Strategies for Water Hyacinth Control

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INTERNATIONAL EXPERT CONSULTATION ON STRATEGIES FOR WATER HYACINTH CONTROL: BACKGROUND AND JUSTIFICATION

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One of the major problems in water bodies of the tropics and sub-tropics is the floating aquatic weed water hyacinth *Eichhornia crassipes*, which is considered to have originated from the Amazon and has disseminated very quickly in various tropical and sub-tropical countries of Latin America and the Caribbean, Africa, Southeast Asia and the Pacific.

The level of reproduction of water hyacinth is very high in countries where the plant has recently been introduced. The explosive growth rate of the weed is due, to a large extent, to the eutrophication in water bodies. In addition, the absence of natural enemies of the plant contributes to the rapid growth of this weed.

It is well known that biological control is one of the most successful methods to control water hyacinth. The method, practised for example successfully in Australia through the regular release of the weevils *Neochetina eichhorniae* and *N. bruchi*, and the moth *Sameodes albiguttalis*, has been recently adopted in some countries of Latin America and Africa and it is expected to have the same impact as in Australia. However, in many countries the water bodies present very heavy infestations in different sites (fish landing areas, docks, hydroelectric power stations, rivers and dams), and there is a general consensus that other short-term control measures should also be implemented to reduce the weed stands and also to benefit the growth of natural enemies for successful biological control.

Among the short-term control measures there are physical (mechanical and manual) removal and chemical control. All have serious constraints for implementation in water bodies of developing countries of the tropical and sub-tropical regions.

Mechanical removal requires the purchase of harvesters, many of them too costly for most of developing countries. Manual removal requires a large labour force, and Governments of the developing world do not always have the means to pay for this operation.

Chemical control, through the use of certain herbicides such as 2,4-D or glyphosate, seems to be an economically feasible option in some countries, but not in others with less economic development. In addition, in many countries public opinion is strongly against the use of chemicals in water, which is used for drinking purposes.

FAO, taking into consideration the seriousness of the problem and the need to develop a strategy for integrated water hyacinth control, has decided to organize, in close cooperation with USDA and University of Florida, the present expert technical consultation.

EXPECTED OUTPUTS

1. Suitable guidelines for water hyacinth control in developing countries of the tropical and sub-tropical regions. These guidelines should clearly indicate the strategy for implementing available control methods.

2. An updated status report of biological control of water hyacinth (natural enemies and methods for rearing and release available) giving relevant advice on ways for its rapid implementation and success in countries of the developing world.

PARTICIPANTS

Outstanding specialists on water hyacinth control from countries and/or institutions (such as CSIRO, Australia; IITA, Benin; Royal KIT, Amsterdam, The Netherlands; Long Ashton Research Station, University of Bristol and IIBC, UK) and several others from the University of Florida and USDA will actively participate in this meeting. Some other specialists from selected ongoing projects on water hyacinth control have also been invited whose participation may give the necessary background to discussions and debates. These are specialists from Uganda (Lake Victoria), Ghana and Mexico who work closely on water hyacinth control.

STATUS OF WATER HYACINTH IN DEVELOPING COUNTRIES

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SUMMARY

The present paper briefly describes the problems caused by water hyacinth in various countries of Africa and Latin America. It also describes the actions undertaken by FAO and other agencies and/or institutions regarding the implementation of programs for the control of this floating aquatic weed.

The constraints posed by all available control methods are discussed. It is considered that, under certain circumstances, biological control of the weed alone will not be sufficient to effectively reduce the weed stand in a relatively short period of time. Therefore, an integrated approach for the control of the weed is recommended which may consist of mechanical and/or systematic manual removal, and the use of herbicides in particular infested sites. Each method has its own economic and environmental constraints, and practical advice is needed on where and how to use short-term control methods to complement the effect of biological control.

INTRODUCTION

It is not necessary to reiterate the noxious effects caused by the floating weed, water hyacinth (*Eichhornia crassipes*). There are already many papers giving valuable information about the effects of water hyacinth on water loss through evaporation, obstruction of navigation and fishing, and blockage of irrigation and drainage systems (Achmad, 1971; Desougi & Obeid, 1978; Gopal, 1987; Holm *et al*., 1991). Here I prefer to give an overview of the areas infested by water hyacinth in various parts of the developing world, problems caused to their national economies, and constraints to overcome them.

Another aspect to be discussed is the feasibility of implementing specific control methods. There is no doubt that biological control should be the key component in any program for the control of water hyacinth. Biocontrol is an economically feasible and environmentally viable option to control water hyacinth and other aquatic weeds. However, in certain situations, biological control practised alone succeeds only after several years of implementation, and whereas what is needed in some areas of commercial value is drastic reduction in the weed population in short periods of time.

Countries and Water Bodies Infested by Water Hyacinth

If one looks at the latest edition of "The World's Worst Weeds" edited by Holm *et al* (1991) it will be noted that the map of water hyacinth distribution (figure 24 of the book) has significantly changed during the last four years. According to this map most of West Africa, with the exception of Nigeria, was free of water hyacinth, but the reality is that new countries of the sub-region, such as Niger, Benin, Ghana, Ivory Coast and Mali, should now be incorporated into the list of the countries affected by water hyacinth (Table 1). Water hyacinth recently started to thrive in Mali. FAO conducted an aerial survey of water hyacinth infestations in the Niger River, in Niger and in most of Mali four years ago (1991), but already in 1994 mats of different sizes had been noticed in Mali. If control measures are not implemented soon the problem will worsen and will become more difficult to be solved.

Water hyacinth is becoming day by day a very serious problem in many African countries. A high level of weed infestation has been observed in several water bodies of West and East Africa. Due to the absence of effective natural enemies, the most notable infestation is observed in Lake Victoria.

In Lake Victoria in particular, water hyacinth affects the normal activities of fishermen and transporters of goods. When fish landings are severely infested, boats are sometimes trailed to the shore. On certain occasions when fishermen have to wait for a while in order to get going to the shore, they risk finding the entire catch rotten. Normally transporters of goods and fishermen consume two to three times more fuel when water hyacinth infestation is high and the fish catch is reduced by 50-75%. In the Owen Fall Hydroelectric station water coolers and generators are often damaged by the presence of parts of water hyacinth mats. When this happens a generator has to be switched off for maintenance and this means the loss of 15 Megawatts of electricity for a while, i.e., a blackout in one of the urban areas of Uganda.

To effectively control water hyacinth in Lake Victoria, preventive measures should be implemented in the Kagera River where every minute 15 mats of different size run with the flow of the river into the lake. Here there is a serious political constraint because the river is shared firstly by Burundi and Rwanda, and then by Tanzania and Rwanda. Tanzania may be asked to implement such a preventive program, but this would be illegal if the Rwanda Government is not also consulted. At present it is not difficult to realize that the situation in Rwanda is very unstable and water hyacinth will remain a secondary problem.

In Egypt the infestation is not reduced by the current mechanical removal practised in the country. The use of herbicides has been banned and biological control has still to be developed in the country.

In South America, Bolivia is the latest country affected by water hyacinth. It is important to point out that the plant exists in Santa Cruz de la Sierra, i.e., the warmest region of the country, but due to the presence of various natural enemies water hyacinth does not constitute a weed. However, its recent appearance in San Jacinto dam of Tarija's temperate area (close to the borders with Argentina and Paraguay) is a serious problem during the summer.

In Southeast Asia it is well known that water hyacinth is a constraint to navigation and other economically important activity, but in some of these countries suitable bioagents have been released combined with manual removal in a permanent system, by which the water hyacinth stand tends to be reduced. In addition, the removed mass of the weed is used for various purposes, including the production of handicrafts.

Although the high incidence of water hyacinth is undesirable everywhere, landlocked countries such as Bolivia, Mali, Uganda and Zimbabwe suffer economically more than others because inland water bodies are the only sources of fish, which, particularly in Africa, may constitute the main source of protein for human consumption.

Table 1. Main Water Bodies Infested by Water Hyacinth in Developing Countries

Region: Latin America and the Caribbean

Country	Infested sites and region
Bolivia	San Jacinto dam, Tarija.
Colombia	In lagoons outside of Amazonia.
Cuba	Commercial dams in Western and Central part of the country.
Mexico	Lakes Chapala and Guadalupe, the Santiago River and several other dams in the centre and south of the country.

Region: Africa (including northern part of the continent)

Angola	Kwanza River and related irrigation network.
Benin	So and Ouémé rivers, Lake Nokoue.
Burundi	Kagera River.
Egypt	Nile River and related irrigation network, and Northern lakes.
Ghana	Tano Lagoon and Accra/Tema water areas.
Ivory Coast	Tano Lagoon, Comoé River, Ono Lake.
Kenya	Lakes Victoria and Naivasha.
Malawi	Zambesi and Lower Shire Rivers, Lake Malawi.
Mali	Niger River.
Niger	*Ibid.*
Nigeria	*Ibid.*
Rwanda	Kagera River.
Sudan	Nile River.
Tanzania	Lake Victoria, Pangani, Kagera and Sigi Rivers.
Uganda	Lakes Victoria, Kyoga and Kwania.
Zaire	Congo River, Lake Albert.
Zimbabwe	Lake Chivero and Manyame River.

Region: Southeast Asia. There are various countries in this region facing problems of water hyacinth infestations, these are southern part of China, Thailand, Vietnam, Laos and Indonesia.

Actions Undertaken for Water Hyacinth Control

Various FAO projects (TCP) within the Technical Cooperation Program have been implemented in several countries. Some results of these projects are given below:

1. TCP/NER/9155. This project implemented in 1991, carried out a survey to recognize the magnitude of the water hyacinth problem in Niger River. It also formulated a long-term (4-year) project which it was hoped would be financed by the European Economic Community. The aerial survey revealed severe infestations of water hyacinth in Niger's part of the river and in Gaya, i.e., part of the border with Nigeria, but in Mali's part the weed was completely absent. The weed is currently controlled through tedious and labourious manual removal, which is considered by national authorities as the main control method to be practised in any control program of water hyacinth. Due to various financial reasons and other misconceptions of the control program to be developed, the project document has to be reformulated.

2. TCP/UGA/9153. In 1991, the Government of Uganda and FAO launched this short-term project to assess the current situation of water hyacinth infestation in the Ugandan sector of Lake Victoria and in Lake Kyoga. This project strongly recommended the initiation of immediate control measures at the national level, while preparations were made for regional level cooperation and operations.

3. TCP/RAF/2371. In response to the previous project, FAO agreed to provide assistance to the Governments of Kenya, Rwanda, Tanzania and Uganda, all affected by water hyacinth. Within this project, a 4- to 5-year term project document was formulated by a technical team to establish a technically-sound system of water weed control in East Africa which was submitted for funding to the World Bank. Training on biological control of water hyacinth was also carried out and consensus from countries obtained for the introduction of the weevils of the *Neochetina* genus into the sub-region. Host specificity and selectivity tests of the bioagents were also carried out in Kenya and Uganda. This year, within the framework of this project, FAO has again fielded a technical team to formulate an emergency action program for immediate water hyacinth control in Uganda.

4. TCP/EGY/2358. This was a very short project, where the water hyacinth problem in Egypt was surveyed in the Nile River and lakes of the northern part of the country. A project document for control action was finalized and submitted to the Government of Egypt to seek suitable and interested donors. The weed is controlled through mechanical or manual removal, with running costs of more than US$ 7 million every year. This physical removal does not achieve any significant reduction of the weed stand. Egypt has possibility to develop a good biological control program. Extensive host specificity tests have been carried out on the two species of weevils (*Neochetina* spp.) which confirmed the safety of these bioagents. In addition, in the country there is an effective pathogen

(*Alternaria eichhorniae*) for water hyacinth control (Charudattan, 1995, personal communication).

5. TCP/BOL/2255. The project has been conducted in the San Jacinto dam which is located in the temperate region of Tarija, Bolivia. Water hyacinth is a serious problem for fishing in summer. The project has introduced weevils from Santa Cruz de la Sierra (the warmest area of Bolivia) into Tarija and a rearing unit has been established in an area close to the lake. The removal of small stands of the weed in the lake and related rivers during spring has been recommended to prevent high water hyacinth infestation.

6. TCP/CUB/2355. This was implemented to develop a program for the introduction of natural agents for the control of water hyacinth and other aquatic weeds (mainly *Pistia stratiotes*). Cuba has an extensive network of dams constructed to provide water for irrigation, but they are also used for fishing particular species. The level of infestation is high in several big dams and control measures are urgently needed. The weevil *Neochetina eichhorniae* is present in nearly all reservoirs throughout the country, while the presence of the moth *Sameodes albiguttalis* was confirmed by the consultancy of Dr. Wendy Forno (CSIRO, January 1995). Another weevil, *N. bruchi* was introduced from colonies originating from the PanAmerican Agricultural School "El Zamorano", Honduras. A rearing unit was set up in areas outside Havana, i.e., in the aquaculture centre, and training seminars were conducted by international consultants on rearing, release and control strategy.

7. GCP/GHA/026/EEC. This is a two-year project financed by the EEC and technically executed by FAO, aiming at control of water weeds in Ghana. Consultancies on weed control and fish stock protection have been carried out. The project aims to establish surveillance system of aquatic weeds, set up of units for rearing relevant bioagents for water hyacinth and other water weed control, and implement short-term control measures if needed in areas with a high level of water weed infestation.

8. IVC/94/G31. This project, financed by the Global Environment Facility (GEF) of the UN, should start very soon in the Ivory Coast, and its water weed component will be executed by FAO. Such a project will provide effective technical cooperation with Ghana for water weed control in the Tano Lagoon. As in other projects, biological control will be the key component in weed control activities.

In all these FAO projects, outstanding specialists on biological control of water weeds from IIBC, Ascot, UK, and CSIRO, Australia, have actively participated in various consultancies and planned training activities.

In addition to all these projects, there have been other activities aiming at aquatic weed control in countries such as Mexico where there is a serious water hyacinth problem. The control approach chosen is intensive chemical control using the herbicides 2,4-D or glufosinate-ammonium. FAO recommended that Mexican institutions give more emphasis to biocontrol. In fact, the weevil *Neochetina eichhorniae* is already present in many water bodies, while *N. bruchi* was in quarantine by April 1994.

FAO has now received further requests for FAO technical assistance on water hyacinth control, from Mali and Angola.

In addition to FAO projects and activities on water weeds other projects are in the pipeline or in the formulation stage. Among these are: 1. Formulation mission conducted by Royal KIT, Amsterdam, in 16 West African countries, financed by ECOWAS; a project in Malawi to be executed by IIBC and financed by ODA; a project for water hyacinth control in Lake Kyoga with financial and technical support from Australia; and projects technically executed by IITA in various African countries.

Control Methods and Constraints

1. Biological control

In nearly all cases institutions and agencies working on water hyacinth control rate biological control as a key component in control programs.

The most popular bioagents have been the weevils *Neochetina* spp., but little has been done with *Sameodes albiguttalis*. In many cases where the bioagents were to be introduced difficulties were faced because not every institution working with these bioagents is able to provide sufficient number of the insects and sometimes the distance is too great to bring the insects into the country.

Another aspect to be discussed and agreed upon is the method to be adopted for rearing and release of the weevils. Some institutions release water hyacinth plants infested with larvae of the insects, while CSIRO rears the insects in big pools and releases significant amounts of adult weevils during a year. From the economic point of view the latter seems to be more cost-effective than the former. It would be easy to involve fishermen and other members of the communities in release of adult weevils at low cost, while the release of infested plants requires transport plus fuel.

Transport is a problem in all developing countries as is fuel. Therefore, all projects dealing with the control of water hyacinth should foresee the establishment of various rearing units in areas near to infested sites in order to facilitate the release of the insects. In each unit there should be at least one technician highly skilled in rearing and release methods, plus an auxiliary. In such a way transport will not be required and funds, formerly set aside for this operation, can be used to pay the salary of the technical and auxiliary personnel, thereby generating some employment and income in the country.

If biological control is not implemented in an adequate way, its reputation will be damaged. This normally happens when release of the weevils is not carried out systematically and the level of water hyacinth infestation is very high. From the biological point of view, there should be a population threshold of the weevils needed to reduce the weed stand and, based on this, advice on the number of the insects and frequency of release should be given, but this does not happen. There are many papers on biocontrol of water hyacinth, but nothing has been found by the author on this aspect.

It is time to do something practical regarding the use of pathogens against water hyacinth. Previous reports discussed the usefulness of the fungus *Cercospora rodmanii* (Charudattan, 1983), and at present there are indications that *Alternaria eichhorniae* is also effective. If there were a simple method for reproducing these fungi, it would be feasible to do this locally at low cost. Advice on application methods should also be provided. There are many different projects on water hyacinth control in the pipeline and a component on the use of pathogens for weed control may also be included. This would possibly prevent the use of chemical herbicides in water bodies in the near future.

2. Other control methods

In many circumstances it is naive to believe that biological control alone will control all water hyacinth stands. Therefore other control methods should be implemented.

There are three other possible control measures: manual and mechanical removal, and chemical control through the use of herbicides. All these methods have particular constraints, and conditions, including level of infestation, and the characteristics of infested sites should be known before implementing them.

Manual removal demands a high labour force but, if systematically implemented it may be of great value to reduce a moderate stand of the weed. In Malaysia, in various sites water hyacinth has been successfully controlled through the combination of manual removal with biological control (Nai Kin, 1995, personal communication). Manual removal may also be of help in temperate areas where the weed stand is low. In this case removal of the weed becomes an important preventive measure. However, in highly infested areas, manual removal does not seem to be a technically effective or economically feasible method.

Mechanical removal is more effective in highly infested areas, but here some harvesters would be needed plus fuel and maintenance costs of the machinery. Without effective financial support to permit the purchase of the machinery and supply of fuel it is doubtful whether mechanical removal will be widely implemented in many developing countries.

Physical removal poses a serious problem with the mass of water hyacinth removed. It is true that the mass may be used either for mulching in perennial plantations or a small part (only very small) for handicraft production, but in the first case transportation would be a problem. Not all developing countries have the means available to transport the mass of water hyacinth to the plantations.

In Mexico, the weed is not removed and is simply chopped up and left to sink into the water. The author wonders to what extent this method depletes oxygen in water and causes fish mortality. According to the Mexican specialists this method is widely used in USA water bodies.

Chemical control is the other option. Public opinion all over the world is against the use of herbicides in water bodies, but the use of herbicides seems to be unavoidable in certain circumstances and, if they are used properly and with caution environmental problems can be avoided. In addition to the environmental concerns, another constraint is the need to purchase simple spraying equipment to be mounted in a boat to apply the herbicide.

Among the herbicides glyphosate is the safest for use in water, but cost of application (no less than US$ 28/ha) would be prohibitive in some countries. Another option is 2,4-D, sometimes wrongly confused by public opinion with the already banned 2,4,5-T. The herbicide 2,4-D seems to be safe for fish, is rapidly degradable in the environment and much cheaper than glyphosate.

Applications of any of these herbicides should be made in specific infested sites, but never in overall application to the whole infested area to avoid a depletion of water oxygen due to rapid incorporation into the water of the destroyed water hyacinth mass.
When to implement any of these methods and how to combine them with biological control? These questions may be raised but unfortunately may be left unanswered.

CONCLUSIONS

The design of a particular program of water hyacinth control in developing countries is not an easy task. There are socio-economic constraints which may prevent the practice of any particular control method: public opinion led by the journalists of the country who will rightly question all matters regarding the introduction of any bioagent, chemical compounds, practice of any control measure, the lack of equipment, funding and sufficient personnel trained on control methods to be developed. In addition, there might also be the lack of suitable link between the national institutions involved.

It is important to continue studies to improve water hyacinth control, but meanwhile there is also a need to design control strategies based on the level of water hyacinth infestations and national socio-economic constraints.

Water hyacinth is without any doubt the major aquatic weed problem all over the tropical and sub-tropical regions of the world. Its incidence in water bodies causes enormous problems to the economies and the environment of the countries. Therefore, technically sound programs of control of the weed should be rationally developed and implemented.

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Region A - West Africa

Benin - Neuenschwander

Ghana - DeGraft-Johnson

West Africa - Pieterse

BIOLOGICAL CONTROL OF WATER HYACINTH IN BENIN, WEST AFRICA

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SUMMARY

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae) was first reported in Benin in 1977 and about 10 years later became the major floating water weed in the southeast, obstructing boat traffic and fisheries. Water hyacinth multiplies in the permanently fresh water swampy upper reaches of the So river and in tributaries of the Oueme River. From there it is moved by wind and water flow to the coastal lagoons. The coastal lagoons are brackish during the dry season and water hyacinth eventually dies.

In 1991, *Neochetina eichhorniae* (Warner) (Col.: Curculionidae) of South American origin was imported from Australia via quarantine in Britain to Benin. A small infestation of the fungus *Beauveria bassiana* (Bals.) Vuill. (Hyphomycetes) was eliminated from the colony before release by sterilizing eggs and rearing a fungus-free generation. Between late 1991 and mid 1993, about 24,100 *N. eichhorniae* were released at 12 localities along the Oueme River, in the head waters of the So River and, recently, in northern Benin. Regular monitoring revealed feeding scars by adults on leaves and tunnelling by larvae in petioles at all release sites. By August 1995, *N. eichhorniae* had spread over the entire infested area. Monitoring of several sites, which continues, revealed a reduction in coverage by water hyacinth and a corresponding increase in the number feeding damage attributable mainly to adult *N. eichhorniae*, within two years of release.

Neochetina bruchi Hustache was imported in 1992. A total of about 7,700 weevils were released in eight localities since mid 1992. Offspring was recovered in most localities, but spread was slow. Since 1993, a total of about 2,400 *Sameodes albiguttalis* (Warren) (Lep.: Pyralidae) was released in one area between 1993 and 1995. Frequent sampling and monitoring of light traps did not show any recovery of this species.

In summary, *N. eichhorniae* and *N. bruchi* are established in Benin in a situation that is typical for coastal West Africa. The weevils have an impact on the water hyacinth despite the negative impact of water flow, wind, penetration of salt water, and removal of infested water hyacinth by fishermen. From 1993 to 1995, both species were therefore sent to Ghana, Kenya, Tanzania, Uganda, and Zimbabwe, and *N. bruchi* only to Nigeria, for release and/or local rearing.

Biological control of water lettuce *Pistia stratiotes* L., by means of the weevil *Neohydronomus affinis* Hustache, was initiated in Senegal and Benin.

INTRODUCTION

Water hyacinth, *Eichhornia crassipes* (Mart.), of South American origin, has become a major floating water weed in Africa. In West Africa, it infests rivers and lagoon systems linking adjacent countries, and interferes with water use, fishing and transport, sometimes cutting off entire villages (Holm et al., 1977; Guillarmod, 1979; Akinyemiji, 1987; Mitchell *et al*., 1990). Recommendations from a workshop held in Harare, Zimbabwe in 1991, stated that "biological control is the cost effective, permanent and environmentally friendly method" for control of this weed (Greathead & Groot, 1993).

In Benin, water hyacinth was first sighted in 1977 (L. Fagbohoun, personal communication). Since 1988, it has become a serious weed, affecting the lower reaches of the Oueme River as well as the So River with the 1000 Km^2 flood plain and the connected lagoons. Each dry season, the salinity of the lagoon rises above the limit lethal for water hyacinth (Holm, *et al*., 1977) and the plants die. By the end of 1993, the river system of the Mono, including its coastal lagoons and Lac Aheme, remained unaffected. Water hyacinth also occurs in the far north of Benin along the Niger River.

The Queme flood plain is the main dry season agricultural production area of the country. In addition, 23,747 tons of fish and crustaceans (Gbagidid, 1991) were caught in 1990 by 24,360 full-time fishermen, and its rivers and swamps produce 65% of the country's fisheries catch (80% of the inland production). This production is now in jeopardy. Each year, waterways are blocked by water hyacinth and villages that can only be reached by boat are often cut off from access to markets, health care centres, etc. Time-consuming mechanical clearing is the only means of temporarily relieving their plight. In addition, water hyacinth affects fishing directly by covering the open water surface or clogging fish traps.

The host specific weevils, *Neochetina eichhorniae* (Warner) and *N. bruchi* Hustache (Col.: Curculionidae) are the most important biological control agents used against *E. crassipes*, with notable successes in Argentina, Australia, India, Sudan, and U.S.A. In some of these countries, the moth *Sameodes albiguttalis* (Warren) (Lep.; Pyralidae) was also established and successfully complemented the action of the weevils (reviews in Harley, 1990; Julien, 1992). It is generally several years before these biological control agents make a significant impact (Jayanth, 1988, Center *et al*., 1989; Grodowitz *et al*., 1991).

Benin is the first country in West Africa to release biological control agents against water hyacinth. The beneficial insects were introduced and mass-reared by the International Institute of Tropical Agriculture (IITA) and released and monitored in collaboration with the lagoon fisheries project in Cotonou, supported by the Gesellschaft für Technische Zusammenarbeit (GTZ). The first results concerning the release and establishment of *Neochetina* spp. in Benin were described in detail by van Thielen *et al*. (1984). They are summarized and up-dated in the present text.

In addition, releases of *S. albiguttalis* and shipments of both weevil species for rearing and release in other African countries are documented. Finally, first releases of *Neohydronomus* *affinis* Hustache against another floating water weed, water lettuce, *Pistia stratiotes* L., are documented. This weevil species was imported from Zimbabwe, where it had been established (Chikwenhere & Forno, 1991) from material from Australia (Harley *et al.*, 1990).

Monitoring Water Hyacinth in Relation to Water Flow and Quality

The development of water hyacinth infestations in southern Benin has been studied since 1991. On the So River, water flow, water quality, and infestations of water hyacinth were assessed at 15 stations by the GTZ project. The stations were spread over 28.7 km from Ganvie to Togbota Ague, where the river emerges from a vast, but inaccessible, swamp system.

On the So River, complicated interactions between salinity, water flow, wind, and fishermen influenced the dispersal of water hyacinth. By the end of the dry season in April 1992, the border of salinity lethal to water hyacinth of 0.6%, was recorded furthest upstream, about 25 km north of the mouth of the river into the lagoon at Ganvie. In the lower reaches of the river, salinity attained a maximum of 2.46% with a pH of 8.3 a month earlier, and all water hyacinth was killed by the end of May. In the permanent breeding sites of water hyacinth in the head waters of the So, by contrast, salinities varied between 0 and 0.06% and pH between 5.5 and 7.5. Throughout the year, nitrogen concentrations were so low that no positive reaction was ever obtained. Up to May, water flow ceased and prevailing winds from the south transported water hyacinth from south to north, i.e., 'up river'. The lowest water level was recorded in May.

After May, rainfall increased, water flow down the river was reestablished, and water hyacinth started drifting down as small floating mats. At the same time, the water at several sites became turbid due to suspended soil particles. However, prevailing winds were from the south and water hyacinth were carried upstream whenever water flow was weak. By the end of June, measurements throughout the river showed salinity levels below 0.6% and from July to December, the So was carrying brown-coloured fresh water. With the inflow of fresh water, iron levels increased continuously and conditions for plant growth became favourable. Even at the lowest stations, water hyacinth started accumulating again along the river shore, some germinating from seeds. By mid-September, water levels had reached their maximum and the large swamps were inundated. Water hyacinth mats increased in size up to a maximum in October and gradually blocked the narrow parts of the river. The largest single blockage observed was 6.2 km long. When waters started receding in November, many water hyacinth plants were stranded and eventually died. For the first time in many months, winds ('harmattan') started blowing from the north.

From November 1992 to April 1993, mats of water hyacinth increased continuously in size and density until salinity crept up the river to the same level as in the previous year and the plants again started to die. During 1994 and 1995, essentially the same cycles were observed, yet water hyacinth densities were reduced.

Water hyacinth populations were also strongly affected by man. Many fisherman removed water hyacinth to service fish traps or to free enclosures along the river, so-called `acadjas', which are used to attract fish for breeding and capture by nets. Plants remained, however, untouched in the vicinity of a local shrine.

Rearing Exotic Natural Enemies of Water Hyacinth

A shipment of 2000 adult *N. eichhorniae* was sent by the Commonwealth Scientific and Industrial Research Organization (CSIRO), Brisbane, Australia, through the quarantine of the International Institute of Biological Control (IIBC) in Silwood Park, Great Britain. Arrived at IITA Cotonou on May 25, 1991, the shipment was held overnight in cool storage. On examination with the Benin quarantine authorities, some dead weevils (10 out of 2000) showed signs of infection by the entomopathogenic fungus *Beauveria bassiana* (Bals.) Vuill. (Fungi; Hyphomycetes). This necessitated rearing a generation of fungus-free weevils from sterilized eggs for field release.

For mass rearing, two pairs of fungus-free adults were confined to a bucket containing five plants for one day and transferred to new plants the next day. The buckets were set up each day providing 70 infested plants per week. Infested plants were used for field release within 15-20 days of oviposition. This procedure allowed us to mass culture by retaining a few buckets with plants in the insectary and using about 90% of all infested plants for release.

No fungus was detected in a shipment of 800 adult *N. bruchi* received from CSIRO on August 4, 1992. The same rearing techniques as above were used with this species.

Of *S. albiguttalis*, 500 larvae were received from CSIRO on August 23, 1993 and passed through quarantine. In the insectary, this species was reared on water hyacinth in small containers inside cages with screen sides and a glass top.

Releasing Exotic Natural Enemies of Water Hyacinth

The number of weevil larvae released was estimated from the number of eggs counted on the ligules and at the base of the petiole. However, eggs are difficult to find and in a preliminary experiment in which 25 eggs were counted on six plants, 55 adults developed. This ratio was used to estimate the number of *N. eichhorniae* larvae released up to June 1992, when the procedure was temporarily changed and eggs were artificially inserted into petioles.

For release, infested plants were transported in buckets and placed individually into mats of healthy water hyacinth. The numbers released are given in Table 1. All releases were made in agreement with the Beninois quarantine authorities and involved intensive discussions with the elders and fishermen in adjacent villages.

Released sites are given in Table 1. *N. eichhorniae* was released in the upper reaches of the So River with permanently fresh water and on tributaries or ponds near the much larger Oueme River. The control site, Gbodje, was on a tributary of the So. Weevil-infested water hyacinth carried downstream would not easily reach this site. Flooding often prevented visits to the other sites. *N. bruchi* was released further south near the Oueme and in swamp land north of the So, all sites being well separated from those from *N. eichhorniae* (Table 1). Both species were also released locally in the northern Borgou province, where a priest had kept water hyacinth as an ornamental and, upon his departure in 1986, the plants had been dumped into the next pond.

From late 1991 to mid 1993, a total of about 17,500 larvae and 6,500 adults of *N. eichhorniae* were released at 12 sites, and 5,500 larvae and 2,100 adults of *N. bruchi* at eight sites (Table 1). At most sites, releases were made at two places within a stretch of 1 km of the river. In several villages, adults from the mass-culture were released after the first recovery had already been made. This was an important public relation exercise. A total of about 2,400 *S. albiguttalis* was released in two nearby sites off the Oueme river near Sagon between the end of 1993 and August 1995 (Table 1).

Monitoring Exotic Natural Enemies of Water Hyacinth
Monitoring for *Neochetina* spp. was carried out every 2-3 months along the main waterway of the So and in two separate sites near Sagon on the Oueme. The spread of the weevils was estimated from feeding scars by adults, larval tunnels, and the recovery of adult beetles.

For months after the release, infestations remained localized on a few square metres around each group of release plants, which were blocked. At one site near Togbota Ague, e.g., fishermen removed most infested water hyacinth, despite numerous information campaigns. At a nearby site adjacent to a sacred (`fetish') forest, however, people did not disturb the plants because of cultural taboos. When the river started flowing, infested water hyacinth plants were carried downstream. They lodged among uninfested water hyacinth plants so that, even in the most highly infested mats, only 50% of all leaves showed feeding scars.

At Tevedji, *N. eichhorniae* infestation increased rapidly among water hyacinth of a pond. By April 1992, 50% of all leaves showed feeding damage, and larvae and adults were found frequently. By then, 80% of all leaves had long petioles. Soon after, many leaves turned brown due to an infestation by the fungus *Myrothecium roridum* Tode ex Fr. (Fungi, Hyphomycetes). By October 1992, all leaves - 90% with long petioles - were damaged by *N. eichhorniae*. Plants were often brown and dying, flowering had ceased and only very few daughter plants were produced. By October 1993, water hyacinth population density had been reduced and by mid-1995 grasses had grown into the weakened water hyacinth cover.

During the 45 months since the first release, *N. eichhorniae* populations have increased and spread. In a light trap, consisting of an illuminated bedsheet, numerous *N. eichhorniae* adults of both sexes were caught over a distance of sometimes over 100 m from the nearest water hyacinth, across bush. By the mid-1995, all accessible water hyacinth infestations had this weevil. Monitoring of several sites, which continues, revealed a reduction in coverage by water hyacinth and a corresponding increase in the number of feeding holes in the leaves within two years of release.

Among the sites where *N. bruchi* had been released, one was destroyed by fishermen. At two sites, one of them near a `fetish' forest, the infestation remained undisturbed. Five months after release, feeding scars were found on only a few leaves; but half an year later, feeding scars were numerous, adult beetles were recovered, and the infestation had spread 500 m. Despite the presence of *N. eichhorniae*, these populations persisted, but up to 1995 were not able to spread far.

S. albiguttalis was monitored by searching for larval tunnels and adult exit holes, by rearing plant samples, and observing insects attracted to illuminated bedsheets. Despite intensive searching, no recovery could yet be made.

Collaboration with National Programs
Based on the experience in Benin, adults of both weevil species were sent to Ghana, Uganda, Zimbabwe, Kenya, and Tanzania, and *N. bruchi* only was sent to Nigeria (Table 2). Some were released and some were used for local rearing. The results of these activities are presented by other participants in this workshop.

The recipients of these insects were all members of the national biological control programs. During the implementation phase of the biological control project against the cassava mealybug, Plant Health Management Division (PHMD) had assisted national scientists to coordinate their research in sustainable plant protection, particularly biological control, drawing together concerned scientists and administrators from the different ministries, national institutes, and universities. This assistance was coordinated and executed by the Technology Transfer and Training Unit (TT&TU), with German, Swiss, and Austrian funding. It usually consisted in training (in-country courses on monitoring of a particular pest and its natural enemies and their rearing, degree-related training), materially assistance (laboratory equipment, travel allowances, cars, insectaries), as well as provision of exotic natural enemies. This organization constituted the framework, in which biological control of floating water weeds could and can be executed efficiently and speedily.

Another aim of TT&TU is to support south-south cooperation. With this perspective in mind, 200 water lettuce weevils, *N. affinis*, originally supplied by CSIRO to Zimbabwe, were brought to Cotonou for maintenance on November 20, 1993. When Senegal was ready to accept this species, about 1000 were shipped to the Senegalese national program and support was provided for surveys and further rearing (Table 2). The beetles were used for rearing and release in the Reserve du Djoudj, on the Mauritanian border, where water lettuce, *P. stratiotes*, caused problems in the famous nature reserve.

From the same weevil cultures, a total of 1700 adults were later released in six localities in the lower reaches of the Mono River, where *P. stratiotes* is covering up swamps that are important fishing grounds (Table 3). Two months after the release, larvae were recovered in both monitoring sites.

Table 1. Releases of two weevils, *Neochetina eichhorniae* and *N. bruchi*, and the moth *Sameodes albiguttalis* for biological control of *Eichhornia crassipes* in Benin, from 1991 to 1995, and their status in August 1995

Species	**Locality**		**Date**	**Number of** **adults**	**immatures**	**Result**[1]
N. eichhorniae	Togbota Agué		11-12-91	0	3158	E
			19-02-92	0	4002	
	Sagon/ Lac Sélé		23-12-91	35	1136	E
			22-04-93	600*	0	
	Sagon/Lihu		23-12-91	0	696	E
	Sagon/Tévèdji		17-02-92	30	3301	E
	Togbota Oudjra		16-03-92	0	2207	(E)
			10-08-92	1500*	0	
			23-12-92	884*	0	
	Kpokpago		17-04-92	200	1677	E
	Akpomè		29-05-92	315	0	(E)
			07-12-92	985*	450	
	Sagon/Tévèdji[#2 SITE]		21-01-93	800	0	E
	Togbota Agué/ Douaffa		22-02-93	800	0	E
	Kpokpago/ Bossa		03-05-93	100	600	E
	Kpokpago/ Yaago		03-05-93	130	300	E
	Banikoara		07-06-95	200	0	?
Total				6579	17527	
N. bruchi	Danko/ Togbodan		14-10-92	150	295	E
			23-03-93	150*	692	
	Forêt Danko		14-10-92	100	492	E
	Danko/ Agonguè		14-10-92	50	372	E
	Adjohon/Gouti Sêkanmey		25-11-92	400	0	E
	Djigbe/ Togoudo		25-03-93	562	603	E
	Djigbe/ Déué		06-05-93	130	1750	E
	Sagon		15-07-94	120	1328	R
	Banikoara		07-06-95	450	0	?
Total				2112	5532	
S. albiguttalis	Sagon		13-12-93	0	162	NR
	Godolo		27-01-94	0	165	NR
	Sagon		16-07-94	0	284*	
	Sagon		03-03-94	0	115*	
	Sagon		28-03-94	0	125*	
	Godolo		27-04-94	0	187*	
	Sagon	10 to	26-05-94	0	705*	
	Godolo		16-06-94	0	300*	
	Sagon	16-2 to	11-07-95	0	230*	
	Sagon		28-08-95	0	150*	
Total				0	2423	

1 E= establishment, i.e., recovery after ≥1yr; (E)= establishment highly probable, but result confounded by renewed releases before 1 yr had passed; R= recovery, i.e., after ≤1yr; NR= no recovery.
* Additional releases to speed up eventual impact or to improve chances for establishment.

Table 2. Shipments of weevils, *Neochetina eichhorniae* and *N. bruchi*, for biological control of *Eichhornia crassipes*, and of *Neohydronomus affinis* for biological control of *Pistia stratiotes*, from Benin to other African countries from 1991 to 1995, for rearing and release

Species	Country/Locality	Date	Number of adults
N. eichhorniae	GHANA, Accra	15-07-93	200
	UGANDA, Kampala	30-07-93	600
	ZIMBABWE, Harare	15-10-93	600
	KENYA, Nairobi	05-11-93	250
	TANZANIA, Kibaha	01-04-95	118
N. bruchi	GHANA, Accra	15-07-92	200
	UGANDA, Kampala	30-07-93	200
	ZIMBABWE, Harare	15-10-93	600
	KENYA, Nairobi	05-11-93	250
	NIGERIA, Lake Kainji	01-02-95	250
	TANZANIA, Kibaha	01-04-95	250
N. affinis	SENEGAL, Dakar	18-07-94	1037

Table 3. Releases of the weevil *Neohydronomus affinis* for biological control of *Pistia stratiotes* in the southern Mono province of Benin and status in August 1995

Locality	Date	Number of adults	Status[1]
Adjaha	20-06-95	240	R
Lètan	20-06-95	320	?
Sè	20-06-95	320	R
Batoto	20-06-95	300	?
Nissouna	20-06-95	50	?
Sazuè Houndjonoudji	21-07-95	250	?
	24-08-95	220	?

[1] see Table 1.

DISCUSSION

Water hyacinth has been brought under good biological control in a number of countries (Harley, 1990), including the Nile system in Sudan (Beshir & Bennett, 1985). The incidence of adult feeding and the recovery of larvae and adults indicate that *E. eichhorniae* as well as *N. bruchi* are firmly established in Benin. The two weevil species differ slightly in their ecological niche, *N. bruchi* preferring bulbous leaves (DeLoach & Cordo, 1976). In Benin, *N. eichhorniae* proved to be the dominant species and is now found in all sites where water hyacinth occurs.

There still is no evidence of establishment of *S. albiguttalis* twenty months after the first release. It must, however, be remembered that initial establishment and dispersal of this species was also slow in Florida (Center, 1984).

The situation with water hyacinth in Benin is typical for coastal West Africa, but differs from infestations in many other parts of the world. In Benin, extensive annual flooding makes access difficult and continuously changes the basis against which weed densities are measured. This asks for a variety of monitoring techniques, including aerial photography, as discussed in van Thielen *et al.* (1994).

Another, more critical, variable is that the lower reaches of the infested waterways become saline during the dry season so that water hyacinth is killed. The immature *Neochetina* spp. in these plants die. However, adults can fly and may relocate to undamaged plants. It is known that salt water intrusion (probably to a lesser extent than found in the present study) did not slow biological control in Louisiana, USA (Center *et al.*, 1989). Continued monitoring in Benin will reveal whether *Neochetina* spp. populations increased sufficiently to reduce water hyacinth to non-noxious levels.

In the present study, we often encountered a conflict between scientific recording of the slow spread and impact of theses biological control agents and the perceived need for action to satisfy the fishermen. This resulted in repeated releases in the same localities, which were scientifically unnecessary but politically important. It was observed that the slow impact of these beetles undermined the initial confidence of the fishermen and lowered their willingness to leave release sites untouched. Under the conditions of rural Benin, the use of growth retardants to speed up control (Center *et al.*, 1982; Van 1988) is however, considered impossible. Whether the use of indigenous pathogens (Charudattan, 1990), particularly *M. roridum* (Caunter & Seeni, 1990), a common cosmopolitan pathogen of many different plants, is possible remains to be seen.

Both weevils have meanwhile been sent to other countries where IITA through its TT&TU supports plant protection activities. In order to achieve control of floating water weeds, other exotic species often need to be targeted too. All are best controlled by classical biological control (Center *et al.*, 1989; Harley *et al.*, 1990). For this reason, the water lettuce weevil, *N. affinis* was imported from Zimbabwe with the assistance of TT&TU for release in Senegal. IITA, in collaboration with other institutions worldwide, is now ready to assist all countries of the region in a comprehensive control of floating water weeds.

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GROUP DISCUSSION

Orach-Meza: Is it possible that these insects might undergo some sort of adaptation or genetic change which would allow them at later stage to attack other plants. In fact, when we tested adult weevils in the laboratory, they fed on banana, cabbage, but they were not capable of reproducing on these plants.

Neuenschwander: As you just confirmed, these insects are very specifically linked to water hyacinth. Under forced condition in the laboratory, they indeed might nibble on other food sources, but they are not capable of reproducing on another plant than water hyacinth. It has never been observed in other biological control projects that such specific arthropod agents would change their hosts.

Neser: How do they attach themselves to the particular species of water hyacinth?

Neuenschwander: The links are very specific. The larvae tunnel in the petioles of the leaves, descending into the heart of the plant. The pupae are in cocoons attached to the roots in open water. Interestingly, pupae survive also if the surrounding water is of very bad quality and low in oxygen. With this biology, the weevil would not be expected to attack terrestrial plants, for example.

Pieterse: Do you know whether *Neohydrnomous affinis* has been released in the Djoudj National Park in Senegal?

Neuenschwander: To the best of my knowledge, Senegal rears the weevils in Dakar and in Richard Toll, and had probably made releases also in the nearby Djoudj park. Communication among scientists within the same country is, however, a perennial problem.

Terry: Do you note the presence of pathogens?

Neuenschwander: Yes, we do, but we do not know their effects.

Charudattan: I'll make the point that we are often ignorant as to the types of pathogens that are present. We know what are present in the United States and South America. Some good work has been done in Australia and we are working with scientists in many other countries. Perhaps Africa will have the answer for biological control with pathogens.

INTEGRATED CONTROL OF AQUATIC WEEDS IN GHANA

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INTRODUCTION

Until the implementation stages of the Volta River Project at Akosombo, no systematic work had been conducted on the aquatic plants/weeds in Ghana. However, taking a cue from the problems caused by the 'Kariba weed' *Salvinia molesta* in Lake Kariba soon after its formation, the University of Ghana established the Volta Basin Research Project and conducted preliminary studies on the aquatic plants of the Volta Basin. These initial studies formed the basis of scientific studies on the aquatic flora of Ghanaian water bodies.

Since these beginnings in the early 1960s, various water bodies (lakes, lagoons, streams, rivers, ponds and dug-outs country-wide (Fig.1) have experienced the invasion, establishment and growth to nuisance proportions of various species of water plants. These include submerged (*Ceratophyllum, Vallisneria, Potamogeton*), free floating (*Pistia, Salvinia, Azolla*), emergents (*Echinochloa, Vossia, Phragmites, Typha*) and 'Sudd' formers (*Scirpus, Leersia, Vossia, Echinochloa*), among others.

The establishment, growth and proliferation of aquatic weeds interfere with the proper utilization and management of the water resources in Ghana for a variety of purposes. In this respect, noxious aquatic weeds adversely affect the Ghana Government's desire to provide safe and adequate potable water for the people and industry, reduce the fisheries potential in large water bodies and fish culture ponds, block drainage, irrigation canals and pumps; screens and turbines of hydroenergy production plants, spoil the aesthetic value of water for recreation and tourism and finally threaten the existence of wildlife populations.

The management of aquatic weeds in the country have been mostly on ad hoc basis and involves manual or mechanical removal and the application of herbicides. These methods have often either had no long term advantages, been too expensive or invariably unacceptable particularly in impoundments for potable water production. The use of biological control started in the mid 1980s with the receipt from Israel of the grasscarp *Ctenopharyngodon idella*. Following that a two-year biological control program for water hyacinth funded by the Austrian Government with support from International Institute of Tropical Agriculture/Plant Health Management Division (IITA/PHMD), Cotonou, was initiated in 1993.

The current two-year project on Integrated Control of Aquatic Weeds in Ghana, supported by EEC through FAO, was began in September 1994. The emphasis is on the biological control of the floating water weeds *Eichhornia crassipes* (water hyacinth), *Salvinia molesta* (Kariba weed) and *Pistia stratiotes* (water lettuce).

OBJECTIVES

The project aims at assisting the Ghana National Water hyacinth Control Committee which is coordinated by the Environmental Protection Agency (EPA) of Ghana to undertake public education and awareness programs on the problems, causes and management of noxious water weeds in Ghanaian water bodies.

Furthermore, it is to assist in the conduct of research and management activities concerning noxious aquatic weeds in Ghana.

Finally, it is to help develop and initiate appropriate methodologies, strategies and technologies to ensure the sustainability of aquatic weeds management programs in Ghana. In this respect, it is envisaged that the long-term vision in aquatic weeds management will be the strengthening of the biological control capabilities.

PROGRESS OF PROJECT

Surveillance
Various water bodies countrywide have been surveyed and their locations, uses and weed infestations/cover recorded (Tables 1 and 2). In addition, the major aquatic and semi-aquatic macrophytes encountered in Ghana have been documented (Table 3). The alien species recorded include *Eichhornia crassipes* (Pontederiaceae) in 1984 in Accra and 1990 in Tano lagoon; *Limnocharis flava* (Butomaceae) in 1994 in Wiwi and Subin rivers in Kumasi; *Salvinia molesta* (Salviniaceae) in 1994 in Tano lagoon; *Vallisneria gigantea* (Hydrocharitaceae) in 1995 in Birim River at Bunso.

Public Education/Awareness Campaigns
The print and electronic media have been used at various points to educate the public nationwide. In addition, whenever water bodies are visited the project interacts with the local peoples who are briefed on aquatic weeds, their problems and how the locals could help curb their spread and effect control. In addition, all water-related agencies and the Plant Protection and Regulatory Services have been advised to be more vigilant to look out for these alien weeds.

A video documentary is being made whilst posters (on the floating weeds) are being printed for countrywide distribution.

Since the project was informed of the invasion of the Red, Black and White Voltas in Burkina Faso by water hyacinth, the District Assemblies in the Northern, Upper East and Upper West regions of Ghana which border on the three river systems, have been briefed on the implications of the invasion to the riverine peoples and the country as a whole.
The project believes that intensive countrywide public education holds the key to curbing the spread of these noxious weeds in Ghana. The aim is to confine the noxious weeds to their present locations in Ghana.

Control Methods Instituted
Some manual and herbicidal treatment have been conducted on small scale in Accra. The efficacy of treatment and costs involved are presented in Table 4. The EPA has not cleared for use 2,4-D the herbicide of first choice. It is envisaged that large field trials with glyphosate, which has been cleared, will be conducted after the mission of a representative from Mosanto (glyphosate manufacturer) to Ghana in September 1995 to assess the project's needs.

In addition, the project has given advise to the Volta River Authority in the management of 'Sudds' along the shoreline of the Kpong Headpond. The 'Sudds', some up to 1 metre in thickness and heavy (450 to >1000 kg per metre square), floating in up to 3 metres depth of waters are being effectively but slowly manually cleared at about US$2,000 per acre.

Biological control of water hyacinth first initiated through the IITA in 1993 has been the basis of the colonies of *Neochetina bruchi* and *Neochetina eichhorniae* being reared at the University of Ghana and Jewi Wharf (or Tano lagoon) respectively. More rearing units are to be set up on the Tano Lagoon. An animal house at the University of Ghana has been rehabilitated for use as an insectarium to rear the bioagents. Currently the project has received 200 adult beetles of *Neohydronomus affinis* from Plant Protection Research Institute in South Africa, to rear for the control of *Pistia stratiotes*. A rearing unit is being set up in the Kpong Headpond for field rearing of the *Neohydronomus* beetles.

Also expected in the near future are the bioagents *Cyrtobagous salviniae* for *Salvinia* and *Sameodes albiguttalis* for water hyacinth. The numbers of *Neochetina* beetles released on monthly basis so far are presented in Table 5.

The insects since their release have become well established throughout the Ghanaian side of the Tano/Abby Lagoon (see Figs. 2 and 3). Some have been recorded from the Ivorian side at Frambo.

A physical barrier (50-100 metres long) made out of bamboo is to be erected to protect and free the Jetty at Jewi Wharf on the Tano/Abby Lagoon Complex from the floating weeds.

A Steering Committee whose membership was drawn basically from the National Water hyacinth Control Committee was inaugurated in June 1995 (see attached for membership). It will oversee and advise on the activities of the project in Ghana.

To enhance the project's work, some office equipment and software have been procured. A field vehicle with a driver, field assistants and a secretary to complement the work of the Coordinator.

In conclusion, the project on Integrated Control of Aquatic Weeds, though initially a two-year program, hopes at the end of the project to have created first and foremost awareness amongst the Ghanaian public, especially the riverine communities, on the problems of aquatic weeds and how to manage them. This, the project believes, if successful will be half the problems of weeds management solved. The next is to ensure that managing authorities of water bodies with weeds problems/envisaged weeds problems develop the capacity to combat the weeds using available expertise, strategies, manpower and material resources. Furthermore, call for the strengthening of the capacity of the Plant Protection and Regulatory Services of the Ministry of Food and Agriculture to police all entry points into Ghana to check the importation of unwanted flora into the country.

Last but not the least, the project hopes to institute a network for the exchange of ideas and expertise on water weeds management.

MEMBERSHIP OF STEERING COMMITTEE ON PROJECT GCP/GHA/026/EEC - INTEGRATED CONTROL OF AQUATIC WEEDS IN GHANA

The members of the Steering Committee are drawn basically from within the membership of the National Water hyacinth Control Committee which is coordinated by the Environmental Protection Agency (EPA) of Ghana.

They are made up of the following:
Chairman: The Executive Director, Environmental Protection Agency (EPA)
Members:

1. Representative of the FAO Regional Office for Africa, Accra.
2. Representative of the Volta River Authority (VRA)
3. Representative of the Ghana Water & Sewage Corporation (GWSC).
4. Representative of the Plant Protection & Regulatory Services (PPRS) of the Ministry of Food & Agriculture.
5. Representative of the Ministry of Foreign Affairs.
6. Representative of the Ghana Armed Forces.
7. Representative of the Information Services Department of the Ministry of Information.
8. Representative of the Institute of Aquatic Biology (IAB).

Table 1. Some major water bodies, their locations and use

NAME OF WATER BODY	REGION	DISTRICT	MAP COORDINATES		USAGE
VEA	Upper East	Bolgatanga	0°54'W	0°57'N	Irrigation/Fisheries
TONO	Upper East	Kasena Nankani	1°10'W	10°54'N	Irrigation/Fisheries
BONTANGA	Northern	Tolon Kumbingu	1°04'W	9°30'N	Irrigation/Fisheries
AKUMADAN	Ashanti	Offinso	2°00'W	7°30'N	Irrigation
BAREKESE	Ashanti	Atwinma (Owablagya)	1°50'W	6°54'N	Potable Water/ Fisheries
OWABI	Ashanti	Atwima	1°54'W	6°45'N	Potable Water
NOBEWAM	Ashanti	Ashanti Akim North	1°20'W	6°42'N	Irrigation
OKYEREKO	Central	Awutu/Afutu/Senya	1°25'W	5°27'N	Irrigation
KWANYARKO	Central	Ajumako Gomoa	1°20'W	5°30'N	Potable Water
MANKESIM	Central	Mfantsiman	1°00'W	5°27'N	Irrigation/Fisheries
KAKUM (BRIMSU)	Central	Cape Coast	1°20'W	5°15'N	Potable Water
INCHABAN	Western	Shama Ahanta East	1°45'W	5°3'N	Potable Water
TANO LAGOON	Western	Jomoro	3°00'W	5°10'N	Transport/Fisheries
KPONG HEADPOND	Eastern	Asuogyaman	0°06'E	0°57'N	Potable Water/Power Generation/Fisheries
ASUTUARE	Eastern	Manya Krobo East	0°15'E	6°10'N	Irrigation
LOWER VOLTA RIVER	Eastern/Volta/Greater Accra	Manya Drobo East/North & South Tongu/Dangbe/East/Anio	0°10'E-0°45'E	5°45'N-6°10'N	Irrigation/Fisheries/ Transport
ADIDOME	Volta	North Tongu	0°36'E	6°10'N	Irrigation
AFIFE	Volta	Ketu	0°57'E	6°10'N	Irrigation/Fisheries
WEIJA	Greater Accra	Accra Metropolitan Area	0°20'W	5°36'N	Potable Water Fisheries/Irrigation
DAWHENYA	Greater Accra	Dangbe West	0°05'E	5°48'N	Irrigation/Fisheries

ASHAIMAN	Greater Accra	Tama	0°03'W	5°45'N	Irrigation
VOLTA LAKE	Northern, Brong Ahafo, Volta, Ashanti, Eastern	Many	0°24'E-1°30'W	6°10'N-9°15'N	Power Generation/ Transport/Fisheries
PAWN PAWN	Eastern	Manya Krobo Asuogyaman	0° Greenwich 6°15'N-6°30'N		Fisheries/Transport/ Power Generation
DAYI	Volta Lake	Kpandu	7°30'N-7°36'N	0°20'E	Fisheries/Transport/ Power Generation
AFRAM	Eastern	Kwahu North, Kwahu South, Fanteakwa, Manga Krobo	6°36'N-6°58'N	0°05'W-0°50'W	Power/Fisheries/ Transport/Irrigation
OBOSUM	Eastern	Kwahu North	7°12'N	0°15'W-0°08'W	Fisheries/Transport/ Power Generation
DWIJA	Eastern/Brong Ahafo	Kwahu North, Sene	7°30'N	0°05'E-0°12'W	Fisheries/Transport/ Power Generation
SENE	Brong Ahafo	Sene	7°30'N-7°45'N	0°40'W-0°10'W	Fisheries/Transport
DAMANGO	Northern	Damango	9°06'N	1°48'W	Power Generation
BUSUNU	Northern	Damango	9°12'N	1°32'W	Potable Water/ Animal Watering/ Fisheries
ACHUBUNYO	Northern	Damango	1°32'W	9°10'N/1°40'W	Potable Water/ Animal Watering/ Fisheries
NVEYE	Western	Jomoro	5°00'N-5°25'N	2°53'W-2°56'W	Potable Water/ Animal Watering/ Fisheries
TONO RIVER (A to B)	Western	Jomoro	2°54'W-2°56'W	5°05'N	Fisheries/Transport
TANO RIVER (B to C)	Western	Jomoro	2°54'W	5°03'N-5°05'N	Fisheries/Transport
SAKUMO LAGOON	Greater Accra	Tema	0°02'W-5°35'W		Fisheries/Ramsar Site
KORLE LAGOON	Greater Accra	Accra	0°10'W	5°30'N	Fisheries/Ramsar Site

Table 2. Water bodies, their weed problems and managing authorities

Name of Water Body	Major Weed Genera	Area Covered by Weeds	Managing Authority
BAREKESE	*Pistia, Ceratophyllum Oxycaryum, Polygonum*	11-40% 71-100% (During Harmattan)	Ghana Water & Sewerage Corporation (GWSC)
OWABI	*Ceratophyllum, Leersia Ludwigia, Typha*	11-40%	Ghana Water & Sewerage Corporation (GWSC)
NOBEWAM	*Cyperus, Typha*	11-40%	Irrigation Development Authority (IDA)
OKYEREKO	*Typha, Pistia, Ludwigia, Panicum*	11-40%	Irrigation Development Authority (IDA)
KAKUM (BRIMSU)	*Pistia, Leersia, Polygonum*	11-40%	Ghana Water Sewerage Corporation (GWSC)
TANO	*Vossia, Leersia, Eichhornia, Salvinia*	11-40%	Central Government (Jomoro District)
KPONG HEADPOND	*Typha, Ceratophyllum, Vossia, Vallisneria, Phragmites, Potamogeton Echinochloa, Pistia*	41-70%	Votal River Authority (VRA)
ASUTUARE	*Aponogeton, Ceratophyllum Nymphaea*	1-10%	Irrigation Development Authority (IDA)
LOWER VOLTA RIVER	*Typha, Vallisneria, Phragmites, Ceratophyllum, Vossia, Potamogeton, Echinochloa*	71-100%	Central Government Ghana Highways Authority (GHA)
WEIJA	*Typha, Ipomoea, Echinochloa, Ceratophyllum, Oxycaryum, Leersia, Pistia*	11-40%	Ghana Water & Sewerage Corporation (GWSC)
DAWHENYA	*Echinochloa, Panicum, Nymphaea*	1-10%	Irrigation Development Authority (IDA)
ASHAIMAN	*Panicum, Nymphaea, Typha*	1-10%	Irrigation Development Authority (IDA)
SENE	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)

DAMANGO	*Pistia, Nymphaea, Panicum, Paspalum, Cyperus*	1-10%	Damango District Council
BUSUNU	*Pistia, Nymphaea, Cyphaea, Cyperus, Paspalum, Alternanthera*	1-10%	Busunu Town Committee
ACHUBUNYO	None	0%	Achubunyo Town Committee
NVEYE	*Eichhornia, Salvinia, Pistia, Vossia, Nephrolepis Cyrtosperma*	41-70%	Jomoro District Council
TANO RIVER (A to B)	*Eichhornia, Vossia, Cyrtosperma*	71-100%	Jomoro District Council
TANO RIVER (B to C)	*Eichhornia, Vossia, Cyrtosperma*	71-100%	Jomoro District Council
SAKUMO LAGOON KORLE LAGOON	*Typha, Pistia, Paspalum, Ipomoea, Cyperus* *Eichhornia, Pistia, Ludwigia, Typha, Paspalum*	11-40% 11-40%	Tema Municipal Assembly Accra Metropolitan Assembly
PAWN PAWN	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
DAYI	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
AFRAM	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
OBOSUM	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
DWIJA	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
SENE	*Pistia, Scirpus, Vossia, Ceratophyllum, Echinochloa, Polygonum*	11-40%	Volta River Authority (VRA)
DAMANGO	*Pistia, Nymphaea, Panicum, Paspalum, Cyperus*	1-10%	Damango District Council

BUSUNU	*Pistia, Nymphaea, Cyphaea, Cyperus, Paspalum, Alternanthera*	1-10%	Busunu Town Committee
ACHUBUNYO	None	0%	Achubunyo Town Committee
NVEYE	*Eichhornia, Salvinia, Pistia, Vossia, Nephrolepis Cyrtosperma*	41-70%	Jomoro District Council
TANO RIVER (A to B)	*Eichhorniae, Vossia, Cyrtosperma*	71-100%	Jomoro District Council
VOLTA LAKE	*Pistia, Polygonum, Vossia, Ceratophyllum, Echinochloa*	1-10%	Volta River Authority (VRA)
TONO	None	0%	Irrigation Company of Upper Region (ICOUR)
VEA	None	0%	Irrigation Company of Upper Region (ICOUR)
INCHABAN	*Pistia, Ludwigia*	1-10%	Ghana Water & Sewerage Corporation (GWSC)
MANKESIM	*Pistia, Nymphaea, Polygonum, Ceratophyllum, Cyperus*	11-40%	Irrigation Development Authority (IDA)
KWANYARKO	*Pistia, Echinochloa, Ceratophyllum, Typha*	11-4-%	Ghana Water & Sewerage Corporation (GWSC)
AFIFE	*Cyperus, Typha*	1-10%	Irrigation Development Authority (IDA)
AKUMADAN	*Oxycaryum (Scirpus), Alternanthera, Cyclosorus, Azolla*	71-100%	Irrigation Development Authority (IDA)
ADIDOME	*Pistia, Cyperus, Ludwigia*	11-40%	North Tongu District Assembly
BONTANGA TANO RIVER (B to C)	None *Eichhornia, Vossia, Cyrtosperma*	0% 71-100%	Irrigation Development Authority (IDA) Jomoro District Council
SAKUMO LAGOON	*Typha, Pistia, Paspalum, Ipomoea, Cyperus*	11-40%	Tema Municipal Assembly
KORLE LAGOON	*Eichhornia, Pistia, Ludwigia, Typha, Paspalum*	11-40%	Accra Metropolitan Assembly

Table 3. Major aquatic and semiaquatic macrophytes encountered in Ghana (Life-form: EM (emergent); FF (free-floating); FL (floating-leafed); SU (submerged); * - alien species

LIFE FORM	SPECIES	FAMILY
EM	*Alternanthera sessilis*	Amaranthaceae
FF	*Azolla pinnata*	Salviniaceae
SU	*Ceratophyllum demersum*	Ceratophyllaceae
EM	*Commelina gerrardii*	Commelinaceae
EM	*Cyclosorus striatus*	Thelypteridaceae
EM	*Cyperus articulatus*	Cyperaceae
EM	*Cyperus difformis*	Cyperaceae
EM	*Cyperus distans*	Cyperaceae
EM	*Echinochloa pyramidalis*	Gramineae
EM	*Echinochloa stagnina*	Gramineae
* FF	*Eichhornia crassipes*	Pontederiaceae
EM	*Ficus trichopoda (=congensis)*	Moraceae
EM	*Ipomoea aquatica*	Convolvulaceae
EM	*Leersia hexandra*	Gramineae
* EM	*Limnocharis flava*	Butomaceae
EM	*Ludwigia stolonifera*	Onagraceae
EM	*Luffa aegyptiaca*	Cucurbitaceae
EM	*Mimosa pigra*	Mimosaceae

Table 3 continued. Major aquatic and semiaquatic macrophytes encountered in Ghana (Life-form: EM (emergent); FF (free-floating); FL (floating-leafed); SU (submerged); * - alien species

LIFE FORM	SPECIES	FAMILY
FL	*Nymphaea lotus*	Nymphaeaceae
EM	*Panicum maximum*	Gramineae
EM	*Paspalum orbiculare*	Gramineae
EM	*Phragmites karka*	Gramineae
EM	*Pistia stratiotes*	Araceae
EF	*Polygonum senegalense (senegalense)*	Polygonaceae
EF	*Polygonum senegalense (albo-tomentosum)*	Polygonaceae
EM	*Potamogeton octandrus*	Potamogetonaceae
EM	*Rhyncospora corymbosa*	Cyperaceae
FF	*Salvinia nymphellula*	Salviniaceae
* FF	*Salvinia molesta*	Salviniaceae
EM	*Scirpus cubensis*	Cyperaceae
EM	*Typha domingensis*	Typhaceae
SU	*Utricularia stellaris*	Lentibulariaceae
SU	*Vallisneria aethiopica*	Hydrocharitaceae
* SU	*Vallisneria gigantea*	Hydrocharitaceae
EM	*Vossia cuspidata*	Gramineae

Table 4. Types and costs of water hyacinth control methods in 1995

TREATMENT	COST PER HECTARE GH ¢ (US $)	EFFICACY
Paraquat (Gramoxone) 10% Solution	604,800 (504)	90% Success 7 days after 1st Application. 100% success 5 days n after 2nd Application.
Glyphosate (ROUNDUP) 2% Solution	645,000 (538)	75% Success 7 days after 1st Application. 98% success one week after 2nd Application.
Physical Removal	6,200,000 (5,166)	Regeneration up to 20-30% of original area covered before removal 4 weeks after treatment.

NB: Average Dollar Rates US$1 = ¢1,200

Table 5. Releases of bioagents in the Tano/Abby lagoon complex

DATE	SITE	NOS. BIOAGENTS RELEASED	
		NEOCHETINA BRUCHI	***NEOCHETINA EICHHORNIAE***
February 26, 1995	V	244	192
April 1, 1995	VI	139	149
May 6, 1995	V	735	283
June 10, 1995	VII	259	464
July 8, 1995	VII	276	576
August 12, 1995	V	250	607
* March 5, 1994			
March 5, 1994	I	727	-
August 20, 1994	II	-	899
August 20, 1994	II	221	-
	IV	-	320

GROUP DISCUSSION

Pieterse: The 2,4-D test has not been cleared by your EPA, right? I see that you have the tested paraquat, on what basis was this decided?

de Graft Johnson: We have tested this on very small areas within Ghana. Now for next year's testing we hope that glyphosate and 2,4-D will be used. These will be very limited, on some small streams and applied from a craft. Now, before this we haven't attempted using Gramoxone (paraquat) on any large scale. In fact it wouldn't be cleared for use. But we saw a situation where we thought we must get rid of water hyacinth quickly and those infestations were in a small stream. So we quickly went in for the easiest available chemical. In addition, the stream was not being used for anything like drinking purposes. So we quickly went out there and used paraquat to wipe out water hyacinth in that stream. It is not implicit that paraquat would be used on any trials next year by the project.

As regards the problem with 2,4-D, I still can't understand. It appears that the Technical team of the Environmental Protection Agency, may have their own biases. I presume that is why there is the delay in clearing it. I have given the agency some available literature on the herbicides. It appears that someone insists that there is some literature which states that 2,4-D has something to do with haemoglobin or combines in the blood. I can't be too sure about that now. However, this person is insisting that there should be more information on that. Because of that the other members in the Technical Group cannot find their way to say, "O.K., go ahead and use it." I presume that is the result and you can't go ahead and use that herbicide.

There is also a possible use of some harvesters. We have in Ghana about 3 harvesters, 2 of British make. One is used on the Lake Volta and one on the reservoirs that provides water for Kumasi. That kind of harvester is not very efficient. You fix the cutter and after the cutting is done you have to remove the cutter and put on the rake. This harvester is called a Water Devil - it's British made. There is a harvester of German origin (Navalis) which is used in the lower water Volta River to clear landing sites for the ferries that ply the river.

Regarding the question of repairs to these crafts, the crafts have been imported, and the spares are not easily available. The Navalis harvester was out of order for months during the rehabilitation of one of the bridges in the lower Volta. The company undertaking the bridge repairs rehabilitated the harvester and is using it to clear the weeds in the area.

Otherwise it was out of use because the blades were blunt and they couldn't have replacements.

I believe there is a program between the Ghana Government and the Japanese Government. If it is approved, the Japanese Government would provide some harvesters, which we hope to use in the Tano/Abbey lagoon to clear access to villages and the Jewi Wharf that has often been blocked by these floating weeds, until certain other management practices could be put in place. But as far as I am concerned the agreement is not being signed and it's supposed to be harvesters plus barges, spares and some trucks.

Charudattan — What are the health effects of 2,4-D?

de Graft Johnson — We would appreciate having documents that detail the health effects of 2,4-D because we don't have access to that much information. So, if this is available and we have them either through the course of our stay here or later on, we could give it to the technical people who are in the process of having these chemicals. The information can help these people with their assessment.

Haller — There was a Swedish study and a study done in the mid-western United States on nontoxic nymphoma - a type of cancer. Those studies were reported about 5 years ago. And now the National Cancer Institute has done a thorough survey as well as the American College of Toxicology and we have a publication on that. Also the EPA is re-registering 2,4-D, glyphosate, and the entire aquatic group of herbicides. Re-registration of 2,4-D was supposed to happen, all brought up to standards by January of 1996. There have been some delays; maybe by January of 1997 it will be fully re-registered with all of the studies that have to be done before the registration. The word on the street, among the people that are using the materials, and the industry as well, is that there is no red flag, there is no major problems, and the availability 2,4-D to use in water in the U.S. will be continued.

Labrada — What about the formulation?

Haller — There will be 2 formulations used in the U.S.; actually 3 formulations. 1) 2-4,D acid - when the salt hits the water the acid, breaks down and you end up dealing with the acid. So, all of the registration studies had to be done with the acid. 2) The amine salt and the other salt that we used in submerged weed control is the butoxy form, used in the Tennessee valley and on up into Canada. So there are 3 and really 2 that are commercially available. The amine and the butoxy are both used in U.S. and Canada.

The maximum contamination level that is allowed in water in the U.S., 0.1 mg per litre, in potable water. The typical half-life in water ranges from 3 to 7 days for the amine. This number is established by the Environmental Protection Agency and it is at least 100 fold less than in the no-effect level.

De Graft Johnson — As I said earlier, it would be good to have publications to be given to our Environmental Protection Agency to have a look at. Then they will decide for or against allowing 2,4-D to be used. If there is anything that we are going to do, it has to be on a small scale, until the time that 2,4-D is approved.

Charudattan — Where from do you normally get all of your information or literature?

de Graft Johnson — Sometimes from the companies themselves, if they are willing to give it; sometimes they don't. I think its the agents who really know. Once the company wants to sell anything to Ghana, it has to seek clearance from the Agency. So I am surprised that they (Agency) doesn't have that much information. They should have more information on these things or they should insist that all the chemical companies give them as much details as possible if they don't have the right access to them.

THE WATER HYACINTH PROBLEM IN WEST AFRICA AND PROPOSALS FOR CONTROL STRATEGIES

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SUMMARY

Although the harmful effects of water hyacinth (*Eichhornia crassipes*), the world's most troublesome aquatic weed, are generally known, it seems impossible to stop its further spread. In the late 1970s water hyacinth was first observed in West Africa. Currently it is a serious problem in lagoons and rivers of the coastal regions of Ivory Coast, Benin and Nigeria. Recently, water hyacinth also invaded the Upper and Middle Niger river systems in Mali, Niger and Nigeria. It is expected that in the near future the Niger Inner Delta in Mali, which is one of the major wetland areas in Africa, will be infested. Recognizing the need for an integrated approach to manage the water hyacinth problem and to prevent a further dispersal in West Africa, the African Development Bank provided ECOWAS (the Economic Community of West African States) with a grant for a study of the current state of affairs. This study, which started in 1994, will last 18 months. It also includes the preparation of follow-up projects in areas where this is urgently needed. Six project proposals were drafted. In addition to a coordination unit for aquatic weed control at ECOWAS headquarters, these include five regional proposals for integrated control of floating aquatic weeds. Management of water hyacinth will mainly focus on a combination of biological control by means of the insects *Neochetina eichhorniae*, *N. bruchi* and *Sameodes albiguttalis*, and physical control by means of machines. However, manual control methods may also be applied if appropriate and economically feasible. Special attention will be devoted to public awareness campaigns to prevent further spread of water hyacinth and other exotic aquatic weeds in West Africa.

INTRODUCTION

Since water hyacinth [*Eichhornia crassipes* (Mart.) Solms], the world's most troublesome aquatic weed, was spread by man out of its original habitat in South America, it has left a trace of misery in tropical areas around the world (Pieterse, 1978; Gopal, 1987; Pieterse & Murphy, 1990). In the absence of its natural enemies the reproductive potential of this scourge is enormous. In addition, the water hyacinth's free-floating habit makes it a very effective colonizer of newly invaded fresh water bodies. It rapidly out competes other plant species and forms dense floating mats, which may completely cover the water surface. Consequently, the often multi-functional use of infested canals, rivers and lakes becomes seriously hampered. In addition to direct harmful effects, such as impeding transport of irrigation and drainage water, hindering navigation, interfering with hydroelectric schemes, it also brings about indirect negative effects. These include increased water loss by means of evapo-transpiration (transpiration via the plants) and increased health hazards by the formation of habitats which are favourable for the development of vectors of human diseases, such as malaria and schistosomiasis.

The water hyacinth tragedy is closely connected with its exotic, hyacinth-like flowers. This insidious plant is commonly marketed as an ornamental and it is astonishing that in most tropical areas, until the present day, strict regulations have not been enforced to prevent further dispersion. If it had been a relatively new phenomenon, this lack of legislation could have been more understandable. However, as far back as the 1890s, the plant already choked waterways in Florida, after it was introduced in the USA around 1884. Before the beginning of the twentieth century large scale control programs were initiated in the USA and from that time on the dangerous characteristics of water hyacinth have been common knowledge. In spite of the fatal invasion of the southern states of the USA, water hyacinth was spread into Africa, South East Asia and Australia in the early 1900s, mainly via introductions into botanical gardens. Thereafter it gradually started its dramatic advance in tropical and sub-tropical regions all over the world.

Although water hyacinth had been introduced in the Nile delta in Egypt around 1910, serious problems on the African continent did not occur until the 1950s, when dense masses developed in the Zaire river in Zaire and in the White Nile in the Sudan (Mitchell *et al.*, 1990). Subsequently, it was reported from the Pangani river in Tanzania, the Incomato river in Mozambique, the Sabi and Makabusi rivers in Zimbabwe, the Kafue river in Zambia and the Swartkops and Vaal rivers in South Africa.

Although in the infested areas in Africa control programs were implemented (Lebrun, 1959; Holm *et al.*, 1969; Koch *et al.*, 1978), further spread of water hyacinth on the African continent was not effectively stopped. During the past decade this has led to large scale infestation of Lake Victoria in East Africa as well as an alarming spread of water hyacinth in West Africa.

First reports on the occurrence of water hyacinth in West Africa appeared in the late 1970s. It was striking that these outbreaks were near big cities, such as Accra, Cotonou and Abidjan, and it may be assumed that the plants had been traded on flower markets. In the 1980s, water hyacinth rapidly became a problem in the coastal areas of Ivory Coast, Benin and Nigeria. In 1988 the Nigerian Federal Ministry of Science and Technology, with assistance of the Economic Community of West African States (ECOWAS), organized an international workshop on "Water hyacinth, Menace and Resource" in Lagos, Nigeria (Oke *et al.*, 1988). Recently, water hyacinth also invaded the Upper and Middle Niger river systems in Mali, Niger and Nigeria.

Recognizing the need for an integrated approach to cope with the water hyacinth problem as well as with other noxious floating aquatic weeds, ECOWAS requested the African Development Bank to finance a project on the current state of affairs. The proposed project, covering a period of 18 months, includes a study of the spread of water hyacinth and other noxious floating aquatic weeds, and the degree of infestation, in the ECOWAS region. An additional objective of the project is to prepare follow-up projects in the most heavily infested areas. It was proposed that these follow-up studies would focus on integrated control programs emphasizing biological and physical control. Only under certain conditions would chemical control be considered, such as in case of small-scale infestations of exotics, in newly invaded areas and in emergency situations.

In 1992 the African Development Bank provided ECOWAS with a grant to carry out this project. It was named "Control of Floating Weeds in the ECOWAS Member Countries" and was started in June 1994.

Details on the Spread of Water Hyacinth in West Africa

Water hyacinth was first reported in the region in 1977 (L. Fagbohoun, cited in Van Thielen *et al.*, 1994) in Benin. It started clogging up waterways in the Ouémé-Sô river system as well as in the Sô river with its adjacent flood plains and connected lagoons. Recently it also invaded tributaries of the Niger river in the far north of Benin.

In Nigeria, infestations of water hyacinth in the Badagry Creek, bordering Benin, were reported in local newspapers in 1982, and in 1985 the alarm of the invasion of Nigerian coastal creeks and lagoons was raised by one of the national newspapers. Since 1985, water hyacinth has spread throughout most of the inland coastal waters, rivers and creeks of the Delta area in Nigeria. Recently, it also invaded Lake Kainji (Farri & Chizea, 1995; Kusemiju 1995) and the river Niger upstream from this artificial lake. In Lake Kainji infestation is still relatively low, however, in certain parts of the lake a shore vegetation of water hyacinth has developed up to 5 metres wide.

In Ivory Coast water hyacinth appeared in the Ono lagoon, near Abidjan, at the beginning of the 1980s, after it was preceded by another exotic floating weed, *Salvinia molesta* D.S. Mitchell, a few years earlier (Bard *et al.*, 1991; Guiral & Etien, 1991). Subsequently, water hyacinth spread via the Comoé river into the Ebrié lagoon, between Grand Bassam and Abidjan.

In western Africa *S. molesta* is currently restricted to the lagoon system in Ivory Coast and the Tano lagoon, which is situated on the border of Ivory Coast and Ghana.

In Ghana, water hyacinth was first observed in the Accra/Tema metropolitan area in 1984 (DeGraft-Johnson, 1988). It was probably introduced as an ornamental in the East Legon quarter and spread via the Odaw river. Flowers of the water hyacinth were sold in the streets and subsequently the weed spread to the Kpeshie lagoon, which is Accra's main sewage outlet, and a lagoon at a distance of 45 km (the Sakumono lagoon). In 1990 water hyacinth appeared in the Tano lagoon, situated between Ghana and Ivory Coast. These plants had been transported from the Abidjan area via the lagoon system. Vast stretches of water hyacinth currently occur in the Tano lagoon. Together with hippo grass (*Vossia cuspidata* (Roxb.) Griff., they form large floating islands, on which even a bush vegetation has developed in certain areas. In the Tano river water hyacinth only occurs in the vicinity of the lagoon. It does not occur upstream, which also points to a spread of the weed from Ivory Coast. Water hyacinth is still absent in other areas of Ghana.

According to various sources, water hyacinth was first observed in Mali around 1990. From the area around the city of Bamako, where it has probably been sold as an ornamental, it rapidly spread into the river Niger and adjacent water bodies. Currently, infestation in the area around

Bamako is alarming. During the rainy season dense masses are flooded out of the creeks and tributaries into the main river.

In addition to the Bamako District, water hyacinth has spread into the Niger river system up to the Timbuktu region, which would imply that it has already infested the Niger Inner Delta. However, reliable data concerning the delta are still lacking. This delta is one of the major wetland ecosystems in Africa and a habitat for a large number of animal and plant species, including migrating birds from other African regions as well as from Europe. The floodplains are also important grazing lands for cattle. A large scale development of water hyacinth in the delta area could be disastrous.

In the Republic of Niger water hyacinth was first reported in the Niger river near the city of Niamey in 1988. Subsequently, the water hyacinth vegetation markedly increased and became a nuisance in the 1990s. During the 1994 rainy season water hyacinth plants were spread over the floodplains into the mouths of the tributaries in Tillabéry and Ayorou regions, 150 km upstream of Niamey. Less than 100 km of the total 550 km of the river Niger in the Republic of Niger is currently still free of water hyacinth. In 1992 water hyacinth plants were first recorded to flow into Nigeria via the Niger river.

According to the survey conducted in the framework of the project "Control of Floating Weeds in the ECOWAS Member Countries", water hyacinth did not occur in the other member states, with the exception of one site in The Gambia (a pond near the capital Banjul). However, after the survey a local newspaper in Burkina Faso reported that it was observed in some of the reservoirs in this country.

Ongoing Control Programs and Projects

Nigeria

In Nigeria, water hyacinth could be manually controlled during the first years of its invasion. However, in 1985 the infestation had increased to such an extent that manual control in the coastal waterways was no longer successful, and mechanical harvesters had to be introduced. Manual control in the coastal areas is currently mainly exerted to clear water hyacinth plants from canals, and mechanically treated areas. However, in the country's interior manual removal, organized through local initiatives, remains the major control method.

In 1985 the Nigerian Government established a National Committee on Water hyacinth, based at the National Agency for Science and Engineering Infrastructure (NASENI). This Committee coordinates activities through 5 sub-committees covering surveillance, biological, mechanical and chemical control, and practical uses of the weed. It has established bilateral relationships with both the republics of Benin and Niger. Furthermore, state and local Governments through various departments and ministries, as well as River Basin Authorities, involved in the management of water bodies, are in close contact with the National Committee on Water hyacinth.

Mechanical harvesting of the floating weeds proved to be very expensive as equipment needs to be available in sufficient numbers to enable regular clearance. Due to lack of funds, mechanical harvesting in the coastal areas is carried out on an ad-hoc basis by local companies. It is mainly concerned with opening water bodies which are completely blocked.

In light of the recent infestation of the Niger river, the Nigerian Government spent the bulk of its total budget for aquatic weed control of 2 million Naira in 1994, to mechanically clear the Niger upstream of the Kainji reservoir. At present, it is part of NASENI's program to purchase a large number of small units of mechanical harvesters, and to distribute these to local governments of the Niger river areas. Furthermore, it is planned to use physical barriers, such as booms, to increase the effectiveness of mechanical control efforts.

Chemical control of water hyacinth has been investigated by the Institute of Ecology of the Obafemi Awolowo University in Ile-Ife. Some creeks and channels in the Ogun, Ondo and Delta states were sprayed either aerially or from boats, and a high mortality rate was obtained by applying glyphosate, diquat, and terbutryn. However, the Nigerian Government is not in favour of chemical means of control, due to their negative effects on the environment and risks to human health. In this context water pollution by decaying weeds is also taken into consideration.

Biological control is considered by the Nigerian Government as a major tool for long term management of the water hyacinth problem. In 1992, rearing of the water hyacinth weevil, *Neochetina eichhorniae* (Warner), started at The Nigerian Institute for Horticulture (NIHORT), and releases are now in progress at various sites along the Niger river. So far, no weevils have been released by NASENI in the coastal states of Nigeria. However, the presence of weevils was recorded on water hyacinth plants in the Badagry Creek in 1994, which drifted into Nigeria from the Benin Republic, where weevils have been released. As the weevils were observed only recently, their effect on reducing the water hyacinth population has not become visible as yet.

Benin

Manual control through local initiatives is the major method of control. Mechanical harvesting is not practised. A biological control program started in 1991 by importing the weevil *N. eichhorniae* from Australia. This weevil was reared by the Plant Health Management Division of IITA (the International Institute of Tropical Agriculture), located in Cotonou, and released by the Department of Fisheries in Benin in cooperation with GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit). In addition, in 1992 the weevil *N. bruchi* Hustache was introduced and released in Benin. The development of the weevils is currently monitored in the various creeks and lagoons, but it is still too early to determine its impact on reducing the water hyacinth population.

Ghana

Chemical control.

In 1994 a chemical control program against water hyacinth was carried out, coordinated by the Institute of Aquatic Biology, in the city of Accra and adjacent areas. The herbicides which were used included paraquat and glyphosate. Water hyacinth seems to have been eradicated in the lagoons. However, it is still present in the small streams in Accra.

Biological control

A two-year project on the control of water hyacinth and other floating weeds in Ghana, coordinated by FAO and financed by the European Union was started in September 1994. This project will mainly be concerned with the control of water hyacinth by the weevils *N. eichhorniae* and *N. bruchi*, as well as the moth *Sameodes albiguttalis* (Warren), the weevil *Cyrtobagous salviniae* Calder & Sands for the control of *S. molesta* and the weevil *Neohydronomus affinis* for the control of the indigenous floating weed *Pistia stratiotes* L. Prior to the start of this project, in April 1994, *N. eichhorniae* and *N. bruchi* were released in the Tano river lagoon. These insects had been obtained from IITA in Benin and had subsequently been reared in ponds at the University of Ghana in Accra. Within the framework of the project "Control of floating weeds in the ECOWAS member countries" the release site was visited on October 29, 1994 and it was observed that the insects were spreading. The two-year project will also be concerned with mechanical and chemical control of aquatic weeds in Ghana. It is carried out by the Institute of Aquatic Botany (established in 1961 by the Council for Scientific and Industrial Research in connection with the formation of the Volta lake) and the University of Ghana.

Ivory Coast

Physical control

In the Ebrié lagoon system, situated between Abidjan and Grand Bassam, a control strategy was implemented based on the installation of barriers as well as the reopening (in 1987, 1989 and 1992) of the outflow of the river Comoé near Grand Bassam. This outflow was silted up after a new connection between the lagoon and the ocean was dug near Abidjan (the Vridi canal). The aim of using barriers is to confine floating weeds to the eastern part of the lagoon and in the creeks and river Comoé. However, if pressure of the floating weed masses increases, the bamboo barriers are not always strong enough and will break. By opening the outflow of the Comoé river large masses of floating weeds flooded into the ocean. These operations were very costly and caused several inconveniences, such as the breaking up of the road along the coast from Grand Bassam to Abidjan and destruction of various houses. As far as the weed control measures are concerned, an additional advantage of opening the river outflow near Grand Bassam was that this led to an increased salinity in the lagoon. Due to risks of coastal erosion it is not decided to permanently open the river outflow.

Biological control

In the framework of the project FEM (Fonds Mondial pour l'Environnement) it is scheduled to start a program on biological control of water hyacinth, *P. stratiotes* and *S. molesta* in Ivory Coast.

Niger
In 1989 the Department of Fauna, Fisheries and Fish Culture of the Ministry of Hydraulics and Environment started a public awareness campaign on the potential danger caused by water hyacinth. Subsequently, in 1991 a FAO mission was conducted on the aquatic weed problem in the Niger river. As loss in fish yields amounted to 40%, due to interference of water hyacinth plants with the use of nets, a manual control program was initiated. It was estimated that clearing 1 ha required 25-45 man-days.

Mali
In Mali, there are no governmental projects dealing with water hyacinth, and control of this weed is mainly conducted by hand through local initiatives, and by the electricity company. There are also proposals by interest groups to clear the Niger river from Baako to Ségou. In 1994 a World Bank mission was undertaken to determine the spread and the socio-economic impact of the presence of this weed in the Niger river system.

Proposed Follow-Up Projects Within the Framework of ECOWAS
In the draft final report of the project "Control of Floating Weeds in the ECOWAS Member Countries" six follow-up projects have been identified. These include:

1) An ECOWAS coordination unit for aquatic weed management;
2) Integrated control of floating weeds in the coastal areas of Benin and Nigeria;
3) Integrated control of floating weeds in the Middle Niger River Basin;
4) Integrated control of floating weeds in the Upper Niger River Basin;
5) Integrated control of floating weeds in the Tano River and reservoirs in Ivory Coast and Ghana;
6) Integrated control of floating weeds in the Lower Senegal River system.

The projects will mainly be concerned with the floating aquatic weeds water hyacinth, water lettuce and water fern. Water lettuce is endogenous in Africa, whereas water hyacinth and water fern are exotics. In all regions where follow-up projects are planned, water hyacinth is the most important aquatic weed, with the exception of the Lower Senegal River system. In this region, where water hyacinth does not occur as yet, problems have arisen with water lettuce after the construction of the Diama Dam, which prevents the inflow of salt water. Due to a change in ecological conditions, i.e. the brackish water has become fresh, dense mats of water lettuce have developed in various lakes.

So far water fern has only been observed in the lagoons in Ivory Coast and in the Tano lagoon on the border of Ivory Coast and Ghana. The ECOWAS Coordination Unit will coordinate and monitor projects of regional significance with the aim to pass on experience to the member countries. It will support the relevant national agencies in member countries in identifying and preparing projects, and, where necessary, in attracting external finance. Project implementation would be left to the member countries themselves.

The unit will also assist in institutional development and data base management, including geographic information systems (GIS), and in recording the environmental and socio-economic impact created by floating weed infestations.

In addition, the unit will establish a documentation centre containing data on the distribution of floating weeds, the methods of their control, their environmental and socio-economic impact, and their utilization, although this aspect will only be taken into consideration if mechanical harvesting is performed, and the collected floating weed material can indeed economically be used as a source of fertilizer or biogas, etc. Articles, leaflets and posters will be designed and issued to attract public awareness, and programs will be made for educational and training purposes.

The ECOWAS mandate, permitting harmonization and coordination of policies, programs and regulations, enables the unit to make a contribution to the legislation of using chemicals and biological control agents in various countries. The unit will render assistance to the Scientific and Technical Research Council (STRC) of the Organization of African Unities (ONU), which has its headquarters in Lagos. Among other things, STRC is engaged in examining the phytosanitary aspects of food products as well as of chemicals, including biological control agents, used for medical, agricultural and industrial purposes. STRC has its Inter-African Phytosanitary Council in Juanda, Nigeria, and deals with quarantine, standardization and legislation. The unit is in a position to avoid or solve potential regional conflicts caused by the use of certain products, which might be allowed in one country, but forbidden in another. This is done by examining complaints, assisting in settling disagreements, and by harmonizing legislation procedures in the countries concerned.

The direct objectives of the five regional projects are to establish, in concert with the governments of the countries involved, as well as with ECOWAS:

1) a fully equipped administrative and operational unit to implement the control program;
2) facilities for rearing biological control agents;
3) release of biological control agents and monitoring them in the release areas (which will include a study of their development and the damage they inflict upon the weeds at selected sites, with the aid of local communities);
4) implementation of physical control methods which will include the use of harvesters;
5) integration of biological and physical methods of control;
6) technical training in biological control and other techniques where appropriate.

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Region B - East and Southern Africa

Malawi - Terry

South Africa - Neser

Uganda - Orach-Meza

THE WATER HYACINTH PROBLEM IN MALA_I AND FORESEEN METHODS OF CONTROL

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INTRODUCTION

Alarmed by the proliferation of water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in the Lower Shire Valley and the reputed adverse affects of the weed on artisanal fisheries, the Mala_i Government Department of Fisheries sought assistance from the UK Overseas Development Administration (ODA) to characterize the problem and recommend a program of control. ODA's response was to hire the author as a consultant to visit Mala_i in September-October 1991 to (a) make recommendations for long term control and possible utilization of water hyacinth, (b) assess the impact of water hyacinth on fish stocks and the fishing industry, (c) discuss a weed monitoring and control program, and (d) prepare a project proposal on the control and utilization of water hyacinth in Mala_i. Literature reviews, a survey of the Lower Shire (Fig. 1) and consultations with Mala_i Government departments resulted in a report (Terry, 1991) from which much of this paper has been extracted.

Lower Shire, the Problem Area
The Lower Shire extends from the Kapachira Falls (ca. 15°54_ S) to the confluence with the Zambezi River after crossing Mala_i's southern border with Mozambique. It meanders through a flood-plain for a distance of about 200 km passing through two large marshes, Elephant Marsh (ca. 500 km^2) and Ndinde Marsh (ca. 150 km^2), which are important fisheries providing more than 10,000 tons of fish per year. Annual variations in water level and flow rate are 1.92 m and 635-1,404 m^3/sec, respectively. The lagoons and marshes are usually shallow (<2 m), with standing or slowly flowing water and make ideal habitats for aquatic macrophytes, especially floating plants (Blackmore, Dudley & Osborne, 1988). Shorelines can vary by over 1 km between the normal high and low water levels. Water hyacinth is left stranded on the muddy foreshore as the water recedes. Floods occasionally flush water hyacinth from the Lower Shire, a factor which may be detrimental to the establishment of biological control agents, as was found in South Africa (Cilliers, 1991).

The climate of the Lower Shire Valley is characterized by two well defined seasons: a dry season from May to October and a rainy season from November to April (SVADP, 1975). The annual rainfall is about 813 mm in the northern part of the Valley and about 711 mm around the centre. Temperatures fall to their lowest in June when the mean minimum and maximum for the Valley are 13.4 and 27.4°C, respectively. Temperatures rise rapidly through September to a mean monthly maximum of 37.5°C in October. Daily maxima of 40.9° C are quite common at this time. Such a climate is conducive to the growth of water hyacinth and the main predators that have potential as biological control agents.

The only report seen of chemical analyses of water in the Lower Shire is by Hastings (1976) who recorded monthly values at two sites, Chikwawa (near site no. 18) and Chiromo (near site no. 6). A summary of the variations within one year are shown in Table 1. It is not known what effect the use of agricultural fertilizers is having on nutrient levels in the Lower Shire but it is probably fair to assume that the increased use of fertilizers in the highlands (Dr G.K.C. Nyrendra, personal communication) accounts for some of the changes. Effluent and fertilizers from the SUCOMA sugar estate (near site no. 15) are entering the Shire River but the amounts are not known.

Table 1. Range of values for the chemical and physical analyses of River Shire water in 1975 (after Hastings, 1976)

Factor	**Chikwawa**	**Chiromo**
Water temperature (^{o}C)	20 - 27.5	17 - 27
Oxygen (ppm)	8 - 11	1 - 5
Oxygen (% saturation)	98 - 145	15 - 54
pH	8 - 10	7.5
Conductivity (μmmos/cm^2)	210 - 360	220 - 315
Chloride (ppm)	6 - 10	6 - 10
Total phosphate (ppm)	0.19 - 5.0	0.03 - 2.55
Nitrogen as nitrate (ppm)	4.7 - 11	5.9 - 25
Nitrogen as ammonia (ppm)	ND - 0.32	ND - 0.12

ND = not detected

Hastings (1976) also reported on the levels of DDT in fish in the Lower Shire. This insecticide was found in most fish samples, with the greatest amounts found in fish high up the food chain. These levels were below the limits defined by FAO as being acceptable (Dr. G.K.C. Nyrendra, personal communication). DDT is no longer used but cotton is extensively grown in the valley and is treated with other insecticides which could be entering the water, mud and biota of the river and marshes. Insecticides used in the highlands could also find their way into water courses entering the Lower Shire. Products currently being used in Mala_i include pyrethroids (several types), pirimiphos-methyl, carbaryl, dieldrin (use restricted), disulfoton, aldicarb, endosulfan and parathion-methyl. Residues of these products may have implications for the survival of predators that are released for the biological control of water hyacinth.

The main crops of the Lower Shire Valley are cotton, sugar cane, maize, groundnuts, pigeon peas, pearl millet, sorghum and rice. A range of vegetables and fruits is also grown. If herbicides are deployed to control water hyacinth, great care will be needed to avoid spray drift or excessive contamination of water used for irrigation. Cotton is particularly sensitive to 2,4-D, one of the cheapest and most effective herbicides applied to water hyacinth. Potential biological control agents of water hyacinth must not harm crops grown in the Valley. Water chestnut (*Trapa natans*

L.), a rooted aquatic macrophyte in the marshes and lagoons, is consumed by local people and, although it is a weed in its own right, should also not be harmed by any biological control organisms.

The Valley is one of the finest grazing areas in Mala_i and supports large numbers of livestock. However, cattle and goat populations are too high and overgrazing has become a problem, with a concomitant increase in soil erosion. There is potential for feeding livestock with water hyacinth, perhaps alleviating shortages of fodder.

Morphology of Water Hyacinth in the Lower Shire

The size of water hyacinth plants in the Lower Shire is very variable. Short plants of about 20-30 cm with swollen petioles are very common in lagoons and marshes. They are particularly prevalent on drying mud where very small plants of 10 cm or less are able to withstand occasional trampling by livestock. Large, slender-petioled plants of 60-70 cm are also common throughout the lagoons and marshes. They are also found in the muddy margins but are less robust than the small plants. The healthiest and largest plants (about one metre high) were found at Alumenda (site no. 14). Large and small plants can be found growing together or in separate colonies, but flowers are most commonly seen on the small plants.

Flowers of water hyacinth are borne on a terminal inflorescence. Each spike can have 4 to 35 flowers, but specimens examined on the small, swollen-petioled plants in the Lower Shire had 7 to 12 flowers with an average of 9.3 ± 1.35. Where the tall, slender-petioled plants had inflorescences, there were usually slightly more flowers (up to 16) per spike. The average style length of the flowers was 25.15 ± 0.48 mm, placing it within the mid-stylous classification used by Gopal (1987). Water hyacinth has three short and three long stamens. The average dimensions of the Lower Shire samples were 6.08 ± 0.59 mm and 19.52 ± 1.09 mm. With these dimensions of styles and stamens, the Mala_i material resembles that found in Brazil (Gopal, 1987).

The biomass of water hyacinth in Bangula Lagoon (area 10 km^2; water hyacinth cover 35%) was estimated to be 30,000 tons fresh weight (equivalent to 1,500 tons dry weight). If the same density was present throughout the marshes and lagoons of the Lower Shire, the total mass of water hyacinth would be 2 million tons fresh weight (100,000 tons dry weight).

Growth of Water Hyacinth

The conditions required for germination of water hyacinth from seeds in Mala_i are not known but the prevailing environment is comparable to conditions that promote germination elsewhere. A possible scenario is that seeds are produced in the shallow lagoons where they drop into the mud. As water levels fall, the mud and seeds dry out until water levels rise once more in the wet season. The seeds then germinate and contribute to the flush of water hyacinth often seen in the wet season.

Water hyacinth has a reputation for its formidable growth rate, a major factor in its success as a weed. The following statistics quoted by Gopal (1987) are an indication of what can happen under favourable conditions of climate and nutrient availability:

- sevenfold increase in spread in 50 days (India);
- edge of the mat extends by 60 cm per month (USA);
- 2 plants can multiply to 1,200 in 120 days;
- 1 plant can multiply to 65,000 in a normal spring season (Louisiana);
- surface area increases by an average of 8% per day (USA);
- the cover can double every 6.2 days;
- 50% increase in weight can occur in 7 days.

Such prodigious growth rates were not apparent during the survey of the Lower Shire. If they had occurred, the cover on Bangula Lagoon (site no. 5) could have increased from 35% to 100% during the 10-day interval between the first and last visits of the survey. This did not occur; in fact no change in cover was apparent. It is possible that water hyacinth had reached a stable population for the available nutrients. However, the capacity for extremely rapid growth is present in the Lower Shire, as was witnessed after the floods of 1989. Judging by the large numbers of flowering water hyacinth plants, it appears that October, at least, is primarily a period for seed production rather than growth. The periodicity of growth has considerable implications for whatever method of control is used, be it chemical, mechanical or biological.

Apart from climatic and nutritional factors, disease and predation could affect the growth and vigour of water hyacinth. During the survey, it was possible to see vigorous healthy plants, as well as plants senescing through being left stranded on drying mud banks. It was common to see blotches and blemishes on leaves, though none appeared to be so extensive as to be killing the plant. Harley (1991) noted the presence of water hyacinth mite (*Orthogalumna terebrantis*) which he claims may be having a depressing effect, especially in Elephant Marsh. Water hyacinth plants growing at the muddy periphery of marshes were judiciously avoided by all livestock grazing in the area.

Distribution of Water Hyacinth in Mala_i

Water hyacinth was first seen in the southern part of the Shire River in 1968 (Harley, 1991, quoting a local fisherman). The first official record is by Seyani and Patel from the National Herbarium who collected specimens (nos. 383, 384 and 444) from Marka, near the southern border with Mozambique, in July 1975. It was not observed in Bangula Lagoon (site no. 5) or the Shire River near Chiromo (near site no. 6) during a botanical survey in 1975-76 (Procter, 1981) but it was present in the Lagoon by 1980 when it was collected and described by Blackmore, Dudley and Osborne (1988). The latter first noted water hyacinth in the Namichimba Lagoon, approximately 4 km north of Chiromo (i.e., near to site no. 7 on Fig. 1) in their botanical survey of the Shire Valley in 1979-80. Laisi (1993) states that water hyacinth is present in the Shire River but is not a serious problem in Mala_i.

Local fishermen at Mpandeni (site no. 8) claimed that they first noticed water hyacinth in 1976 but it did not become a serious problem until the 1980s. The first observation of water hyacinth at Chisamba (site no. 12) by a local fisherman was 1986, ten years after it was noticed on the opposite bank of SE Elephant Marsh. A Fisheries Department Officer stated that the weed first appeared at Alumenda (site no. 14) in 1987. The most northerly observations of water hyacinth during this survey were Bilonzo (site no. 16) on the western side of Elephant Marsh and Chichele (site no. 10) on the eastern side. It was observed at all sites south of these locations but it was not seen, nor was it claimed to be present by local fishermen, at Kamuseche, Mlomba, Kanjedza Lagoon and Gumbwa Lagoon (site nos. 17, 18, 19 and 20, respectively). Based on the survey and on written and verbal evidence, the distribution of water hyacinth in the Lower Shire between 1975 and 1991 can be estimated (Fig. 2).

In 1991, no other records or observations were known of water hyacinth as a weed in Mala_i but it was present at several places in the country. Living specimens were seen at the National Herbarium, Zomba and in a small ditch at Kapalasa Farm, Namadzi, near Zomba. It was reputed to be present in ponds at Blantyre Zoo and garden pools of homes in Lilongwe. Water hyacinth flowers are sold in Blantyre and Lilongwe markets. Rumours of its occurrence in the Shire River between Lake Mala_i and Mangochi proved to be unfounded by Harley (1991) who made a careful search of the river. In March 1995, its presence was confirmed by C.R. Riches (personal communication) upstream and downstream of the bridge over the Shire River at Mangochi, indicating that Lake Malombe and the southern end of Lake Mala_i are now infected. If it has not already done so, water hyacinth will undoubtedly spread downstream of Lake Malombe where it will threaten the hydroelectric scheme at Liwonde Barrage and other utilities on the Shire River, eventually infesting the Kanjedza and Gumbwa Lagoons (site nos. 19 and 20, respectively) in the northern part of the Lower Shire Valley.

There are no known records of water hyacinth from Lakes Chiuta or Chilwa but historical precedents from other countries indicate that water hyacinth will invade all waterways in Mala_i which are conducive to the growth of this weed. A proposed new irrigation scheme in the Lower Shire will become infected by water hyacinth and other aquatic weeds, as will the reservoir that will form behind the planned barrage at Kapachira Falls. Fisheries, hydroelectric schemes and aquatic amenities are under threat from this inevitable invasion.

Fishermen's Perceptions of the Water Hyacinth Problem

With one exception, at Mwala (site no. 7), fishermen and Fisheries Department Officers at all locations claimed that water hyacinth is a problem wherever it occurs. The reasons for this were consistent:

• **Access to fishing grounds**

Dense mats of floating water hyacinth form an almost impenetrable barrier to canoes. Water hyacinth covers fishing areas near the shore and necessitates long or time-consuming journeys to reach open water. Instead of canoe journeys of half an hour or less, fishermen are forced to spend two or three hours reaching their destinations. At Bitilinyu (site no. 1), fishermen take five hours to reach fishing grounds on the far side of Ndinde Marsh where they stay for up to two weeks before returning. At Bangula Lagoon (site no. 5), fishing was abandoned at one time in 1991 because of water hyacinth. Fishermen had abandoned Alumenda (site no. 14) for the same reason and moved to the eastern side of Elephant Marsh. They claimed that more time could be spent fishing if it was easier to reach the fishing grounds.

• **Placement of nets**

All types of nets are difficult to place where water hyacinth is present. There is insufficient clear water for the use of cast nets and seine nets. Clear patches in the weed must be cut for placement of gill nets. Long lines and nets left in the water are swept away by the weed, reducing catches and causing losses of fishing gear.

• **Reduced fish catches**

Fewer fish, by number and weight, are found in water hyacinth areas. The diversity of species is also smaller in the presence of this weed: only catfish and chambo (*Tilapia* spp.) are found among water hyacinth but other species occur in open water. Fish catches are sometimes so poor that fishermen abandon the area, as was noted at Bangula Lagoon (site no. 5) and Alumenda (site no. 14). At Chisamba (site no. 12), a local fishermen claimed that fish catches have halved since water hyacinth first appeared in 1986.

• **Occurrence of water hyacinth**

Opinions varied as to when water hyacinth was most common and troublesome:

-water hyacinth is worse at high water levels in November to January (Bangula Lagoon, site no. 5);

-water hyacinth covers most of the surface when water levels rise in March to May (Mpandeni, site no. 8);

-water hyacinth is swept away when water levels rise in March to May (Mchacha, site no. 9);

-there is least water hyacinth in the wet season, November to January, because it is washed away (Chichele, site no. 10).

Severe flooding in 1989 purged water hyacinth from the Lower Shire but it reestablished and achieved high densities within a few months. Recovery is also rapid after annual high water levels flush water hyacinth from lagoons and marshes. All evidence from local fishermen, most of it factual and some anecdotal, confirmed that water hyacinth is a severe problem in the Lower Shire.

Effect on Fisheries - Statistical Records

Selected records of fish catches and units of effort used to catch fish with different types of gear from 1976 to 1990 were analysed. This was a convenient time-frame in terms of water hyacinth invasion. Three areas were selected for analysis: West Ndinde Marsh (water hyacinth present from the early 1970s, i.e., throughout the selected time-frame), Bangula Lagoon (water hyacinth present from 1980) and North West Elephant Marsh (water hyacinth first noted in 1986 but still absent from the northern parts). If water hyacinth was affecting the fisheries, one would expect to see changes in the fish catches and catches per unit of effort from the time that the weed infection was first noted.

Annual fish catches in the three areas studied are shown in Figure 3. Wide fluctuations have occurred with peak catches being made in 1989. If there is any trend, it is that catches increased between 1984 and 1990. No deleterious effect of water hyacinth is seen in these statistics.

Fish catches at the three study areas, expressed as a percentage of the total catches in the Lower Shire, are presented in Figure 4. Since 1983, the percentage of fish taken from West Ndinde Marsh has increased, perhaps reflecting the intensification of fishing due to the presence in the area of large numbers of refugees from Mozambique. No effect of water hyacinth can be detected.

Fish catches alone are not a reliable statistic as they give no indication of the effort used. Virtually without dissent, fishermen claim that fish catches are lower and it is more difficult to catch fish in the presence of water hyacinth. These claims are not substantiated by statistics from the study areas for catch per unit of effort (CPUE):

- **Seine nets (one unit of effort = one pull of the net).**

Year to year variations of CPUE were very large, probably masking the effects (if any) of water hyacinth. Seine nets are particularly difficult to use when water hyacinth densities are high along the shore line.

- **Gill nets (one unit of effort = 100 metres of net)**

A three- to four-fold increase in CPUE occurred in NW Elephant Marsh between 1978 and 1990 (Fig. 5), despite the invasion of water hyacinth in the mid 1980s. CPUE in Bangula Lagoon is fairly constant but there may be a decline in value at West Ndinde Marsh. Water hyacinth makes it harder to place gill nets but no effect on CPUE is evident.

• **Long lines (one unit of effort = 100 hooks)**
For inexplicable reasons, CPUE in Bangula Lagoon was exceptionally low in 1985 and 1986 but this does not coincide with the first reported incidence of water hyacinth. There appears to be an upward trend in CPUE in NW Elephant Marsh, starting before water hyacinth invaded and continuing afterwards.

• **Fish traps (one unit of effort = one trap)**
A decline in CPUE in Bangula Lagoon coincides with the appearance of water hyacinth but the weed was still a problem in 1988-90 when fish catches were high.

• **Cast nets (one unit of effort = one throw of the net)**
Statistics for 1976 and 1977 in Bangula Lagoon were erroneous and have been omitted. CPUE at the three locations do not indicate a negative effect of water hyacinth (Fig. 6). In fact, there appears to be an upward trend in CPUE following the invasion of water hyacinth into Bangula Lagoon and NW Elephant Marsh. Cast net fishing is particularly vulnerable to water hyacinth because it requires clear areas of water.

It is difficult to reconcile differences between the opinions of the fishermen and the Fisheries Department statistics without assuming that either the fishermen were mistaken or the statistics are inaccurate.

Although the statistics do not indicate negative effects of water hyacinth on fish catches, it cannot be assumed that those effects are not present. Wide fluctuations in catches and CPUE occurred which could mask the effect of water hyacinth. It is also possible that fish stocks in the Lower Shire have increased in response to the increasing supply of food (phytoplankton and zooplankton) resulting from increasing nutrient status of the water. It could be argued that, were it not for water hyacinth, fish catches would have been even higher. However, no data exists on changes in plankton and fish populations in the Lower Shire.

Whilst it is generally assumed that water hyacinth has adverse effects on fisheries, there are also possible advantages. Small floating islands of water hyacinth can provide spawning areas and safe havens for fish. In parts of S.E. Asia, fishermen are known to anchor small floating islands to attract fish which are then easier to catch. There is a possibility that by restricting access to fishing grounds in the Lower Shire, water hyacinth is enforcing localized close seasons which are beneficial to the fishery. The weed could also help to prevent overfishing, although there is no indication that fish populations are being threatened by the current fishing capacity (R.D. Makwinja, personal communication). It is widely accepted in countries where water hyacinth occurs that fish populations and catches are reduced by the weed. In West Bengal, 45,000 tons of fish were lost due to water hyacinth in the early 1950s (Gopal, 1987). In the USA, experiments in fertilized ponds (area 0.04 ha, average depth 0.9 m) containing 0, 5, 10, and 25% cover of water hyacinth, showed that fish (*Tilapia aurea*) production was reduced by about 50% in ponds with 10 and 25% cover (McVea & Boyd, 1975). The authors attribute this to a reduction in phytoplankton growth due to shading and the removal of phosphorous from the water. Comparisons between small ponds under controlled conditions and the complex ecology of the

Lower Shire need to be treated with considerable caution but the indications are that water hyacinth at densities of less than those often found in the Lower Shire can cause large reductions in fish productivity.

Other Effects of Water Hyacinth
It is probable that water hyacinth in Mala_i has the same or similar detrimental effects as in other countries, though few or no records exist. These include:

a. reduction of phytoplankton through shading;
b. increased loss of water through evapotranspiration;
c. increased siltation;
d. changes in water chemistry;
e. obstruction. Water hyacinth already reduces access to fishing grounds but it will also interfere with navigation and block barrages, dams and weirs as it becomes more widespread in Mala_i;
f. human health can be affected where water hyacinth provides refuge for harmful animals and vectors of disease like malaria, encephalitis, schistosomiasis, filariasis, etc.;
g. wetlands, such as the Lower Shire, become ecologically impoverished as the natural wildlife is replaced by water hyacinth. In financial terms, this could affect the tourist potential of Mala_i's lakes and marshes but the ecological damage is immeasurable.

Options for the Control of Water Hyacinth
The relevance to Mala_i of the three main categories of control, physical (manual and mechanical), chemical and biological are discussed below, together with preventative measures that can be taken.

Mechanical control
Mechanical control has the advantage that it is environmentally benign, providing that water hyacinth is removed from the water before it is destroyed. It can then be utilized for mulch, compost, etc. or destroyed by desiccation or burning. The problem is to remove the water hyacinth.

• **Manual methods**
Manual removal of water hyacinth with simple hand tools is probably the most widely practised method of control used in developing countries. It can involve rakes, booms and boats to collect, remove and extract the weed from waterways. It is a very labour-intensive method of control but it can be practical for small lakes, narrow streams or canals and for removing small infestations on large water bodies. Manual control is impractical for large water bodies and is not, therefore, appropriate for the lagoons and marshes in the Lower Shire, except to clear small areas around landing beaches and in the fishing grounds for setting nets.

• **Floating barriers**
Barriers can be used to accumulate floating clumps of water hyacinth to prevent the weed from reaching, for example, water intakes and sluices on dams and barrages. Water hyacinth has to be removed at regular intervals to avoid damage to the floating barriers. There is little or no practical application for this method of control in the Lower Shire but it might have utility for the Liwonde Barrage.

• **Mechanical harvesters**
Many mechanical devices have been developed for removing water hyacinth from water. They are usually mounted on floating platforms and consist of belts, cutters, forks, etc. to remove the weed from the water after which it is ejected onto the bank, placed in barges, transported on conveyor belts, with or without crushing to remove excess water. Mechanical harvesters are used in countries such as the USA, and there are records of a diesel-powered weed-cutting boat having been transferred from Lake Chilwa to the Lower Shire in 1973 (Hastings, 1976). It was introduced to Ndomo, on Elephant Marsh, to make access channels through *Typha* and *Phragmites* stands but it proved a total failure due to constant breakdowns. Water hyacinth is an easier target for mechanical control and reliable equipment is available, but at a high price.

Some indications of costs are provided by Mara (1976) who estimated that $83.35 per hectare (1976 prices) would be needed to control water hyacinth on a lake of 165 hectares with one mobile harvester in the USA. By extrapolation of these figures, the cost of controlling water hyacinth on the whole of Bangula Lagoon (i.e. 10 km^2) would be $83,350 which, at 1995 prices, would be in the region of $175,000 - $235,000. Even if the costs were one tenth of this amount, they would be too high, especially as the treatments would need to be repeated at least annually and probably more frequently. It is very difficult to derive accurate costs for mechanical control in Mala_i but, even allowing for very large margins of error in the above figures, it is clear that they exceed local resources.

Chemical control
Many herbicides have been used for the control of water hyacinth, including terbutryn, ametryn, amitrole, diquat, paraquat, glyphosate and 2,4-D. Other herbicides have been used experimentally, including products that have shown promising control of water hyacinth, but they are generally more expensive than existing products.

Chemical control of water hyacinth has the advantage of being effective within the treated area and fast acting. There are, however, several disadvantages which militate against the use of herbicides on a large scale in the Lower Shire:

• Effects on nontarget organisms. Aerial application would be the only feasible method which could be employed on the scale needed for Lower Shire. Even with the most careful application, herbicide spray would contact other plants growing in association with water hyacinth in the marshes and lagoons. Damage to these plants and the organisms associated with them, would be environmentally undesirable. Crops in the Shire Valley might also be exposed to spray or vapour drift and residues of herbicides applied. Cotton is very sensitive to 2,4-D, one of the most widely used herbicides against water hyacinth.

- Deoxygenation of water. The rapid kill of large areas of water hyacinth adds a considerable amount of organic matter to the water body. The decay of this material extracts oxygen from the water which, in severe cases, can lead to the death of fish and other aquatic organisms.

- **Release of nutrients.** As water hyacinth decays, nutrients are released into the water which degrade water quality, increase algal blooms and produce other symptoms of eutrophication.

- **Recolonization by untreated plants.** It is virtually impossible to spray all water hyacinth plants because there are always some concealed amongst other aquatic vegetation and are inaccessible. The untreated plants are foci for rapid reinfestation of treated areas, thereby necessitating further treatments at regular intervals.

- **Cost of herbicide usage.** In the USA, chemical control of water hyacinth is estimated to cost $74 per acre ($183 per hectare). At this price, it would cost $183,000 for a single treatment of the whole of Bangula Lagoon, an unacceptably high amount. In Sudan, over one million Sudanese pounds per year were being spent on herbicide treatments against water hyacinth on the Nile but control was not achieved (Hamdoun & Tigani, 1977).

The only persuasive argument for large scale use of herbicides would be if water hyacinth could be eradicated, albeit at considerable cost, from the Lower Shire. Unfortunately, this would be impossible to accomplish. However, limited use might be feasible for controlling small areas and as a damage-limitation exercise to eradicate or contain new infestations.

Biological control

Biological control involves the use of living organisms which kill or damage target weeds to which they are highly specific. Following their release, a decline in the target weed should take place as the populations of the biological control organisms increases. Eventually, a balance is reached where the weed densities are reduced to acceptably low levels and the control organisms are present at densities sufficient to suppress the weed without eradicating it. If the weed was eradicated, the biological control organism would also be eradicated and would not be available to counter new introductions of the weed.

Many organisms are associated with water hyacinth. Gopal (1987) lists over 90 arthropods and 10 fungi; Harley (1990) lists six arthropods and three fungi from around the world which are reported to cause damage to this weed and must therefore have some potential as biological control agents. Four arthropods are widely reported as having been used to control water hyacinth:

Neochetina bruchi Hustache (Coleoptera: Curculionidae)

This insect, known as the chevroned weevil, damages water hyacinth by tunnelling through the petiole and feeding on the leaf and stem. Tissues of translocation are destroyed during feeding and this results in death of the leaves and reduction in growth of the plant. *Neochetina bruchi* has been released as a biological control agent in India, Panama, Sudan and the USA (Julien, 1987), Argentina and Indonesia (Gopal, 1987). In Sudan, this weevil reduced the population of water hyacinth by 25% within four months and, in Argentina, a 50% cover of water hyacinth was reduced to 8% in two years.

Neochetina eichhorniae Warner (Coleoptera: Curculionidae)
This species, known as the mottled weevil, damages water hyacinth by tunnelling into petioles and rhizomes and by feeding on the petiole and leaf surface. As with *N. bruchi*, leaves are killed and growth of the plant is reduced. *Neochetina eichhorniae* has been released in Australia, Egypt, Fiji, India, Indonesia, Papua New Guinea, South Africa, Solomon Islands, Sudan, USA, Zambia and Zimbabwe (Julien, 1987). It has a similar range to *E. bruchi* but is better favoured in autumn and winter seasons. The two species coexist, possibly because they have different oviposition sites on water hyacinth plants. Significant control of water hyacinth in Australia, Sudan and the USA has been attributed to this insect. In countries near to Mala_i, establishment of *N. eichhorniae* after release in 1971 has not been confirmed in Zambia and Zimbabwe. Following the 1974-75 releases of the weevil at six sites in South Africa, flooding on the Vaal and Swartkops rivers flushed water hyacinth plants and the immobile *Neochetina* larvae out of the system and temporarily deprived the remaining adult weevils of a host plant (Cilliers, 1991). One site was drained and the remaining sites were extensively treated with herbicides which had a detrimental effect on establishment of the weevils. *Neochetina eichhorniae* has now become established in South Africa where it has survived floods and herbicide applications and dispersed to areas where it was never released.

Orthogalumna terebrantis Wallwork (Acarina: Galumnidae)
This mite, damages water hyacinth by tunnelling into the petiole and feeding on leaves. It has been released in Egypt and Zambia (Julien, 1987) and Gopal (1987) claims that it has also been introduced to Fiji and Zimbabwe. It has been ranked fairly low for its efficiency as a biological control agent but, by producing tunnels in the petioles, infection sites for pathogens are established and oviposition and feeding by *N. eichhorniae* are encouraged. Julien (1987) reports only temporary establishment of *O. terebrantis* in Zambia but it appears to have spread into Mala_i where Harley (1991) reports that it may be having a depressing effect on the growth of water hyacinth.

Sameodes albiguttalis Warren (Lepidoptera: Pyralidae)
Larvae of this pyralid moth tunnel through petioles of water hyacinth causing necrosis and waterlogging. It has been released as a biological control agent in Australia, Panama, Sudan, the USA and Zambia (Julien, 1987). Its establishment has not been confirmed following release in Zambia but it appears to have been quite successful in Australia and Sudan.

The fungi, *Acremonium zonatum* (Sawada) Gams (previously referred to as *Cephalosporium zonatum* Sawada) and *Cercospora piaropi* Tharp, have been spread around the world with water hyacinth (Harley, 1990). On their own, these fungi are not particularly damaging but effects are often increased when the plants are stressed by insect attack. *Cercospora rodmanii* Conway (a close relative of *C. piaropi*) is probably the most promising biocontrol pathogen. It has given excellent control of water hyacinth in Florida and has shown promise as a microbial herbicide (mycoherbicide). There may be potential for the use of this organism in Mala_i.

It is impossible to predict whether biological control of water hyacinth in Mala_i will be a success but there are ample reasons for optimism. Harley (1990) cites successful control with *Neochetina* spp. in the following countries:

Argentina
- 67% control in 4 years with *N. bruchi*;
- 90-95% control in 6 years with *N. bruchi*;

Australia
- collapse of water hyacinth populations over two years;

India
- 95% control in 2_ years with *N. eichhorniae*;
- 90% control in 3¼ years with *N. bruchi*;

USA
- over 90% control in 3 years with *N. bruchi*.

The specificity of these insects has been extensively tested and there is virtually no threat of damage to crops grown in Mala_i. Harley (1990) lists 107 different plants from 52 families, representing a wide range of terrestrial and aquatic species that have been tested as hosts of *N. bruchi*, *N. eichhorniae* and *S. albiguttalis* in the USA and India. It is therefore unnecessary to implement extensive and costly screening programs or to build quarantine facilities in Malawi. Insects bred in Australia, for example, could be taken to IIBC in UK where they would be screened before export to a holding facility in Mala_i, a procedure which satisfies the regulations of the Inter-African Phytosanitary Council. The insects would then be released at selected sites in Malawi where their spread and efficacy would be monitored.

A possible disadvantage of biological control in the Lower Shire is that seasonal and irregular flooding could flush away the water hyacinth and its biological control agents, as has been reported in South Africa. This would not be so extreme as to eradicate the agents but it may be advantageous to supplement their natural reestablishment by reintroductions. In order to do this, rearing facilities for the insects would need to be established in Malawi at a location which is not subject to seasonal or irregular flooding of the Shire River, such as Kasinthula fish farm.

The advantage of successful biocontrol is that a self-perpetuating system is created after the organisms have been released and become established. When biological control is properly conducted, it is safe, environmentally responsible and has a high benefit to cost ratio (Harley, 1991).

Integrated control
There is evidence that combinations of treatments can be more effective for controlling water hyacinth than individual treatments. The biological control agents *N. eichhorniae* and *O. terebrantis*, for example, are often sympatric in distribution, have nearly similar temperature requirements and have a synergistic relationship. The efficacy of a fungal mycoherbicide prepared from *Cercospora rodmanii* has been considerably enhanced when applied to water hyacinth in the presence of *Neochetina* weevil. It is quite possible that biocontrol agents released in Malawi will interact, perhaps synergistically, enhancing the efficacy of the control.

Interactions between chemical and biological control have been demonstrated. Herbicides can be used to reduce the vigour of water hyacinth but without harming the biocontrol agent. Paraquat, glyphosate and 2,4-D have all been used to enhance the effects of *Neochetina* spp. Plant growth regulators also have this potential: paclobutrazol, for example, in combination with *N. eichhorniae* gave 95% control of water hyacinth in the USA but the weevil alone gave only 24% control in the 8-month study period (Van, 1988). It is also possible to use herbicides to reduce water hyacinth populations to low levels prior to the introduction of biocontrol agents, thereby giving the agents time to become established and better able to suppress regrowth of the weed. However, extensive herbicide applications in South Africa had a detrimental effect on colonies of *N. eichhorniae* (Cilliers, 1991).

In Malawi, emphasis should be placed on biological control of water hyacinth in the Lower Shire but, as outbreaks of the weed occur on other water bodies, combinations of biocontrol agents, herbicide treatments and physical removal should be employed to rapidly eliminate water hyacinth before it becomes established.

Preventative control
The best method of controlling water hyacinth is to prevent it from invading areas where it is not yet present. A priority for all government departments involved in Mala_i's water resources must be to prevent further spread of this weed.

One of the first actions must be an information exercise which informs people of the dangers of water hyacinth and instructs them to destroy the weed if it is growing on their property. Sales of water hyacinth must be prohibited and imports should be banned. Laws exist to ban the growth and sale of water hyacinth but they have probably never been enforced. Under Mala_i's Noxious Weed Act, water hyacinth is a declared noxious weed and penalties for offenders include fines and/or imprisonment. The Department of Research and Environmental Affairs is probably the most appropriate organization to implement an information campaign, supported by the Departments of Fisheries, Water, Irrigation and Agriculture.

A monitoring program is needed to identify new infestations of water hyacinth, particularly on Lakes Chilwa, Malombe, Mala_i, Chiuta and associated rivers. Staff in relevant Departments, especially Water, Fisheries and Irrigation, need to be trained to recognize water hyacinth and other threatening weeds. This training should include instruction on how to eradicate new infestations.

Monitoring and information campaigns do, of course, incur costs. However, these costs will be negligible compared to damage that will occur if water hyacinth becomes more widely established in Mala_i's lakes and water bodies.

Utilization of Water Hyacinth

Water hyacinth in Mala_i has potential utility for mulch, compost, paper, biogas and fodder but only the latter has more than a minimal prospect for adoption. Mala_i has a shortage of fodder in the dry season, a problem that has been addressed by the FAO Crop and Agro-Industrial By-products Utilization Project which was exploring the use of biomass such as maize bran, banana leaves, sugar cane tops, etc. as fodder. In 1991, the Chief Technical Adviser on the project indicated a willingness to evaluate water hyacinth but it is not known if this was done.

There is clearly some potential for the utilization of water hyacinth in Mala_i but the statement by Gopal (1987) is as appropriate to this country as to others, "The harmful effects of water hyacinth on the environment and man cannot be mitigated by the newly discovered utility. .... The developing countries need not encourage propagation of the weed for utilization. .... The interests of mankind can only be safeguarded by seeking effective control of water hyacinth, not by its utilization."

Summary of Foreseen Methods for the Control of Water Hyacinth in Malawi

a. The Government of Malawi is advised to implement a program of control of water hyacinth to (a) alleviate existing problems in the Lower Shire (b) eradicate (if not too late) new outbreaks in Lakes Mala_i and Malombe, and (c) minimize the threat to other water bodies in the country.

b. Biological control of water hyacinth should begin as soon as possible. A project supported by the ODA Natural Resources Institute and implemented by the CABI International Institute of Biological Control is about to commence in Malawi.

c. Large scale control by mechanical and chemical methods is not advised because they are too expensive and would achieve only limited or transient success. However, isolated pockets and new, small outbreaks can be treated to contain, if not eradicate, the weed.

d. A public information exercise should be employed to warn of the dangers of water hyacinth and to advocate destruction of plants. Existing noxious weed legislation with regard to water hyacinth should be enforced.

e. Government Departments with interests in the utilization of water resources should form a coordinating body to oversee the control and monitoring of water hyacinth.

f. The Malawi Government should support and collaborate with neighbouring countries in controlling water hyacinth and other noxious aquatic weeds.

g. The Malawi Government should implement a system of monitoring water bodies that are at risk of infection by water hyacinth. Training on the recognition and control of water hyacinth, and other potentially serious aquatic weeds, should be given to staff whose duties already require regular visits to threatened water bodies.

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GROUP DISCUSSION

Pieterse — I think to prevent further spread there could be many controls. Perhaps the costs are too high and perhaps you need to still increase the effect. We need to do something more.

Terry — I think the point is that, capabilities are not there. One thing I didn't mention and it is a pointed concern is that there is annual flushing of those marshes which washes out a lot of water hyacinth. I am concerned that if you take the water hyacinth plants out you are taking away the insects and other biocontrol agents too. And I think that this problem with *Sameodes* in South Africa is also mentioned in a paper. So biocontrol may work with repeated introductions, I am not sure. Chemical control and counter-control I have ruled them out in the lowest area. But where the new infestations are coming in the north I think we sort of fabricate action; that would be the ideal method to use. Where you have got these new outbreaks, you go in and use chemicals and counter control. Whatever it costs to do it. And I hope that the Malawians will do that. But there is no cheery area. I cannot see or scope the control beyond the biological.

Pieterse — If you only concentrate on biological control, will you be successful? Let's say that after five years the problem will be solved. People are really sceptical; they say, "well its really not working at all". So, I am myself a little bit worried.

Terry — That's a good point.

Cofrancesco — How did you come up with the 3-year time frame? You want to have a success. What we have seen in, the operations in the U.S., is that it may take longer than 5 or 6 years to start seeing some major impact. When the insects were first used in Louisiana in 1974 there wasn't a systematic approach to it. Around 1979 there was a lot of skepticism about whether or not biological control is even going to be very effective. Still we started seeing an increase in effect in a 5- or 6-year period of time. You have to make sure and state what your objective is going to be and that you are actually establishing a population, etc. and indicate to the people that if you see a decline it might be subsequent to the time of the program.

Terry — That's a good point. Your comment is interesting. What is a reasonable time to expect a result? I certainly don't expect anything in 3 years. We have established the infrastructure: the insect release and so on and the training done. But when can the Malawians realistically expect to see some results. Are you saying five years is the minimum?

Cofrancesco I think you are going to have to go at least five years to see something. The other thing is I noticed that you were saying that water hyacinth was moving upstream. Any idea how? Are boats moving it upstream or is it just a sequential movement of the plant or something?

Terry I wasn't sure; it is very, very slow moving. Water hyacinth can blow upstream providing the current is not too great. I suspect it is a combination of natural movement and the boats. The funny thing is that at the north of the area we asked the fishermen if they knew of water hyacinth. They don't even know about it up there. It is just a few miles from where the infestation was because they stay in that particular area and fish. The only thing is that they don't know that. Very parochial.

Neser I am very glad that you are looking at this very objectively at the beginning of the program. I agree that you can not afford not to introduce the biocontrol agents. They should be introduced; I don't think there is any doubt about that. But we should be careful not to create false expectations and allow the program to oscillate between the perception that biocontrol is going to fail or it is not doing what is expected and that we must switch to another strategy. Chemical control is also after a while perceived to be too expensive and that it is going to fail. Meanwhile, we are back to biocontrol and everybody loses confidence in the whole process. I think it should be well planned in the beginning when the agents are introduced. At the same time do something about a plan which will keep people encouraged that they are achieving a goal and not to try and attack those large weed infestations that might be present. Once you have little objectives then everybody is feeling like they are achieving something. I think that was our unhappy experience in South Africa that if people see something that isn't working then they lose courage and interest. I think that Australia had this experience with water weeds in Asia; it is to get the local people very, very interested and involved. They must see or be aware of the insect damage and say this is a good thing to have. So, I think a program will be very necessary in the beginning and it is important to play down the possible effects of the biocontrol agents initially. And then there is the as cost of glyphosate, which is getting cheaper. Because the patent has expired and there are other companies coming into the market, the price is being lowered due to competition. Our cost when we calculated by air, was about 15 Rand, or $4 a hectare.

Terry That's a lot lower than our prices.

Neser Yes, this is now based on our latest costs for renting an aircraft, time for spraying, and time for refuelling. Of course, these things are available on site, and the materials at that price. By boat it works out to about $50 per hectare, with labour and everything included at present prices.

Stocker I might start buying herbicide in South Africa. That is way less than anything that we are paying for.

Terry What is your chemical cost?

Neser It is about $4 per litre.

Haller $4 per litre of glyphosate! Wow! That is wonderful.

That is one of my points: the cost per hectare of spray - I don't know how to best approach this. But it is obviously a government or private industry type of approach on the herbicides. Glyphosate is the safest herbicide that can be used and it is registered in the United States. It has minimal irrigation restrictions and it has very remote chances of any human problems. The problem with United States is that glyphosate is $30 a litre. So it is very expensive for us because it is under patent by Monsanto. Yet, glyphosate, if you talk to a chemical engineer can be made in a tub; it is very easy to make and it is going out of patent in a little while. So, that might be something to consider: to get your cost down, get a clean chemical industry to make its own glyphosate. Then the cost might come down. Whereas yours is $16 a gallon, we are paying $80 a gallon. We are paying four times what you are paying.

Neser Our prices has come down dramatically, I think almost to half. This is because Monsanto is lowering the price.

Haller It is because of the patent structure. For aquatic use it takes more to register the product; it takes more studies, more toxicology, etc. So they charge $80 a gallon. If you are a forester, you get the same gallon with a different name on it for $40 a gallon.

Terry Certainly the document we will produce from this meeting is going to address cost. If it is going to be of any use in these developing countries you have got to know what it is going to cost. You raised an issue there; can I just come back to that point? This is a research project, although it is trying to solve a problem as well. I am not implementing it but IIBC is implementing it; they talked about releasing at least three insects. Now, is the best approach to release all three insects everywhere, or is it best to release them in different areas, and monitor each insect, or is there an alternative approach? Tony (Tony Wright), I think you said that you have no data on this because you released them all together.

Wright — *Sameodes* spreads well. I am not sure of the necessity to consistently use multiple releases. Anyway I would like to be sure that it is established someway in the local area.

Terry — One approach to managing the water hyacinth problem in Mala_i could be to spend the ODA project funds (ca. $400,000) on mass release of known insect predators. However, this would lead to little understanding of the problem and the activities of the predators. ODA can better capitalize on its investment by studying the efficacy of the biocontrol agents and learning something which can be applied to other water hyacinth infestations.

Neser — I have no experience with the competition between the two species or relative ease of establishing them. I think it may be wise to release *Neochetina*, most of it completely established, first. It is not the easiest one to establish. I think that there is a need to be concerned with *Sameodes* and the two weevils. But if *N. bruchi*, for instance, tends to be the one that takes a little while and doesn't establish easily, then I would say first establish that one and then the more successful one. Rather than vice versa. But eventually, I think the insects sort themselves out for the habitat. If in Malawi the water hyacinth is still in an expanding situation rather than as confined dense infestations, *N. bruchi* may well be extremely successful in establishing easily there.

Wright — We should mention that *Eichhornia* is the most successful plant. I wouldn't like that to go unannounced at the moment, since these proceedings are being recorded.

Neuenschwander — For practical reasons I would release them very far away from each other but although that is not the point that I wanted to mention on Mala_i - particularly since you asked for recommendations. I would pay particular attention to instilling a sense of ownership, that the people of that country feel they have ownership. I would pay close attention to the structure and make sure that you have the powerful associates who can coordinate the efforts.

Terry — We are quite well aware of that and one of the reasons it has taken four years to get this project going is because the Fisheries Department has to go talk to Environmental Development, Irrigation Department, Water Department - everybody that had vested interest - were consulted over this project and it took three and a half years to get the agreement to go ahead. So, we think the Malawians have vested interest; they are going to support it.

Labrada	The point is that ODA is going to grant this assistance. The government of Malawi recently requested technical assistance protocol from FAO for water hyacinth. FAO refused to avoid any duplication of efforts.
Orach-Meza	I am asking that because you see the area is so small, just a few hundred square miles.

AN INTEGRATED WATER HYACINTH CONTROL PROGRAMME ON THE VAAL RIVER, IN A COOL, HIGH ALTITUDE AREA IN SOUTH AFRICA

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INTRODUCTION

Factors Influencing Alien Plant Control on the Vaal River

1. Water use

The three main categories of water use are

* urban use in the Gauteng Province and in the Free State, both with a growing number of informal settlements
* recreational use, e.g., 14 holiday resorts near Parys and numerous other activities including fishing, boating and swimming
* agriculture, industry and mining activities.

2. Responsibility for the Vaal River

There are several bodies responsible for maintenance of the Vaal River system to ensure continued use

* DWAF and the Rand Water Board
* agriculture, industry and mines
* private landowners, who are responsible for maintaining the river in the Free State.

3. Pollution

This is an important factor. Sources of pollution are:

* agricultural enterprises on the surrounding land involving the use of fertilizers which are introduced into the river through run-off
* industrial and mining enterprises using vast quantities of water which is eventually returned to the river, but with varying levels of pollutants in the effluent
* informal settlements in the catchment areas of the river with inadequate facilities for the disposal of wastes
* urban areas in Gauteng responsible for introducing pollutants to the river.

The resultant additive effects of the pollutants from these sources are the increased levels of nutrients available for plant growth in the river. The effects of these artificial growing conditions are evident in both the rapid rate of algal growth and also greatly increased growth rate and size of the plants, notably water hyacinth, parrotfeather (*Myriophyllum aquaticum*) (Vell.) Verdc. and other aquatic plants.

This has important implications in terms of both biological and chemical control options, which if not managed correctly, will prove ineffective in the long term.

4. Available resources

Presently these include a labour force of some 25 and one supervisor, a supply of herbicide (glyphosate) and the following equipment

- 20 flat-bottomed boats, each with a motorized sprayer. It may happen that all the boats are not in use at the same time, the number used is dependant on the area and water hyacinth infestation to be sprayed
- several cables stretched across the river, augmented by natural and man-made barriers e.g., islands, bridges, weirs, pipelines, sandbanks

* five knapsack sprayers. Aircraft is hired for spraying.

Evaluation of Current Control Methods

The following methods have been used to spray water hyacinth with glyphosate:

- Aerial spraying has taken place occasionally since 1986 along the stretch of river at Greyling's Drift
- High pressure motorized units mounted on boats have been extensively used in the area below Regina Bridge
- Knapsack sprayers are used along the river banks in limited areas.

Other Factors Affecting Control Operations

- Adjacent agricultural enterprises and municipalities have limited the areas and thus the degree to which aerial spraying could be used as a control option due to the possibility of spray drift.
- Mechanical control is facilitated by the use of cables stretched across the river. This accumulates water hyacinth and allows cost-effective spraying at these points. However, this option is becoming limited since some of the cables have been removed over recent years.
- The occasional regulated increase in water flow from Vaal Dam to Bloemhof Dam has a limited effect of moving some of the water hyacinth downstream.
- At present there is no management plan to control alien plants in the riparian zone, i.e., the river banks and canals leading from the river. This results in the following problems:
- limited access to the river
- increased difficulty of canal maintenance
- reduced aesthetic appeal for resorts
- a seed source is provided for further invasion.

Alien Plants Present in the River System

Three main categories of alien plants were identified according to their impact in the Vaal River.

1. Alien plants in the river with present major impact
- water hyacinth

2. Alien plants with future major impact
- parrotfeather (*M. aquaticum*)
- red waterfern (*Azolla filiculoides*)
- reeds (*Arundo donax*), bulrush (*Typha capensis*) and the two indigenous weeds *Phragmites mauritianus* and *P. australis*.

3. Alien plants along the banks with moderate impact
- willow (*Salix babylonica*)
- syringa (*Melia azedarach*)
- poplar (*Populus x canensis*)
- wattles (*Acacia dealbata* and *A. mearnsii*)
- gums (*Eucalyptus* spp.)
- sesbania (*Sesbania punicea*)
- prickly pears (*Opuntia ficus-indica* and *O. imbricata*)
- inkberry (*Cestrum laevigatum*)
- cockleburs (*Xanthium spinosum* and *X. strumarium*)
- spear thistle (*Cirsium vulgare*).

Impact of Alien Plants Present on the Vaal River System Water Hyacinth

The plant causes the following problems:

- very dense infestations result in an increased (25-40%) water loss through evapotranspiration (H.H. Bosman, DWAF, personal communication 1995)
- accumulations of this weed at blockage points increases the threat of flood damage to structures such as bridges, weirs and pumps
- siltation of the river is promoted which in turn creates a suitable habitat for the secondary invasion of parrotfeather, red water-fern, reeds and bulrushes
- the plant decreases the oxygen levels in the water which adversely affects fish populations as well as most other forms of water life
- infestations offer breeding sites for mosquitoes and bilharzia carriers as well as other vectors of disease organisms
- indigenous plants are suppressed and their presence threatened by the weed's strong competitive ability for resources
- accessibility to the river and the consequent use of the river for recreation, and by industrial, agricultural and domestic consumers is reduced.

Problem Areas and Current Control

Holiday resorts. Owners of some holiday resorts spend considerable time and money to control water hyacinth and have erected a cable to keep this stretch of river free of the weed, thereby allowing access to the water. The resort owners' motivation to control water hyacinth is in direct proportion to the impact of the weed on their stretch of water frontage. Control is thus sporadic and does not offer a long-term solution

Bridges. Natural blockages occur with the very real threat of serious damage to structures such as road and rail bridges and pump stations when the blockages of weed reach large proportions at these structures. Limited and sporadic control takes place here, but then only when the threat has become great.

Vaal Reefs Mine. Attempts are made to remove the dense infestations of water hyacinth mechanically from the section of the river that affects them-but only when the weed becomes a problem for them.

Department of Water Affairs and Forestry. Water hyacinth is sprayed in a zone stretching over approximately 90 km. Unfortunately this zone is located at the lower end of the water hyacinth infestation. Apart from biocontrol, no regular chemical or mechanical control is done on the 200 km zone above this. This area is thus a source for repeated reinfestation downstream.

Biological Control

The proper use of natural enemies such as specific insects, mites and pathogens to control a weed is target specific, environmentally friendly, and, once suitable agents are established, permanent. Although slow, it is a natural process, and usually a long-term option to control. It is usually cost-effective. Populations of biological control agents typically closely follow the population curves of the target weed. In biological control the aim is not eradication of the weed but rather maintaining it at low levels. A residual population of weed will thus always be present.

The acceptable or maintenance level must be determined by the land managers concerned. In this system, for free-floating aquatic weeds and especially for water hyacinth, ideally biological control should result in plants sufficiently suppressed by the natural enemies to provide "open water" for most of the year.

So far the real effect that the natural enemies have on water hyacinth has only become apparent after several years and then usually at the beginning and end of a growing season. The number of years to obtain an appreciable effect will be dependent on climatic factors, the extent and density of the water hyacinth infestations, and the rate of insect population increase. In turn this will also depend on several other variables, e.g., water quality and floods.

Biological control in this particular river system could be relatively slow compared to more tropical areas because the agents are affected by plant condition, and both plants and agents by climatic conditions. Most of the above-water parts of the plants are killed by frost during the winter. Natural increase and decrease of the weed will still occur, possibly seasonally or over a number of years, but levels should be lower than before. The occasional massive seasonal floods, now largely tempered by dams, could have a large impact on plant and natural enemy populations.

The ultimate aim is the reduction of not only water hyacinth but also the cost of control over the short and long term.

Available host-specific natural enemies
Neochetina eichhorniae and *N. bruchi* (weevils)
Sameodes albiguttalis (moth)
Orthogalumna terebrantis (mite)
Cercospora piaropi, C. rodmanii and *Alternaria eichhorniae* (fungal pathogens).

Two new agents, the small mirid bug *Eccritotarsus catarinensis* (Carvalho) and the noctuid moth, *Bellura densa*, are under investigation in quarantine in Pretoria. At least the first should be ready for release during the 1995/96 summer, pending the results of specificity testing being completed.

Originally only *N. eichhorniae* was imported, and much later *S. albiguttalis* and *N. bruchi*. After importation and quarantine screening the weevils were released without further host specificity testing, the host-specificity testing done in the USA and Australia having been accepted as sufficient. For *S. albiguttalis* additional host testing was done in South Africa. After three years the necessary permission was obtained and the moth was released from quarantine.

The mite *Orthogalumna terebrantis* was introduced and established in quarantine in 1989 and released when found to be already present in the eastern Transvaal (1990). The pathogen *Cercospora piaropi* was found to be established in the Mpumalanga (eastern Transvaal) lowveld in 1987 and *Alternaria eichhorniae* in the Western Cape in 1990. These three natural enemies have been widely redistributed with the two weevils and has become established in different areas. The two weevils, *A. eichhorniae* and the moth *S. albiguttalis* became established on the Vaal River.

All these natural enemies were well established by 1995 and are still being distributed to minor water hyacinth infestations in South Africa. Through monitoring plants with these natural enemies over the past six years it was evident that they are contributing to the control of water hyacinth.

Biology of the Natural Enemies
Neochetina eichhorniae and *N. bruchi*. The adults hide in the leaf sheath around the central growth tip of the plant. At night they emerge and feed on especially the two youngest leaves. Adult feeding scars are rectangular and only the upper cell layers are removed. The females lay eggs in the petioles and leaf disks. The larvae hatch and burrow into the petiole where their mines are visible as dark lines. They burrow down into the plant crown, eventually pupating in cocoons attached to the water hyacinth roots below the water surface. Development of *N. eichhorniae* (egg to adult) is taken to be completed in about 120 days in summer and that of *N.*

bruchi in about 90 days. The feeding of the adults and larvae causes the leaves to die prematurely and the eventual stress on the plants reduces growth and even causes die-back.

Sameodes albiguttalis. The eggs are laid on the leaf. The hatching larvae burrow into the leaf stalk and the internal feeding of larvae leaves translucent areas in the petiole. The feeding activity also causes the petioles to rot. The larvae pupate within the petiole. A generation is completed in approximately 30 days.

Orthogalumna terebrantis. Adults of the water hyacinth mite are just visible to the naked eye as shiny dark brown dots. They lay eggs in the leaf disk and the immature stages burrow in the leaf tissue. The resultant damage is visible as thin parallel tunnels, which, if abundant, cause the leaves to dry out and die.
The pathogens are present throughout the year but the lesions are conspicuous only during the cooler months, generally from March to June. *Cercospora rodmanii* is the most important pathogen.

Parrotfeather (*Myriophyllum aquaticum*). Problems are the same as those described for water hyacinth. There are presently no herbicides registered in South Africa for the control of this emergent, mat-forming weed. However, glyphosate or glyphosate trimesium provides limited control over a short period. Biological control investigations have been initiated and the first agent has been released in the Vaal River region and elsewhere in South Africa.

Unless controlled, parrotfeather is expected to increase in importance as water hyacinth is brought under control. This is why biocontrol agents are being investigated and populations monitored even though this species is not a major problem yet.

Red waterfern (*Azolla filiculoides*). As with parrotfeather, biological control investigations have been started. One agent is in culture but has not been released so far.

Reeds. These include Spanish reed (*Arundo donax*), bulrushes (*Typha capensis*) and the indigenous *Phragmites* spp. As siltation increases as a result of other weeds trapping sediment and flood deposition and sediment accumulation at barriers such as weirs, there is an increase in favourable habitat for colonization by reeds.

These reeds can be controlled by the use of herbicides such as glyphosate and proprop.

The need for an integrated control approach

The extent of the water hyacinth problem warrants an integrated control approach where chemical, mechanical and biological means are used in effective combinations. Integrated control should be implemented in such a way that the different control methods supplement each other and where possible have an additive effect. Chemical control should be reduced as biological control gains momentum. Biological control, otherwise augmented if necessary, would thus be the most cost-effective long term objective.

An Integrated Control Plan
Over the past nine years control operations were sporadic and carried out in an unplanned manner, with the exception of the 90 km buffer zone. This has resulted in no real progress being achieved. Furthermore the motivation, enthusiasm and support shown by the land owners were being eroded as a result of the apparent lack of progress.

It became increasingly evident that there was a need for an integrated control programme to achieve the long-term goal: <u>reducing the infestations to levels that are acceptable to land owners and that can be easily maintained</u>. This integrated control plan aims at optimum use of biological, chemical and mechanical control methods. The success of this plan depends on the support and involvement of all parties concerned with the Vaal River.

Control Strategies
The options for different control approaches, initial actions, and combinations of methods for follow-up and maintenance as outlined below, should be read with reference to Fig. 1.

Control Strategy 1 (classes 7 & 5)

Description
Dense mats of water hyacinth stretching across the width of the river and extending to cover large areas. These infestations are unsuitable for spraying from boats.

Priorities for control
Class 7 (priority rating 7)
There is no threat to infrastructures such as rail and road bridges, and pump stations, or the cost of control is excessively high, or if there is the danger of eutrophication or if there is surrounding indigenous vegetation or cultivated land in close proximity.

Class 5 (priority rating 5)
There is a threat to these infrastructures during times of flood and the infestation is a source for continual reinvasion downstream.

Other dense infestations have high or low priorities dictated by any other specific reason identified by the river system manager.

Procedures

Initial control
Class 7
No immediate control effort is necessary. Instead, wait for flood waters to break up the infestation into smaller more manageable units. Introduce biological control agents. Alternatively, the priority for this area becomes higher once effective control of other infestations is achieved. When this occurs, treat as for Class 5.

Aerial spraying is not recommended if the infestation lies in a section of river surrounded by a predominance of indigenous vegetation, or if the surrounding area is sensitive due to crops that may be damaged by spray drift. In addition, aerial spraying should be avoided if river flow is slow, since this would encourage eutrophication due to the build-up in dead material. Alternatively, the infestation could be sprayed during the growing season a portion at a time (see below).

Class 5
If the infestation is classed as high priority for control, then the only practical cost-effective method to be considered is that of aerial spraying (refer to Table 1). This is done in the middle section of the infestation and results in a strip of dead plant material. Water flow eventually moves the dead material downstream, and a central channel is formed which allows access by boat. This operation should be carried out in February or early March (late summer) at the latest.

Follow-up control
A survey is done in late September/October to assess the success of the aerial spraying and whether an access channel has been formed down the centre of the river. The follow-up operation which involves spraying from boats should take place from October to February.

The boats each have a crew of three, a motorized sprayer with a tank capacity of 200 l, a lance fitted with two nozzles (one to spray up to 3 m and the second up to 10 m) and applied at a pressure of 800 - 1000 kPa. Glyphosate (3% in water) must be applied at a rate of 400 l/ha (12 l glyphosate/ha).

The operators must ensure that the boat moves at a constant speed. They travel in one direction spraying water hyacinth on one bank only. They then turn around at mid-day and return spraying the other bank thus ending where they started. It is important that refilling points be established along the day's route to minimize time wastage.

CLEAN water must be used for the mix and NOT river water as this contains sediments which impede the action of glyphosate.

Costs

Aerial spraying
The hire of a fixed-wing aircraft costs R2,500 (c. US$680) per hour and for a helicopter R1,800 per hour. During this time around 50 ha of dense infestations can be treated by a fixed-wing aircraft. This includes 20-25 minutes spraying time and the rest of the time is needed to refuel and replenish the herbicide spray tanks. The tank capacity is approximately 1,500 l and this includes 300 l glyphosate. Approximately 6 l glyphosate per hectare is used on water hyacinth. At a cost of R15/l (for Roundup), the control of 50 ha of dense infestations will be R750 ($200).

Motorized boat sprayer for follow-up operations

Three labourers per boat can spray approximately 4 ha per day, using 12 l glyphosate/ha. At R15/l this works out at R180/ha and labour costs at 0.75 man days/ha.

Table 1. Application parameters for aerial spraying

Application speed	215 km/h
Flying height	± 2 m above plants
Spray width(swathe)	23 m
Spraying equipment	Boom with 55 TeeJet 6520 nozzles
Boom angle	150° with the horizontal
Flow rate	255.67 l/min for 55 nozzles
Pump type	Wind driven centrifugal
Spraying pressure	22 " Hg
Tank capacity	1800 litres

Control Strategy 2 (classes 1 & 4)

Description
Dense accessible infestations of water hyacinth of manageable size which are cost-effective to control. These are suitable for spraying from boats.

Infestations occur usually along the river at fixed points, e.g., bottlenecks and man-made structures. Control of this size of infestation is cost-effective since spraying occurs at these accumulation points, i.e., the search factor/time is reduced when controlling *accumulated* small infestations. It is imperative to control these infestations while still manageable.

Neglecting spray operations of these manageable infestations will lead to an increased size due to, e.g., accumulation from other plants upstream and the rapid growth of the plant. Neglect thus results in an unmanageable infestation which is more costly to control. In the mean time introduce biological control agents.

Priority for Control
Class 3 (priority rating 1)
Infestations are manageable and accessible for control.

Class 4 (priority rating 4)
Infestations are manageable and *partially* accessible for control.

Procedures

Initial and follow-up control
These infestations are fully (Class 1) or partially (Class 4) accessible to spraying from boats as described above (Strategy 1, Follow-up control)

Maintenance control
At this level, it is not necessary to spray the scattered single or small clumps of plants which could be effectively controlled through the use of biological control agents or left to accumulate downstream.

Costs

Motorized boat sprayer for follow-up operations
Three labourers per boat can spray approximately 4 ha per day, using 12 l glyphosate/ha. At R15/l this works out at R180/ha and labour costs at 0.75 man days/ha.

Control Strategy 3 (Classes 2 & 3)

Description
Class 2 infestations line the river banks (average distance from banks is 1-3 m) and directly prevent access to the river. These infestations are accessible to spraying from boats.

Class 3 infestations consist of plant material that accumulates or is an expansion of the perimeter of existing infestations. These should be contained. Introduce biological control agents.

Priority for Control
Class 2 (priority rating 2). The infestations are manageable and accessible for control.

Class 3 (priority rating 3). Further accumulation of live plants to the perimeter of infestations is avoided, e.g., by the use of additional cables upstream or spraying from boats, i.e., the infestations are contained.

Procedures
Initial and follow-up control

Spray from boats and reduce Class 2 infestations to a distance of 0-2 m from the river banks. Class 3 infestations on the perimeter of existing infestations are reduced as much as possible to achieve containment.

Maintenance control

Once Class 2 infestations are reduced to maintenance level, i.e., scattered single or small clumps of plants, there is no need to spray. Instead, plants are effectively controlled through the use of biological control agents.

Control Strategy 4 (Classes 6 & 8)

Description

All those small and awkward infestations that do not fit any other class for control and where the effort of control by other means than those expressed below are uneconomical at this stage. Introduce biological control agents.

Class 6 consists of isolated small clumps or single plants unsuitable for chemical control. These may be in backwaters or eventually accumulate downstream at obstructions.
Class 8 consists of inaccessible infestations unsuitable for chemical control, e.g., around islands, underneath and amongst other vegetation.

Priority for Control

Class 6 (priority rating 6) is unsuitable for chemical control and is left to accumulate downstream for more cost-effective control operations at a later date. Introduce biological control agents.

Class 8 (priority rating 8) is unsuitable for chemical control and therefore makes ideal nurseries for biological control agents.

Procedures

For Class 6 infestations, accumulations downstream can be treated as for Class 1.

For Class 8, introduce biological control agents during the period October to beginning March and monitor the success of their establishment.

Costs

The present nominal cost of introducing biological control agents to Class 8 infestations is R500 per starter colony. The cost of monitoring the success of this establishment is largely absorbed when assessing follow-up requirements for the spraying operations. After establishment, no further releases are required as these agents usually disperse well. Further releases may be necessary to create more fronts in water hyacinth infestations covering a large area.

It is important to avoid spraying at the sites of introduction, i.e., regard these as reserves that should not be disturbed, but conserved as a source for further dispersal and/or manual distribution. A cable can be erected to further safeguard these "nurseries".

Mechanical Control

Mechanical control can be a very effective control option in certain instances on the Vaal River system. This takes the form of spanning cables across the river and these are lowered or raised to regulate the movement of infestations in a manner beneficial to the control program, e.g., to assist accumulation of isolated plants into manageable infestations which are cost-effective to control either by aerial spraying or by boat. Alternatively, these can be used to systematically split large infestations into small units which are then more manageable and can be treated as Class 1 infestations.

Control of Alien Plants in the Riparian Zone

Attention can be given to this region once the control program for water hyacinth is well in hand. During the winter months, when spray and biological control operations are reduced, the labour resource can be employed to control high priority areas on the river banks (e.g., at access points).

Here, a combination of initial mechanical control operations during winter months and follow-up chemical control of regrowth during the summer months is the most cost-effective combination of control methods in terms of control and available resources. The rate and extent of initial mechanical control *must* be carefully regulated to ensure that the essential follow-up operations do not lag behind.

RECOMMENDATIONS

1. Complete eradication of water hyacinth is an unrealistic goal for land managers. Rather the goal must be to reduce and maintain infestations at an acceptable level as determined by management and other parties concerned.

2. The situation with respect to alien plants is a complex matter. This will be seen once certain measures for the control of water hyacinth have been successfully carried out. Other aquatic weeds will become more prominent as they fill in the gaps left by the water hyacinth. It is thus clearly obvious that long-term control strategies are required to maintain the levels of control that have been achieved, i.e., the acceptable levels of control.

3. The reduction in pollution to the Vaal River system is imperative for the control of aquatic weeds since, as mentioned, their growth rate is tremendously increased, thus requiring shorter periods between follow-up control and an increase in costs. Biological control agents are also less likely to keep up with the growth of the weed.

4. The use of cables is an important tool for more effective mechanical and chemical control operations, as the physical size of infestations may be manipulated or broken into smaller manageable units for control. Cables may also be of value in keeping infestations from forming directly around immovable barriers such as bridges. Thus cables that were removed should be replaced and extra cables placed in strategic areas.

5. Control light infestations first (refer to Fig. 1). This is the basic principle of alien plant control for a number of reasons, i.e., it prevents small infestations from increasing to unmanageable proportions, rapid progress is made at relatively little cost and motivation of the labour force and management is more easily maintained.

6. Identify and protect future nursery sites for biological control agents. These sites act as sources for further distribution.

7. Integrated control is required, i.e., a combination of mechanical, chemical and biological control methods, which will act in a supplementary and additive manner for the most cost-effective control.

8. Monitor implementation of the plan and the resulting costs and decrease in alien plant control. This will identify problem areas and situations in which cost savings can be made.

9. Establish a "flood fund" and resources and determine strategies required for unexpected movement of, or changes in, infestations.

Uncoordinated control operations carried out in an unplanned manner result in disappointing progress and inefficient use of resources. This can be improved by the development and use of the devised alien plant control plan.

AGRICULTURAL RESEARCH COUNCIL
PLANT PROTECTION RESEARCH INSTITUTE
ALIEN PLANT CONTROL PLAN

What is a management plan?

- Suitable for mono-specific or multi-species infestations of alien plants
- Based on reliable surveys and mapping of these infestations
- Aimed at systematic reduction of the infestations
- Makes use of locally registered herbicides
- Integrated control comprises mechanical, chemical and biological control methods
- Budgets are drawn up for the land managers
- Aims for the land managers to become competent and independent in alien plant control

What are the advantages of following an ARS-PPRI management plan?

- Drawn up by a team with experience in many related fields

- Latest technology from international herbicide companies
- Visible progress with alien plant control
- Scientifically and ecologically sound
- Practical, affordable and flexible
- Tailored to the land manager's needs

Additional options offered by ARS-PPRI

- Two day training courses aimed at management level
- Two day training course aimed at unskilled and semi-skilled labour
- Weedout: Software program to aid decision making with control operations (pamphlet available from ARS-PPRI)
- Weedout containing land manager's data on alien plants
- Financial projections to aid budgeting in future years

GROUP DISCUSSION

Charudattan	Could you explain the associations between *Eccritotarsus* and *Bellura* and their host-water hyacinth? Are they new associations?
Neser	To my knowledge *Eccritotarsus* and water hyacinth is not a new association; the insect was collected on water hyacinth. It is a small bug that lives precariously and it sucks the juice of the plant. I have one slide here which shows a little bit of the damage; I didn't come prepared to talk about the bug. This one is *Bellura*, the one of which we know so much about because it borrows down the crown of the plant and it leaves the plant progressively more damaged. It's a very large noctuid larva. I am not sure; the insect was originally described from Santa Catarina, in Brazil and was found only in Rio de Janeiro later and in Santa Catarina. It multiplies very, very rapidly in quarantine and all that we know is that it seems to feed also on *Pontederia* in our host testing. That is all we know at this stage .
Charudattan	There appears to be some concern that *Bellura densa* may feed on *Colocasia esculentum*, which is an economically important crop in many parts of Africa and Asia.
Neser	That was the first point that we thought would be a risk. Larvae transferred to *Colocasia* burrowed into the corms and feed on them. But newly hatched larvae has so far never survived on *Colocasia*. They are pushed out of the plant leaf tissue by mucilage and killed without fail. So we have not discarded *Bellura* so far. However, because it is a risk to *Colocasia*, we are holding onto it as long as we can and continuing the tests. I hope that we will find various other insects on water hyacinth.
Orach-Meza	There are two questions I would like to ask: the first is in connection with the winter effect on the water hyacinth. What is the period during the course of the year when the plant is not growing at all? And secondly, what happens to the biological control agents during winter?
Neser	The process sets in about April which is about late Autumn, until September/October. The growth of the plant stops in April and it resumes in October - the tenth month. So it is a long period. Cilliers and I have found that looking under the match dates ones near the crown you would still find *Neochetina* and *Sameodes* survive the winter. There are, of course, always a few plants sheltered amongst bushes along the edges that do survive. It isn't as if they are all killed or all affected that badly. The crowns of the plants remain alive and the water temperature does not go all that low. Cilliers thinks the temperature doesn't have a severe effect on

the insects, but I think that is debatable. We think that the affected plants die back and the plants affect the insects - this may have a very slowing effect on the weed.

Center Do plants that are weakened by the insects succumb to the colder temperatures?

Neser Cilliers finds that plants having larval tunnels present in plants those tend to die earlier than those without a lot of tunnels. So, she has been monitoring this and it seems that the weaker plants do die.

One thing that I would like to comment on is this: we make the assumption that it is best to spray the water hyacinth as late as possible in the season, when the majority of the population of weevils will be in the adult stage. So we try and not do any chemical control until February, which is quite late in the summer, instead of spraying early in the season when water hyacinth is still in the initial phases of build-up. And this is based on a gut feeling because glyphosate apparently is not harmful to adults. I have no idea when one has *N. bruchi* and *N. eichhorniae* mixed and the populations go up and down in 1, 2 and 3 generations. That is something that one will have to look at when the plants are being sprayed. Because our aim is to recommend to the department of water affairs to spray only 75% of an infestation and always leave the other 25% edge unsprayed as a reservoir for insects. That is what we hoped to do and allow the insects to migrate, but whether they migrate or not, I don't know.

WATER HYACINTH: ITS PROBLEMS AND THE MEANS OF CONTROL IN UGANDA

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INTRODUCTION

The rapid increase in the growth and spread of the water hyacinth (*Eichhornia crassipes*) on the waters in Uganda, since it was first observed on Lake Kyoga by Twongo et al. in 1987, has already become an alarming problem for fishing and navigation as well as for other economic activities dependent on these waters. It is now spreading extensively on Lakes Victoria, Kyoga and Albert and on the River Nile in Uganda. Water hyacinth has also been reported as an extremely dangerous weed economically in many countries within the Tropics and Subtropics (Gopal 1987, Labrada et al., 1994).

The history and present state of knowledge concerning the systematics, morphology, development, biology and ecology of water hyacinth has been reviewed by Gopal (1987). It is known (i) to be a successful invader of freshwater, nutrient-rich, eutrophic environment, (ii) to have high rates of vegetative growth and multiplication, (iii) to have a fairly wide ecological amplitude, and (iv) to exhibit great phenotypic plasticity.

Ever since it has been introduced to areas outside of South America where it has no natural enemies, it has created innumerable problems for man such as; interference with the use of water by causing direct obstruction to navigation, by blocking water intake points, by degrading water quality for domestic use and by checking water flow in irrigation channels. It has also been responsible for drastic changes in the plant and animal communities of the freshwater environments, particularly fish kills, besides serving as an agent for dispersal of several deadly diseases (Thompson, 1991; Willoughby et al., 1993; Orach-Meza, 1995).

The exact period when this weed was introduced into Uganda is not certain, but it began to proliferate on Lake Kyoga earlier than 1987 when the weed was sighted by the staff of the Uganda Freshwater Fisheries Research Organization (Twongo, 1988). The gravity of the situation was quickly realized, and it was decided by the Government to embark on a campaign for the control and eradication of the plant (Orach-Meza, 1988, 1990). All the Regional and District Services in the areas being infested by the weed were also requested to cooperate in the fight against the invasion. Recent aerial and ground surveys and updates by FAO/UN (Thompson, 1991 and Baarveld et al., 1995) and the European Union (Agroconsulting, 1994) in collaboration with the Fisheries Research Institute and the Fisheries Department in Uganda

(Twongo, 1995, Orach-Meza, 1995) revealed that as much as 90% of the shorelines of the affected water bodies are covered by the weed and that this is fast spreading outward into the open water. An action- oriented control program has since been prepared involving manual, mechanical, biological and chemical measures (Orach-Meza, 1994; FAO/UN, 1995), although only the manual and biological control programs are being implemented already.

The Nature of Its Invasion

In Uganda, the water hyacinth is found as mats of floating plants, attached to the vegetation on the river banks, or as islands of plants floating freely on the water. It is also found at times above water level on damp river banks.

A single shoot of the plants is enough to start the spread. It may be carried up-stream on steamers, boats, canoes or nets, but it may also move up-stream by other yet unknown means. The plants increase rapidly and spread as islands of floating plants that may become stranded on river banks when the water level falls and float again when the water level rises. Floating islands gather together as mats in the lee of river islands, on the inside of river bends, on windward side of peninsula or in quiet lake bays. In Lake Victoria, large numbers of plants have gathered in the northwestern bays of the lake. Those blown on sandy beaches are seen dying in mass. A few mats are on the leeward side of Ssese Islands. In Lake Kyoga, large numbers have penetrated along narrow channels leading to fish landing centres on the southern part of the lake. They are also found in clumps often 10 or 15 metres wide fringing the papyrus on the eastern and southern shores of Lake Kyoga. Several inlets and fish landings are completely obstructed. Ferry crossings at Bukakata, Masindi Port, Paraa and Laropi are often completely blocked.

It has been reported that where seeds are produced, they may be the cause of a new outbreak of water hyacinth after they have been apparently completely cleared (Gopal, 1987). It is, therefore, possible that seeds may be transported over considerable distances on the feet of birds or animals. Seed production has been reported from Zaire (Evans, 1963), and although it has not yet been observed in Uganda it is likely that it may have been the cause and source of the present invasion.

The Effects of Water Hyacinth Invasion

The socioeconomic implications of the problems of the weed in Uganda are several: The lakes and rivers are of great significance for fisheries, inland water transport, hydroelectric power generation, municipal and rural water supplies, recreation, rainfall and a pool for aquatic genetic resources. Types and characteristics of the impacts are as follow:

Fisheries

Concern over the threat by water hyacinth to the thriving fisheries of Uganda has intensified. The lakes and rivers in Uganda supply on the average 220,000 tons of fish per year. The subsector contributes some US $ 88 million to GDP and US $ 39 million to export earnings. Furthermore, the subsector contributes to food security, income generation and employment opportunities to the local and poorer members of the riparian communities.

Water hyacinth concentrations affect the fisheries through blocking fish landing sites, swamping fish breeding areas and impeding fishing activities which are reflected in reduced level of production, a reduction in species diversity of the catch, poor quality of fish, rising costs of operation, lower incomes to the fishermen and higher prices to consumers. The invasion of the bays by the weed has caused fish to migrate to open waters particularly in Lake Victoria and has thus reduced the potential of the bays for fishing, spawning and nursing. The cover of the landing sites is already causing fishermen to take longer time to land and motorized canoes to consume more fuel per catch of fish.

Inland water transport
The mats of water hyacinth has resulted in disruptions, delays and rising costs of inland water transport sector. The effects of these inconveniences are already being felt widely within other sectors of the economy served by railway-wagon ferries on Lake Victoria, highway ferries across rivers and channels and inland canoe transport which are important trade routes. Water transport happens to be the only means of communication and a source of livelihood to some of the riparian communities.

Water supplies and intake points
The supply of water for both domestic and industrial purpose in the urban and rural areas is being threatened by the presence of water hyacinth. Blocking of water intake points is already threatening to lead to higher operating costs for producers in other sectors of the economy. Screens and filters of urban water processing plants are often plugged by the residues of decaying plant materials. The decaying organic matter pollutes the water and reduces its quality. Women who normally fetch the water in the rural areas are the most affected.

Hydro-power production
Heavy mats of floating water hyacinth is already pressing on the dam at Owen Falls Power Station. The turbines of the power station at the dam are often shut down in order to clean the intake-screens of the turbines and plugged filters of the cooling system. This results in the reduction of power production, power outrages and financial losses. Manual removal is costing the Uganda Electric Board (UEB) about U.S. $ 1 million per day already.

Environment and health
Blocking of light penetration impedes photosynthetic actions thereby breaking down life cycles and food web systems in the water. Biodiversity is reduced leading to reduced population of living organisms.

Physical reduction of water bodies (eutrophication) may be gradually taking place due to the decomposition and sedimentation of rotten weeds and other organisms. Eutrophication also reduces water quality due to the fermentation of dead organisms.

The massive cover by the weed may be increasing the rate of evapotranspiration resulting into the problems of water balance.

The weed has also been reported to impact negatively on the health of the communities. It provides habitat for vectors of malaria and bilharzia, and it harbors poisonous snakes. It is suspected to transmit amoeba, dysentery and typhoid and to cause severe skin rashes. Its roots turn water muddy and dirty, making the water supply unsuitable for drinking and for other domestic uses. This impact poses additional burden on the limited health services and facilities available to the poor rural communities.

Methods of Control or Eradication

The methods chosen for the eradication of water hyacinth must depend on the condition of the area to be treated and the various factors (environmental, social and economic) making up the problems as a whole. It is often of great advantage to tackle the problem of the weed control or eradication as early in their development as possible so that the best drastic methods may be used.

The Government of Uganda has, therefore, opted for immediate action to control the weed as the cost of doing nothing now would result eventually into enormous economic loss to the country. Basically, integrated approach of employing manual, biological, mechanical and chemical measures is being adopted. Several activities have been implemented by the Government within the limits of the resources available with a view to controlling the spread of the weed. These include the following:

Surveillance of water Hyacinth in Uganda

Aerial and ground surveys have been conducted and are being regularly updated to establish the extent and magnitude of the distribution of the weed nationwide (Thompson, 1991, Twongo, 1994, Bagnall, 1994, Baarveld et al., 1995). Plans are also underway to investigate and verify factors that control the movement of water hyacinth across the lake and their propagation. In addition, the effects of control strategies and measures employed on the water shall also be monitored.

Public awareness campaigns

A formal public awareness campaign was launched in 1991 which included the distribution of posters and leaflets to the public up to the parish level; this was followed by the mobilization of clusters of communities living within the vicinity of areas infested by the weed to participate in physical removal and burning (Orach-Meza, 1995). The campaigns are stressing the importance of not growing and spreading water hyacinth, of not polluting water, and of reporting new infestations to appropriate authorities. Information on control measures being employed, particularly on the use of chemicals, is being disseminated. In addition, there is a law in place prohibiting the possession, propagation and introduction of the weed in other areas.

Physical or manual method

Manual removal of the weed is ongoing under government financing with the objective of keeping fish landing sites, water abstraction points and water intake points around the country open so that the routine economic activities can continue uninterrupted. This involves removing the weed from the sites using efficient hand tools and protective covers such as rakes with long handles, ditchbank knives, spades, forks, wheelbarrows, gumboots and hand gloves. The weed removed is carried to dry ground, dehydrated and burnt. But the rapid rate of increase of the weed in addition to the magnitude of its distribution is already making manual method uneconomic, as it is a slow and inefficient process for large and heavy mats.

Biological control method

Biological control which means the direct or indirect destruction of one organism by another is rarely very effective in large bodies of water like in Uganda or on large masses of the weed. Two weevils, *Neochetina eichhorniae* and *N. bruchi* are already in the country and are being multiplied and released onto the weed. However, considering the present magnitude and distribution of the weed, the effectiveness of the few weevils is highly limited. To be effective, billions of agents must be procured to match the weed in rate of increase and which is extremely expensive.

Due to their slow multiplication rate and action, the weevils are being considered as a major component of the long-term measures for maintenance control of the weed under the integrated plan. This will ensure that when the emergency removal is undertaken, the weevils will be available for deployment to prevent weed expansion.

Mechanical control method

It is the considered view of the Government of Uganda that floating weed harvesters should initially be deployed to reduce the magnitude of the weed quickly before the integrated approach is brought to bear for maintenance control. A study in this direction was carried out by Bagnall (1994).

The recommended control measures will be used at sites where cleaning of water hyacinth is urgently needed and manual removal cannot be implemented, e.g., heavy infestations in large bays. A couple of floating-type harvesters are already being procured by the Government. Although the machines are expensive and have high running costs, they provide immediate predictable means of removal of the weed from the water.

Chemical control method

In the absence of mechanical harvesters, and as biological agents have not yet established themselves for effective control, the option left as a quick solution is to initiate a rigorous herbicide spray program. Pilot studies to verify the efficacy, safety to health and environmental friendliness of suitable herbicides for application are underway. This is being followed by training technicians on the precautions required in the application of the chemicals to control the weed. The chemicals identified as suitable shall then be applied on selected and heavily infested isolated weed locations as a short-term measure (FAO/UN, 1995). Correct scientific methods of application of herbicides shall be followed so that no threat to environmental conditions and human health would occur.

CONCLUSIONS

The danger that water hyacinth is posing is already a real one. The economic consequences may soon become extremely serious. The cooperation of every member of the public is essential if the weed is to be brought under control.

Urgent control measures are needed to deal with the current crisis with water hyacinth, while efforts are made by researchers to deal with the deeper and systematic problems that are the real cause of the water hyacinth explosion in an aquatic environment. The handling of the immediate crisis is straight forward given the resources required. After careful assessment of the options for control, experts in the region (LVEMP, 1995) have recommended that all the methods be used right away, including chemical method which seems necessary at this juncture. The risks of using herbicides are real but more modest than those associated with other pesticides and agrochemicals already in more common and widespread usage in the lake basins than the chemical control agents identified for use on the water hyacinth. The only caveat is that a chain of responsibility must be clearly defined, especially with regard to safety precautions around the use of the chemical control agents.

Three main activities are to be undertaken: First is to get rid of the really gross accumulation of the weed as quickly as possible; second is to intensify the multiplication of biological control agents as a major component of the integrated long term control of the weed; and third is to put money into research on water hyacinth growth, propagation rates and dispersal dynamics. It is only in this way that the menace of the water hyacinth in Uganda shall be brought under maintenance management control.

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Region C - Australia

Wright

AN OUTLINE OF WATER HYACINTH CONTROL IN AUSTRALIA

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INTRODUCTION

History and Importance

It is now 100 years since water hyacinth was first introduced to Australia and for about 95 of them the weed has been causing serious problems. The first obvious problems caused by large floating mats related to interference with water traffic, but in time it became obvious there were other deleterious effects including those on water quality, pumping and water use, fishing and biodiversity. Property damage during floods, water losses due to evapotranspiration and potential human health problems are other reasons the weed became, and has remained, Australia's most serious freshwater aquatic weed. Water hyacinth is a declared noxious plant in the states of Queensland, Victoria, Western Australia, the Northern Territory and in certain areas of New South Wales. In Tasmania it is listed as a prohibited weed.

Important water hyacinth infestations still occur in rivers, streams and natural and man-made water impoundments in coastal regions of Queensland and New South Wales, however the potential distribution of water hyacinth includes most water bodies in Australia. In 1977 the cost of controlling water weeds in Australia was estimated at between $1.5-$2.0 million annually, however even at the time the Australian Weeds Committee cautioned that the actual costs, including overheads, were much higher. Fresh water is a precious resource in Australia and its management is of particular importance, so control of excessive growths of water hyacinth and other aquatic weeds has been of widespread interest for decades.

OPTIONS FOR CONTROL

Nonbiological Control

Chemical and mechanical control methods have been used since the early 1900s to combat water hyacinth, mostly with limited success. Eradication of large infestations of the weed has been rare and, parallelling overseas experience, usually has had little long-term effect, even after the introduction of phenoxy herbicides in the late 1940s. This poor history of control is due partly to the weed's rapid growth rate and partly to its ability to reinfest via the seed bank or by flood-borne plants. By contrast, control of small infestations with herbicides has often been very effective, but is heavily dependent on skilled operators who maintain long-term vigilance for appearance of regrowth or seedlings. The herbicides most commonly used have been 2,4-D, diquat and amitrole. Over the last twenty years, the fear of pesticides damaging human health and the environment has severely hurt the public standing of chemical control methods for weeds.

There has been one example of successful control of a 7,000 ha infestation using a combination of chemical and mechanical controls with water management. In this case water management involved modifying water flow with banks and so drying large areas of land. The main channel was mechanically cleaned and large scale aerial and ground spraying occurred. Although very successful, this is a unique case for Australia where not only these techniques could be applied, but also where the natural drainage pattern of a large land area could be permanently modified without causing widespread alarm.

Biological Control
In 1974, the Brisbane laboratories of the CSIRO Division of Entomology commenced a biological control program against water hyacinth by obtaining permits to import the two weevil species, *Neochetina eichhorniae* and *N. bruchi*. Colonies were imported into quarantine from the USDA Aquatic Plant Management Laboratory in Fort Lauderdale. However, due to lack of information on interspecific competition it was decided not to proceed with studies on *N. bruchi* until more was known about the performance of *N. eichhorniae* in Australia and the performance of both species in the field in the USA. The colony of *N. bruchi* was destroyed and host-specificity studies were commenced on *N. eichhorniae* to satisfy Australia's rigid quarantine requirements. Although much was already known about the water hyacinth problem in Australia, in early 1975 a questionnaire survey of local government authorities was used to further define the nature and extent of the problem.

Liberations of *N. eichhorniae* started in September 1975. The weevil established readily, showing most activity on tall, densely-packed plants with slender petioles. Over the next few years many infestations showed increasing levels of weevil damage, decreased plant and infestation dimensions and the establishment of other plant species on the weed mat. At one monitoring site, death and subsequent collapse of patches of water hyacinth commenced just two years after the initial release of *N. eichhorniae* adults. By the beginning of 1978 weevil populations had reached a sufficiently high level in south-east Queensland to allow field collections of adults to supplement releases of laboratory reared insects.

In 1977, a pyralid moth, *Sameodes* (also called *Niphograpta*) *albiguttalis* was obtained from the USDA. Following host-specificity testing, field releases started in October 1977 over the same range as the liberations of *N. eichhorniae*. Damage by the moth was more severe on water hyacinth with bulbous petioles typical of rapidly expanding infestations or growing at the open water margins of dense infestations. The distribution of damage was patchy and probably because of the moth's high dispersal ability, the centres of larval activity changed position irregularly within infestations. Good natural dispersion also resulted in the moth establishing at infestations up to 20 km from release sites so field collection of infested plants for redistribution was not necessary as often as originally planned.

In early 1981 a third biological control agent, the pyralid moth *Acigona* (also called *Xubida*) *infusella* was imported from Brazil and first releases were made in September 1981. Although it initially appeared to have become established in the field, populations were not sustained and it apparently died out. In 1995 it was again imported to Australia for further study.

By the late 1980s it was decided to reintroduce *N. bruchi* into Australia when further study by USDA personnel in Florida on field interactions between the weevils *N. eichhorniae* and *N. bruchi* indicated there is a greater impact on the control of water hyacinth when both weevil species were present than when either species is present alone. At the time it also appeared that the best levels of biological control had been achieved in southern USA and in the Sudan where both species of *Neochetina* had been released. A third factor supporting the decision to reintroduce *N. bruchi* was an indication that *N. bruchi* had greater tolerance of cool climates than *N. eichhorniae* and could therefore be more effective in areas of Australia where *N. eichhorniae* had only a marginal impact on the weed.

In August 1989 CSIRO imported stocks of *N. bruchi* from the USDA and in December 1990 following host-specificity testing the first releases were made. A large breeding program was established at CSIRO laboratories in Brisbane, the New South Wales Agriculture Research and Advisory Station in Grafton and the Queensland Lands Department Tropical Weeds Research Center in Charters Towers. Since then, it has become established at infestations between far north Queensland and Sydney, NSW. Although *N. bruchi* populations have increased well at most sites (to the point where the species comprises over 80 percent of the weevil population at one study site), at some sites the population has increased only slowly or has remained disappointingly low. Studies are underway to indicate the importance of plant nutrition on the growth of *N. bruchi* populations.

INTERNATIONAL COLLABORATION

Over many years there has been very rewarding interaction between Australian and overseas scientists working on biological control of water hyacinth and this has resulted in several publications and a great broadening of our knowledge and experience. In particular the association with USDA scientists has been very helpful in the development of Australia's biological control program. However most formal collaboration has been with scientists and research institutions in Southeast Asia.

In 1990 with the support of the Australian Center for International Agricultural Research (ACIAR), CSIRO Brisbane and the National Biological Control Research Center (NBCRC) in Bangkok, Thailand, commenced a joint project to establish *N. bruchi* in both countries and to extend the work to neighbouring countries. Thailand had already introduced *N. eichhorniae* from the USDA in 1979 to counter their massive water hyacinth problem but like Australia recognized the need to establish a complex of agents on the weed. A starter colony of *N. bruchi* was taken to NBCRC quarantine in July 1990 and field liberations commenced in May 1991. Since then widespread releases of the weevil have occurred throughout Thailand mostly using locally-reared insects.

Although biological control techniques against aquatic weeds had been greatly under-utilized in Southeast Asia, interest in biological control of water hyacinth in the region grew as the project developed. Malaysia, which had received *N. eichhorniae* as an accidental import (probably from Thailand) in the early 1980s, expressed interest in receiving a starter colony of *N. bruchi* and the first shipment was taken to quarantine at Serdang in April 1991. The Malaysian project was directed by their Working Group on Aquatic Weeds comprising, amongst others, representatives of the Department of Agriculture (DOA), the Malaysian Agricultural Research and Development Institute (MARDI) and the now-defunct ASEAN Plant Quarantine Center and Training Institute (ASEAN-PLANTI). Field liberations of *N. bruchi* commenced in Malaysia in May 1992.

The first shipments of *S. albiguttalis* were taken to Thailand in October 1993 and to Malaysia in March 1994. Field liberations of *S. albiguttalis* began in Thailand in April 1995. In Malaysia, host-specificity testing of *S. albiguttalis* is complete and releases should commence shortly.

By 1994 research institutes in Vietnam and Indonesia having national mandates for agricultural research in their respective countries were committed to developing biological control programs against water hyacinth. The respective institutes were the Vietnam Biological Control Research Center (VNBCRC) of the National Institute of Plant Protection (NIPP) in Hanoi and the Southeast Asian Regional Center for Tropical Biology (SEAMEO-BIOTROP) in Bogor, Java. In January 1995 a new collaborative project, again supported by ACIAR, was launched to link research on biocontrol of water hyacinth in five countries, Australia, Thailand, Malaysia, Vietnam and Indonesia. The project will allow development of local insect rearing facilities for continuation or commencement of distribution of agents already present in the countries, the introduction of agents not already present in the countries but available elsewhere, and to evaluate potential additional agents, for example the moths *Bellura* (= *Arzama*) *densa* and *Acigona* (= *Xubida*) *infusella*. Monitoring of water hyacinth infestations to confirm establishment and performance will be undertaken in all countries. Experience gained in field evaluation techniques should have important flow-on benefits to other biological control projects. Studies of the ecology of the agents, their interactions with each other and the target plant and the incorporation of biological control into management of aquatic systems will mainly occur in Australia. Training features prominently in the project, bringing benefits to the project and increasing regional expertise and the capacities of individual institutions to conduct their own biological control work in future.

The first shipments of *N. bruchi* to Indonesia occurred in February 1994 and to Vietnam in October 1994. Host-testing is complete in both countries and field liberations of the weevil are expected to commence shortly. Shipments of *S. albiguttalis* to Indonesia and Vietnam are planned for late 1995.

In January 1993 a project supported by AUSAID commenced with the Papua New Guinea (PNG) Department of Agriculture and Livestock under which CSIRO would provide biological control agents and expertise to counter PNG's rapidly increasing water hyacinth problem. *Neochetina eichhorniae* was already established in a number of areas following an intentional introduction of the weevil in 1986 and in these areas reductions in infestation size are now occurring. As part of the project, *N. bruchi* and *S. albiguttalis* were introduced and liberated in 1993 and 1994, respectively, although establishment of *S. albiguttalis* has not yet been confirmed. There has also been a considerable effort in redistribution of *N. eichhorniae*, and after three years a significant reduction in the area covered by water hyacinth has already been achieved at one site with high degree of eutrophication as a result of the two weevil species.

GROUP DISCUSSION

Wright	(Referring to slides) You would assume that in a site like this, if the site was completely covered and there is successful biological control, the infestation would be reduced to an equilibrium level; but we don't know what the equilibrium level is. By the way, even if there are a few plants left you'll find in them the weevil.
Haller	Based upon other water bodies in Australia, what is that dynamic equilibrium; is it varied from water body to water body? Or how many water bodies do you have that are being maintained in the 5 or 10% level with *Neochetina* and *Sameodes*.
Wright	It is around 20 and 35%; in the summer - that is about the worst time of the year. This slide shows another typical scene: we have the open water margin, we have these smaller plants, and the *Neochetina* has worked.
Center	How long do you plan to do this type of monitoring?
Wright	Four years maximum. This sequence (shown in slides) is over 4 maybe 5 years where the water hyacinth is very heavily attacked. This is *N. eichhorniae* by itself; there is no *N. bruchi* there. This is just a few weeks ago in Thailand, the first release of *Sameodes* in this area, Hanoi. You just have to clear a little passage in front of the houses. They are also trying to grow turnips, a vegetable, there and the water hyacinth is interfering with that. A team of men going to Hanoi to manually collect the water hyacinth. This is in Malaysia. The main source of protein for this family is fish grown on that waterway. Here we have barricades in central Java that are used to try and protect a hydro-electric plant from an influx of water hyacinth. This is in central Java where this man here in the front has organized groups and villages to help in the collection of insects. He started out paying some of the villagers and children to collect and bring them back. In some of these areas collection and distribution of agents has become a past time. Apparently because they have ownership of this project and it is one of the reasons I think some of the collaborative projects have worked much better for us than some of the AID project. With an AID project it is tempting and when the money has run out, well, that's all that happens. This is just another example of trying to get people working and sharing experiences in farm work. It has been very successful and I am very glad about being involved in this.

Discussion after slides

Charudattan — In your experience, do you think *Sameodes* is doing much better in Australia and the Far East than what I see in Florida? In Florida it has always has been very spotty. You don't find *Sameodes* that often.

Wright — I agree with that. It is patchy but it is also very easy to underestimate anything like that.

Charudattan — In what way?

Center — You'll see it come into an area and will hit 65 - 70% of the plants and, in some cases, kill 1/2 of the plant. However, this is just for a short while and then it is gone. Unless you happen to be right there when it is happening, you totally miss it. That is why it has been so hard to evaluate. It is hard to set up a study that will time it correctly.

Charudattan — First, I would like to know what is the proportion of the total area infested by water hyacinth, namely percentage of water bodies, in Australia that is under biological control. Second, do you release the insects every year in an infested area?

Wright — I will answer the second question first. We released the numbers that are available to us. So, if we had 1000 we'll release 1000. In Thailand occasionally they have had only about 50, but they have succeeded in getting establishment from these 50. In Papua New Guinea (PNG) the numbers have been quite high - I think since the start of the year something like 50,000, roughly. One of the reasons we could see such good results in PNG, rapidly, is that the appropriate of numbers of insects were released originally. Assuming a normal population growth curve and start with a large number of insects, you are automatically starting farther along by avoiding the initial lag phase. Does that sound reasonable to you? So, you just do what you can; the more the better. There are other tactics that could be more important than sheer numbers in a particular spot such as releasing the insects high in the water drainage area so the infestation is uppermost in a river system. If the insects get lost then they are going to go down. Do your releases in an area where the insects are likely to be protected, than in an area where a spray operator may come along and clean out the water hyacinth. There are so many things you can do; I don't like the person releasing the insects to worry about the actual numbers of release.

	The first question, what proportion of the infested area is under control? Some people would say that they all are under some sort of control. The percentage that is under the final level of control in Australia is the ultimate equilibrium point. I would say probably about 30% of the infestations are all under biological control. Very few infestations are being tackled chemically. It is just too difficult to do. If you are in charge of one of the government departments and you want to spray chemicals in Australia, then you really have to go through the hoops. On top of that you have to deal with the public and even your kids who are concerned about the use of chemicals.
Haller	In 1977 they were spending between $1.5 and 2 million on water hyacinth control?
Wright	That was an estimate.
Haller	Right now you are spending zero, right?
Wright	Most sites are not sprayed chemically. There are some important sites where a lot of money is being spent. And as long as they have permission to spend the money it will continue.
Haller	How has the cost of water hyacinth control in Australia changed in 1977, 1987, and it is now almost 1997?
Wright	I don't know. In fact I don't know anybody that knows. And to get that information one will make local government authorities know that they are spraying. Very often they are trying to hide the fact that they are doing much spraying.
Orach-Meza	What level of salinity is in the water in the areas you mentioned? We have areas where there is salt water intrusion during the dry periods.
Wright	The level of salinity is constantly changing.

Region D - North America

Mexico - Martinez

United States

Haller
Cofrancesco
Center

WATER HYACINTH PROBLEMS IN MEXICO AND PRACTISED METHODS FOR CONTROL

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INTRODUCTION

Situation of Water Hyacinth in Mexico

Estimates made from information available in 1993 for 114 dams and lakes indicate that approximately 62,000 ha in the country have been infested by aquatic weeds, or 24% of ha total flooded surface. The most prevalent species is water hyacinth, present in 40,000 ha of the infested surface, followed by pondweed (*Potamogeton* sp.), cattail (*Typha* spp.), hydrilla (*Hydrilla verticillata*), water lettuce (*Pistia stratiotes*) and duckweed (*Lemna* spp.).

Information available for irrigation districts indicate that aquatic weeds are a problem in 12,000 km (27%) of irrigation canals and 19,000 km (63%) of drainage canals.

Phosphorus was one of the most important elements with regard to proliferation of water hyacinth. An estimated 231,000 metric tons per year enter lakes and dams from agriculture, husbandry, municipal and industrial sources in Mexico (Limón, 1989).

Efforts to Control Water Hyacinth in Mexico

Efforts to control aquatic weeds through harvesting methods, began at Lake Pátcuaro, Michoacán, in 1974 with the use of a boat with a skiploader and an automobile motor, are producing encouraging results. Again in 1974, the same method was applied in the Manuel Avila Camacho Dam, in Puebla with basically the same results.

In 1985, water hyacinth control was implemented at the Requena Dam (Hidalgo), including a ban on the dumping of waste waters in the dam, water level management to dry and burn the plants along the shore and the use of a domestically manufactured triturator. The dam was cleared of the plague. The machine's efficiency was approximately 355 metric tons/8 (Gutierrez & Bravo, 1990).

Chemical controls began in 1958, with the use of 2,4-D in Lake Cajititlán, Jalisco. The lake remained free of the plague for seven years, after which the problem escalated to major proportions and, since then, physical and mechanical methods have been employed.

In 1975, experiments were carried out with sodium arsenate, sodium chlorate, trichloro arsenate, mineral acids, caustic soda, esteron, 2,4-D amine, diquat and paraquat in combinations and at different doses. The results were satisfactory; however, the herbicides and other substances were toxic and affected the local flora and fauna.

PRESENT NATIONAL WATER HYACINTH CONTROL POLICY

The Aquatic Weed Control Program (Programa de Control de Malezas Acuáticas, PROCMA) was created in January 1993 by presidential decree. The program was developed by the Mexican Institute of Water Technology (IMTA).

PROCMA must identify the regions which are affected by infestations and the plants present, and evaluate the best means of eliminating or reducing the infestation considering the site, the quality and use of the water to be treated, and the resources available for the task. The maintenance schedule to be observed must be developed and documented for delivery to users when the clean body of water is returned to them.

Three principles have been established:

(1) reduce the weeds to a manageable level and maintain this level through a firm user commitment to observe the maintenance program developed for the body of water;
(2) use methods most suitable to the ecosystem and water uses (i.e., biological and integral control);
(3) formulate an integral watershed-level program which will include the control and maintenance operations.

Chemical and Mechanical Control Activities of PROCMA
Three different control strategies were developed for three distinct bodies of water which had in common neither use, depth, size nor geographic location (Fig. 1). Water level management was considered the most adequate for the Tacotán Dam. The water was released to the Trigomil Dam, downstream and 105 ha of water hyacinth were left to dry on the shore and were burned by the users (fishermen). The remaining 100 ha were dusted, by helicopter, with 3.3 kg/ha of 2,4-D. The dam was then closed for 21 days. This first treatment was 60% effective. The remaining 40% was not sufficiently damaged to sink. However, with the combined effect of a reduction in population and a loss of turgidity, a greater surface area was made available. Diquat, a contact herbicide, was applied 55 days later at a rate of 1.7 kg/ha and provided 100% control. The dam was cleared after 110 days of operations.

For the Trigomil Dam, a combined chemical-mechanical program was prepared. The water from the dam is used in the El Grullo Irrigation District, restricting the time during which the dam may be closed and the chemical used. Glyphosate (Rodeo^{TM}), at 3.35 kg a.i./ha, was selected as there are no restrictions on its use in irrigation water. One-half of the infested area (104 ha) was treated initially; the remainder was sprayed 38 days later. The herbicide's action was irregular, with some areas showing excellent results while others reacting very slowly. The product was applied during the growing season, based on results from small-scale laboratory tests performed at the laboratory, which indicated greater effectiveness at that time (Gutiérrez, 1993). Though the plants sank slowly and inconsistently, there was a noticeable reduction in plant growth in most areas. There was also a marked change in the consistency from strong, healthy plants with an intense green colour to yellow individuals which fragmented easily at the touch. Sinking was calculated in 20 to 40 hectares. The second dose was applied as scheduled and two triturators began a 15 day campaign to accelerate sinking, after which approximately 160 ha of water hyacinth had been eliminated and 100% control was attained.

At the Miraplanes Dam (Fig. 1), the presence of a large area of cattail affected the decision to use glyphosate. Westerdahl and Getsinger (1988) state that glyphosate is very effective against this species. Three treatments were programmed. The first was done from a small plane at 3.5 kg/ha. The second was 25 days later, from helicopter at 3.33 kg/ha and the third using the same method 207 days after the first. Fifteen days afterward, 70% of the dam was cleared. Three months later, the dam was totally weed-free.

The results of the analyses for residues of 2,4-D indicated that levels never exceeded 0.1 mg/l, the maximum accepted level for drinking water. Residues of 2,4-D, glyphosate and diquat were not detected in analyses of tissues of edible fish (tilapia, carp and catfish) and sediments. The low levels found in water may be explained by dilution and degradation, supporting claims of low persistence (Gutiérrez *et al*., 1994). The assimilation of the triturated or treated biomass into the water column modified its quality by incorporating nutrients and diminishing the dissolved oxygen through an increase in the COD. However, the change in quality was due mainly to an affluent in which high concentrations of organic material and other nutrients were detected. No dead fish were observed during or after the treatment period. Studies made of the biological communities (benthic and planktonic) in the Tacotán, Trigomil and Miraplanes dams indicated that they were unaffected (Gutiérrez *et al.,* 1994).

Chemical control, as shown in the experience obtained, is reliable, efficient, cost effective and safe if the recommendations of the manufacturer and governmental control agencies are strictly observed. Cost per hectare for the products used in Mexico were: 2,4-D US $120; diquat, US $150; glyphosate, US $210. The equivalent cost of mechanical control is US $610-760, almost six times more costly. Product efficiency in this project was: 2,4-D > diquat > glyphosate.

Biological Control Activities of PROCMA
In order to develop preventive maintenance programs, IMTA initiated in 1993, a project to establish biological control of water hyacinth in Mexico. The two principle facets of the project are the utilization of two weevil species *Neochetina eichhorniae* and *N. bruchi*, and indigenous pathogens.

Technology Transfer
During a cooperative survey made in 1993 by the IMTA and the United States Department of Agriculture (Dr. Jack DeLoach and Dr. Ted Center), four insects and a mite attacking water hyacinth were found in Mexico: the weevil *Neochetina eichhorniae*, the stem boring *Sameodes*

albiguttalis, the aquatic grasshopper *Cornops aquaticum*, the scarab beetle *Dyscinetus* sp. and the mite *Orthogalumna terebrantis*. All of these are host specific to water hyacinth (except *Dyscinetus*) and native in South America. Of these natural enemies, only *Cornops aquaticum* and *Neochetina eichhorniae* were reported in Mexico prior these survey.

Neochetina eichhorniae was introduced to Mexico from the USA at the end of the seventies in an effort to establish a biological control (Bennett, 1984). However, other reports indicated its presence as early as 1967 (O'Brien, 1976). *Neochetina eichhorniae* is now well established from the central to southern areas of the country. Populations averaging from 0.07 to 7.10 per plant have been observed on that region.

In 1994, a culture of *Neochetina bruchi* was obtained from USA. In order to insure that parasites, predators or pathogens are not transferred with the insects, *N. bruchi* was maintained in quarantine conditions in IMTA laboratory. After obtaining a clean culture, a rearing of *Neochetina* was built. The Institute has a greenhouse equipped with 8 ponds ($2m^2$ by 1m deep), and 20 screen ponds (2 m^2 by 1 m deep) located outside the greenhouse. In this installations, IMTA has developed a rearing method to produce about 700 insects per month. Field releases were started in April 1995, in one location in the north and three sites in the central part of the country. Currently, a research about the population dynamics of *Neochetina* spp. is being conducted at Chapala Lake, Jalisco.

Research of Indigenous Pathogens

In order to search for the occurrence of pathogens of water hyacinth and document their distribution and the impact on this weed in Mexico, a survey was made in 1994 in collaboration with Dr. Charudattan of the University of Florida. Water hyacinth plants with symptoms of disease were collected during the rainy season in 46 infested sites from the southern to the central part of Mexico.

Amongst others, four diseases were commonly found in the surveyed areas. They were, in the order of frequency of sightings: the zonate leaf spot caused by *Acremonium zonatum*, a *Cercospora* leaf spot caused by *Cercospora* spp., the *Rhizoctonia* leaf blight caused by *Rhizoctonia solani*, and an *Alternaria* leaf spot caused by an unidentified species of *Alternaria*. Based on symptoms observed in the field, two other pathogens may also occur in Mexico, namely, *Myrothecium roridum* and a bacterial agent capable of causing chlorotic halo around insect feeding spots on leaves. All of above pathogens have been shown to hold potential as biological control agents in the United States, South Africa, Australia, and Egypt. They are safe, easily culturable in a laboratory and inexpensive to provide sufficient inoculum for field trials. Currently, the pathogens found remain to be tested to determine their virulence, safety, and suitability as bioherbicide agents for use in Mexico.

CONCLUSIONS

The weed control program includes 13 bodies of water. Table 1 summarizes the advances obtained until June of 1995. The bodies of water, clear of weeds, are turned over to the users together with a maintenance manual.

Experience has taught us that the first phase of the control program must employ massive attack techniques for an important reduction in coverage, such as that seen with the use of chemical agents and triturators. The second phase should utilize all of the modern know-how combined with an integrated management program to keep the population under the weed threshold. This is where biological control can be an important component.

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Table 1. Progress of water hyacinth control up to June, 1995

Body of Water	Area (ha)	Control method	Advance
Trigomil, Jal.	*Flooded area: 393 Infested area: 211	Chemical: 1,2 Mechanical: 4 *N. eichhorniae*	Clear and delivered to users July 93
Tacotan, Jal.	*Flooded area: 463 Infested area: 205	Chemical: 1,2,3 *N. eichhorniae*	Clear and delivered to users July 93
Miraplanes, Jal	*Flooded area: 73 Infested area: 73	Chemical: 1 *N. eichhorniae*	Clear
Zumpango Lagoon, State of Mexico	Flooded area: 2,000 Infested area: 750	Chemical: 2,3 Mechanical: 4	90%, remainder to be treated
Rojo Gómez Dam, Hidalgo	Flooded area: 350 Infested area: 250	Chemical: 3	250 ha treated
Endhó Dam, Hidalgo	Flooded area: 1,260 Infested area: 300	Chemical: 1,3 Mechanical: 4 *N. eichhorniae, N. bruchi*	Clear
Chapala Lake, Jalisco	*Flooded area: 108,000 Infested area: 18,000	Chemical: 1 Mechanical: 4 *N. eichhorniae, N. bruchi*	Beginning of chemical control and user participation. Integrated project under design
El Salto Dam, Jalisco	Flooded area: 700 Infested area: 192	Chemical: 3	192 ha treated
La Vega, Dam, Jalisco	Flooded area: 2,000 Infested area: 82	Chemical: 1	82 ha treated
Hurtado Dam, Jalisco	Flooded area: 560 Infested area: 27	Chemical: 1	27 ha treated
Solís Dam, Michoacan	Flooded area: 6,490 Infested area: 2,600	Chemical: 3	2600 ha treated
Lake Guadalupe, State of Mexico	Flooded area: 450 Infested area: 400	Chemical: 1,2,3 Mechanical: 4	99% clear
Chicuili Dam	Flooded area: 22 Infested area: 11	Mechanical: 4	Clear

Codes: 1. Glyphosate 2. Diquat 3. 2.4-D 4. Trituration *Evaluation from LANSAT TM

GROUP DISCUSSION

Center	*Neochetina eichhorniae* was actually recorded in Mexico in the east coast by Veracruz back in the late 1960s before anybody had introduced it anywhere for biocontrol purposes.
Martínez Jiménez	Yes, but I give the date of introduction as 1976 because we then received the official permission to introduce *N. eichhorniae* in Mexico. We know that before there are other reports in literature of *N. eichhorniae*, but the official introduction for Mexico is this date.
Stocker	So, did you say that *N. bruchi* was going to be released in 1995 or have they already been released?
Martínez Jiménez	No, we started to release the *N. bruchi* in February 1995.
Haller	Is water hyacinth native to Mexico? You are stating a logical evidence that it is.
Martínez Jiménez	I don't know. There is no scientific paper to show if this is true or not.
Labrada	It is probably from Mexico but there is no evidence. Many people agree that it is probably from there.
Haller	Water hyacinth's pollen is very easily identifiable in lake sediments. It was identified in the Yucatan area 24,000 years ago. What may have happened is that during the ice age water hyacinth might have been pushed back and it had to be reintroduced. But the pollen records are real clear that Central America including the Yucatan might have been the native area for *E. crassipes.* I can't argue. It is supported in literature that *N. eichhorniae* has been found in Central America as well as Mexico in the Yucatan.
Charudattan	If we look at the geographic distribution of pathogens of water hyacinth, we may be able to pin point the original home of water hyacinth. Of all the pathogens known to attack this plant, only one, *Uredo eichhorniae*, is an obligate parasite. This pathogen must have co-evolved with water hyacinth in its original range. This rust fungus has never been found outside of South America, although it was originally described from the Dominican Republic. This would indicate the native range of water hyacinth to be inclusive of the area from Dominican Republic to temperate South America.

Neser I am going to respond of Charu's comment on the rust *Uredo eichhorniae*. It is possible that many of the organisms including the fungi could have been transported with the plants because this is the plant that has started all over the world as living specimens and not as seeds. Because we have had organisms arriving in South Africa, fungi and the mite without having introduced them. So I suspect that many of the pathogens of water hyacinth we see around the world might have originated in South America and then transported.

Wright My recollection of Spencer Barrett's (University of Toronto) work suggests that water hyacinth is definitely of amazonian origin.

Center Going back to the introduction of *Neochetina* in Mexico, I was under the impression that the rate of infection of the weevil was much higher than what you said.

Martínez Jiménez We have only *N. eichhorniae* collected in Lake Chapala, but out of 100 insects, we found 2 or 3 with *Nosema*. We are not sure if it is *Nosema* because there were very few infected individuals and only in one instance. So we thought it is not a very important measure of *Microsporidia*; we don't know if it's really a *Microsporidia*.

Cofrancesco Is that the reason why you can't ship the weevils from fields sites in the country, say from Chapala to another location, without having to go through quarantine?

Martínez Jiménez Now, yes.

Cofrancesco Why?

Martínez Jiménez Because I think, it is a risk if you take the insect from one location and put it in another. Maybe this insect can have a pathogen like *Beauvaria* or another. And it is not a very good way to work with the insects. So, you need to put all of your insects under quarantine conditions and then release in every place. With *Neochetina* this is a big problem, because *Neochetina* have a long life cycle; they take three months to produce the adult stage. It is impossible in some cases to do this work.

Haller Are you maintaining Miraplanes Dam and Trigomil Dam under maintenance control?

Martínez Jiménez Yes. We don't use anymore chemicals because they are a political problem in the Jalisco area. When you say, "You need to use chemicals," most of the people say " chemicals are dangerous they produce cancer", but I think people don't know. If they use chemicals it is important to use them in a good way. We need to teach people how to use chemicals, because in Mexico it is very difficult to attack this kind of infestation only with one type of control. We need to use a massive attack with chemical, mechanical or another control. And then we know it is important to put another kind of control like biological control in a maintenance program. When we started control programs in Trigomil, Tecalitlan, and Miraplanes, we started a research on how *Neochetina* controls water hyacinth in a maintenance program. We now know that there is no increase in infestation of water hyacinth. So, we think *Neochetina* has a role in this ecosystem.

Labrada — In Chapala, in particular, is there a balance between water hyacinth infestation and in the population of *Neochetina*?

Center — There are areas that seemed to be devastated by the weevils and there are other areas with not much weevil damage at all.

Haller — Historically, Lake Chapala has had water hyacinth before. In the 1960s Lake Chapala was covered with about 50,000 hectares of water hyacinth and it disappeared inexplicably. And this could be a biological control agent which comes in and wipes it out. Now that is the largest system I have ever heard of in the world where you have that large an infestation and it just disappears. There are only two reasons that could have caused the disappearance of water hyacinth. One, you had a biological agent that came in and wiped out the plants or two, in that particular system you had a tremendous amount of pollution from the Lerma River which would have caused the decline in the water hyacinth. Nevertheless, they did disappear and it was well documented.

Martínez Jiménez — That is right; they had disappeared there before. If they declined due to the beetles, that's fantastic.

Orach-Meza — One would wonder as to how the reinfestations of water hyacinth would come about once it has been cleaned off. I mean, because the pathogens and insects have established themselves in such a way that you should have already attained what you call maintenance control. But occasionally a population explosion of water hyacinth occurs and I was wondering what causes it.

Martínez Jiménez — I think it is due to the water and weather conditions.

Labrada — Is *Orthogalumna* generally present in all stands of water hyacinth?

Martínez Jiménez	We have found *Orthogalumna* and this mite is nearly always related with *Acremonium* incidence.
Labrada	What I noticed, even in certain countries of Africa, *Orthogalumna* is present, for example, in Lake Victoria. In Cuba, whenever you have *Orthogalumna* in a stand, you have *Acremonium*.
Martínez Jiménez	In Mexico we have some *Acremonium* in Tabasco, in Lake Chapala, but in Chapalas we did not find *Orthogalumna*, for example. So, I think we need to study this relationship. But I think it is not in the Chapala. In Jalisco *Acremonium* is not related with *Orthogalumna*. In Carasco, yes, in this case.
Center	Is there an obligate relationship between the two?
Orach-Meza	I was wondering whether there is a kind of succession - of several of these bioagents including pathogens? Whether there is a period when one particular species comes up and as its population drops another species or another type of agent comes up in such a way that the water hyacinth level is always maintained at a certain level.

<u>Notes added by Charudattan during the editorial process:</u>

The association between *Orthogalumna terebrantis* (the water hyacinth mite) and the zonate leaf-spot causing fungus *Acremonium zonatum* is merely casual but it is a significant one in terms of the frequency of occurrence in many parts of the world.

Charudattan *et al.*, (Weed Sci. 26:101-107, 1978) and Del Fosse (Pages 93-97, in: T.E. Freeman, ed., Proc. IV Int. Symp. Biol. Control of Weeds. Univ. Florida, Gainesville, FL 32611) have shown that this relationship is the result of the sticky fungal spores being carried about by the mites and eventually lodged into the mite emergence holes. The spores probably also are washed into the holes by rain water or dew. These holes appear to offer ideal "incubation chambers" and infection foci. Hence the reason for the presence of the zonate spots surrounding the emergence holes.

OPERATIONAL ASPECTS OF CHEMICAL, MECHANICAL, AND BIOLOGICAL CONTROL OF WATER HYACINTH IN THE UNITED STATES

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INTRODUCTION

The background and justification document for the FAO Conference on water hyacinth contains two statements that require clarification and qualification, a discussion of which will serve as an introduction to this paper.

The first statement requiring clarification is: "reproduction of water hyacinth is very high . . . due to a large extent to eutrophication . . ." The nutrient requirements for maximizing growth and reproduction of water hyacinth is relatively high, but the impression that excessive anthropogenic enrichment is required for rapid growth is not correct. Water hyacinth was introduced into Florida in the 1890s when few people lived in the state. These plants were very prolific in Florida's naturally rich waters, which are also known for their high fisheries production.

Florida contains a wide range of geologic formations which result in lake waters naturally ranging from oligotrophic to eutrophic. Table 1 provides a comparison of two lakes in Florida representing a lake (Redwater) where water hyacinth grows very slowly, in contrast to the very rapid growth and reproduction which occurs in a lake such as Orange Lake. Although the total nitrogen, pH, chlorophyll a, phosphorus, etc. are similar between the two lakes, the calcium content of Redwater Lake is below the minimum 5 to 10 mg/l Ca that Newman (1987) reported as critical for optimum growth of water hyacinth (Table 1). Consequently, the range of growth of water hyacinth in Florida waters naturally varies from nil in very oligotrophic lakes to near optimum in meso- to eutrophic water bodies.

Based upon the information noted above, it is likely that growth rates of water hyacinth vary widely among Florida lakes depending upon their nutrient status. As a general rule, lakes that are productive fisheries usually support high growth rates of water hyacinth.

Another statement in the meeting background and justification section that requires qualification is: "It is well known that biological control of water hyacinth is one of the most successful methods to control water hyacinth." This statement is somewhat misleading as it suggests that current biological control agents present in the United States can be used routinely as an operational means of water hyacinth control.

While the published literature (Cofrancesco *et al*., 1985) attributes major declines in water hyacinth populations in Louisiana to *Neochetina*, state authorities continue to utilize mechanical and herbicidal control techniques for water hyacinth management. During 1995, nearly 50,000 acres of water hyacinth in Louisiana (of a November 1995 estimate of 186,000 total acres) were treated with herbicides, primarily 2,4-D amine (L.V. Richardson, personal communication).

Neochetina and *Sameodes* have also been present in Florida for the past 20 years, but water hyacinth declines of the scale reported from Louisiana have not occurred. It may be that there are less water hyacinth plants in Florida to support large insect populations, or possibly water hyacinth grows more rapidly or Florida has a longer growing season than Louisiana. Water management authorities in Florida spend between $1 and 2 million/year on mechanical and chemical control of water hyacinth.

The data in Figure 1 provide a comparison of water hyacinth acreage in Louisiana (from Cofrancesco 1994 and R. Brassett, personal communication 1995) with air temperature records (U.S. Weather Bureau, NOAA) for Baton Rouge, Louisiana from 1975-1995.

The graph (Fig. 1) plots the number of freezing degree days which occurred annually during this time period. Similar to growing degree days used by horticulturists, a freezing degree day is considered freezing if at anytime during a 24-h day the temperature is 32°F or below. If a low temperature of 22° F is recorded, it is interpreted as 10 freezing degree days. This index considers not only the number of freeze events that occur, but also factors in the severity of the freeze, both factors determining the effects of cold weather on water hyacinth survival (Penfound & Earle, 1948). The data in Figure 1 presents the cumulative freezing degree days on a calendar-year basis. The 20-year average number of freezing degree days is the horizontal line on the graph at 94 freezing degree days per year.

A major decrease in water hyacinth acreage occurred in Louisiana the last half of the 1970s. Plants decreased from an estimated one million acres to less than 100,000 acres in 1980. It has been suggested (Cofrancesco *et al*., 1985) that this decrease resulted from activity of *Neochetina* which were introduced in Louisiana in 1974; however, it also coincides with 5 (1976-1980) consecutive years of below average winter temperatures.

Although warmer than average winters occurred between 1986 and1992, a rapid increase in water hyacinth acreage was not noticed. This may be due to a lag period in recovering from a decade of cold winters, the effects of a very cold 1989, the activities of the biocontrol insects, herbicidal control, or a combination of these with record drought years in the lower Mississippi River basin during this period. Heavy rains beginning in 1992 and for six consecutive they were warmer than average winters from 1990-95 have now resulted in regrowth of water hyacinth in Louisiana with an estimated November 1995 acreage of 200,000 acres. Additional data from Louisiana needs to be collected and evaluated to confirm the temperature hypothesis. The data may also be confounded by control programs. The rapid regrowth presently occurring suggests that temperature significantly affects water hyacinth growth rates, as noted by Owens and Madsen (1995).

Similar weather and water hyacinth infestation data (J. Coward, personal communication 1995) are presented in Figure 2 for Ross Barnett Reservoir in Jackson, Mississippi for the period 1975-95. Water hyacinth and biocontrol insects were first noted in the reservoir in the mid-70s but water hyacinth never became a problem until 1992-93, apparently following above average winter temperatures at this northern extreme of water hyacinth distribution in North America. The reduced water hyacinth acreage in 1994-95 is the result of bringing the water hyacinth plants under maintenance control by aerial (1993) and airboat herbicide treatments (1994 and 1995). These data supports the hypothesis that below normal winter temperatures, similar to that which occurred in Baton Rouge, LA, from 1975-1985 suppressed the growth of water hyacinth in the Ross Barnett Reservoir during the period of initial infestation. Further data are being analysed to prove or disprove these hypotheses; however, based upon the information provided above, the extent of the role *Neochetina* and *Sameodes* had in reducing water hyacinth acreage in Louisiana between 1975-1980 is unknown. This same reduction in water hyacinth plants apparently did not occur in Florida over the same time period despite record freezes in 1983 and 1985 which destroyed citrus groves as far south as Orlando, Florida. The average freezing degree days in Orlando, FL for 1975-95 is 19 days (data not shown).

From a biological control perspective, the introduction of the three insects into the United States has successfully resulted in the insects naturalization and widespread natural dissemination. From an operational weed control perspective, the insects have not resulted in definitive, documented reductions in water hyacinth populations.

The published literature documents a few small scale examples of successful water hyacinth biocontrol in Florida. Space does not allow a full evaluation of each of these examples in this paper, but a review of these cases suggests, along with data from controlled experiments, that the success of *Neochetina* and *Sameodes* is very closely related to nutrient status and growth rates of water hyacinth and extreme temperature and/or drought events.

The effects of growth rates of water hyacinth on efficacy of insect and disease biocontrol is clearly indicated upon close examination of papers by Van and Center (1994) and Charudattan *et al.* (1985), respectively. Van treated water hyacinth in concrete vaults with the growth inhibitor paclobutrazol and added *Neochetina* to the experimental units. The combination of reduced growth by paclobutrazol and *Neochetina* activity resulted in a 95% reduction in biomass of water hyacinth compared to a 24% reduction in biomass resulting from *Neochetina* alone. Also, Charudattan noted that, water hyacinth, under good growing conditions, outgrew the effects of the applied fungus *Cercospora rodmanii* if the plants produced a new leaf every 5-7 days. It was later shown that a combination of herbicide or growth regulators and *C. rodmanii* application effectively controlled water hyacinth.

In summary, the release of insect biocontrol agents in the United States has not "successfully" controlled water hyacinth plants in an operational perspective. These insects have become established and may be reducing the vigour of water hyacinth plants and controlling them in nutrient or other growth-limited situations. However, they have not measurably reduced the need for operational water hyacinth control programs in waters in which water hyacinth plants have historically been a problem. In addition, although discovered over 20 years ago, the fungus *C. rodmanii* is not currently commercially available and its combined use with herbicides or plant growth regulators (none of which are registered for aquatic use) does not appear economically feasible in the near future in the United States.

Mechanical Harvesting

Advances in mechanical harvesting of aquatic plants, particularly water hyacinth plants, have been few in the past 2-3 decades primarily due to the large biomass, water content and bulk (volume) of these plants. In effect, removing 200 tons/acre (500 tons/ha) of water hyacinth plants from point A to point B costs at least $2/ton based upon 20 years of cost analysis (Thayer & Ramey, 1986).

In the study cited above, it was noted that the average cost of 23 mechanical harvesting contracts in Florida over the previous 2 decades resulted in an average cost of harvesting water hyacinth plants of $4,649/acre. Many of these evaluations were based upon the production values of the Aquamarine/Aquarius/Limnos/Altosar systems which consist of a harvester with a typical capacity of 2 to 6 tons/load and a storage capacity of 12-20 cubic yards/load.

A newly developed machine for large scale harvesting projects, has not been fully evaluated for water hyacinth control but differs from previous machines in its size (12 ton, 30 yd^3 capacity) and ability to carry large loads (Tables 2 and 3). The Kelpin 800 and its predecessor were designed to harvest and self-unload trash coming into Lake Gatun, Panama Canal Zone from flooded rain-swollen rivers. The debris consisted of water hyacinth, logs, brush, and other vegetation. The machine harvests 40 tons/h of floating vegetation and moves an acre (200 tons/acre) of water hyacinth in 5 h. This production is relatively high when compared to previous machines.

Herbicidal Control

The data in Table 4 indicates the herbicide and application cost of the three herbicides registered in the United States for control of water hyacinth. Each of these herbicides are registered for aquatic use by the U.S. Environmental Protection Agency (EPA) and there is much known about the residues, metabolites, application and safe use of these products. The 2,4-D amine has been used in the U.S. for water hyacinth control since 1946, diquat since 1956 and glyphosate since 1978. The relative cost of these herbicides are glyphosate > diquat > 2,4-D, and each has its advantages and disadvantages. Basically, if each is applied according to label instructions, no adverse environmental or human health problems will occur. All three products are currently being re-registered by the USEPA to bring all data to current standards.

Each product has water (potable), fish and shellfish tolerances, do not bioaccumulate and are effective against water hyacinth if properly applied. All products have short half-lives in water, are nontoxic to fish and are widely used in the United States. The annual use of herbicides for control of water hyacinth in the states of Florida, Texas, Louisiana and California approaches $6 million annually.

In addition to the above, triclopyr is also effective on water hyacinth and is currently being reviewed for registration by the USEPA. All herbicides used in the United States must be approved by the USEPA. Further information on aquatic herbicide use and residues in water is available in Joyce and Ramey (1986).

Every discussion of aquatic weed control eventually revolves to the bottom line of cost/acre to implement. Biological control of water hyacinth (if it occurs) is inexpensive and, pending biological surveys to ascertain safety in a receiving country, should be considered for introduction. Insects currently introduced into the United States should not be expected to solve the water hyacinth problem in large-scale situations. Herbicidal use is the next most cost-effective option and has been proven safe and effective. Extensive data exist to evaluate any potential human or environmental impact in countries they are used. Finally, the last and most expensive option, but of immediate results is that of mechanical chopping or harvesting. The high costs of harvesting cannot be offset by utilization because forage and green plant production in most developing nations is not a limited resource, certainly not limited enough to offset the high cost of harvesting.

In summary, there are only two options that are available operationally to control water hyacinth; herbicidal and mechanical control. The use of plant pathogens for water hyacinth control remains experimental and is not operational at this time. The safe use of herbicides should be emphasized. Considering the increased disease (malaria, yellow fever and encephalitis) incidence as a result of weed infestations, the remote possibility of human health effects caused by herbicides is greatly offset by known effects of the presence of aquatic plants. The immediate results attained by mechanical harvesting also demands consideration with recognition of the economic limitations of current technology.

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Table 1. Comparison of water quality in two lakes in North Central Florida in which water hyacinth grows very slowly, or very rapidly. Data from University of Florida LAKEWATCH Program - 1993

	Redwater	**Orange Lake**
pH	6.5	7.3
Alkalinity (mg/l)	4	18
Conductance (µS/cm)	64	67
Calcium (mg/l)	3	17.9
Total P (µg/l)	34	31
Total N (mg/l)	0.9	1.3
Secchi (ft)	3.2	4
Chlorophyll a (µg/l)	29	18
Colour (Pt-Co)	64	54
Hyacinth Growth (Personal Observation)	Slow	Rapid

Table 2. Overall characteristics of the Kelpin 800 harvester, Orange Lake Trials Summer 1995

Overall Length	70 ft	21.2 m
Transport Height	7 ft	2.1 m
Operating Height	17 ft	5.2 m
Weight	15 tons	13,600 kg
Draft (empty)	20 inches	50 cm
Draft (loaded)	36 inches	90 cm
Conveyor		
Length	20 ft	6.1 m
Width	9.5 ft	2.9 m
Cutting Depth	5.5 ft	1.7 m
Storage Bay		
Length	29 ft	8.8 m
Width	10 ft	3.0 m
Height to rail	2.75 ft	0.85 m
Capacity (vol)	30 yd^3	23 m^3
Capacity (weight)	12 tons	11,000 kg
Speed		
Unloaded @ 1500 RPM	3.97 miles/hr	6.4 km/hr
Loaded @ 1500 RPM	4.04 miles/hr	6.5 km/hr
Fuel/Power		
Diesel Fuel	1.0-1.5 gph	3.7-5.7 l/hr
John Deere 6 Cylinder	120 h.p.	____

Table 3. Performance characteristics of the Kelpin 800 harvester on floating plants in Orange Lake, Summer 1995

Floating plants:	200 tons/acre
Frogbit and/or	45.3 kg/m^2 83 lbs/yd^2
Water hyacinth	224.5 m. tones/ha 93% water
Typical load under above conditions	
Swath=	225' (68 m) long x 9.5' (2.9 m) wide
Swath area=	237.5 yd^2 (197m^2)
Swath weight=	19,712 lbs. (9.8 tons/load) = 8,960 kg
Loading time	9 minutes
Unloading time	6 minutes
Total	15 minutes/load without transport time
Time to harvest and unload/acre:	
.05 acres/15 minutes	
1.0 acres in 300 minutes = 5 hours/acre or 12.4 hours/ha	
Tons/hour = 40 tons	

Table 4. The approximate cost of herbicides, rates applied, and cost of application for water hyacinth control

Herbicide	Approx. cost (USA)	Active ingredient	Typical dose/acre (lbs/acre)	Cost of product (per acre)	Maximum number of treatments	Total cost per application: Boat ($40/A)	Total cost per application: Air
Glyphosate (Rodeo)	$80/gallon	4 lbs/gallon acid equiv.	3 lbs/acre 0.75 gallons/acre	$60/acre	2X	$100/acre	$75/acre
Diquat (Reward)	$70/gallon	2 lbs/gallon cation	1.5 lbs/acre 0.75 gallons/acre	$52/acre	2X	$92/acre	$72/acre
2,4-D (Weedar 64)	$10/gallon	3.8 lbs/gallon acid equiv.	2.9 lbs/acre 0.75 gallons/acre	$8/acre	2X	$48/acre	$23/acre
METRIC (Units as Noted)							
Glyphosate (Rodeo)	$21/litre	480 g/litre	3.4 kg/ha 7.0 l/ha	$147/ha	2X	($99/ha) $246/ha	$187/ha
Diquat (Reward)	$18/litre	240 g/litre	1.7 kg/ha 7.0 l/ha	$126/ha	2X	$225/ha	$176/ha
2,4-D (Weedar 64)	$3/litre	455 g/litre	3.3 kg/ha 7.3 l/ha	$19/ha	2X	$118/ha	$59/ha

Cost of Boat Application: Most ground application by boat with 2,4-D or diquat will use 100 to 150 gallons of water as diluent per acre (900 to 1400 l/ha). Glyphosate calls for use of 50 to 75 gallons diluent/acre (1.0 to 1.5%) or 450 to 700 l water/ha. Typical cost of application by airboat in Florida is $35 to $50/acre to $86 to $124/hectare.

Cost of Aerial Application in Florida is typically $1/gallon glen or approx. $0.30/litre flown. Glyphosate label states 3 to 20 gallons of diluent per acre. Thus 7.0 litres of glyphosate mixed with 37 gallons of water/ha = total cost of $39 to 40/hectare application cost. Diquat, a contact herbicide usually is applied in 20 to 40 gallons of water plus a surfactant to get even coverage of water hyacinth. For aerial application of 2,4-D we would use 9.3 litres of 2,4-D plus 120 to 140 litres of water per hectare (12-15 gal/acre) for an application cost of approx. $40/hectare.

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GROUP DISCUSSION

Charudattan What we are trying to do, over and again, I think is wrong. Biological control is never to be thought of as something that can give you eradicative control. In the example you gave of only 30% of the introduced agents being successful, I think it came from a review of classical biocontrol by Les Ehler. If this estimate is correct, the majority of the introduced insects, despite the efforts to establish, don't establish at all. But you need to look at the intricacies of the relationships between water hyacinth and the biocontrol agents over a long term and you cannot use a chemical yardstick to measure success. That is what we are trying to do here. Yes, chemicals give you immediate control; if you look at it from the fact that we are using chemicals year after year, we have to say that chemical control is also not effective in the long run. We have the objective of bringing down the population levels of water hyacinth with the biological agents and creating a level of permanent stress. Hopefully, the job of chemical control is made easier by the biological control agents.

Haller If you get down to the true effect of *Neochetina*, as Ted Center's data show, it occurs during the first few weeks of the spring in the year. In north Florida, when you see plants regrowing and about when they are 0.3m tall, they are usually very heavily infested. So, then these plants start growing the 15th of April and the spray crews are not out there until the 15th of June or 1st of July. And Ted's data shows that there is a lag period there; whereas we used to be out there on the 15th of June. I am not saying that chemicals are the only way to go. When we were in Mexico and every country I have gone to, recommend that you introduce every tool you got. But there is a wide-spread impression that *Neochetina* is all you need. And the gentleman from Malawi asked, "what is going to be in Malawi in 10 years from now after we introduce *Neochetina* and *Sameodes*"? Well, my answer to that is that if you have a real nutritious system, the larvae will have as many water hyacinths there or nearly as many as what is currently there. So, I think he better get his people to expect that the insects are going to only slow it down and not solve the problem. But after 20 years or 25 years of being in this field, we just somehow need to get more predictable with water hyacinth control.

Charudattan What threw me off was the comment by the gentleman from Africa coming here to see the success of biological control. We have a purpose in reporting scientific studies even if they are of limited scope. You can read these reports and people have come to ask me, "Oh, *Cercospora* is so highly successful." "Yes",..."exactly, see what I say".

Haller — Right. That is when we put the operational hat on and ask "Are the managers using it?" And for one reason or another they are not, but I can see very clearly that if you can just forget what we see day in and day out among ourselves, read the American literature and if we take 5 people from a foreign country who have never heard of us before and have them read the American literature, I bet you that they will conclude that there are probably no water hyacinths or probably very few water hyacinth problems in the south-eastern part of the United States. Any comment?

Orach-Meza — Yes, that's correct.

Neuenschwander — That's not right.

Cofrancesco — I have a question. You mentioned that the pond that you sprayed twice had no fish in it to begin with - the reason there were no fish was because you drained it?

Haller — No, there were actually 3 ponds to begin with. There were no fish to begin with because of water hyacinth; you can't get any oxygen underneath. And then we drained one of the ponds and, just to make sure, we did some fish sampling by electric fishing but we didn't find any. But one of the ponds, because it was a dam with a drain, we were able to drain it, put a screen across the front and there were just no fish in it. We let that pond down to measure organic matter and other things.

Cofrancesco — Regarding the temperature data you recounted, I think you should pick up the data from New Orleans because Baton Rouge is too far north from the area where the biocontrol program is operating.

Haller — Well, I agree. All I am trying to come up with is a reason for such a decrease in water hyacinth population. The graph from Jackson, Mississippi, although it is colder here, shows that the data you showed now was a little bit misleading because what you showed was averaged maximum and minimum temperatures. So, you don't get the extremes. Water hyacinth is a tropical plant and is affected by extremes. Also, I have not finished looking at these data; I am going to get more data for Louisiana to find out what happened from 1965 to 1975.

Cofrancesco — Actually what I was curious about is this: I know we don't have the data on the water hyacinth part, but you might be able to dig up the temperature data prior to 1975 and see what higher temperatures did. We had seen extremes of cold or warm from the 1900s to 1975 and water hyacinth was a problem in Louisiana for the years 1905 forward in the Mississippi river system; it was never eliminated. So, there would seem to be some validity to your argument that if you knew there was a problem the whole time and that it has been through many courses of events of temperature increases, I would find it very unusual not to see a 5- or 6- year span where you had extremely cold temperatures in that region before 1900.

Haller — From 1900 to 1960 there was no maintenance control going on; maintenance control is here when you are spraying 25,000 to 40,000 acres/year.

Cofrancesco — But that 25,000 to 40,000 acres are still the same area proportionally that they sprayed in 1976 when they sprayed 80,000 acres with 1.2 million total water hyacinth acres.

Haller — Right. But in this particular case the freezing weather knocked the plants back to 40,000 acres of 100,000, which is 40%.

Cofrancesco — But the plants are only starting off from about 200,000 acres or 150,000 at the beginning of the growing season. They have been able to regrow; the cold that you are talking about is an event in the winter time. You can expose 20 plants to freezing conditions and drop out 50% of those plants, but you still have 10 that are going to regenerate. You are not seeing a regeneration of the ability to regrow in those plants in the years you are talking about during the growing season.

Haller — Right; but you may have a thousand that can regrow the following summer whereas here you only have 10 that can regrow; the growth potential is a hundred fold less.

Stocker — When it is called freezing days, it is actually an accumulation number. We have no 150 freezing days ... it is actually added up in the number of days in the freezing temperatures and multiplies into the severity of the cold temperatures.

WATER HYACINTH CONTROL PROGRAM IN USA

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INTRODUCTION

Water hyacinth (*Eichhornia crassipes*) is an aggressive floating plant species native to South America that was introduced into the United States at the 1884 Cotton States Exposition, New Orleans, LA.(Sanders *et al*., 1985). Since its introduction, water hyacinth has spread or been distributed throughout the southern United States and California (Godfrey & Wooten, 1979). The ability of water hyacinth to infest a wide range of freshwater habitats and its tremendous growth rate (Penfound & Earle, 1948; Center & Spencer, 1981) have made it one of the most troublesome aquatic plants in the world.

The U.S. Army Corps of Engineers (CE) has been involved in the management of water hyacinth since the late 1800s. The River and Harbors Act of 1899 directed the CE to remove aquatic vegetation (water hyacinth) that was hampering the operation of navigable waterways in Florida and Louisiana. Modifications to this act have, over the years, expanded the responsibility of the CE to include waterways influencing navigable waterways.

To manage exotic aquatic plants, three general methods are available--mechanical/cultural, chemical, and biological. The CE has conducted extensive studies on all three methods. All have positive and negative aspects that should be considered when determining the management strategy to be employed. A number of key factors need to be examined in the development of a management strategy for problem aquatic plants: 1) identify the target plant, 2) identify the habitat the plant is occupying, 3) determine how the target plant reproduces, 4) determine whether the target plant is already being stressed, 5) determine the type of management that is required, and 6) determine what resources are available for management.

Mechanical

The oldest method is mechanical/cultural control. This can be as simple as the manual removal of individual plants or as sophisticated as the use of specialized equipment specifically designed to remove a certain type of vegetation. A number of different types of mechanical equipment were developed or modified for the removal of water hyacinth from waterways. Large draglines were placed on barges and fitted with special rakes designed to remove the plant material. Also, special cutter and push boats were developed that would cut or grind the vegetation or push it to a location where it could be harvested. The Corps of Engineers also experimented with a CO_2 laser that could be mounted on a barge and would burn the vegetation down to the water surface.

Other control methods considered were the construction of structures that inhibited plant populations or the manipulation of the water levels to stress water hyacinth infestations. In addition, attempts were made to modify the habitats used by water hyacinth plants to stimulate the development of beneficial competitive plant communities.

In general, mechanical/cultural methods give rapid results for the management of small water hyacinth populations. If the infestation is small and not widely distributed, problem plants can often be managed by their physical removal. The plants can be removed by hand or with the use of small mechanical equipment, and the problem will rapidly and economically be eliminated. In this situation there is usually only minimal damage to the surrounding natural habitat. If the water hyacinth population is extensive, however, the removal of the plant population is more difficult and costly. The utilization of removal equipment over large areas can sometimes cause extensive damage to aquatic habitats and becomes extremely costly to conduct. Also, removal of large areas of vegetation cannot be accomplished rapidly.

Chemical

The use of chemicals to regulate populations of exotic aquatic plant pests has progressed through many phases. Water hyacinth was the first major target aquatic plant for chemical control. Inorganic chemicals (ammonia, sodium chloride, barium chloride, sulfuric acid) (Bose, 1945) were first used, along with organic chemicals such as formaldehyde (Bose, 1923). These chemicals were only marginally successful and caused additional problems in the environment. Copper sulphate has also been used and shown to be effective in inhibiting the growth of water hyacinth (Sutton & Blackburn, 1971 a, b).

The herbicide 2,4-D is currently the leading chemical for both use and efficacy on many problem aquatic plants, particularly water hyacinth. The impact of this chemical on water hyacinth was first reported in 1946 (Hildebrand, 1946). Plants sprayed with this chemical exhibit a twisting and curling of the leaves within 24 h, and begin sinking in a few weeks (Penfound & Maynard, 1947). The impact of the herbicide is impressive, and it can be applied from land vehicles, boats, or aircraft.

A number of other chemicals have also been identified for use against water hyacinth. Diquat and paraquat have been used to control this noxious aquatic vegetation, especially in areas where ornamental plants or crops are susceptible to 2,4-D. Glyphosate, another chemical used on water hyacinth and other aquatic vegetation, has the advantage of having low toxicity to fish and it rapidly decomposes in soil and water.

In general, chemicals are effective in reducing nuisance aquatic vegetation. Most chemicals affect a broad target population so their impact may not be limited to just the nuisance plant. The action of the chemicals is usually rapid, requiring only a few weeks to see extensive impact. Chemical applications are usually less expensive than mechanical/cultural control methods but may have to be repeated on an annual basis.

Biological

To date, biological control projects have been initiated in over 70 countries on more than 100 species of nuisance species (Julien, 1987). The first utilization of insect biocontrol agents to manage a noxious plant in the United States was in 1902 when *Aerenicopsis championi*, a beetle, was released in Hawaii to control lantana (Weber, 1956).

Most problem plants in the United States, particularly in the aquatic and wetland environments, are exotic species. The plants (weeds) usually have been introduced into favourable environments without their natural enemies. These exotic plants have the ability to increase rapidly, out-competing the native vegetation for habitat and resources (Harley & Forno, 1992). At present, the most successful biocontrol programs to manage aquatic plant growth in the United States have used insects from the native range of the problem plant. Generally, this is known as the "classical biological control."

The classical approach is based on the concept that the target plant has natural control agents present in its native range, and the introduction of these natural enemies will re-establish the pressure that the noxious plant normally experienced. In this approach, control agents (natural enemies) are introduced into areas that are not part of their native range to manage an introduced noxious plant (Harley & Forno, 1992). The process of introducing biocontrol agents can be divided into five phases--overseas surveys, overseas research, quarantine research, release and establishment, and technology transfer. In general these agents are host-specific arthropods, nematodes, or plant pathogens.

The U.S. Army Corps of Engineers and the United States Department of Agriculture - Agriculture Research Service (USDA-ARS) began cooperative research on biological control of aquatic vegetation in 1959. The first target plant studied was alligatorweed (*Alternanthera philoxeroides*). Overseas research and quarantine studies identified three insect agents that could be released--the alligatorweed flea beetle (*Agasicles hygrophila*), alligatorweed thrips (*Amynothrips andersoni*), and alligatorweed stem borer (*Vogtia malloi*). The initial releases of these agents began in 1964, and redistribution of the populations still continues. All of these agents are established throughout the range of alligatorweed in the United States (Coulson, 1977, Cofrancesco, 1988) and these insects have had a major impact on alligatorweed populations (Cofrancesco, 1988).

At present, only North Carolina has a small program to treat alligatorweed with herbicides in ditches. All the other states rely on the biocontrol agents to provide enough impact to keep the population level of alligatorweed below problem levels. In 1963, more than 97,000 problem acres of alligatorweed existed in the United States; in 1981, there were less than 1,000 problem acres of alligatorweed (Cofrancesco, 1988).

The second plant targeted for biocontrol technology was water hyacinth. Overseas surveys were conducted in South America to find potential biocontrol agents of water hyacinth. A number of insects were found that fed on water hyacinth in its native range and studies were initiated to determine which insects would be good biocontrol agents. These studies were conducted at the

USDA-ARS Laboratory in Argentina. Three potential insect biocontrol insects agents were identified and introduction permits were requested (Sanders *et al*., 1985).

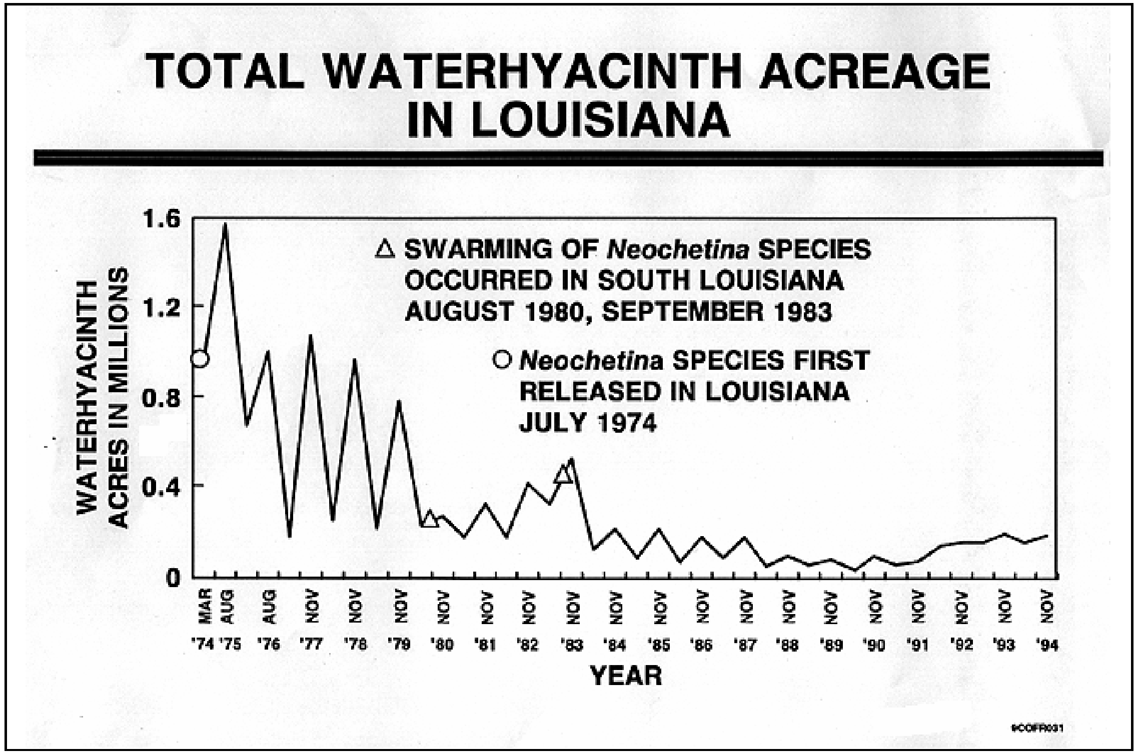
In 1972 the mottled water hyacinth weevil (*Neochetina eichhorniae*) was the first insect approved for release as a biocontrol agent of water hyacinth. The initial releases were conducted in Florida, however this insect has now been released in seven other states. Both the adults and the larvae feed on the plant. Adults remove the upper leaf surface and larvae penetrate the petiole and feed on internal tissues. As the larvae grow, feeding proceeds down the petiole to the plant crown (DeLoach & Cordo, 1976a). These insects stress the plant; however, their true impact on the plant population takes years to become apparent.

The second biocontrol agent released on water hyacinth was another weevil, the chevroned water hyacinth weevil (*Neochetina bruchi*). The first release of this insect occurred in Florida in 1974 (Sanders *et al*., 1985). The chevroned water hyacinth weevil occupies very similar niches in the plant as the mottled water hyacinth weevil and its impact to the plant is similar to that of *N. eichhorniae* (DeLoach & Cordo, 1976b).

The last biocontrol agent released on water hyacinth in the United States was the Argentine water hyacinth moth (*Sameodes albiguttalis*) native to South America. The initial release was made in Florida in 1977. This insect has a life cycle of approximately 30 days (DeLoach & Cordo, 1978; Center, 1981a). The larvae are the only life stage that feed on the plant and they are usually found on the smaller more bulbous plants (Center, 1981b). The impact caused by these insects varies between sites, often well established populations of these insects will move from locations for no apparent reason (Sanders *et al*., 1985).

In general problem areas of water hyacinth still exist and chemical spray control operations continue. The biocontrol insects are having a significant impact on the water hyacinth populations but this is occurring in areas where the insect population levels are allowed to buildup. These insects have relatively long life cycles, so population build-up is slow. Dramatic reductions in the acreage of water hyacinth have occurred in Louisiana (Goyer & Stark, 1981, 1984), where prior to the insects being released the acreage of water hyacinth reached 1.2 million acres (Cofrancesco *et al*., 1985; Center *et al*., 1989). Presently, there are approximately 200 thousand acres in the state (Fig. 1). Similar declines have also been noted in Florida and Texas. Although problems still exist, the biocontrol agents are stressing the plants, and research is underway to develop better management procedures for these agents and to examine the biocontrol potential of new agents.

Figure 1. Water hyacinth Averages in the Spring and the End of Growing Season in Louisiana (1974-1994). Data Provided by the Louisiana Department of Wildlife and Fisheries.



Biological control agents require time for their impact to be observed but, once established, populations usually remain present. The biocontrol agent will never completely eliminate water hyacinth but it can reduce the plant below problem levels. While the development and implementation of biological controls takes time, the long-term cost in management is often significantly less than other control measures and less harmful to the environment.

CONCLUSIONS

All of the various control methods have been employed in the United States to manage water hyacinth populations. Each method has beneficial and limiting factors associated. It is the resource managers, role to select the most suitable method or combination of methods to achieve the type of management required with the resources available.

In areas where recent, small infestations of water hyacinth occur mechanical or chemical controls of the plants will give rapid management. In situations where more extensive infestations occur water hyacinth management can be achieved rapidly using chemical controls, however, applications will need to be repeated under a maintenance program. Biological controls offer long term stress on the plant population that needs only minimal efforts to maintain. Agents should be maintain, particularly in back water areas where the agents can develop large populations. In general, areas that have large infestations of water hyacinth need to develop an integrated approach to management that utilizes the strengths of each of the control methods.

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GROUP DISCUSSION

Stocker: What was the year of the after picture in the Texas site?

Cofrancesco: About 1984-86.

Stocker: And since then? Any plants at all?

Cofrancesco: Only in the fringe.

Stocker: Have you looked at the insect populations?

Cofrancesco: No, the baseline data have not been there to really do any kind of work -- 1981-84, before and after.

Stocker: Is it an usual site of any kind? Was there a slug of nutrients in there, or anything?

Cofrancesco: No, but we haven't seen the plants come back in that area. Water hyacinth being such an easily dispersed plant that floats around, you could have 100 in 1 a confined area and you could take away 40 of those and it could look like a 100% coverage too.

Wright: Was *Sameodes* released at this site?

Cofrancesco: *Sameodes* was not released right at the site where we found it but close by. But we found it at the site.

Haller: You said that the *Neochetina* or the combination of insects work best in the backwater areas which were undisturbed. Are those areas still free of water hyacinths?

Cofrancesco: The acres that they have are greatly reduced from the acres they had in 1976-1977. If you look at the acreage of the Achapalia Basin or of the Port Allan District, there is still water hyacinth in all of those areas but at a much lower level. That is where the drop in the acreage figures come from for the total state.

Haller: How much does that relate to that flood you mentioned? Has the water level gone down?

Cofrancesco: The flood was really above the 1.2 million acre area. It is really in the 1.75 million acres range. This information was provided by the Louisiana State Game and Fish Commission.

Haller — And you have seen that similar thing happen in other areas before?

Cofrancesco — I haven't been in the field in Florida enough to say that.

Center — I don't think Florida would have anything comparable to that many acres. How many acres did you say?

Cofrancesco — Probably less than 80,000 acres a year.

Haller — Wouldn't you think that if you had 100 acres or a 10-acre patch and you just left it alone, then it should be controlled by the insects as well as a 100 acre patch would, or a 1,000 acre patch, a 10,000 acre patch, or a 100,000 acres would. Why would the insects not control the weed, if you have 100,000 acres of water hyacinth that are left alone for 10 years?

Cordo — I think that what happened within Louisiana. The plants were large to start out with when the insects were first released. The plants in Louisiana get stressed from frost, freezes, but not severe but enough to burn back the tops. If the plants aren't stressed sufficiently from frost, the crowns can overwinter. The plant is then left with tremendous growth potential when the new season comes along. The insects stress the plant, causing them to be reduced in stature. This makes it much more susceptible to cold and freezes. The resources and the reserves in the plant are not there. What we are seeing is that the plant is not being reduced, but the ability of the plant to regrow being taken away. The plant doesn't have the capability for the tremendous regrowth potential. If you had plants that were not impacted, if they are unaffected, you can see in one growing season hundreds of plants produced from one plant. What is happening as a result of biological control is that the plant is being impacted and stunted or it is not able to accelerate its growth in the fashion that it had been able to do previously.

Wright — In Louisiana there have been tremendous declines in water hyacinth; has there been any change in the drainage pattern?

Cofrancesco — Not over all. A couple of things we looked at up until that 1984 and 1985 include the temperature values which show that the Achapalia Basin is unique because the Port Allen area, which was along the coast, could have salt water intrusion coming up. People had asked about salt water intrusion, if there was less of a drainage flow. Ted Center and I did a paper on it showing the rain fall patterns over time and the temperature patterns. Rainfall varied but it didn't look like it varied much between the times we saw reductions and not. So with the salt water intrusion, the acreage of water hyacinth in that area still followed the same oscillating pattern as now. The one key factor was that the Achapalia Basin has barrier against a salt water intrusion (a lock) at Morgan City in the Achapalia Basin. The Corps of Engineers has put the lock there so that the rice farmers can use the water supply for their crops. If there is salt water intrusion coming up the Achapalia, the rice crop is going to go down. So, we know that there is no salt water intrusion in Achapalia yet; it still follows the overall pattern for the state and for the water hyacinth population in the state in general. We are not seeing any big changes in drainage patterns along those lines that I can tell. But, there could be data out there that I don't know about.

Cordo Have you seen any impact from *Bellura densa*?

Cofrancesco We have seen an impact from *Bellura*, the problem is we see it being severely impacted by native predators and parasites. We did some studies on *Bellura* and developed a diet with Chuck Quimby when he was at the USDA-ARS Stoneville Lab on raising *Bellura*. And we reared it, made master races out of it, and we saw a lot of damage initially but the population never would build up. The predator population always built up as fast as that of *Bellura*. So we were never able to sustain a population at any site.

Stocker You have documents on swarming of *Neochetina* on at least 2 major occasions in Louisiana and these were, I remember, very massive swarming. Where else in the world are we seeing swarms like these?

Cofrancesco I have not heard of another instance. The place where we saw the swarming was in a school that had just put up some mercury vapour lamps and they were located right between the Achapalia Basin and the Mississippi river. They had these mercury vapour lamps installed just for a month when all of a sudden hundreds of thousands of weevils started to swarm towards the light.

Haller I have a question regarding the operational use of the insects. You take something like Lake Okeechobee. What you are saying is that you have to have a half million to a million acres - a high infestation - before you can get a real wipe out from the insects?

Cofrancesco No. It's not that easy. If it was that easy we would have solved the water hyacinth problem already.

BIOLOGICAL CONTROL OF WATER HYACINTH IN THE UNITED STATES

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INTRODUCTION

Three insects, all originally from Argentina, have been released as biological controls of water hyacinth in the United States. Two are weevils, *Neochetina eichhorniae* and *N. bruchi*, released in Florida in 1972 and 1974, respectively. The third was a pyralid moth *Sameodes albiguttalis* released in Florida in late 1977. The biologies and life histories of these species are discussed in detail in Center (1995). Three native North American species sometimes severely impact water hyacinth populations, as well. These are the noctuid moth *Bellura densa*, the oribatid mite *Orthogalumna terebrantis*, and the spider mite *Tetranychus tumidus*.

Impact of Bioagents

Several studies demonstrate the impact of biological control agents on water hyacinth under controlled conditions (Forno, 1981; Center *et al*., 1982; Del Fosse *et al*., 1976a; Del Fosse, 1978; DeLoach & Cordo, 1976; Bashir *et al*., 1984; Goyer & Stark, 1981; 1984; Van & Center, 1995) and in the field (e.g., Center & Durden, 1986; Center, 1987; Goyer & Stark, 1981; 1984; Cofrancesco, 1985; Cofrancesco *et al*., 1985; Wright, 1979; 1981; DeLoach & Cordo, 1983; Jayanth, 1987; 1988; Girling, 1983; Beshir & Bennett, 1985). These papers, as well as others in this proceedings adequately summarize the impacts of these insects; so I will not deal with them here. Rather, I would prefer to focus on the interactions between the plant and the insect, i.e., what the biological control agents, particularly the weevils, do to the plants.

Beginning in the early 1970s, we monitored several water hyacinth populations to determine the effects of *Neochetina eichhorniae*, *N. bruchi*, and *Sameodes albiguttalis*. We successfully documented the decline of water hyacinth at a north Florida lake after first developing baseline data (cf. Center & Spencer, 1981; Center, 1994). The decline occurred over a 4-year period and coincided with the attainment of peak weevil populations (Center et al., 1990). In addition, numerous water hyacinth declines induced by these insects have been documented both in the United States and abroad (Beshir & Bennett, 1985; Bodle, 1988; Center, 1987; Center & Durden 1984; 1986; Center *et al*., 1990; Cofrancesco, 1985; Cofrancesco *et al*., 1985; DeLoach & Cordo, 1983; Girling, 1983; Goyer & Stark, 1981; 1984; Haag & Center, 1988; Jayanth, 1987; 1988; Wright, 1979; 1981). Despite this profusion and diversity of evidence, skeptics dismiss this as anecdotal and prefer to invoke other causes, no matter how far-fetched, to explain these declines (however, cf. Center, 1987). As a result, biological control in the United States has not received the attention it warrants, particularly as a component in integrated management schemes.

Incompatibilities among Control Approaches

I conducted two studies that were sponsored by the Florida Bureau of Aquatic Plant Control, Department of Environmental Protection (DEP) to address the issue of field efficacy. The first investigated the compatibility between biological control and traditional water hyacinth maintenance procedures. Biological control agents tend to be scarce at sites where water hyacinth is subjected to periodic herbicidal treatment. I have always attributed these deficits to instability associated with the periodic, but temporary, absence of plants at sites frequently treated with herbicides. Obviously, if the plants do not persist, relatively immobile stages of biological control agents that depend upon the plant, will not thrive. It would be logical to assume, then, that when plants later reappear (from seeds or surviving fragments), the weevils might not be present to suppress growth. We therefore compared weevil populations, as well as the status of the water hyacinth populations, between managed and unmanaged sites to determine if this perception was real or imagined. Samples were collected at 54 sites, half of which were under "maintenance water hyacinth control" (water hyacinth maintained at the lowest feasible infestation level, hereafter referred to as managed sites) and half were not (unmanaged sites). The sites were distributed throughout Florida, with 9 of each type in each of three sections of the state (north, central, and south). Criteria for site selection included the proviso that water hyacinth was present at each site and that the maintenance history was known.

Water hyacinth populations at managed sites represented earlier phenostages, (incipient or colonizing stages) typical of regrowth from herbicide treatment, and harbored few biological control agents. Also, the plants were of high quality, being more succulent, with higher concentrations of tissue nitrogen. In contrast, populations at unmanaged sites exhibited high levels of stress induced by herbivores (primarily water hyacinth weevils) and were of lower quality (as evidenced by reduced nitrogen levels and other nutrients in leaf tissues). The proportion of biomass allocated to floral structures was nearly five-fold greater at managed sites than at unmanaged sites. Thus, plants subjected to periodic control allocated proportionately more energy to sexual reproduction than plants at unmanaged sites. This points out the need to retreat water hyacinth infestations as soon as regrowth is initiated, preferably before the plants begin to flower, to minimize seed production.

Comparisons of coverage were misleading, because site selection was based on the presence of plants. Thus, sites where complete control had been attained would not have been chosen. Nonetheless, total water hyacinth coverage was consistently lower at managed sites (an average of 15% as compared to 60% at unmanaged sites). This attests to the efficiency of maintenance programs. However, none of the unmanaged sites were completely covered by water hyacinth, despite the lack of any control efforts over a period of several years. Prior to the introduction of biological control agents, comparable sites would have consistently been covered bank to bank (Center, personal observation). Although we could not determine whether this reflected increasing or decreasing water hyacinth populations, the condition of the plants indicated that coverage was probably on the wane. This, we feel, attests to the impact of the weevils, which had probably occurred over a period of several years.

Adult weevil counts at unmanaged sites exceeded the counts at managed sites by three-fold on a unit area basis and by nearly five-fold on a per plant basis. Total weevil density (larvae+adults) was about two-fold greater at unmanaged sites than at managed sites (97 vs. 54 insects/m^2). After factoring in the 4-fold difference in water hyacinth coverage, the differences in total weevil populations between the two groups was at least eight-fold but weevils were virtually nonexistent at some managed sites.

We also sampled the weevil populations at these sites and dissected a proportion of the adult weevils to assess their reproductive condition. Fecundity was positively correlated with leaf nitrogen concentrations, so weevils were generally more fecund at managed sites, despite their fewer numbers. This suggests that sustained weevil attack induces a reduction in plant quality (cf. Center & Van, 1989) which, in turn, causes reduced fecundity of the weevil population and a easing of herbivory. These results also suggest that maintenance procedures reverse this to some degree, but, because of the concomitant loss of the herbivore population, their population response is delayed. Hence, this provides clear possibilities for integrated control using herbicides to minimize infestations and maintain plant quality while employing techniques to avoid devastating reductions of the weevil populations. Appropriate application of this information could produce longer term control at less cost.

Water Hyacinth Weevils as Growth Suppressants

The realization that water hyacinth coverage was often incomplete even at unmanaged sites caused us to consider the possibility that the weevils mainly retarded rates of mat expansion (data on statewide acreages in Louisiana also suggests this possibility, see the paper by Cofrancesco). All previous studies focussed on induced changes within a solid mat (usually on a per unit-area basis), assuming that reductions would occur and would be observable. No one had ever examined the effects of biological control on rates of coverage. It is certainly more desirable to prevent plants from infesting an area of water rather that to remove them after the area is infested. We addressed this at two sites, the first being the St. Mark's River in northern Florida, by creating incipient infestations of water hyacinth in plots that allowed space for the plants to expand into and measuring the rate at which this expansion occurred.

The plots consisted of two frames, one encompassing an area of 10 m^2, the other an area of ca. 84 m^2. The smaller inner frame was filled with small water hyacinth plants and was centred within the larger frame. The thin inner frame held the original plants in place but allowed them to grow outward. We measured plant coverage within the outer frame by marking grid coordinates on the outer PVC-pipe. We then mapped the distribution of the plants and measured area of coverage from the maps using an image analysis system. Ancillary data included the status of the plants and the reproductive condition of the weevil populations. Five plots were inoculated with 0, 1000, 2000, 3000, or 4000 weevils, which represented the normal range usually observed in the field. Plots were inoculated in April and data were collected at 4 to 6-week intervals over the course of one year. At the St. Mark's River site, plants in the control plot covered the available space very quickly, attaining 45 m^2 coverage by late July and 56 m^2 by December (a 6-fold increase). The other plots ranged from 13 to 29 m^2 by late July and from 18 to 36 m^2 by December. Growth rates were generally consistent with treatment levels, with the 3000-weevil plot growing the least and the 1000-weevil plot growing the most (except for the control). The exception was the 4000-weevil plot which grew nearly as much as the 1000-weevil plot, probably due to early deterioration of the plants and a consequential decrease in the weevil population. This gave the plants most of the growing season to recover. Nonetheless, plants in all plots that were inoculated with weevils expanded more slowly than those in the control plot.

The total plant population (density per plot) increased initially in all plots, with peak numbers inversely correlated with inoculation rates. Populations attained peak levels of about 3000 plants in the control plot by September and remained steady thereafter, but, after an initial surge, populations declined in all of the plots that received weevil inoculations. The larger plants seemed to persist, so the plants that died were probably the younger, smaller shoots. In addition, the canopies of the plots inoculated with weevils opened up, exposing the water below, whereas complete canopy coverage was maintained in the control. This reduction in the canopy was related to reduced leaf size on plants exposed to weevil treatments. For example, in the control plot at the beginning of October the average leaf size was 115 cm^2, whereas in the plot inoculated with 4000 weevils the average leaf size was 48 cm^2 on the same date. Hence, the effect of the weevils was to cause the water hyacinth mats to expand more slowly relative to the controls and to open up the canopy. This was brought about by increased mortality and reduced plant size and leaf area (Fig. 1). Although the weevils failed to eliminate the mat, herbicidal management of the plant populations would not have been urgent and could have been more easily accomplished.

This study was later repeated at a second site in southern Florida with similar results, although the mat in the control plot expanded much more rapidly. Together, the resultant information debunks many misconceptions about biological control of water hyacinth. For example, it is commonly believed that water hyacinth populations outgrow the weevil populations. If this were true, the average number of weevils per plant would steadily decline until the plants no longer had additional space to grow into. Yet the weevil intensity (number per plant) in the controls steadily increased indicating that weevil numbers outgrew plant numbers. Also, even though the mats receiving the highest weevil inoculations only doubled in size over the 8-month period, they did increase. Obviously, if this occurs at field sites over a period of years with no control measures being taken, water hyacinth infestations will eventually cause problems, even when the plants are exposed to intense herbivory and the mat expansion rate is slow. This explains why surface coverage was relatively high at unmanaged sites in our earlier study. At any rate, this study clearly shows that any number of weevils is better than none.

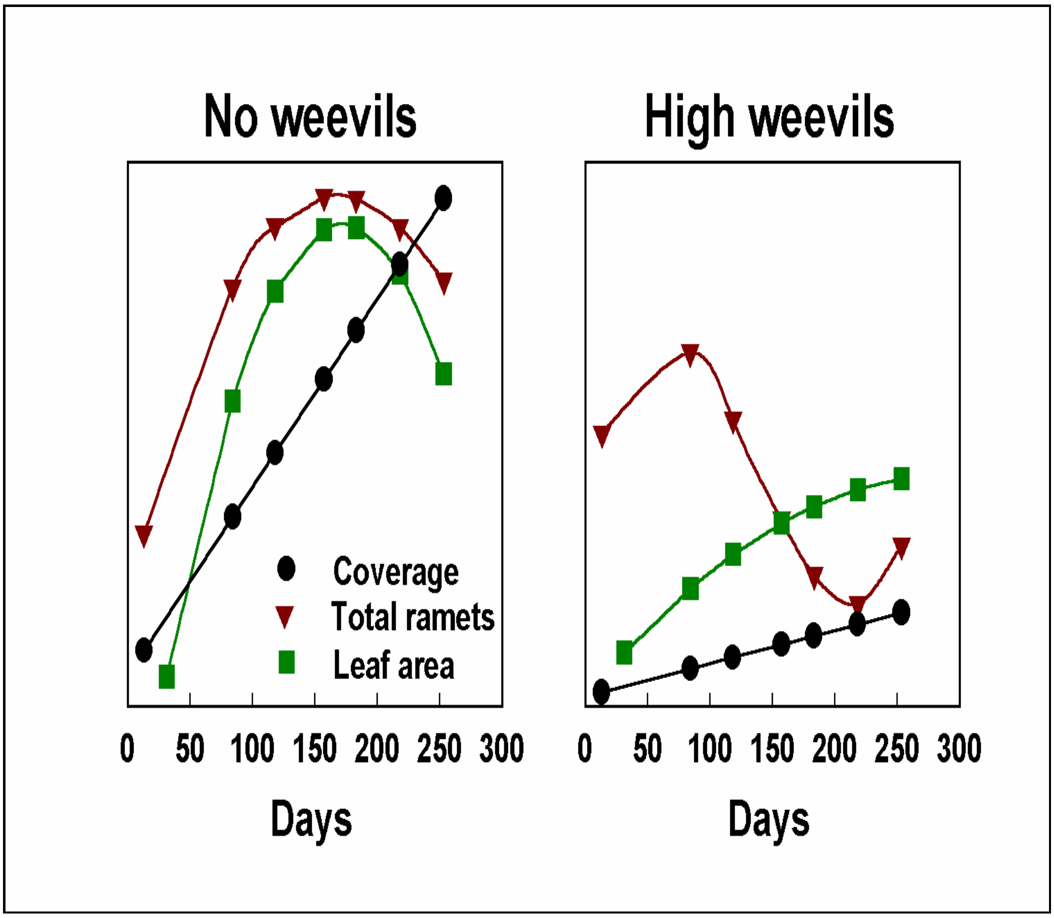

Figure 1. Partial results of a study conducted at the St. Marks River in northern Florida which compared the effects of inoculating 10 m^2 water hyacinth mats with high levels of water hyacinth weevils (300 weevils/m2, initially) vs. no initial inoculation of weevils. The data show water hyacinth population growth (total ramets per plot), plant size (area per leaf), and rates of mat expansion (coverage).

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GROUP DISCUSSION

Orach-Meza — So far we have not really heard anyone talking about the enemies of *Neochetina eichhorniae* and *N. bruchi*. Most likely they may have many natural enemies but I don't know whether any has been identified.

Center — The insects themselves have a slight advantage of being inside the plant for a good part of their life cycle. So, they are not really exposed to many natural enemies. But certainly birds eat weevils, and dragon flies and can take a heavy toll of *Sameodes*. Our biggest concern is Microsporidia which take a heavy toll of *Sameodes*. We now have found them on *Neochetina* at some sites locally at very high levels. So, the impact of disease is probably more significant.

Orach-Meza — When the insects get attracted to light I thought that would expose them quite a bit and I had the impression that they used to go underneath the leaf during the course of the day. But then, from your explanation they appear to get attracted to light at night.

Haller — At night is when they are out feeding on the leaf surfaces; during the day they go down to the crown of the plant. They don't always fly. There is flight reproduction syndrome that they go through. Periodically they will develop flight muscles and they will fly. But most of the time if you look for flight muscles you won't find them. If you do, they are in a very, very low proportion of the adults.

Orach-Meza — Regarding the rate of growth you illustrated on the growth chart, I was wondering the time when you started measuring the growth. If it was around the time you released the insects there, there would obviously be no difference in the growth rate. Because the time period is about three months, if you started measuring growth from the time you just inoculated the plant with the 2,000, 3,000, or 4,000 weevils, obviously it would have had no effect yet on the plant. So, the growth rate would not have had any effect on the plant.

Center — But they obviously did have an affect on the plant.

Orach-Meza — In that period of 3 months?

Center — Well it was actually a period of 250 days. Yes, in this graph, I cut it off because by the end of this point the plots were all of about the same coverage. But this one is about 220 days. I think there is a misconception here, namely, that the weevils take 90 to 100 days for one generation. That is not true; they will go through a generation in about 4 or 5 weeks.

We have tagged the adults and released them in the field and found them 11 months later still laying eggs. But the time of egg to adult is only about 42 days. The pupal period is only about 6 days, but most of the data you see on that is about 30 days. And that is because the pupa will develop and reside in the cocoon for several weeks before it emerges. And I think that is why there is so much data in the literature about the pupal period being 30 days; it is only about 7 days.

Haller — I would like to look at that graph again. And the reason being is that you stated that the plants do not out grow the weevils.

Center — I didn't show that for this site.

Haller — You have a tremendous site difference. What my hypothesis has been, or has developed into, is that water-quality differences make an enormous difference. So, if your plant is growing rapidly, it is in fact outgrowing the weevil; the plants are getting ahead of the weevils in terms of growth rates. Successes and failures then can be very important based on water quality and your sites. Did you do any water quality analysis?

Center — No, I have had difficulty with the water quality analysis in the past. That is why we did the tissue analysis, because what is in the plants is more important in this study.

Haller — We used to do water analysis routinely but we never could really draw any conclusions, so we now look at the plant nutritional composition. And it tells us a lot more. How do you feel about that?

Center — We have had water quality analysis done and found nothing was meaningful to us.

Haller — But if you have 10 systems that don't flow and 5 that are managed and 5 that aren't - according to the type of water hyacinth that we are looking at, it is undescriptive. So, you have a lot of nutrients in the bottom but there is hardly anything in the water. That doesn't mean there aren't nutrients; a lot of nutrients are going into those systems.

Orach-Meza — What is the reason you give for not continuing your investigation?

Haller — No, the investigation is still going on.

Haller — In the St. Mark's river, your data indicate that you have much better plant reproduction, plant biomass, lamina size, number of stems, etc. Yet, in the St Mark's river we assumed the nutrients were more limited.

Center — The patterns were the same; the magnitudes were different. But you have to expect variable results depending upon the sites.

Haller — So you and I agree on something!

Stocker — Did you make any assessment of the degree of control in general for your unmanaged site?

Center — Yes. I would say about 30% for each site. We tried to estimate coverage, but it was very hard to do because first of all the criterion was that there had to be plants there. So, if there was a site where herbicidal control was affecting the plants it wouldn't have been included. Likewise, if we had a site that was completely controlled, it wouldn't have been included.

We had some degree of a problem when we tried to estimate coverage: we got about 15% coverage on average versus about 50% coverage for the unmanaged sites. The surprising thing is that back when I first started working with water hyacinth in 1972 these sites that were not managed would have been 100% covered by water hyacinth, with out a doubt. Now, they are about 50-60% covered. And the sites have had years to accumulate these populations because most of them haven't been treated in 7 or 8 years at least.

Wright — There is just one interesting thing about your data. In Thailand we get spots where there is still a lot of water hyacinth and they aren't under biological control according to a judgement made by the Thai workers.

Center — We really haven't fully understood what is affecting us. We have monitored sites and we see the growth; we have this large-scale geographic area in Louisiana, we have tank studies, and we have these open noncaged field studies-all pretty much saying the same thing. The biological control agents are really impacting these plants but they are not always taking the plants out. And I hope that the first slides that I showed demonstrated that they will sometimes take the plants out completely. So, I really don't think there could be any question about the effectiveness of biocontrol anymore.

Stocker — If I can make just one point about the data in your overhead that is being talked about, an alternative interpretation is that the treatment wasn't strong enough and you need more weevils to get the same amount of control.

Center We put the weevils together in the beginning at the same time. We did not allow the weevils a chance to get in there and get established and build up and then tried to start the study. If we had done this, we might have seen something totally different. But by the time they established it took a few weeks for the eggs to hatch. There were small larvae by the time the plants were growing. The larvae mature and get to be large larvae before they actually start to produce the damage. Then we get the second generation at which point some of the plants have up to 25 second generation larvae per plant. But then, when we started to see the plant quality deteriorate, the weevil population was strong. They are responsible by far, but I think they then got into a sort of maintenance phase. They stay there, a small population stays around, waiting for the plants to produce new growth. They will then impact the plants and keep them at that level. A number of the plants will escape and they will get ahead of the weevils again. One way the plants do that is by fragmenting and drifting off. You get one isolated little plant that does not have a weevil on it, drifting down the river, lodging in the trees, and before you know it, you have a big population developed without any weevils on it, or very few, and it takes a long time for the weevils to get on these plants and build up. One of the objectives behind this study was to see if it would be feasible to go in early during plant regrowth after treating with herbicide and seeing the weevils in infancy developing on regrowing plants. I think it would be feasible but it would probably be cheaper just to spray them. If there came a time where we couldn't spray or herbicides weren't allowed anymore, maybe we could do something like that. And maybe other countries can make that choice as well.

Special Section:
New and Additional Agents for Biological Control and Steps in Implementing Integrated Management Programs

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RECOMMENDATIONS FOR FINDING AND PRIORITIZING NEW AGENTS FOR BIOCONTROL OF WATER HYACINTH

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INTRODUCTION

The following recommendations were written to be presented at this workshop. They are based on discussions with Dr. Ted Center and on his paper "Biological control of weeds: water hyacinth and waterlettuce" (Center, 1994). Many of the comments mentioned here were transcribed from that publication.

Biocontrol of Water Hyacinth with Insects

Water hyacinth has been a major weed problem in the waterways of the U.S. Southeast since the beginning of the century. Although the arthropods have been found suitable for the biological control of terrestrial weeds since the early 1900s, water hyacinth, together with other aquatic weeds, started receiving attention only in the early 1960s.

In 1961 Dr. George Vogt, an ARS scientist, began faunal surveys in South America to find biological control agents of alligatorweed and other aquatic species. During 1962 Mr. A. Silveira-Guido initiated the first exploration specifically directed towards finding potential biological control agents of water hyacinth and was the only one to conduct comprehensive, long-term surveys.

In 1962, USDA-ARS established a laboratory near Buenos Aires, Argentina, to further this research. At first, the laboratory was committed to research on alligatorweed insects but later, after the arrival of Dr. B.D. Perkins in 1968, emphasis shifted to water hyacinth. Dr. Perkins was succeeded in 1971 by Dr. C.J. DeLoach, Jr., who remained until 1974. The role of these two scientists was to test known insects for possible introduction to the United States, and they did not further the surveys that had been done by Silveira-Guido.

Because of the worldwide interest in water hyacinth control, Dr. Fred D. Bennett, then of the Commonwealth Institute of Biological Control (CIBC), also explored for biological control agents that might be suitable for introduction into African and Asian countries of the British Commonwealth (Bennett, 1972). He and Dr. Helmut Zwölfer conducted faunal surveys in Guyana, Surinam and Brazil during 1968. Despite the brevity of these surveys (5 Feb-25 Mar, 1968), they found several insects not listed by Silveira-Guido. This suggests that more thorough, wider-ranging surveys might reveal many others.

Arthropods Found in South and Central America

The arthropods collected from the water hyacinth mats in its native range of distribution constitute a list of about 43 different organisms. However, most of them hardly cause noticeable damage and they have no value as biocontrol agents. About a dozen species were thought to have potential either by the damage observed or because of their predictable specificity. Only a few insects have been found to significantly reduce the growth of water hyacinth and detailed studies have been undertaken on their biology and host specificity. Of these, only the species of *Neochetina*, *Orthogalumna*, *Sameodes* and *Acigona* have been considered worthy of introduction to other countries.

Need for Additional Agents

Water hyacinth infestations still cause problems in Florida and Louisiana: despite vastly reduced acreage due to growth-suppressing effects of water hyacinth weevils (*Neochetina* spp.) and improved maintenance techniques, the states of Florida and Louisiana still spend a combined total of $5 million annually on water hyacinth control. One problem is that water hyacinth populations are often not allowed to persist long enough for the weevils to build large populations. Then, when seeds sprout or regrowth occurs after herbicide treatments, the weed population rapidly overwhelms the limited number of insects present. Consequently, the weevils have minimal impacts in managed ecosystems. The moth *Sameodes albiguttalis*, on the other hand, thrives on the water hyacinth phenostage that typifies the weed population during regrowth after herbicidal control. Unfortunately, populations of this insect are sporadic, possibly due to a high incidence of disease, and the plants quickly grow beyond an acceptable stage.

New Agents are Needed

New agents are needed [particularly those with capabilities for rapid population increase] to enhance the current level of control. It is therefore necessary to either develop the means of managing populations of currently available biological control agents so as to increase compatibility with herbicidal control or to seek new biological control agents, particularly those with capabilities for rapid population increase.

Strategies to Find New Usable Agents

If the need for additional agents for water hyacinth is accepted, then there are two ways of finding them: additional explorations for new agents and screening of previously known potential candidates.

Additional Surveys to Find New Agents and to Assess Potential of Selected Candidates

Although the probabilities of finding new agents in the native range of the weed seem low, future explorations could also focus in assessing the host range of potential candidates and in getting more information on insects already recorded. Some of these species, along with undiscovered species that will be found during the proposed new surveys, might be promising biological control agents. Available information should be periodically reviewed and the most attractive candidates identified. These should then be further developed via additional foreign studies and/or quarantine research. The case of the mirid *Eccritotarsus catarinensis* illustrates the possibilities of new findings. Although this insect was found by Bennett in his first surveys, it was not until recently in the late 1980s when Dr. S. Neser discovered, near Rio de Janeiro, that is has the capability of seriously damaging water hyacinth. Another example of room for new findings is the Delphacidae leaf hopper found by the author ovipositing in the leaf petioles of the weed in northern Argentina. This association has never been reported before.

Screening Selected Potential Candidates

A number of species have been mentioned in different contexts as having potential for biocontrol. They were recommended for further studies either for their apparent specificity, damage, high reproductive potential and omnipresence. They are *Thrypticus*, *Cornops*, *Palustra*, *Argiractis*, *Chalepides*, *Dyscinetus*, *Taosa*, *Poeciloscarta*, *Eugaurax*, *Hydrellia*, *Chironomus* and few others. However, many of these can not be taken further for they lack the minimum level of specificity required.

Priority Ranking of Potential Candidates

On the basis of the available information for the organisms mentioned, three species stand up from the rest. They are *Thrypticus*, *Cornops* and *Palustra* that have the predicted specificity and damage to warrant further studies of suitability.

***Thrypticus* sp. (Dip.: Dolichopodidae)**

This insect was first found to cause considerable damage to a small patch of water hyacinth at Santos in Brazil (Bennett, 1968). Nearly all the plants attacked had extensive rotting of bases of the stems and in many cases the stems had collapsed completely. The larvae, a few mm long, bore through the stem bases just above the water level. Horizontal tunnels open at both ends and are typical of the damage by this insect. The tunnels are blackish in colour due to the presence of frass and rotting tissues. *Thrypticus* sp. was tentatively included by Bennett and Zwölfer (1968) in their list of insects warranting further attention. It was the most ubiquitous species that they encountered during their exploratory surveys in northern South America. Neiff *et al*. (1977) reported considerable damage caused by it in Argentina. We have no information on the effect of this damage or on the specificity of this insect; however, they can cause extensive damage to the leaf petioles (Center, 1975).

***Cornops aquaticum* (Orth.: Acrididae)**

Three species of grasshoppers in the genus *Cornops* (*C. aquaticum* Bruner, *C. longicorne* (Bruner), and *C. scudderi* Bruner) have been associated with water hyacinth. *Cornops aquaticum* is known from Argentina and Uruguay (Silveira-Guido & Perkins, 1975), *C. longicorne* from Brazil and Surinam (Bennett & Zwölfer, 1968) and *C. scudderi* from Belize (Bennett, 1970). However, all specimens collected on water hyacinth by Bennett and Zwölfer were later identified as *C. aquaticum* except for a single, probably incidental, specimen of *C. paraguayensis* (Bennett, personal communication; Roberts & Carbonell, 1979). *Cornops aquaticum* and *C. scudderi* differed only in minor ways (Bennett, 1970) and later revision of the genus synonymised both names under *C. aquaticum* (Roberts & Carbonell, 1979). Hence, *C. aquaticum* is the only species known from water hyacinth.

Silveira-Guido (1965) described *C. aquaticum* as feeding on the epidermis of leaves and petioles of *E. crassipes* and *E. azurea* Kunth. The adult female uses her ovipositor to create a chamber within a water hyacinth petiole in which to lay eggs. This requires soft tissue which, in itself, confers a degree of host-specificity. *Cornops aquaticum* was rarely found upon *Pontederia* spp., and was an important component of the herbivorous fauna associated with water hyacinth. Later, Silveira-Guido and Perkins (1975) conducted studies on the host range of this species. They indicated that, in the field, *E. crassipes*, *E. azurea* and rarely *Pontederia cordata L.* sustained damage from *C. aquaticum* and that only the two *Eichhornia* species were acceptable for oviposition and egg development. Laboratory tests verified these results, and confirmed that *C. aquaticum* was specific to Eichhorniae and safe to introduce into the United States. However, Bennett (1970) found that *C. aquaticum* (as *C. longicorne*) would feed on several species of plants under starvation conditions. Nymphs could complete development on *Commelina*, however, and when other plant species were included in tanks along with water hyacinth, the adults and nymphs fed only on water hyacinth. This insect is probably quite specific but, because of the artificial nature of laboratory conditions, this specificity is difficult to prove. More studies are needed. We propose to conduct additional field studies to determine the extent to which this insect utilizes other plants in the field.

***Palustra silveiraguidoi* (Lepidoptera: Arctiidae)**

Although this species apparently prefers *E. azurea* to *E. crassipes*, it is nonetheless reportedly restricted to the genus *Eichhornia*. It may therefore be a viable candidate for water hyacinth control, especially if it does not attack pickerelweed, like the closely-related *P. azollae* does. It is apparently rare, and Silveira-Guido (1965) provided only limited observations. It has never been considered further, but if it is as specific as indicated, perhaps it should be.

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GROUP DISCUSSION

Charudattan — I see a basic assumption here that an insect has to be well adapted in order to be considered for introduction. For example, in a case like *Palustra*, the natural enemy may lack temporal synchrony, lack of environmental synchrony, and all that. An agent like that may in fact build up to very high population levels when released into a new geographic area. I am not sure whether the lack of synchrony should be a limiting factor.

Cordo — Oh yes, I agree. I think the number one concern is if we have host specificity; highly specific insects deserve attention regardless of other characteristics. I agree.

It was suggested by some in the past to look for natural enemies, not in the weed's native range but in the fringe of that distribution, because in that situation there may be agents that are not found elsewhere.

Neser — An insect at a very localized distribution in the country of origin of the weed is probably not going to be so adaptable in a new situation.

Terry — Are there different strains in *Neochetina* and can one select or breed for a super *Neochetina*?

Cordo — I don't know.

Center — There are different strains in such a wide range. There are probably differences in cold tolerance and things like that. I guess you could probably breed a super strain if you knew exactly what the characteristics are, like production or short life cycle. I suppose you could-I don't think anybody has ever tried to do that with any biocontrol agents in weeds although breeding for pesticide resistance in the predatory mite has been done so that when walnut trees are sprayed with pesticides the mite (biocontrol agent) population is not wiped out. Nobody has ever really done anything comparable to this in weed biocontrol, that I recall.

Neser — It might be important in the future to select resistance to all sorts of heavy metals. To be able to recollect them in heavily polluted areas and use those if you intend to use them in an area where there are many industrial pollutants.

Stocker — How many different introductions have come out of Argentina? Do we have 8 major populations out there or a few of them?

Center	I think they are relatively few shipments of original insects from Argentina and almost of all the rest of them were from the United States.
	Did you get your insects (referring to South Africa) from the United States or from Australia?
Neser	United States.
Stocker	Probably all the weevils that exist on water hyacinth in the world are from, about 2 or 3 shipments were from Argentina?
Center	You know it's a very common phenomenon, it turns out that all of the grass carp in North America came from one shipment from Malaysia, from one batch of fish that came from Southern China.
Cordo	In the case of *Sameodes* it is probably even less.
Center	Yes. *Sameodes* came from probably no more than a 100 individuals.
Cordo	We were having difficult problems in the past in collecting insects because the heavy incidence of Microsporidian infections.
Neser	Particularly, I would like to see more introductions, just to encourage the diversity and genetic stability and so on. But I think we are all too frightened of Microsporidia ruining the effect that we have. But I would be certainly in favour of reintroducing *Sameodes* and *Neochetina* from different widespread situations.
Neuenschwander	Do you know under what condition were the agents collected - under high population conditions?
Cordo	You mean the population of *Neochetina*?
Neuenschwander	No, not only *Neochetina*, also the others. Were they all collected under high populations of the host, the water hyacinth?
Cordo	Well it varies. Sometimes from a big patch of water hyacinth; sometimes in small ditches; so it varies.
Neuenschwander	Because that has proved to be an important factor in other insect collections.
Center	Do the reports indicate that it is better if collected from small populations of hosts?

Neser	Isn't it correct that *Neochetina eichhorniae* was collected in Argentina, which is really outside the natural distribution of water hyacinth, but *N. bruchi* was collected within distribution, way south of the natural distribution?
Charudattan	I think there was a reason for going there-that region was climatically similar to the region where those insects were supposed to be released. And of course Argentina was accessible back then for this type of research work, but Brazil was not.
Neser	It looks as if there is a real need to look in climatic regions in the Amazon Basin. And we have a project in mind, the European Union with Brazil and Portugal, just to see if maybe we can fill that gap and do better surveys in Brazil, specially in the Amazon Basin.
Cordo	Charu, what is the situation of pathogens in Brazil? Are pathogens very well known in Brazil?
Charudattan	No, surprisingly there have been few surveys done in the Amazonian regions.

PATHOGENS FOR BIOLOGICAL CONTROL OF WATER HYACINTH

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INTRODUCTION

Water hyacinth continues to pose problems worldwide in spite of the best human efforts to control it. It still ranks as the world's worst aquatic weed. Massive colonies of water hyacinth buildup when the plant is introduced into new areas that are conducive for its proliferation, or when the natural ecological balance of water bodies is upset due to human activities such as impounding of flowing waters by dams, channelling, and allowing the buildup of eutrophication. Several tropical and subtropical areas of world, including some in the region of origin of the plant, are currently experiencing serious problems with water hyacinth infestations. The problems are very severe especially in countries where human activities and livelihood are intimately tied to public water resources. Attempts to control the weed by conventional methods, mainly by mechanical or manual removal and chemical herbicides, are providing only temporary, but costly solutions. Moreover, the use of chemical herbicides is often prohibited because people and livestock depend heavily on these water resources. Finally, some of these nations also lack the necessary public finances and infrastructure to manage the expensive chemical control programs.

The only logical, long-term, and sustainable solution is to employ an integrated approach to water hyacinth management in which biological control agents play the central role. Biological control, especially by using insects, has been highly successful in reducing water hyacinth infestations in the southern United States and several other countries. We all can remember how severe the water hyacinth problem was like in regions such as the southern United States *before* biocontrol agents were established and how much cost savings have accrued since the biocontrol program was implemented. Furthermore, there are a number of controlled studies that have confirmed the roles of insects, pathogens, and the combination of insects and pathogens in causing water hyacinth populations to decline. Our studies have also confirmed and reinforced the view that insects and pathogens can be effective partners in integrated control of water hyacinth. On the contrary, chemical herbicides, to be effective in integrated control, must be applied carefully and selectively; if not, they can actually nullify biocontrol by disrupting the natural buildup of biocontrol agents or by completely eliminating local populations of the agents.

Biological control refers to *pest suppression in a gradual and long-lasting manner*. Some agents, such as certain pathogens used as bioherbicides, can provide quick and high levels of control; but such agents are the exception. Generally, biological control is not meant to be synonymous with *quick killing,* which the chemical herbicides can offer. However, notwithstanding the success of water hyacinth biocontrol programs in many countries, I feel there is scope for further improvements in the effectiveness of biological control. This would require the deployment of additional agents to complement the existing ones; the purpose here is to increase the level of biotic stress such that the plant's capacity for compensatory growth and population resurgence are curtailed. In many weed biocontrol systems, it has been necessary to use a suite of biocontrol agents to achieve sustainable, practical levels of control. Such an approach appears essential for water hyacinth.

Among available natural enemies, plant pathogens have not been fully and fairly assessed. Despite the history of water hyacinth problem, very little scientific and technical literature appears to exist in many countries concerning the occurrence and impact of native natural enemies of this weed, especially of microbial pathogens. Furthermore, compared to other control options, only limited research has been done on pathogens and much of our early attempts in the 1970s stopped short because of lack of commercial interest and a general naivete about the bioherbicide technology. Since then several newer studies have been completed which have helped us to understand the epidemiology and host-pathogen dynamics of water hyacinth pathosystems as well as the technological feasibility of bioherbicides. Therefore, there is now a reason to focus renewed attention on plant pathogens.

Several highly virulent pathogens of water hyacinth occur in different parts of the world (Table 1). Among them are *Acremonium zonatum, Alternaria alternata, A. eichhorniae, Bipolaris/Helminthosporium* spp., *Cercospora piaropi, C. rodmanii, Myrothecium roridum*, *Rhizoctonia solani*, and *Uredo eichhorniae*. However, only *Cercospora rodmanii* and *Alternaria eichhorniae* have been studied to a significant extent. Other virulent pathogens have not been fully evaluated; efforts should be made to study their potential.

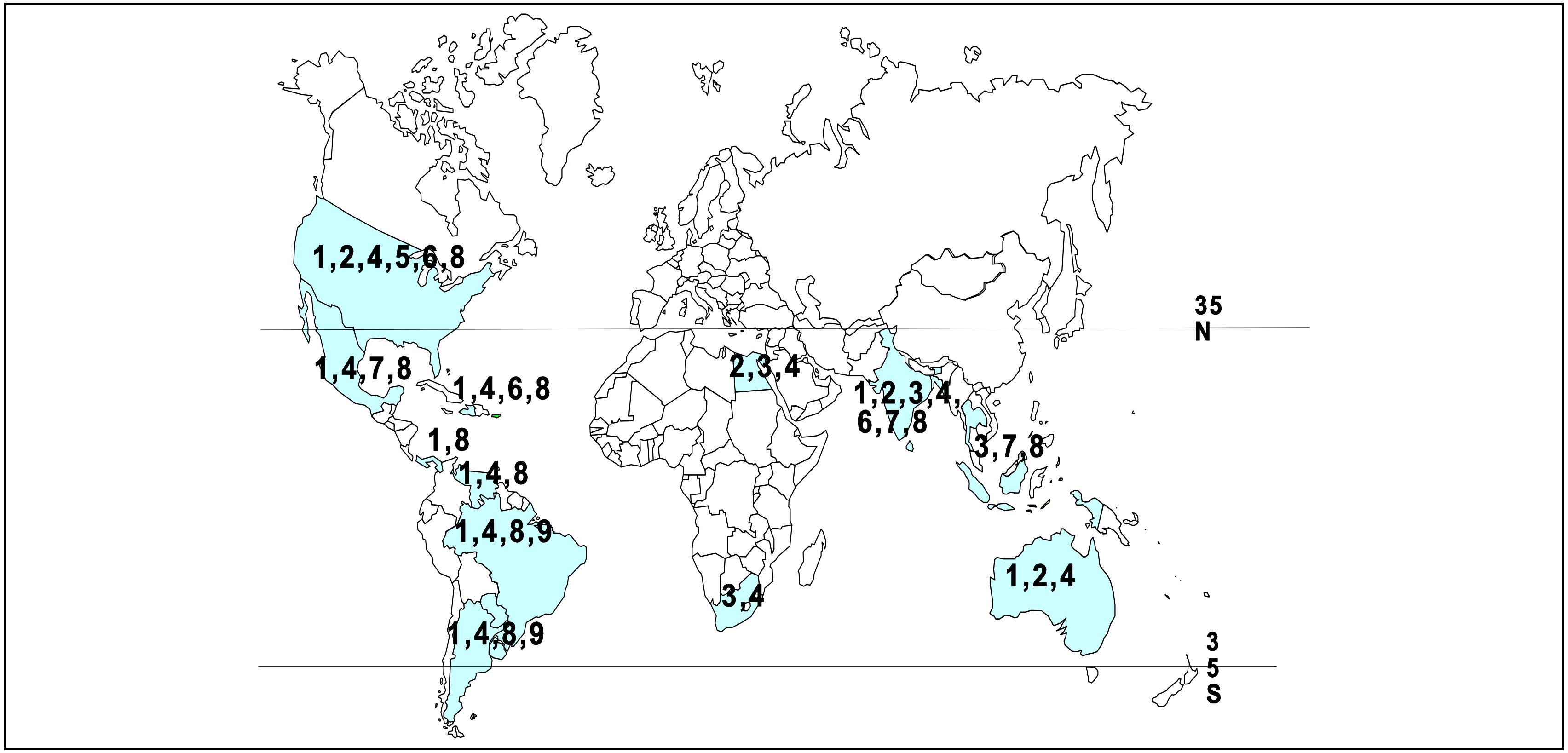
Acremonium zonatum

This fungus causes an easily identified necrotic zonate leaf spot characterized by spreading lesions most noticeable on the upper laminar surface. On the lower surface, which is normally protected from direct sunlight, the area directly under the spot may have a sparse layer of white fungal growth (mycelium). Each spot may be small (2 mm diameter) to large (>3 cm diameter); the spots may coalesce, covering most of the lamina. The zonate pattern may not be evident in new infections when most spots are small. This disease has been reported to occur on water hyacinth in Australia, USA, and many countries of Central America, South America, and Asia (see distribution map; Fig. 1). This disease is often associated in the field with infestations of *Orthogalumna terebrantis*, the water hyacinth mite.

Table 1. Status of Research and Development of Pathogens for Biological Control of Water hyacinth

Pathogen	Efficacy Tested Greenhouse	Efficacy Tested Field	Host Range Tested and Found to be Safe	More Research Needed on	Practical Use Possible
Acremonium zonatum	Yes	No	Yes	Yes: Field Efficacy	Yes
Alternaria alternata	No	No	Not tested	May not be needed	Doubtful: Efficacy
Alternaria eichhorniae	Yes	No	Yes	Yes: Field Efficacy	Yes
Cercospora piaropi	No	No	Not tested	Yes: All aspects	Yes
Cercospora rodmanii	Yes	Yes and Efficacy	Yes	Yes: Formulation	Yes
Helminthosporium/ Bipolaris spp.	Yes	No	Not tested	Yes: All aspects	Doubtful: Safety
Myrothecium roridum	No	No	Not tested	Yes: All aspects	Doubtful: Safety
Rhizoctonia solani	Yes	No	Not tested	Yes: All aspects	Yes
Uredo eichhorniae	Yes	Yes	Yes	Yes: Life cycle	Yes
Bacteria	No	No	Not tested	Yes: All aspects	Unknown

Figure 1. **A Provisional Distribution Map of Major Fungal Pathogens of Water Hyacinth (*Eichhornia crassipes*)**



Numbers in the map refer to the occurrence of the following pathogens in the respective regions:

1: *Acremonium zonatum*	2: *Alternaria alternata*	3: *Alternaria eichhorniae*
4: *Cercospora piaropi*	5: *Cercospora rodmanii*	6: *Helminthosporium/Bipolaris* spp.
7: *Myrothecium roridum*	8: *Rhizoctonia solani*	9: *Uredo eichhorniae.*

Figure 2. Model for the Discovery and Development of Bioherbicides followed in the USA

Survey for potential pathogens and collect disease specimens
↓
Isolate, identify, and confirm pathogenicity of prospective pathogens
↓
Determine biocontrol efficacy and safety to nontarget plants (host range) in greenhouse trials
↓
Determine the epidemiological requirements for biocontrol efficacy in controlled experiments
↓
Develop methods for large-scale production of inoculum for field trials
↓
Confirm biocontrol efficacy in miniplot trials
↓
Apply for patents on the bioherbicidal use of promising agents
↓
Seek a potential registrant (could be an individual, industry, or Third Party Registration, Inc.)
↓
Seek extramural support (through an industrial partner, IR-4, Small Business Administration grants, or Third Party Registration, Inc.) to seek an EPA Experimental Use Permit (EUP)
↓
Develop industrial processes to produce a bioherbicide formulation
↓
Confirm biocontrol efficacy under field conditions (in experimental plots under 10 acres, as mandated by the EPA)
↓
Develop efficacy data under EUP
↓
Simultaneously, develop toxicology data (this is done by EPA-approved toxicology laboratories)
↓
Develop a product label
↓
Register the agent as a bioherbicide

Note: see text regarding my reasons for the inapplicability of this model to developing countries.

Alternaria spp.
Two species of *Alternaria, A. eichhorniae* and *A. alternata* have been reported to occur on water hyacinth in different countries such as Australia, Bangladesh, Egypt, India, and South Africa. *Alternaria alternata* appears to be a relatively weak, opportunistic parasite, whereas *A. eichhorniae* is a highly virulent pathogen that appears to be host-specific to water hyacinth. It has been shown to have good potential as a bioherbicide agent and occurs in Bangladesh, Egypt, India, Indonesia, and South Africa.

Bipolaris/Helminthosporium spp.
Several species of *Bipolaris* and *Helminthosporium* (two related genera), have been reported to attack water hyacinth in various countries. One species in particular, *B. maydis (=B. stenospila)* causes a severe leaf blight of water hyacinth in the Dominican Republic. The isolate we tested was also highly pathogenic to sugarcane, rice, and bermudagrass and therefore it is not likely to be safe for use as a bioherbicide. However, more studies are needed on this and other representatives of these two genera to determine their safety and efficacy as bioherbicides.

Cercospora piaropi and *C. rodmanii*
Symptoms caused by *Cercospora* spp. may be easily confused with those of many other foliar pathogens, especially opportunistic weak pathogens. Two species of *Cercospora,* namely, *C. piaropi* and *C. rodmanii* have been reported to attack water hyacinth in different parts of the world. Both species cause small (2 to 4 mm diameter) necrotic spots on laminae and petioles; the spots are characterized by pale centres surrounded by darker regions. Occasionally, the spots may appear in the shape of "tear drops" and usually the spots will coalesce as the leaf matures causing the entire leaf to turn necrotic and senescent. The senescence is in fact accelerated by the Cercospora disease and the disease can rapidly spread across water hyacinth infestations, turning large areas of the biomass to become brown and necrotic. Under severe infections, the plant may be physiologically stressed, lose ability to regenerate, become water-logged, and sink or disintegrate. *Cercospora piaropi* has been found on water hyacinth in Australia, several countries of Asia, Africa, and the Americas. *Cercospora rodmanii* is a variant that differs from *C. piaropi* in cultural morphology and virulence; for biocontrol purposes it should be regarded as a variant of *C. piaropi.*

Myrothecium roridum
This fungus causes a striking teardrop-shaped leafspot (up to 1 x 5 cm), rounded on the side towards the petiole and tapering to a narrow point in the direction of the laminar tip. The older leafspots will appear necrotic with dark brown margin and the centre of the spot will be covered with discrete white conidial masses. Myrothecium disease has been reported on water hyacinth in India, Malaysia, and possibly Mexico.

Rhizoctonia solani
The symptoms of this fungus may be confused with damage due to desiccant type of chemical herbicides. They are characterized by irregular, necrotic spots and broad lesions. However, unlike chemical damage, the brown necrotic areas are usually surrounded by noticeable, thin, water-soaked margins of darker brown colour than the rest of the necrosis. Rhizoctonia disease

has been reported on water hyacinth from southeastern United States, Brazil, Mexico, Panama, Puerto Rico, India, Malaysia, and Indonesia. This fungus is usually very aggressive and destructive, capable of killing large amounts of water hyacinth biomass in a rapid and complete manner.

Uredo eichhorniae

Uredo eichhorniae is a rust fungus found only in South America, the original home to water hyacinth. The occurrence of this pathogen only inside the native range of water hyacinth, and not outside this range, is to be expected on the basis of ecological theory of host-parasite coevolution. On the basis of this theory, and the well established fact that rust fungi are highly host-specific, this fungus is a highly desirable classical biological control agent that should be developed for worldwide use. Our attempts to import this fungus into Florida was disallowed by U.S. regulatory agencies on the grounds that we do not know the full life cycle of the fungus. Research on this aspect was stopped in the 1970s due to cost-benefit considerations. It is one of my recommendations to this group that research on this agent be re-started.

Bacterial Chlorotic Halo

Water hyacinth leaves damaged by the *Neochetina* weevils are known to be infected by bacteria belonging to *Xanthomonas* and *Erwinia*. Although not much is known about this association between bacterial pathogens and insect attacks on water hyacinth, the occurrence of a condition characterized by a chlorotic halo surrounding the weevil feeding spots has been observed in Florida in the United States, Brazil, Mexico, and Venezuela.

With the exception of *U. eichhorniae*, these fungi are all easy to produce inexpensively and therefore are amenable to development as bioherbicides. Sufficient scientific information exists concerning their geographic distribution, pathology, and epidemiology. Since a majority of them are naturally distributed in several countries, it should be possible to develop native strains for local or regionwide use. This would eliminate fears about introducing exotic pathogens. These agents could be developed through indigenous commercial enterprises or national or regional public institutions, thus offering some entrepreneurial opportunities and a sense of ownership for local citizens.

Although the U.S. model for developing bioherbicides (Fig. 2) is quite workable in technologically and industrially advanced countries, it is a very expensive, lengthy, and cumbersome process that is not likely to be suitable for less developed countries because of the high R&D costs and the regulatory infrastructure necessary to administer biopesticide registration. A cottage-industry-type approach would be more desirable in terms of its efficiency and societal benefit.

Before a biological control program is instituted in any country, it is first necessary to document the occurrence of native natural enemies in that country. This is essential for making a wise choice of biocontrol agents and strategies to follow. For example, a decision to import foreign biocontrol agents may depend on the absence of that agent in the country or the region. If native strains of a pathogen are already present, they should be studied first before introducing new strains from abroad. A clear understanding of the pathogen flora is also desirable and helpful to select the best native strains for development.

I feel there is an urgent global need to develop and implement an integrated scheme to manage water hyacinth rather than relying solely on the chemical treadmill. The integrated management scheme should be based on biological control, using insects and pathogens, as the foundation. It should also include selective harvesting of biomass and a judicious use of chemical herbicides. To expedite this scheme, there should be a coordinated international effort to seek and utilize native pathogens as bioherbicides.

CONCLUSIONS AND RECOMMENDATIONS

1. Among available natural enemies, plant pathogens have not been fully and fairly explored.

2. A number of highly virulent and fairly host-specific pathogens are known to attack water hyacinth in different parts of the world.

3. Nonetheless, large areas of the adventive range of water hyacinth have not be surveyed to catalogue the full suite of pathogens that may be available for development as biological control agents.

4. One obligate parasite, *Uredo eichhorniae*, and perhaps *Cercospora rodmanii* can be used as classical biological control agents in different parts of the world.

5. The life cycle, host range, and biocontrol efficacy of *Uredo eichhorniae* should be determined and research on these aspects should be started and supported immediately as a high priority area.

6. It is feasible to develop native facultative parasites as inundative bioherbicide agents, i.e., different pathogen strains for local use in different countries.

7. Two pathogens native to the African continent, namely *Cercospora piaropi* and *Alternaria eichhorniae*, could be, and should be, immediately taken up for development as bioherbicides.

8. Cottage-industry type of approach, which is quite feasible but so far not attempted, should be tried in order to overcome the high cost of the U.S. model of R&D and the consequent lack of private-industry participation.

GROUP DISCUSSION

Pieterse — It is very difficult to get permission to transport fungi from one country to another. Also, it was about 20 years ago I think when *Cercospora* looked very promising; yet it is still not used. That just shows you how complicated the whole thing is. But in spite of the fact that it is an American fungus, so much experience is not part of the biological control program.

Charudattan — I think I have to clarify something here. *Cercospora* spp. are everywhere in the southeastern United States, whether it is *Cercospora rodmanii* or *C. piaropi*. We know there had been sporadic epidemics of *Cercospora* which have been reported in literature. For example, there is one report that appeared in the Journal of Aquatic Plant Management showing that *Cercospora* was responsible for controlling a small population of water hyacinth in Lake Conroe, Texas in one season. Whether this type of annual outbreaks occur commonly around the world has not been documented because no one is ever there to identify and categorize each mini epidemic. I think that in some of Ted Center's data and my own data, we have found that *Cercospora* disease often plays a significant part at the end of a long stressful biological cycle where you have the insects well established in the plants. We don't have a commercial formulation but I can tell you, if we have mandate to produce it, it's fairly easy to do.

Center — In the studies that I discussed, in the highest two weevil levels, 3,000 and 4,000 weevils per plot, we got really nice build-up of *Cercospora* and there was definitely interaction between the weevils and the pathogen. Not so much in the lower weevil levels and the control, but with the two highest weevil levels there was, especially at the St. Mark's river site.

Labrada — Is it wise to spread in Florida both *Cercospora* species and are there keys for good identification of both species?

Charudattan — It is difficult; you can't really tell the two species apart in the field. You have to culture the two fungi and produce spores and look at the spore morphologies. That is why I said that the difference is not that important for biological control purposes.

Labrada — Regarding deliberate spreading, I see no risks; the benefits could out weigh any risks. I think there is possibility for such a development. We can do this; we can provide good protocols to those countries where the fungi are absent. In the same way as it is done now in some developing countries for the production of *Beauveria bassiana*, namely, in an artesanal way that they produce and immediately apply the pathogen.

Probably we can do something in this aspect. I cannot commit myself, but I would see the possibility as I said in the first day to have at least a pilot program, a small one that we can develop, probably in Mexico and then we can spread this knowledge to all developing countries affected by water hyacinth.

Charudattan — We are in an impasse here: I can show all kinds of good efficacy data based on the numerous studies that I have done. None of those studies will be applicable to EPA if I go to them for registration. They are going to ask for data gathered under Experimental Use Permit (EUP) standards. This could cost up to 2 million dollars, but more realistically, about $200,000.

Haller — I think you have got to understand the situation in the United States: Water hyacinth plants right now are costing us $4 in chemical cost per acre to control. Hydrilla, which is our major problem, is costing us $200 an acre to control. So, all research efforts have gone into hydrilla. We dropped all research work on water hyacinth, after *Neochetina*. Any further introduction, everything, was dropped because water hyacinth is a very minor problem in this country. So that's why Charu is sitting there in his status, that's why Ted is kind of sitting there, he tried to follow through with *Neochetina*, but as long as the cost of water hyacinth control in the United States is $4, $8 or $10 an acre, there is no commercial industry going to be willing to stand the millions of dollars it might cost to register one of these products. That's just an economic reality.
Is the label still valid on *Cercospora*?

Charudattan — No, but it doesn't involve much to get an EUP; I can go to EPA and get an EUP if I have a commercial backup. EPA is that flexible with biological pesticides. However, all that an EUP does is that it authorizes you to do the experimental evaluations under Good Laboratory Practices (GLP). Under the EUP, you generate data that will eventually be used to support the registration.

Haller — But, I mean you could get another. So, there is a regulatory aspect for this and, because of the history of bioherbicides being quite successful, but being very limited in market value (about $500,000 per year) does not encourage a lot of companies to get involved in it.

Cofrancesco — How was the work with *Cercospora* done in South Africa?

Charudattan — The infected plants were transplanted in the field - that's what I understand.

Wright	In the early stages of weevil releases in Australia I saw in a couple of instances where there was presence of *Neochetina* on leaves there was a very obvious increase in the principal *Cercospora* disease.
Cofrancesco	Does University of Florida still hold the patent on *Cercospora*?
Charudattan	Yes, but the patent will expire soon. We patented the use of *Cercospora rodmanii* in 1978; so we are at the end of the patent's life.

STEPS IN IMPLEMENTING INTEGRATED MANAGEMENT PROGRAMS AGAINST WATER HYACINTH

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A. ASSUMPTION

1. No conflict of interest in control options exists, i.e., the need is to control water hyacinth.
2. If eradication is still feasible at an affordable cost, and if infestations are still absent but likely, specific programs are required.

B. THE FOLLOWING HAS TO BE DETERMINED BEFOREHAND

1. Sources of infestation and reinfestation.
2. Restraints on the use of selected chemicals that may locally exist, e.g., 2,4-D or glyphosate, in drinking water.
3. Budget: amount, the period over which the money is fairly certain to be available.
4. Resources available: capability for response for chemical control, mechanical control, implementation of biocontrol, and monitoring.
5. Restraints on introduction of existing biocontrol agents (i.e., which additional tests will be prescribed).
6. Level of residual weed population that is acceptable or allowable, and between which levels fluctuations will be acceptable, e.g., whether occasional temporary resurgences will be tolerable.
7. Time scale in which the aim has to be achieved.
8. Expectations of people involved and "education" required to remove misconceptions.

* Get reliable, irrefutable information where the chemicals can be used safely.

C. ACTIONS WHEN INFESTATIONS ARE PRESENT

*** Important: all expenses are to be prioritized.**

1. Make a survey of approximate extent and density.
2. Decide if eradication is at all feasible. If it is, implement special measures and persist and assess progress at a predetermined time.
3. Define areas most at risk (where most undesirable or not tolerable).

4. Estimate likely increase (development) of the infestations in different areas/types of situations in the infested system (i.e., determine if maximum has been reached; if increase is important or not; if any should be stopped as a priority).
5. Work out priorities for control: i.e., leave largest, nonexpanding patches (discourage exponential recovery/regrowth); remove single plants; work along edges of infestations.
6. Survey for presence of known and other control agents.
7. Implement control measures decided upon. Create refuges for bio-control agents where chemicals are not to be used.
8. Get the community involved: awareness programs, cooperation in rearing, spreading and recording of biocontrol agents, and removal of plants from sensitive areas.
9. Set up infrastructure to deal with the program and enlist expert advisory (person or group or consultant) to get/keep infestations at the levels required.
10. Train local staff in implementation of control packages discussed before.
11. Ensure that everything possible is done to limit enrichment of the water.

D. CONTROL PACKAGES

1. Develop site-specific control packages in consultation with experienced experts. Base these on classes of infestations and priorities for control, and the best follow-up option for each situation in light of B above.
2. Implement available biological control measures wherever possible, making sure that these sites are protected for a sufficient number of years if at all possible, where they will not interfere with cleared areas.
3. Institute a realistic, sustainable program making sure that it is not likely to be abandoned prematurely and without expert consultation.
4. Implement a monitoring system:

a. Progress with control methods.
b. Establishment, levels and spread of control agents.
c. Incidence of succession by other undesirable weedy species.

5. Continue with regular consultation by experts to ensure that the program remains on track, or needs to be adjusted.

CONCLUSIONS AND RECOMMENDATIONS OF THE EXPERT PANEL:

INTEGRATED CONTROL OF WATER HYACINTH IN DEVELOPING COUNTRIES WITH EMPHASIS ON BIOLOGICAL CONTROL

INTRODUCTION

Editor's note: From the expert papers presented, the discussions that followed each presentation, and the general discussion in the previous section (which was edited and synthesized by R. Charudattan) the following broad conclusions and recommendations have been drawn up.

Water hyacinth is still the major floating water weed in the world despite nearly 100 years of attempts to control it. The present expert consultation was therefore held to address the following:

- to describe the state of art with respect to the control options
- to know capabilities
- to coordinate efforts
- to assist developing countries
- to create capability
- to emphasize the importance of training.

The consultants agreed in principle with the following broad conclusions:

The problem should be specified:

A. No infestation
B. A new, isolated infestation
C. Large-scale infestation

The options available are:

A. Biological control (by means of insects)
B. Physical control
C. Chemical control

Recommendations:

A. Prevention
B. Eradication (chemical, physical or both)
C. Public awareness
D. Biological control
E. Chemical control (only for emergency use not for maintenance control)
F. Physical control (depending on need and finances)

I. RECOMMENDATIONS

A. Problem Recognition and Coordination

Water hyacinth is a growing problem in many parts of the world and when infestations are detected, immediate steps must be taken to control them:

1. Causes of water hyacinth infestations should be identified and where possible appropriate remedial actions should be taken.
2. Countries should be encouraged to reduce input of nutrients into water.
3. A publication on biological control techniques for water hyacinth management, should be developed.
4. Also, a publication on all water hyacinth control methods, should be developed.
5. There should be a working group consisting of specialists in all types of control options and the group should meet at least every 4 years to review progress in water hyacinth control.
6. It is recommended that the Center for Aquatic Plants, University of Florida, Gainesville, be the clearing house for literature of water hyacinth.
7. Key personnel in developing countries should receive training in water hyacinth control, especially in biological control techniques.
8. Propagation, import, transport, and sale of water hyacinth should be prohibited by legislation and the law enforced.
9. National, regional, and community-wide cooperation and collaboration in control efforts should be encouraged.

B. Problem Specification and Options

Options available for management of water hyacinth and information needed to implement an integrated control program should be determined.

1. Site-specific needs for control should be identified.
2. Cost of control options (how much resource is available) should be known.
3. Accessibility of area where control is needed should be established.
   a. By road
   b. By air
   c. By boat/airboat.

4. Location of problem within site will also affect the control options and strategies and therefore should be known.
   a. Fringe
   b. Back water.
5. Nutrient inputs into the aquatic system, which will influence the control options and action plans, should be understood.
   a. Artificial
   b. Natural.
6. The nature of the water body should be understood.
   a. Profile
   b. Extent of shore line
   c. Length
   d. Width
   e. Depth contours
   f. Charge/discharge rates.
7. Use of water body and the importance of the different types of use must be determined to tailor the control methods and strategies.
   a. Fisheries
   b. Recreation
   c. Potable water supply
   d. Irrigation
   e. Other.
8. Socioeconomic and environmental impact studies not only that of the water hyacinth but also that of the control measures should be included.

II. IMPACTS OF WATER HYACINTH INFESTATIONS

A. Consequences of Large Scale Water Hyacinth Infestations

1. Impede fishing activities and inland water transport, obstruct hydro-electric generation, affect maintenance of biodiversity, and affect water quality.
2. Increase the incidence of water-borne diseases and water loss.
3. Deteriorate swamps and fish breeding sites, etc.

B. Actions Needed

1. Problem recognition (resolve conflicts over control / no control decisions). FAO recommends action.
2. Must identify responsible agency/individual for action to be initiated in each country.
3. Historical information needed.

4. Long or short-term solution needed, depending on the nature of the infestation.
5. Developing countries need biological control, although biocontrol is slow and the agents are often not present or available for use.
6. Physical control depending, on the situation is also needed, although user countries need finances for this type control.

III. NEW ISOLATED INFESTATIONS

The potential of new infestation to get worse is generally very great since water hyacinth is a highly prolific plant capable of rapid colonization. Therefore, new isolated infestations must be dealt with quickly and effectively to eradicate or contain the weed problem. Further spread should be curtailed to fullest extent possible. A set of specific steps should be taken.

A. Determine the Stage and Extent of Infestation

1. Incipient
2. Colonizing
3. Mature/extensive
4. Senescent

B. Choose a Containment Option

1. Herbicides
2. Mechanical

C. Install an Educational Program

1. Public awareness
2. Train water utility managers
3. Decide whether individuals with water hyacinth on private property be forced to eradicate the plants?

D. Set-up Capability to Manage or Control Water Hyacinth

There will be a need for rapid response; set-up capability to manage or control the weed

IV. SPECIFIC TECHNICAL RECOMMENDATIONS

1. It is essential that biological control be implemented for long-term, sustainable control of water hyacinth.

2. Before any biological control agent introductions are planned, local surveys should rule out the prior existence of the biological control agents proposed for introduction.
3. Monitoring of indigenous natural enemies of water hyacinth along side the introduced agents should be done. Two *Neochetina* spp. (*N. eichhorniae N. bruchi*), *Sameodes albiguttalis* and *Orthogalumna terebrantis* should be used.
4. Establishment, levels of control, levels of introduced agents should be documented.
5. New biological control agents (new agents and new biotypes) should be sought and developed.
   * Among the new agents are:
   Acigona
   Bellura
   Cornops
   Eccritotarsus
   Thrypticus
   Palustra
6. Highly virulent and safe pathogens should be developed and utilized as bioherbicides.
7. The obligate parasite *Uredo eichhorniae* should be researched and utilized as a classical biological control agent.
8. Biological control agents should be introduced according to FAO code of conduct for Introduction of Exotic Biological Control Agents.
9. International cooperation in search, development, and utilization of biological agents is recommended.
10. All available host-range data on *Neochetina* spp., *Sameodes albiguttalis*, and *Orthogalumna terebrantis* should be assembled into a document for review by recipient countries.
11. Releases to assure establishment of exotic insect biological agents should be sustained.
12. Attempts should be made to assure that genetically diverse founding colonies of biological agents are used.

V. CHEMICAL CONTROL

A. Chemical control should be applied only under conditions where water hyacinth infestations require containment or eradication of expanding populations and require immediate control under emergency needs.

B. According to the experience in certain developed countries, 2,4-D and glyphosate are acceptable chemical herbicides for controlling water hyacinth.

C. Herbicides should be applied by well-trained technicians under strict management of scientists and administrators of the affected countries, and under recommended conditions and manner.

VI. MECHANICAL CONTROL

A. For mechanical control, special harvesters should be used which are sufficiently powerful to remove dense strands of water hyacinth and which have been tested under field conditions. Barriers have utility in rivers, provided the accumulated water hyacinth plants are removed at frequent intervals.

1. Mechanical control measures should be used at sites where clearing of water hyacinth is urgently needed and measured control cannot be implemented.
2. Barriers should be installed to collect water hyacinth for removal by harvesters or conveyers or boats along rivers to transfer the plants to the shore.

VII. INTEGRATED CONTROL

A. Integrated control should rely on a combination of biological, chemical, and physical control methods.

B. It should be further studied as to how integration of biological, chemical, and physical controls can be used most effectively to solve specific needs.

VIII. POTENTIAL SOURCES OF INFESTATIONS

Regulatory actions are needed to prevent introduction and establishment of new infestations.

A. Infestations should be characterized with respect to: proximity, size, and likelihood of damage.

B. It should be determined whether border inspections for aquatic plants are a current practice. Are field crews trained to look for problem weed species?

C. Determine: how easy is it to restrict plant introduction? What resources are available to monitor for introductions? This could be a very costly operation.

D. If there are no infestations, educational programs should stress:

1. Public awareness campaigns
2. Surveillance
3. Legal considerations (ban on possession, sale, use, import, etc.)

E. If laws are in place making possession, sale, transport of water hyacinth illegal, they should be enforced (i.e., monitoring, vigilance, set up capability to manage/control, list of most endangered but still weed-free watersheds).

IX. ESTABLISHED INFESTATIONS

Established infestations can provide information of value that could be applied to ongoing and future control operations.

A. How many water bodies are involved?

B. Lessons from historical development of infestations.

C. Large scale infestation:
1. How much reduction is needed?
    a. Short-term control, preferred options:
    1. Mechanical
    2. Chemical
    b. Long-term control, preferred options:
    1. Biological
2. Are biological agents in place now?
    a. Yes:
    1. Augment
    2. Supplement with additional agents
    b. No:
    1. Survey for agent and catalogue agents present
    2. Introduce agents
    3. Develop indigenous pathogens

D. Small-scale infestation
    a. Attempt eradication:
    1. Chemical
    2. Mechanical
    b. Containment:
    1. Biological

E. Economic impact of infestation
    a. High amenity value:
    1. Mechanical

2. Chemical
3. Biological

b. Low amenity value:

1. Biological

X. RESEARCH

Research is essential to develop a sustainable solution to the water hyacinth problem. Given the highly varied nature and extent of this problem worldwide, it is imperative that research on integrated control be undertaken. The emphasis should be on applied answers to the many site-specific, country specific needs.

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APPENDIX:

MEETING AGENDA

September 10-14, 1996, Rolling Hills Hotel and Golf Resort, Fort Lauderdale, Florida, USA

Sunday, 10 September

Arrival of participants, Reception 6:00 pm-7:00 pm

Monday, 11 September

Session I: Welcome and Overview - Chairman, Dr. John Terry.

9:00 Opening remarks - Ms. Christine Kelly-Begazo, International Programs/FANR, University of Florida.

9:30 Explanation of organization/objectives of the meeting-Dr. Raghavan Charudattan, Center for Aquatic Plants, Plant Pathology Department, University of Florida.

10:00 Coffee Break

10:30 Status of water hyacinth problems in developing countries. Dr. R. Labrada, FAO Weed Officer.

11:15 An overview of water hyacinth problems in West Africa and foreseen methods of control. Dr. A. Pieterse, Royal KIT, Amsterdam

12:00 An overview of water hyacinth problems in Lake Victoria. Dr. Orach-Meza, Uganda Fisheries Commission.

12:30 Lunch break

Session II: Control Programs - Chairman, Dr. R. Charudattan.

14:00 The project on water weed control in Ghana, objectives and progress. Mr. DeGraft-Johnson, Coordinator of the project GCP/GHA/026/EEC.

14:30 Development of water hyacinth control program in Australia. Mr. Tony Wright, CSIRO.

15:30 Coffee break

16:00 IITA's program on biocontrol of water hyacinth in Benin. Dr. Peter Neuenschwander, IITA, Benin.
16:45 Discussion

17:30 Adjourn

Tuesday, 12 September

Session III: Control Programs - Dr. Ted Center

8:30 Water hyacinth control programs in South Africa. Dr. Stephan Neser, Plant Protection Research Institute, Pretoria.

9:15 Water hyacinth problems in Mexico and practised methods for control. Dr. Maricella Martínez Jiménez, IMTA.

9:45 Water hyacinth control program in USA. Dr. Al Cofrancesco US Army Corps of Engineers, Waterways Experiment Station.

10:30 Coffee break

11:00 The water hyacinth problem in Malawi and foreseen methods of control. Dr. J. Terry, Long Ashton Research Station, University of Bristol, UK.

12:15 Lunch break

Session IV: Control Methods - Dr. Arnold Pieterse.

14:00 Biological control of water hyacinth in the USA. Dr Ted Center, USDA-ARS, Fort Lauderdale.

15:00 Recommendations for finding and prioritizing new agents for biological control of water hyacinth - Mr. Hugo Cordo, USDA-ARS, Biological Control Laboratory, Hurlingham, Argentina.

15:30 Pathogens for biocontrol of water hyacinth. Dr. R. Charudattan, University of Florida, Gainesville.

16:00 Chemical control of water hyacinth: which herbicides, when and how to apply them. Dr. Thai Van, USDA-ARS.

16:00 Coffee break

17:30 Closure of the second day

13 September

Field day, organized by Mr. Dan Thayer and Dr. Ted Center.

14 September

Session V: Discussion of Control Options - Chairman, Dr. Peter Neuenschwander.

9:00-11:30 Session to discuss technical, environmental and economic feasibility of the control methods at which level of water hyacinth infestation these control methods should be implemented.

Session VI: Conclusions and Recommendations - Chairmen, Drs. John Terry and Ricardo Labrada.

15:00 Approval and discussion of conclusions and recommendations of the meeting.

17:30 Closing address.

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