Harley 1990). *N. eichhorniae* places eggs singly in the leave epidermis, while *N. bruchi* inserts eggs either singly or in groups into the petiole. Newly hatched larvae mine towards the petiole bases and feed in the stems. Fully-grown larvae leave the crown and pupate underwater, making a cocoon of root hairs. This is the main reason why these species can not complete their life cycle on terrestrial plant or aquatic plants rooted in the substrate. The damage caused by the adults is pure mechanical, leading to an increase in leaf mortality. The damage of larvae can lead to decreased leaf productivity through their attack on the meristem (Center *et al.* 1999a). Both species can produce offspring 3 to 4 times per year. Biological control with weevils therefore includes a typical lag-phase of several years to build up the weevil capacity to an effective number. Tests of host-specificity for feeding and development have been reported for a wide range of plants (Harley 1990, Chikwenhere 1994, Hill and Cilliers 1999). These have shown that both weevil species are very host-specific and thus safe candidates for introduction programs.

The moth *Sameodes albiguttalis* lays eggs on the leaves of water hyacinth, preferring areas where the epidermis has been damaged. The larvae develop through five instars which mine the petioles of the plant, causing necrosis and waterlogging. The preference for younger plants or actively growing tissue has ensured that the moth is most effective in areas where populations of mature plants have been thinned by herbicides or mechanical clearing and where there is a constant supply of bulbous plants (Center and Durden 1981). The moth is also effective at restricting the spread of water hyacinth mats because it attacks the bulbous plants along the fringes, which has an added benefit in that these plants tend to produce most flowers (Hill and Cilliers 1999). In its native range, the moth is heavily attacked by parasitoids and pathogens (DeLoach and Cordo 1978). This makes the "quarantine" step in the biological introduction procedure extremely important for successful establishment of this species. Also the moth is highly host-specific. Development can only be completed on waterhyacinth or other Pontederiaceae (Harley 1990). Its efficacy as single biological control is still controversial. The major reason herefore is the insect's requirement for young and actively growing plants, which are not always found in water hyacinth mats.

The mite *Orthogalumna terebrantis* attacks waterhyacinth by producing large number of tunnels (up to 10.000 per plant). The mite prefers injured parts of the leaf for feeding initiation. It has specifically been acknowledged for its induction of kairomone release, which enhances oviposition and feeding by the weevils (DelFosse 1978).

The biology and biocontrol potential of the fungus *Cercospora rodmanii* is well summarised by Freeman and Charudattan (1984). The so-called leaf-spotting disease is characterised by root rot, leaf spots and leaf necrosis. On its own this fungus is not particularly damaging, but effects often increase when plants are also stressed by insect attack. When conditions exist that favour disease development and limit leaf production, *C. rodmanii* can infect and kill leaves faster than the plant can produce new leaves. Lateron, several other fungi, including local species not found in the native range of waterhyacinth, have been reported useful (Charudattan 1997).

The mirid *Eccritotarsus catarinensis* is the most recent agent to be released on water hyacinth. The eggs are inserted in the leafs. The nymphs develop through four instars and feed gregariously with the adults on the leaf undersurface, causing severe chlorosis at high population levels (Hill *et al.* 1999). Laboratory tests on the host range of the mirid strongly suggested that this species is restricted to the Pontederiaceae (Stanley and Julien 1999).

Research on biological control of water hyacinth started in the United States in the 1960s and 1970s. This resulted in the discovery, testing and introduction of several species into the United States for water hyacinth control. These biological control agents (the two weevils *N. eichhorniae* and *N. bruchi*, and the moth *S. albiguttalis*), in combination with strategic use of other strategies (particular chemical and mechanical control) have caused significant reduction in water hyacinth populations in the US. Also Australia and South Africa conducted additional foreign exploration and management research. Waterhyacinth has been brought under sustainable biological control in a number of countries, including, India (Jayanth 1988), Sudan (Bashir 1984), Australia (Harley 1990) and South Africa (Cilliers 1991). Several other countries have reported the successful establishment of biocontrol agents (Benin: Van Thielen *et al.* 1994, Zimbabwe: Chikwenhere 1994).

**Integrated pest management (IPM) approach**

In an integrated pest management, several control mechanisms are combined in a way to maximise the output. Mostly, no single control strategy is fully effective in eliminating the weed (Harley 1990). The choice of the baseline control strategy, on which the other strategies should be built, is essential. It has since long been recognised that biological control is the only cost-effective, permanent and environmentally friendly method to combat these floating aquatic weeds (Delfosse and Spencer 1997). However, it is important to realise that biological control will take some years to establish and have their impact. Biological control alone might therefore not be responsive enough to the plight of water resource users in the short-term. Mechanical and chemical control can contribute to address immediate problems, but should be consistent with long-term, optimal biologically based pest management. Therefore, a combination of biological with chemical or physical means or the control with multiple biocontrol agents has been suggested to optimise desired results and minimise the risk and costs.

Integration of chemical and biological methods has been investigated for waterhyacinth control, both in laboratory conditions and in the field. Several possibilities of integration have been reported.

* Stressing the plant might enhance biological control. One possibility is the application of sublethal concentrations of herbicides. 2,4-D applied to waterhyacinth has been shown to change the plant quality by decreasing leaf hardness and increasing nitrogen content. These changes facilitated the attack of *N.eichhorniae*, *N. bruchi* and *S. albiguttalis* (Wright and Bourne 1990). However, the toxicity of the herbicide to the biocontrol agent should be tested; not only concerning mortality, but also involving sublethal effects like reduced reproductive success.

* Application of lethal doses of herbicides results in the inevitable loss of eggs and non-mobile larval and pupal stages of the weevils. It has been shown that adult

weevils are not affected by these herbicides and can migrate to unsprayed areas. However, migration seems to occur only at certain times during the lifespan and factors needed for stimulation of wing muscle development are still unclear (Haag 1986a). Haag (1986b) stressed the importance of spraying weed mats in the field selectively, and providing a reservoir area of unsprayed plants to "herd" the weevil population. This might allow weevils to survive, feed and reproduce on a restricted mat of healthy plants and assure a sufficient stock to attack newly grown waterhyacinths.

* Center *et al.* (1999b) showed that weevil populations might in some way benefit from herbicidal control. They compared plant quality and weevil populations in sprayed and unsprayed sites. The sprayed sites had smaller, earlier phenostage and healthier plants. Plants at unsprayed sites, where weevil populations were much larger, suffered high levels of stress and showed low growth potential. However, reproductive status of the weevils was higher in the sprayed sites. Herbicidal control improved plant nutritive quality thereby inducing reproductive vigour of the weevils, but ensuring plant regrowth and the need for future control. This suggests that biological and herbicidal control can be integrated, using herbicides to maintain waterhyacinth infestations below management thresholds but in a manner that conserves biological control agent populations.

* Also the integration of a growth retardant (gibberelin biosynthesis inhibitor) with control by weevils has shown to be successful in controlling waterhyacinth infestation (Center *et al.* 1982, Van and Center 1994). Regardless of plant densities, the combined effects were synergistic, with accelerated leaf mortality rates exceeding production rates leading to early plant death.

Another way to enhance control is the integration of several biocontrol agents. Different arthropod enemies can feed on or inhabit different parts of the plant, and thus increase the biotic stress on the plant. Several synergetic relationships between biocontrol agents have been reported and used in biological control strategies (DelFosse 1978, Sanders *et al.* 1982). Charudattan (1984) observed that *C. rodmanii* could eliminate 99% of waterhyacinth plants in combination with *Neochetina*. The insects and pathogens alone were much less effective. Also dual combinations of currently known plant pathogens have shown to increase the plant's level of biotic stress (Morris *et al.* 1999). The effect of *S. albiguttalis* and *O. terebrantis* has been reported to increase in the presence of weevils. Damaged leave cuticle by the feeding of weevils can facilitate oviposition or feeding by moths and mites (Harley 1990).

Some people have proposed waterhyacinth utilisation as an alternative control strategy to encourage weed removal and reduce the costs through economic returns. Several ways of utilisation have been reported: animal feed, compost, paper, biogas (Gopal 1987, Naskar *et al.* 1985). However, utilisation of the harvested product should only be encouraged when an investor intends to make profit on a short-term or provided there are alternative sources of raw material in the case of decline of the waterhyacinth population, once the biological control becomes effective.

## Concluding remarks and reflections

* It is important to acknowledge that the rapid spread of waterhyacinth is a symptom of a much larger problem, namely increased pollution and environmental degradation. All control programs should therefore include efforts to reduce the nutrient loading.

* Management plans should be structured on a site-specific basis, to allow integration of control methods according to the characteristics of each site.

* It might be necessary to include a biological control for other potential weed species. As the waterhyacinth population declines, another weed can spread rapidly and cover the area. Such succession is frequently seen at field sites where

the dominant weed is controlled (Haag 1986b). A good example is the case of Lake Naivasha (Kenya) were a new weed (waterhyacinth) became established after the first one was controlled (*Salvinia molesta*) (Twongo 1998).

* Implementation of a control strategy should always be accompanied by a "public awareness" campaign. Especially when biological control agents are introduced, local communities should be informed and receive proper education. This should allow them to understand some of the less obvious problems associated with the weed (such as the effect on biodiversity, and harbouring of malaria and bilharzia vectors), to understand the process of biological control (including the lag-phase between introduction and effect) and to become familiar with the biological agents and their impact. Community involvement is necessary to achieve a sustainable implementation of biological control (Van Thielen *et al.* 1994; Hill *et al.* 1997).

* Scientists may be proud to provide the idea of an "sustainable integrated water hyacinth management". In several recommendations following international meetings on the waterhyacinth problem, the need for more funds on amelioration of the biological strategy is emphasised (under the motto "the more the better"). Continuing effort to find yet another biocontrol agent might be of interest in scientific terms. However, this might not be the most efficient or relevant way to handle the problem for developing countries. Especially in Africa, efforts of water hyacinth control are currently fragmented and unconnected. Sponsors of programs of water hyacinth management should address more attention to the constraints of actual implementation on all levels. Support and priority should be given to strengthen international communication and to encourage the formation of linkages in order to achieve a co-ordinated pan-African management.

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