

Management of Invasive Aquatic Weeds with  
Emphasis on Biological Control in  
Senegal.

**THESIS**

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## Frontispiece



**Figure i.** *Pistia stratiotes* mat negatively affecting domestic water use at Keur Momar Sarr /Lake of Guiers.



**Figure ii.** *Pistia stratiotes* mat hampering navigation at Djoudj Park.



**Figure iii.** Before *Cyrtobagous salviniae* release: Thick *Salvinia molesta* mat hampering navigation at Ndiatene Marekhor before biological control was implemented.



**Figure iv.** Ndiatene Marekhor after the weevil *Cyrtobagous salviniae* successfully caused the *Salvinia molesta* mat to crash.

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## Abstract

In 1985 the Diama Dam was built near the mouth of the Senegal River to regulate flows during the rainy season and prevent the intrusion of seawater during the dry season. This created ideal conditions upstream of the dam wall for invasion by two highly invasive aquatic weeds, first by water lettuce *Pistia stratiotes* Linnaeus (*Araceae*) in 1993, and then by salvinia *Salvinia molesta* D.S. Mitchell (*Salviniaceae*) in 1999.

This study was focused on the management of *P. stratiotes* and *S. molesta*. Following successes that were achieved elsewhere in the world, biological control programmes involving two weevil species were inaugurated against both weeds and research was focused on several aspects. These included pre-release studies to determine the weevils' host-specificity and impact on the plants in the laboratory, their subsequent mass-rearing and releases at selected sites and post-release evaluations on their impact on the weed populations in the field. Both programmes, which represented the first biocontrol efforts against aquatic weeds in Senegal, proved highly successful with severe damage inflicted on the weed populations and complete control achieved within a relatively short time span.

A laboratory exclusion experiment with *N. affinis* on *P. stratiotes* showed that in treated tubs, the weevil strongly depressed plant performance as measured by the plant growth parameters: mass, rosette diameter, root length, number of leaves and daughter plants whereas control plants were healthy. Field releases started in September 1994 and water coverage by *P. stratiotes* at Lake Guiers was reduced by 25 % in January 1995 and 50% in April 1995. A general decline of 65% in water coverage by *P. stratiotes* was observed in June 1995 and by August 1995, eight months after releases *P. stratiotes* mats were destroyed. Further, although no releases were made there, good results were obtained within 18 months at Djoudj Park water bodies, located 150 km NW from Lake Guiers indicating the potential of the weevil to disperse long distances. In 2005, *P. stratiotes* reappeared and the weevil *N. affinis* has located and controlled all of these *P. stratiotes* recurrences after new releases.

In 1999, *S. molesta* covered an estimated area of 18 000 ha on the Senegal River Left Bank and tributaries (Senegal) and 7 840 ha on the Senegal River Right Bank (Mauritania). Military and Civil Development Committee (CCMAD) and community volunteers made an effort to control *S. molesta* using physical removal, but this costly and labour-intensive approach was unsustainable. Hence, biological control was adopted by Senegal and Mauritania to manage the

weed. Host range tests to assess feeding by *C. salviniae* on *S. molesta* and non-target plants and carried out on 13 crop species showed that no feeding damage was observed on the latter and weevils only fed on *S. molesta*. Field releases of some 48 953 weevils at 270 sites were made from early January 2002 to August 2002. Within one year, weevils were established and were being recovered up to 50 km from the release sites. In a case study conducted at one of the release sites, the *S. molesta* infestation was reduced from 100% to less than 3% 24 months after release.

These results are discussed in the context of the weeds' negative impact on aquatic systems and riverside communities, and in the involvement of these communities in the programmes.

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## Chapter 1

### General introduction and literature review

#### 1.1. Introduction to invasive alien plant species and why they are so important

In the evolution of the city as a habitat, in the conversion of virgin lands to intensified farming, and in the alteration of watercourses with locks, dams and reservoirs, man is the interloper. As a result of his activities and their by-products, new species and numbers of weeds, rodents, insects, and diseases appear where they could not, or did not exist before (Holm *et al.*, 1969).

One of the most limiting resources to development in Africa is the supply of fresh water and yet it changes as civilization draws near. Its quality usually becomes poorer; it is seldom improved by man. Communities, planned and unplanned, locate on the water's edge to use navigation routes, irrigate land and develop power. As a result, the watercourses are heated, polluted and fertilized; the levels fluctuate, and new biological pests are introduced because of man's commercial undertakings and mobility.

Several "explosions" of aquatic weeds in the great rivers and lakes of the warm regions of the world have forced us to recognize the impact of such infestations. They destroy fisheries, interfere with hydroelectric and irrigation schemes, stop navigation, and bring starvation and disease problems to riverine communities (Holm *et al.*, 1969). Because of the high growth rates of floating aquatic weeds, it has often been proposed that they are a valuable resource. They have been used for mulch, compost, fodder, paper making, handicrafts and biogas generation (Ad Hoc Panel on Utilization of Aquatic Weeds, 1976). Several aquatic macrophytes were used for human food during periods of famine in India in 1877 to 1878, for stock food and have potential for methane production (Holm *et al.*, 1977; Tucker and Debusk, 1981; Ayoade *et al.*, 1982).

Most would agree that excessive aquatic weed growth is unacceptable, but some level of aquatic macrophyte presence is necessary for the health of water bodies. However, it is almost always difficult to reach a consensus on how much macrophyte density is desirable in a given body of water. Agencies charged with aquatic weed management as well as scientists debate this point, often reaching conflicting conclusions (Charudattan, 2001a).

A useful review of the issues involved and how this complex topic may be addressed has been provided by Chambers *et al.* (1999). The primary reason for the divergent views on this aspect

of aquatic weeds is that these plants have beneficial values as well, sometimes even when they are present at nuisance levels. They can add aesthetic value to water resources, are widely used as aquarium and aquascape plants, and can promote waterfowl and fish populations (Joyce, 1990). Some weeds like water hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae), *Typha* spp., and grasses that generate enormous volumes of biomass have been tried as a resource for industrial or handcrafted products, including animal-feed supplements, soil conditioners, composts, paper, biogas, and handicrafts (Virabalin *et al.*, 1993; Pandey and Srivastava, 1996; Anonymous, 2000b). However, these uses require a steady supply of aquatic weeds, and maintenance of supply sources is generally incompatible with the need to control these weeds. Furthermore, utilization invariably results in the spread of the weed to new localities as the resource is passed from one community to the next.

## **1.2. Introduction to aquatic weed problems around the world**

The rapid growth of weed infestations has been both spectacular and frightening, and the publicity devoted to several of these problems in the past decade has made us aware of their severe impacts. Aquatic weeds obstruct water flow, increase evapotranspiration, and prevent proper drainage of land. Aquatic weeds may interfere with navigation, prevent fishing and recreation, depress real estate values, and present health hazards (Holm *et al.*, 1969).

In their highly influential book, “The World’s Worst Weeds: Distribution and biology,” Charudattan (2001a) in citing Holm *et al.* (1977) listed just 10 aquatic weeds, including the three most notorious weeds, water hyacinth *Eichhornia crassipes*, water lettuce *Pistia stratiotes* Linnaeus (Araceae), and *Salvinia auriculata* Aublet (Salviniaceae), later identified as *Salvinia molesta* D.S. Mitchell (Salviniaceae) (water fern, giant salvinia, or the Kariba weed). In the quarter century since this book was published, the number of the world’s worst aquatic weeds has grown to about three dozen (Table 1.1). The impacts of dense mats of these weeds include the reduction in quality and quantity of water for urban, agricultural and industrial use, an increase in siltation of rivers, dams and wetlands, a reduction in water surface area for recreation, clogging of irrigation canals and pumps, drowning of livestock that were unable to differentiate between pasture land and weed-covered water bodies, and severe deterioration of aquatic biodiversity (Hill, 1997; 2003). Increase in insect-borne human diseases is another serious problem. Loss of aesthetic value of waterfront communities due to weed growth is also an important concern. Dead biomass from large weed infestations increases the rates of sedimentation and eutrophication and reduces water depth (Charudattan (2001a).

**Table 1.1:** A list of important aquatic weeds Charudattan (2001a).

Botanical name	Common name	Family	Plant type
<i>Alternanthera philoxeroides</i>	Alligator weed	Amaranthaceae	Mat-forming
<i>Azolla</i> spp.	Azolla, water fern	Azollaceae	Floating
<i>Brachiaria</i> spp.	Signalgrass	Poaceae	Emergent, grass
<i>Ceratophyllum demersum</i>	Coontail	Ceratophyllaceae	Submerged
<i>Chara</i> spp.	Muskgrass	Characeae	Submerged
<i>Crassula helmsii</i>	Australian swamp, Stonecrop	Crassulaceae	Submerged, mat- forming
<i>Eichhornia crassipes</i>	Water hyacinth	Pontederiaceae	Floating
<i>Egeria</i> spp.	Egeria, elodea	Hydrocharitaceae	Submerged
<i>Hydrilla verticillata</i>	Hydrilla	Hydrocharitaceae	Floating
<i>Hydrocotyle</i> spp.	Water pennywort	Apiaceae	Mat-forming
<i>Ipomoea</i> spp.	Water spinach, swamp morning-glory	Convolvulaceae	Emergent, mat-forming, wetland shrub
<i>Lagarosiphon major</i>	Lagarosiphon	Hydrocharitaceae	Submerged
<i>Lemna</i> spp.	Duckweed	Lemnaceae	Floating
<i>Ludwigia</i> spp.	Water primrose, primrose willow	Onagraceae	Emergent
<i>Monochoria</i> spp.	Monochoria	Pontederiaceae	Emergent
<i>Lythrum salicaria</i>	Purple loosestrife	Lythraceae	Emergent
<i>Melaleuca quinquenervia</i>	Melaleuca, paper-bark	Myrtaceae	Wetland tree
<i>Myriophyllum</i> spp.	Parrot's feather, Eurasian water milfoil	Haloragaceae	Emergent, mat-forming, Submerged
<i>Nitella</i> spp.	Nitella, stonewort	Characeae	Submerged
<i>Nuphar luteum</i> , <i>Nymphaea</i> spp.	Water lilies	Nymphaea	Emergent
<i>Panicum repens</i>	Torpedo grass	Poaceae	Mat-forming, grass
<i>Paspalum</i> spp.	Paspalum	Poaceae	Mat-forming, grass
<i>Phragmites</i> spp.	Reed	Poaceae	Emergent
<i>Pistia stratiotes</i>	Water lettuce	Araceae	Floating
<i>Polygonum</i> spp.	Smartweed, knotweed	Polygonaceae	Emergent
<i>Potamogeton</i> spp.	Pondweed	Potamogetonaceae	Submerged
<i>Sagittaria</i> spp.	Arrowhead, duck potato	Alismataceae	Emergent
<i>Salvinia molesta</i>	Giant salvinia, Kariba weed	Salviniaceae	Floating weed
<i>Scirpus</i> spp.	Bulrush	Cyperaceae	Emergent
<i>Spartina</i> spp.	Cord grass, marsh grass	Poaceae	Emergent, grass
<i>Sphenoclea zeylanica</i>	Gooseweed	Sphenocleaceae	Emergent
<i>Spirodela polyrhiza</i>	Giant duckweed	Lemnaceae	Floating
<i>Typha</i> spp.	Cattail	Typhaceae	Emergent
<i>Utricularia</i> spp.	Bladderwort	Lentibulariaceae	Submerged
<i>Vallisneria</i> spp.	Eelgrass, tape grass	Hydrocharitaceae	Submerged
<i>Vossia cuspidata</i>	Hippo grass	Poaceae	Emergent, grass

Aquatic weeds cost millions of dollars in lost revenues and control cost. The direct and indirect cost in human suffering in less affluent nations and subsistence communities is immeasurable in monetary terms (Charudattan, 2001a). Hill (2003) citing Schmitz *et al.* (1993) reported that one of the most recent estimates available claims that some US \$ 43 million were spent on the control of water weeds in the state of Florida (USA) between 1980 and 1991. The invasion of rivers, dams and lakes throughout Africa by introduced aquatic vegetation represents one of the

largest threats to the socioeconomic development of the continent (Cilliers *et al.* 2003). This is because the majority of African countries do not have the financial means to attempt to combat these invasions that first world countries do.

### **1.3. Why aquatic macrophytes become invasive**

#### **1.3.1. Non-indigenous vs. native species**

With increasing global trade and rapid transport, non-indigenous, invasive weeds are emerging as a major concern in many parts of the world. According to Simberloff *et al.* (1997), an estimated 5,000 introduced plant species have escaped and now exist in natural ecosystems in America. They compared with about 17,000 native species. While many of the world's worst aquatic weeds are introduced species, native species have also become problematic in some parts of the world, prompting the frequently asked question: "how do native species become problematic in their own native habitats where they are expected to be under control by indigenous, co-evolved natural enemies and plant competition?" The answer lies in the fact that water is a dynamic and unstable medium and most aquatic plants are genetically programmed to multiply and fill an available niche when conditions become favourable (Charudattan, 2001a). Indeed most aquatic plants would be regarded as r-selected species. This can be seen as a recurrent theme in many countries where old man-made reservoirs or an increase in eutrophication due to anthropogenic causes have triggered sudden increases in populations of native aquatic plants to problematic levels (Charudattan, 2001a). The present situation in several Brazilian hydropower reservoirs, affected by *Egeria densa* Planch (Hydrocharitaceae), is a good example (Nachtigal and Pitelli, 2000). According to Charudattan (2001a), generally, when native plants become problematic [e.g., *Typha* spp. (Typhaceae), *Phragmites* spp. (Poaceae), *Pondetaria cordata* L. (Pontederiaceae), and others], the potential for conflicts of interest increases. Some of these plants may be viewed as economically beneficial by some while as a nuisance by others.

#### **1.3.2. Water bodies' eutrophication and lack of natural enemies**

The native range of the most important aquatic weed species is South America and several have been introduced to many parts of the world where they have become problematic, especially in tropical and subtropical regions (Holm *et al.* 1977). Two issues contribute to their invasiveness: the lack of co-evolved natural enemies in their adventive range (Buckingham, 1994) and the presence of nitrate- and phosphate-enriched waters, associated with urban, agricultural and industrial pollution (Heard and Winterton, 2000). In the case of water hyacinth

in South Africa, Hill and Olckers (2001) reported that many of the rivers and dams receive runoff which is highly polluted with nitrates and phosphates arising from agricultural activities. Therefore, the eutrophic waters enhance the growth of water hyacinth and other aquatic plant species, both native and introduced, to such a degree that aquatic weed problems should be regarded as a symptom of eutrophication.

#### **1.4. What control options are available for aquatic weeds?**

Simply put, aquatic weeds are manageable, but at a considerable cost and coordination of efforts. The challenge is to control the aquatic weeds 1) in a cost-effective manner that society can afford, 2) by using the most effective and safe methods available, 3) causing minimal side-effects, 4) with public acceptance of the control practices, and 5) in a sustainable manner that reduces recurrent costs and promotes environmental balance (Charudattan, 2001a). In reality, the problems posed by aquatic weeds are aggravated in many parts of the world (e.g., African countries, Brazil, and others (Charudattan *et al.*, 1995; Fernandez, 2000; Marcondes *et al.*, 2000; Pitelli, 2000; Thomaz, 2000). This is largely due to the limited number of effective tools available for control, governmental restrictions on the use of chemical herbicides, emergence of several native and non-indigenous weeds as new weed problems, and increasing and recurrent cost of aquatic weed control. Agencies charged with aquatic weed management are required to consider the environmental and human consequences of control methods, their cost-effectiveness, and societal affordability (Charudattan, 2001a).

Manual removal and mechanical control by various types of mechanical harvesters and physical control by the use of shading devices such as shade films and water-level fluctuations; chemical control by using herbicides; and biological control are the principal methods of weed control used.

##### **1.4.1. Chemical control**

Chemical herbicides enable control of aquatic weeds quickly and efficiently, although temporarily. Nonetheless, chemical control is the predominant and dependable means of aquatic weed management. The present generation of aquatic herbicides is generally safe when used according to the labelled directions (Charudattan, 2001a). The herbicides most commonly used are 2,4-D amine (2,4-dichlorophenoxy acetic acid), copper, diquat, glyphosate, fluridone, and endothall (Howard and Harley, 1998; Charudattan, 2001a).

Several negative features of chemical control must be considered in decisions to use this method of control. The cost of controlling some weeds, especially to poor or small communities or less-affluent countries, could be discouraging. Although, some weeds can be chemically managed to keep lakes and ponds weed-free for several months or even years, regrowth of the weeds is a common problem (Charudattan, 2001a). There is also an environmental cost in using herbicides. Residues of herbicide in the water and sediments may affect the aquatic environment and kill fish directly or by reduced levels of dissolved oxygen caused by decaying weed. If residues are excessive the water will be unsuitable for human consumption or irrigation (Anon, 1985). Man is becoming more aware of the effects of pollution on the environment, man himself and his livestock. Many communities will no longer tolerate contamination of their environment by pesticides (Harley, 1993).

Another serious issue is the potential shrinking of the already short list of herbicides registered for aquatic use. Presently, a critical issue facing aquatic weed control is the extremely limited choice of herbicides. A reason for this paucity of chemical herbicides for aquatic weed control is said to be due to the relative high cost of development and registration of new products estimated to be around \$15 to 30 million. The aquatic weed market is relatively small (\$ 20-25 million/year) compared to typical markets for major crops such as corn (*Zea mays*; \$ 1 billion/year) (Haller, 1998).

#### **1.4.2. Physical control**

Physical control includes manual and mechanical removal and the use of floating diversion booms. The dense mats of aquatic weed are often composed of large interwoven plants that are difficult to separate. Generally the plants are more than 90% water, mats weigh up to 500 tons per ha and surface area can double in a few days. Manual removal to cut mats into pieces and drag them to the bank is extremely arduous, and even where manpower is plentiful and cheap, it is effective only for small areas (Howard and Harley, 1998). Booms are useful for diverting mobile mats, protecting infrastructure, maintaining shoreline access to water and boat access to landings. However, booms must be cleared at frequent intervals to prevent breakage from the weight of accumulated plants (Goodland, 1995).

Physical removal has obvious limitations of scale and reinfestation is certain to occur from plant fragments and seeds. It is environmentally “safe” and is an useful method for reducing small infestations and for maintaining canals. However, sometimes physical removal can be

quite damaging and non-selective. If physical removal is the only method employed for control of an infestation then the commitment of resources is never ending (Harley, 1993).

### **1.4.3. Biological control**

Biological control is the use of host-specific natural enemies to reduce the population density of a pest (Howard and Harley, 1998). Biological control can be an economically sustainable, environmentally safe, long-term option to manage certain targeted aquatic weeds in multi-use waters. Invasive aquatic weeds that colonize vast areas of water bodies in monotypic stands are ideal targets for biological control. However, biological control is not meant to eradicate a target weed, but merely suppress the weed populations substantially below an economically or ecologically determined threshold, allowing native species to return (Charudattan, 2001a). Two forms of biological control are practiced: 1) introduction of non-native organisms that function in a self-maintaining, host-density dependent manner with their target weeds (the classical or inoculative biocontrol strategy) and 2) augmentation or manipulation of indigenous organisms that, with human intervention, can be made to incite weed-suppression (the augmentative, inundative, or bio-herbicide strategy). In both cases, the objective is to use organisms that can significantly curtail the growth and reproduction of the target weeds without adversely affecting non-target organisms (Charudattan, 2001a).

### **1.4.4. Integrated invasive aquatic plant management**

Integrated control is the use of physical, chemical, and biological methods of control as components of an overall management strategy. As there is considerable variation in the factors determining the status of infestations of aquatic weeds, and in the uses to which the water is put, management strategies should be tailored to particular situations. The emphasis on each of the three components will vary from situation to situation and over time (Harley, 1993). Ideally, the management strategy will avoid mutual interference between different control methods, while maximising use of the water for boat transportation, irrigation, fishing, etc. Strategies for management of water hyacinth, salvinia and water lettuce should have as their long term, cost effective objective, the phasing out of physical and chemical control and total reliance on biological control (Harley, 1993).

The development of effective properly integrated management strategies for floating aquatic weeds is a very complex task demanding an extensive knowledge of weed biology, ecology, and management techniques. The requisite information is not readily available but the application of expert system technology to this problem should give us an interactive, user-

friendly computer program which can be used by aquatic weed control managers across Africa (Harley, 1993).

Several key elements should be included in any long – term aquatic weed management programme. It has been said that aquatic weed control, by necessity, should be local, but the management policies and administration should be coordinated and applied on a broad region-basis (Mitchell, 1996). Cooperation and coordination of efforts by several governmental and private agencies and the public are required to ensure success. Aquatic weeds do not recognize political boundaries, and control efforts mounted in one region may be thwarted if there is a steady influx of weeds and weed propagules from neighbouring areas. Although many countries have laws and regulations to prevent unauthorized introductions of invasive species including plants, new weed invasions do occur at regular frequency. Therefore, preventing establishment and reestablishment of weeds before they reach problematic levels should be a standard operating procedure, and early and timely intervention rather than a belated reaction should be part of this standard. A technical corps trained in the latest weed control techniques should be on hand, and experience should be drawn from prior research conducted in other regions of the world in designing action plans. It may be expedient to adopt successful models of weed control programmes from elsewhere rather than invest in all new indigenous programmes (Charudattan, 2001b). Known ecological impacts of weeds and control methods gathered from other regions should be taken into consideration in assessing the potential local impacts of control methods (Stocker, 2000).

Since prevalence of aquatic weeds is associated in most cases with human activities, such as creation of large reservoirs or irrigation canals, the public's interests must be fully factored in any control operations. In situations where nutrient influx is the primary cause of water-quality deterioration, attempts should be made to stop or mitigate the influx of nutrients, especially phosphorus. The public must also be educated in ways to monitor, preserve, and protect water bodies and assured a sense of ownership of their water resources (Charudattan, 2001b).

According to Charudattan (2001b) the Florida Lakewatch programme in the USA and the Working for Water Programme in South Africa are two good models of public stakeholder involvement in monitoring and protecting water resources from various threats including aquatic weeds.

Control strategies should include all appropriate and effective methods of control. Biological control should be the centrepiece of management programmes for non-native invasive species

and its integration with other applicable techniques should be achieved in a manner that maximizes the effectiveness and benefits (Charudattan, 2001b).

### **1.5. An overview of biological control of water weeds worldwide and more specifically Africa**

The invasive aquatic weeds can form dense mats. Hill (2003) in citing Buckingham (1994) and Heard and Winterton (2000) reported that two issues contribute to the invasiveness of aquatic plants: the lack of co-evolved natural enemies in their adventive range and the presence of nitrate-and phosphate-enriched waters, associated with urban, agricultural and industrial pollution. The invasive aquatic weeds are known to affect water resource management, the continued existence of human riverine and wetland communities, and conservation of biodiversity. Spread between continents and watersheds is largely the result of human activities. Dispersal within a watershed is mostly via floating propagules (Howard and Harley, 1998). Often the explosive growth of aquatic weeds in tropical countries is caused by human interference with their habitat, by the introduction of an invasive exotic plant or by a combination of both (Pieterse, 1990). Forno and Julien (2000) expanded Pieterse's (1990) definition, that plants growing in aquatic habitats can be considered weeds when they interfere with human use of water bodies, to include interfering with the use of water by native fauna and aquatic flora.

Water weeds have invaded many lake and river systems in Africa with severe consequences (Hill, 2003). The status of the distribution and impact of aquatic weeds in Africa and their control has been well reviewed in the proceedings of four workshops, one held in Zimbabwe in 1991 (Greathead and de Groot, 1993); a second one also in Zimbabwe (Hill *et al.*, 1998); a third workshop in Nairobi in 1997 (Navarro and Phiri, 2000) and the fourth in Beijing/China (Julien *et al.*, 2001). Currently there are five aquatic weeds that are especially problematic in Africa: water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae); red water fern, *Azolla filiculoides* Lam. (Azollaceae); water lettuce, *Pistia stratiotes* L. (Araceae); parrot's feather, *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae); and floating fern, *Salvinia molesta* Mitchell (Salviniaceae) (Cilliers *et al.*, 2003). All are free-floating macrophytes are native to South America. The exact date and mode of introduction of these plants in some countries is obscure, but water hyacinth has been present in Africa since the late 1800s, while water lettuce was used as a medicinal plant in ancient Egypt (Holm *et al.*, 1977). In recent times these plants were sought after ornamentals, which would have aided their

dispersal to new areas. In the absence of natural enemies and the presence of nutrient-enriched waters, these aquatic weeds have proliferated and become problematic. Some aquatic weeds have been successfully or partially managed by biological control around the world (Table 1.2).

**Table 1.2.** Notable examples of aquatic weeds managed fully or partially by biological control agents. Data modified from Charudattan (2001a).

Weed	Agent(s) most responsible for success	Country (-ies) where most successful <sup>a</sup>
<i>Alternanthera philoxeroides</i>	<i>Agasicles hygrophila</i> (beetle)	Australia, USA
<i>Eichhornia crassipes</i>	<i>Neochetina eichhorniae</i> and <i>N. bruchi</i> (weevils)	Australia, Benin, India, , Kenya Thailand, Uganda, USA, Sudan, Zimbabwe
<i>Lythrum salicaria</i>	<i>Galerucella californiensis</i> and <i>G. pusilla</i> (beetles)	Canada, USA
<i>Pistia stratiotes</i>	<i>Neohydronomus affinis</i> (weevil)	Australia ,Benin, Congo, Côte d'Ivoire, Senegal, South Africa, Zambia, Zimbabwe
<i>Salvinia molesta</i>	<i>Cyrtobagous salviniae</i> (weevil)	Australia, Congo, Côte d'Ivoire, Fiji, Ghana, India, Kenya, Namibia, Papua New Guinea, Senegal, South Africa, Sri Lanka, Zambia
Several submerged weeds	<i>Ctenopharyngodon idella</i> (fish, carp)	USA, several countries in Europe, the Middle East, and Asia

<sup>a</sup> "Success" represents a general recognition that the weed is no longer a major problem.

The water weeds *Pistia stratiotes* and *Salvinia molesta* are the focus of this thesis. So far they are the invasive aquatic weeds that have spectacularly infested the main Senegalese water bodies: the Senegal River and the Lake Guiers.

## 1.6. Review of *Pistia stratiotes* and *Salvinia molesta*

### 1.6.1. Water lettuce (*Pistia stratiotes*)

#### 1.6.1.1. Origin and distribution of *Pistia stratiotes*

The area of origin of water lettuce, *Pistia stratiotes* Linnaeus (Araceae) is still speculative, being most probably South American (Cordo *et al.*, 1981), as most of its insect natural enemies are on record from this area (Bennett, 1975). South America hosts at least thirteen specialist

phytophagous insects (Dray and Center, 1993) and at least two mosquitoes that are ovipositional specialists (Lounibos *et al.*, 1990), which suggests a lengthy tenure on that continent (Bennett, 1975).

Water lettuce is one of the most widely distributed of all floating macrophytes occurring in all continents, except Antarctica, being now widespread throughout the tropics and subtropics (Holm *et al.* 1977). Probably, the initial spread took place through ballast water in ships from South America (Labrada and Fornasari, 2002).

Water lettuce is widespread in tropical Africa and reported as troublesome in the Upper Nile, Zambia, Kenya, Zimbabwe and the littoral regions of Angola and Mozambique. In South Africa, it is recorded almost entirely in the subtropical regions (Henderson and Cilliers, 1991), and it has been reported in West Africa: Benin, Côte d'Ivoire, Nigeria and Senegal (Ajuonu and Neuenschwander, 2003). The weed is common on many waters in West Africa (Pettet and Pettet, 1970). However, most botanists and researchers consider it foreign to Africa. The possibility that it is indigenous in numerous areas is enhanced by its ancient medicinal use. Although exotic aquatic weeds have been reported to be present in Africa since the end of the nineteenth century (Tackholm and Drar, 1950), they started infesting African freshwater bodies during the early 1950s (Mitchell *et al.*, 1990) and rapidly spread in many countries. The growth of invasive aquatic weeds like water lettuce is extremely fast and this allows them to develop huge infestations in areas where they had not been reported only a few years earlier (Labrada and Fornasari, 2002).

#### **1.6.1.2. Taxonomy, morphology and biology of *Pistia stratiotes***

Water lettuce is a perennial herb in the aroid family (Araceae), a monotypic genus in the subfamily Aroideae (Grayum, 1990). Water lettuce is the only species in the genus *Pistia* and it is not likely to be confused with any other species. There are several indigenous species in the same family, including arum lily flowers, but all are terrestrial herbaceous plants with tuberous roots (Henderson and Cilliers, 1991). Water lettuce plants consist of a rosette of leaves with a tuft of long, numerous fibrous roots, resembling floating lettuces. The leaves which range from 2 to 35 cm long are pale yellow-green, closely overlapping, ribbed, with many longitudinal veins radiating from the base, and softly hairy on both surfaces (Henderson and Cilliers, 2002). The rosettes occur singly or in groups connected by short stolons. The flowers are inconspicuous pale green spathes near the center of the rosette. Each spathe is constricted near the middle, with a whorl of male flowers above and a single female flower below the

constriction. Fruits are many-seeded green berries, and the mature seed coat is thick, golden-brown, and wrinkled (Dray and Center, 2002).

The plant reproduces vegetatively through the formation of stolons and daughter plants (Forno and Julien 2000). The role of sexual reproduction is considered less important than that of vegetative reproduction, although seed germination is an important factor in the dynamics of water lettuce populations (Dray and Center, 1989). *P. stratiotes* reportedly does not produce fruits and seeds in the United States (Dray and Center, 1989). However, seed production occurs in Africa (Holm *et al.*, 1977), India (Mitra, 1966), South America (Da Silva, 1981), and South-East Asia (Bua-ngam and Mercado, 1975). Water lettuce seeds can remain dormant for months, withstand freezing and drought, and still germinate when favourable conditions become prevalent (Pieterse *et al.*, 1981). Studies in Philippine rice fields (Bua-ngam and Mercado, 1975) indicate that seed production plays an important role in the re-establishing of populations after catastrophic destruction. This evidence has important implications for aquatic weed management schemes. Herbicide application is very effective at eliminating infestations, particularly in waterways closed to re-introduction of the weed from other areas. However, viable seeds on benthic sediments will germinate under favourable conditions. These seedlings provide an initial stock which, through vegetative propagation, will reinfest a water body (Dray and Center, 1989).

#### **1.6.1.3. Utilization of *Pistia stratiotes***

Water lettuce has been known in Egypt since the time of Pliny (77 A.D; quoted in Henderson and Cilliers, 1991) who records its use in healing wounds and erysipelas which is a form of cellulitis, a bacterial infection affecting the most superficial layers of the skin. It particularly affects infants and the elderly, but can affect any age group. In Nigeria, Obot and Ayeni (1987) reported that water lettuce is used as part of a concoction for the treatment of influenza. Also, Kio & Ola-Adams (1990) revealed that the plant is used for ulcerative conditions of the mouth and tongue ([www.fao.org/DOCREP/005/T3660E/T3660E02.htm](http://www.fao.org/DOCREP/005/T3660E/T3660E02.htm)). In a study undertaken by Jamil (1999) on some species of the aquatic macrophytes, *P. stratiotes* and *E. crassipes* had a tremendous capacity to remove metal ions from the aquatic environments. Where it is legal to use water lettuce, the plant is a popular ornamental plant, used in effective low growing floating evergreen accent for outdoor pools, ponds and aquariums or indoors in high light conservatory pools (Arnold, 2005). However, according to Howard and Harley (1998) the most

optimistic evaluation of aquatic weeds utilization is miniscule compared with the damage and economic losses that they cause.

#### **1.6.1.4. Negative impact of *Pistia stratiotes***

Water lettuce is a major weed problem in the tropics, where its impact is similar to that of water hyacinth, both on the environment and on the economy of the countries concerned. However, it was not a weed problem in Africa until recently and its weed status appears to be due to the pollution of water bodies and the presence of organic wastes and residues of fertilizers (Labrada and Fornasari, 2002).

*Pistia stratiotes* develops dense mats and its noxious effects include (a) causing an enormous water loss through evapotranspiration, with the consequent negative impact on the water balance in entire regions; (b) clogging rivers and canals; (c) interfering with the activity of hydroelectric power stations (Napompeth, 1990); (d) hampering fishing (Howard and Harley, 1998; Dray and Center, 2002) ; (e) hampering navigation; (f) negatively affecting water control and use for agricultural purposes; (g) displacing of native species, because of the modification of the environmental conditions: mainly due to oxygen depletion in water and sediments, increased sedimentation caused by the roots and excessive shading of the leaves (Labrada and Fornasari, 2002).

It is of equal concern that the plant serves as a habitat for several species of mosquitoes which in turn serve as principal vectors of malaria. The *Anopheles* mosquito, which carries the parasite responsible for malaria, is frequently associated with *P. stratiotes* because the aquatic weed provides suitable shelter and breeding sites and prevents spraying (Dunn, 1934; Bennett, 1975; Holm *et al.*, 1977; Lounibos and Dewald, 1989; Lounibos *et al.*, 1990).

In Florida, water lettuce infests about 1000 hectares of public waterways (after control operations), and a large, but uncounted number of hectares of irrigation and flood control canals (Schardt, 1992). Based on the annual costs associated with controlling water lettuce on at least 4000 hectares of public waterways (Schardt, 1992; Center, 1994), it is reasonable to estimate that total expenditures exceed US \$ 1 million annually in Florida. Other states in the eastern United States spend a combined total of less than US \$ 100,000 per year on water lettuce control (Dray and Center, 2002).

### **1.6.1.5. Control methods for *Pistia stratiotes***

#### **1.6.1.5.1. Chemical control of *Pistia stratiotes***

A number of chemicals are effective against water lettuce (Moody and Awoyomi, 1975; Miller and Pickering, 1979; Madin, 1984; Rosemond *et al.*, 1984; Sharma, 1985; Thayer and Haller, 1985). In South Africa, the only registered herbicide is terbutryn although glyphosate has been used successfully. In small impoundments which are regularly subjected to alternate wet and dry regimes, herbicide control was used to deplete the seed bank as soon as seedlings reappeared after a dry spell. However, this proved impractical, as water lettuce infestations often escaped detection until after the plants had set seed (Cilliers *et al.*, 1996).

#### **1.6.1.5.2. Physical control of *Pistia stratiotes***

The first effort to control aquatic weeds was with hand tools. This method is useful for short term control but regrowth is rapid and it must be repeated again and again. Mechanical control is impractical due to the plant's rapid growth rate (Cilliers *et al.*, 2003).

#### **1.6.1.5.3. Biological control of *Pistia stratiotes***

##### **1.6.1.5.3.1. Introduction**

There are a number of phytophagous species associated with water lettuce around the world. Dray and Center (1993) and Center (1994) discuss the herbivorous entomofauna reported from *P. stratiotes* worldwide. Among the species known or suspected to be plant-feeders, 44 include water lettuce in their diets at least occasionally. The Neotropics harbour 21 water lettuce-feeding insects, including at least 14 species of weevils – many of which are known only from this plant. Natural enemies have seldom been reported from Africa despite the presence of water lettuce there for several millennia (Stoddard, 1989). However, five water lettuce herbivores have been reported from Africa, including a weevil (*Bagous pistiae* Marshall) known exclusively from *P. stratiotes* (Dray and Center, 2002). There are several other likely host-specific weevil species in South America and Asia; however, at present around the world, *Neohydronomus affinis* appears to be highly destructive and adequate to successfully control *Pistia stratiotes* in most situations, without the need for further biocontrol agents (Dray and Center, 1993).

*Pistia stratiotes* has been successfully controlled by the weevil, *Neohydronomus affinis* Hustache (Coleoptera: Curculionidae) previously referred to as *N. pulchellus* (Thompson and Habeck 1989) in Australia (Harley *et al.*, 1984, 1990), Congo (Mbatia and Neuenschwander, 2005) South Africa (Cilliers 1987), and Zimbabwe (Chikwenhere and Forno 1991) (Table 1.3).

Also, *P. stratiotes* is reported to be under variable levels of biological control at many sites by two arthropods *N. affinis* and *Spodoptera pectinicornis* (Hampson) (Lepidoptera: Noctuidae) in Ghana, Papua New Guinea, USA, and Zambia (Julien and Griffiths, 1998).

**Table 1.3.** African countries where the natural enemy *Neohydronomus affinis* has been released on water lettuce<sup>a</sup>

Country	Release date	Impact
Benin	1995	Very effective control
Botswana	1987	Very effective control
Congo <sup>b</sup>	1999	Effective control
Côte d'Ivoire	1996	Very successful control
Ghana	1996	Good control in all locations
Nigeria	Not determined	Unknown
South Africa	1985	Effective control
Senegal <sup>c</sup>	1994	Very successful control within 8 months
Togo	Not determined	Unknown
Zambia	1991	Excellent control
Zimbabwe	1988	Successful control within 14 months

<sup>a</sup> Modified from Julien and Griffiths, 1998.

<sup>b</sup> Mbatia and Neuenschwander, 2005.

<sup>c</sup> Anonymous, 2000a.

#### 1.6.1.5.3.2. The natural enemy *Neohydronomus affinis*

Adult *N. affinis* are small (3mm long) and have a nearly straight rostrum that is strongly constricted ventrally at the base. *Neohydronomus affinis* ranges in colour from uniform bluish grey to reddish brown (depending on age) with a tan, chevron like band across the elytra. The colour pattern is associated with scales and may be difficult to distinguish if they are wet, dirty, or missing (Center *et al.*, 2002).

Eggs are cream coloured and sub spherical (0.33mm by 0.40 mm). Females chew a hole of about 0.5 mm diameter in the water lettuce leaf (usually the upper surface near the leaf edge), deposit a single egg inside this puncture, and close the hole with black frass. The eggs usually hatch within 4 days (at temperatures above 24°C). The young larvae, which are very small (head capsule width of 0.2 mm), burrow under the epidermis and work their way toward the spongy portions of the leaf at a rate of about 1.5-2.0 cm/day (Center *et al.*, 2002).

The first moult occurs when larvae are about 3 days old and the second, 3-4 days later. Second-instar larvae have head capsules 0.25-0.27 mm in diameter; third-instar larvae are 2.5-3.0 mm

long and have head capsules 0.32-0.37 mm in diameter. The larval stages last 11-14 days in total (Center *et al.*, 2002). Third instars are generally found excavating the spongy portions of the leaf where they moult to become naked pupae. Under optimum temperatures, 4-6 weeks are generally required for *N. affinis* to complete the transition from egg to adult (Dray and Center, 2002).

Larval mines are often plainly visible in the outer third of the leaf where tissues are thin, but are less apparent in the central and basal portions of the leaf (Dray and Center, 2002).

Adult weevils chew small holes (about 1.4 mm in diameter) into and through the leaves. The larvae tunnel inside the leaves. This feeding and tunnelling allows water to enter the air filled cells, which leads to water logging and sinking of the plants. The weevils and larvae are temperature dependant, thus it takes longer to effect control in cooler than in warmer areas (Center *et al.*, 2002; Cilliers and Mabulu, 2003).

## **1.6.2. Floating fern (*Salvinia molesta*)**

### **1.6.2.1. Origin and distribution of *Salvinia molesta***

The native range of water fern, *Salvinia molesta* D.S. Mitchell includes a relatively small area (20 000 km<sup>2</sup>) in southeastern Brazil, including the states of Sao Paulo, Parana, Santa Catarina and Rio Grande do Sul (Forno and Harley, 1979). *S. molesta* first became established outside its native range in 1939 in Sri Lanka, via the University of Colombo, Botany Department (Williams, 1956; Room, 1990). It continued to be spread by man to other warm regions of the world in the following decades (Olivier, 1993). It has become established in India (Cook, 1976), Australia (Room and Thomas, 1985; Room, 1990; Creagh, 1992), Papua New Guinea (Mitchell, 1979), Indonesia and Malaysia (Baki *et al.*, 1990); Fiji and New Zealand (Considine, 1985; Farrell, 1978; Holm *et al.*, 1979; Mercado *et al.*, 1974). It was first reported outside of cultivation in the United States in 1995 at a pond in southeastern South Carolina (Johnson, 1995). It has been reported in Madagascar (Room and Julien, 1995), from the Caribbean: Cuba and Trinidad, from South America: Columbia and Guyana (Holm *et al.*, 1979); Africa: South Africa (Cilliers, 1991), Botswana, Kenya, and Zambia (Mitchell and Tur, 1975); Namibia (Forno and Smith, 1999); Côte d'Ivoire, Ghana, Mauritania and Senegal (Labrada and Fornasari, 2002).

*Salvinia molesta* may have been the largest single giant clone with no genetic variability in existence during the early 1980s, when it covered more than 2000 km<sup>2</sup> and weighed more than

20 million tonnes, (Room, 1990). It occurs in natural lagoons, artificial dams, swamps, drainage canals, and along margins of rivers (Forno and Harley, 1979).

#### **1.6.2.2. Taxonomy, morphology and biology of *Salvinia molesta***

The aquatic fern family Salviniaceae is placed within the order Hydropteridales and consists of a single genus, *Salvinia*.

*Salvinia molesta* is a free-floating aquatic fern with a horizontal rhizome just beneath the water surface (Bonnet, 1955; Room, 1983), and each plant is a colony of ramets. Each ramet comprises an internode, a node, a pair of floating leaves, the submerged ‘root’, and associated buds. Each node bears a series of up to three axillary buds that develop successively under normal growing conditions (Room, 1988), and up to six in response to damage (Julien and Bourne, 1986). The ‘root’ is a modified leaf that looks and functions like a root (Croxdale, 1978; 1979; 1981). There is considerable phenotypic variation in the size of ramets, shape of leaves and amount of branching in response to nutrient availability, crowding and damage (Room, 1990). *Salvinia molesta* possesses three different phenotypes or growth stages (Mitchell and Tur, 1975; Ashton and Mitchell, 1989).

The *primary form* occurs as isolated plants in the initial ‘invading’ stage of an infestation. This form has small, oval leaves less than 15 mm wide that lie flat on the water surface.

The *secondary form* occurs when plants have been growing over open water for some time, either freely or on the edge of stable mats. Internodes are longer, with larger, boat-shaped (slightly keeled) leaves that have rounded apices and are variable in size, between 20 mm and 50 mm wide. The entire lower leaf is in contact with the water.

The *tertiary form* occurs when plants are growing in crowded mat conditions associated with mature infestations. Internodes are short with large heart shaped, or oblong and deeply keeled leaves up to 60 mm in width when fully opened.

*Salvinia molesta* is sterile and appears to be genetically uniform. In contrast to evidence of somatic mutations in many other plants (Whitham and Slobodchikoff, 1981); no morphological differences have been found between materials from different countries grown under standard conditions, and there is no evidence of herbivores distinguishing between different populations of the plant (Room, 1990). *Salvinia molesta* is pentaploid, and has a chromosome number of 45 (Loyal and Grewal, 1966). *Salvinia molesta* is not known to reproduce by spores as with other

ferns. It reproduces vegetatively, that is, new plants develop as fragments break off from mature individuals (Mitchell and Harley, 1981). It appears unable to reproduce sexually (Mitchell and Gopal, 1991) and does not produce viable spores. It exhibits anomalies at meiosis which prevent production of fertile haploid gametes. The fact that the plant is asexual and perennial means that the millions of tonnes of the plant worldwide may be clones of a single genetic individual (Werner, 1988; Barrett, 1989).

*Salvinia molesta* spreads at a rapid rate by vegetative reproduction. When the plant is introduced to new habitats, it produces the colonizing stage plants which have thin stems and fragment easily, thus further producing new plants. As plant density becomes greater, larger mature plants are formed which produce tight, intertwined mats (Werner, 1988; Barrett, 1989).

#### **1.6.2.3. Utilization of *Salvinia molesta***

The multitude of economic, health and environmental costs due to *S. molesta* far outweigh any economic value that it possesses. These values include utilization as a compost and mulch, and in Asia, supplementation to regular livestock fodder (Thomas and Room, 1986). However, *S. molesta* is not suitable as a sole source for fodder because high contents of crude ash, lignin, and tannins reduce digestibility (Moozhiyil and Pallauf, 1986).

#### **1.6.2.4. Negative impact of *Salvinia molesta***

*Salvinia molesta*, also known as Kariba weed after its spectacular invasion of Lake Kariba in 1959, is one of the most troublesome aquatic weeds in the tropical and subtropical regions of the world (Henderson and Cilliers, 2002). The ability to grow very quickly and blanket water bodies makes *S. molesta* a highly aggressive and competitive species (Olivier, 1993). In the backwaters, canals, and rice paddies of Kerala, India, *S. molesta* successfully competes with and even replaces water lettuce (Kammathy, 1968). The larger leaf area corresponds to a greater light absorptive area and is a factor in the success of salvinia as a troublesome aquatic plant. Doubling times of leaves of 3.4 days have been recorded in sterile culture, and 8.1 days in Lake Kariba (Mitchell, 1979; Gaudet, 1973). In greenhouse studies, a leaf doubling time as low as 2.2 days has been reported (Cary and Weerts, 1983).

Initially, *S. molesta* forms a single layer over water, but with continued growth the mats become multi-layered and can reach up to 1 m in thickness (Thomas and Room, 1986). Thick mats support other colonizing plants, and the high biomass and stability of such mats make them difficult to dislodge and destroy (Storrs and Julien, 1996).

As with other aquatic weeds, mats of *S. molesta* impede access to and use of waterways for commercial and recreational purposes and degrade waterside aesthetics. The weed can clog water intakes and interfere with agricultural irrigation, water supply, and generation of electricity. It provides habitats for vectors of human disease with socio economic impacts. In developing countries, the impact of *S. molesta* can be devastating because weed mats block the use of waterways for transportation, cutting off access to important services and farms lands (Julien *et al.* 2002, Mbatia and Neuenschwander, 2005). *Salvinia molesta* mats can very significantly impact communities dependent on fish for local consumption (sometimes as the main source of protein) or in areas where fish sales are the main source of cash income (Bennett, 1966; Thomas and Room, 1986). It is also a weed of paddy rice that reduces production by competing for water, nutrients and space (Anonymous, 1987).

Through high growth rates and slow decomposition rates, *S. molesta* reduces the concentration of nutrients that would otherwise be available to primary producers and organisms that depend on them (Sharma and Goel, 1986; Storrs and Julien, 1996). Water under mats of *S. molesta* has a lower oxygen concentration (due to reduced surface area of water available for oxygenation, inhibition of photosynthesis by submerged plants, and consumption of dissolved oxygen by decaying *S. molesta*), higher carbon dioxide and hydrogen sulphide concentrations, lower pH, and higher temperatures than in open water (Mitchell, 1978; Thomas and Room, 1986).

#### **1.6.2.5. Control methods for *Salvinia molesta***

##### **1.6.2.5.1. Chemical control of *Salvinia molesta***

The cage-like arrangement of bristles on the upper surface of salvinia fronds forms a waterproof barrier to herbicides (Hattingh, 1961). In order to breach this barrier with contact herbicides, it is necessary to use a wetting agent (Oliver, 1993). Control with herbicides such as diquat, 2,4-dichlorophenoxy acetic acid (2,4-D amine), and glyphosate can be appropriate if the aim is to eradicate salvinia from small to medium-sized water bodies which have little or no fringing vegetation such as reeds amongst which salvinia can escape detection and treatment. Use of herbicides is generally not practical or economical on large lakes because under average tropical conditions, if more than half the infestation cannot be sprayed every week, growth will occur faster than the weed will be killed (Room, 1994).

##### **1.6.2.5.2. Physical control of *Salvinia molesta***

Physical removal is useful for small areas of water, especially if every last piece of salvinia can be removed as the weed will not regenerate from spores. In larger water bodies, physical

removal is often too expensive due to the great weight of wet salvinia which must be removed and the speed at which the weed recolonises open water. The weed invariably outgrows all manual removal efforts (Cilliers *et al.*, 2003).

Cook (1976) reported that manual control was successful in controlling 1500 ha of salvinia on an Indian hydroelectric reservoir. Thirty men removed about half of the infestation over a three-month period and it required annual repetition to maintain acceptable levels of control (Murphy, 1988). In the Adelaide River, Australia, hand removal and erection of nets at the water's surface were used in the management of salvinia (Miller and Pickering, 1980). Typically, floating booms and wire nets have some value in confining salvinia and maintaining adjacent waters weed-free, but booms are subject to breakage under the pressure of large windblown mats (Thomas, 1976). Booms slung on 5-cm diameter steel cables have been known to break, and anchor points on the banks are pulled out (Thomas and Room, 1986).

Economic constraints are the main reason for a general inadequacy of mechanical control measures (Thomas and Room, 1986). Manual removal is only practical in the early stages of invasion. After the plant is established, biomass to about 80 tonnes/ha and a rapid growth make harvesting and hand removal impractical. In Australia, even in winter, the regrowth of large infestations exceeded the removal capacity of harvesting machines. Mechanical harvesting is not cost-competitive (Thomas and Room, 1986).

### **1.6.2.5.3. Biological control of *Salvinia molesta***

#### **1.6.2.5.3.1. Introduction**

The possibility of the biological control of salvinia was prompted by the appearance of the weed on Lake Kariba in 1959. At that time, the plant had been misidentified as *Salvinia auriculata* Aubl (Schelpe, 1961). Accordingly, when the Commonwealth Institute of Biological Control (CIBC) was commissioned to search for potential biological control agents in South America, collections were made from *Salvinia auriculata (sensu strictu)*, which was widespread there and which appeared to be the same as that which had by then become known as 'Kariba weed', and which was starting to invade several tropical countries (Thomas and Room, 1986).

Surveys for natural enemies were conducted in Trinidad, Venezuela, Guyana, Uruguay, Paraguay, Brazil and Argentina during 1978 to 1981. In 1978, the previously unknown range of *S. molesta* was identified (Forno and Harley, 1979), permitting surveys to focus on the

relatively small native range of the target weed rather than the larger range of the *S. auriculata* complex (Forno and Bourne, 1984).

The natural enemies of *S. molesta* and the related species in the *S. auriculata* complex are listed in Forno and Bourne (1984), including species collected by Bennett (1975). Twenty-five phytophagous species have been recorded from *S. molesta*, compared to 49 species from the four species of the *S. auriculata* complex. Four of these species have been used as biological control agents against *S. molesta*. The first three, a moth *Samea multiplicalis* Guenée (Lepidoptera: Pyralidae), a grasshopper, *Paulinia acuminata* (De Geer) (Orthoptera: Pauliniidae) and a beetle, *Cyrtobagous singularis* Hustache (Coleoptera: Curculionidae), identified during the early exploration (Bennett, 1966), have not been successful control agents. The fourth, *Cyrtobagous salviniae* Calder and Sands, was found during later work (Sands, 1983) and has been extremely successful.

#### **1.6.2.5.3.2. The natural enemy *Cyrtobagous salviniae***

The adult weevils of *C. salviniae* are small, about 2 mm in length and black. Newly emerged adults are light brown on emergence and turn black in about five days. The adult male (1.8 x 0.9 mm) is slightly smaller than the female (2.2 x 1.2 mm) (Cilliers *et al.*, 2003; Julien *et al.*, 2002).

Adults are found on or beneath young leaves, on or inside the developing leaves or among roots. When under water, adults respire by means of an air bubble (called a plastron) that adheres to their ventral surface (Forno *et al.*, 1983). Adults can live several months. Multiple matings occur 5 to 26 days after emergence. At 25.5°C, oviposition begins after 6 to 14 days. Eggs (0.5 x 0.24 mm) are laid singly in cavities excavated by adults in lower leaves, developing leaves, rhizomes, and roots. At 25.5°C, females lay one egg, every two to five days for at least 60 days (Forno *et al.*, 1983; Cilliers, 2003), which hatch in 10 days at this temperature. Newly emerged larvae (1 mm) are white, and feed initially on roots in or on the small buds, and later inside rhizomes, completing three instars in approximately 23 days before pupating in a cocoon. The cocoon is spun beneath the water surface in close contact with or amongst the roots. The prepupae and pupal stages are completed in 10-15 days. The total life cycle, dependant on temperature, is completed in 31-68 days. Dispersal of adults is rarely by flight, but mostly by the weevils walking or dispersed with their free-floating host plant (Forno *et al.*, 1983).

Feeding and larval damage by the weevil depends on levels of nitrogen in the plant (Oliver, 1993). Young larvae feed on the buds (growth tips) and roots while older larvae tunnel into the rhizomes causing leaves to darken and drop off. The majority of the damage by *C. salviniae* on *S. molesta* is caused when the larvae tunnel into the rhizome (Sands *et al.*, 1983). Adult feeding damages the growth tips and young leaves, and damaged plants become waterlogged and sink. The presence of damaged growth tips is the most characteristic indicator of the presence of the weevils. In Africa, several countries have successfully experienced the release of *C. salviniae* on salvinia (Table 1.4).

**Table 1.4.** African countries where the natural enemy *Cyrtobagous salviniae* has been released on salvinia<sup>a</sup>

Country	Release date	Impact
Botswana	1984	Control in 1 to 5 years
Congo <sup>b</sup>	1999	Effective control
Côte d'Ivoire <sup>c</sup>	1998	Effective control
Ghana	1995	Well established at various sites
Kenya	1990	Control except where affected by herbicide
Namibia	1983	Effective control
South Africa	1985	Effective control
Senegal <sup>d</sup>	2000	Very effective control
Zambia	1971	Effective control
Zimbabwe	1991	Good control within 2 years

<sup>a</sup> Modified from Julien and Griffiths, 1998.

<sup>b</sup> Mbatl and Neuenschwander, 2005.

<sup>c</sup> Zebeyou, (pers comm., 2000).

<sup>d</sup> Anonymous, 2000a.

## 1.7. History of *Pistia stratiotes* and *Salvinia molesta* in Senegal

### 1.7.1. Introduction

*Pistia stratiotes* and *S. molesta* have both been introduced to Senegal and have become problematic. Senegal implemented biological control against aquatic weeds for the first time in September 1994 when the introduced weevil *N. affinis*, successfully controlled the water lettuce at Lake Guiers (Anonymous, 1994, 1995). The second time the country has successfully experienced biological control of weed was in June 2000 with the introduction of *C. salviniae* to control *S. molesta* on the Senegal River (Anonymous, 2000a).

However, two factors have contributed to the success of biological control of weeds in Senegal. First, the International Institute of Tropical Agriculture (IITA)/Biological Control Station in Cotonou – Benin initiated, trained and funded the project for several years by the Biological Control Project/Plant Protection Directorate (DPV) of Senegal. Second, and

probably most importantly, is the political willingness of the Senegalese government which is aware that biological control is considered as the only sustainable control option for alien invasive aquatic weed even though, in general, manual removal is invariably the first control option practised in any aquatic weed management programme.

From a legal standpoint, a phytosanitary legislation Compendium was compiled in Senegal in 1960 (Anonymous, 1960). The Decree 60-122 – S. G. of March 10, 1960 states that the control of animal and vegetal pests in Senegal is mandatory. However, water hyacinth, *Eichhornia crassipes*, is the only aquatic weed listed. It is a A class product of which the importation into Senegal is prohibited. Only the Plant Protection Service is allowed to import it for duty scientific research, and in this case, the quarantine is mandatory.

The two invasive aquatic weeds *S. molesta* and *P. stratiotes* were not mentioned in the Compendium, nevertheless today they are of great concern in Senegal and are considered as noxious weeds.

### **1.7.2. History of *Pistia stratiotes* in Senegal**

Diama Dam was commissioned in 1986 and as it was filled up, some water bodies downstream, notably in Djoudj Park became infested with water lettuce. In addition, Lake Guiers linked to the Senegal River by the Taouey River became infested by 1993. These are the first records of the weed in Senegal, but it was probably introduced much earlier. According to the Director of the Water Treatment Plant (SONEES) at Ngnith (Djiby Ndiaye, pers. comm. 1994), water lettuce was observed blocking and clogging the opening for filling of Ferlo Fossil Valley in 1987.

Thus, it was definitely present in 1993 with the huge infestation in Lake Guiers and the Djoudj Park (Anonymous, 1994, 1995), but was probably introduced much earlier. *Pistia stratiotes* is a declared weed in Senegal, and has received a great deal of attention because it interferes with proper use of the Lake Guiers water resources for local communities and mainly for water supply to the capital, Dakar. It was of equal concern that the plant served as a preferred habitat for mosquitoes which in turn served as principal vectors of malaria within the riparian communities.

Prior to 1993, physical control was the only method used by local communities to remove *P. stratiotes* to allow access sites to the lake as fishing landing areas and intake points for

population water supply. Other activities involved NGOs whose attempts at using the plant as a green manure were unsuccessful. However, all these attempts did not solve the problems because of the rate at which the weed grows and the fact that it was extremely labour intensive and ineffective in larger infestations.

### **1.7.3. History of *Salvinia molesta* in Senegal**

*Salvinia molesta* was first officially observed in September 1999 on the Senegal River, near the village of Ndiatene Marekhor, not far from Rosso Senegal, 60 km upstream of the Diama Dam. Initially, *S. molesta* was introduced and cultivated in Khor village for improving foods for poultry. Unfortunately, with the great floods in that year, *S. molesta* was washed into the Senegal River. The invaded zones were partly visible in water bodies and in the channels that divide into the irrigation structures on the Senegalese and on the Mauritanian sides.

To address this serious situation, two meetings were held: the first one on April 19, 2000 a crisis Committee headed by the Ministry of the Environment was held in Dakar; and the second one on April 26 and 27, 2000 was organized in Saint-Louis under the sponsorship of the worldwide alliance for nature (IUCN). The last meeting involved Senegalese and Mauritanian experts, high personalities from the Ministry of the Environment of Senegal and the Ministry of the Rural Development and the Environment of Mauritania (MDRE); representatives of OMVS, the Research and Development Institute (IRD), as well as Wetlands International and the worldwide Lutheran Federation (FLM) of Mauritania. The Saint-Louis declaration was effective and identified problems caused by *S. molesta*, indicating strategies to follow and necessary means to control *S. molesta*. Two control methods were adopted for managing the aquatic weed:

- Physical removal, applied in Senegal by the military and civil development Committee (CCMAD);
  - Biological control, applied, in Senegal, by the Plant Protection Directorate (DPV) of Senegal.
- In view of the difficulties involved with mechanical control and the expense, Governments of Mauritania and Senegal viewed biological control to be the only sustainable method of controlling *S. molesta*, especially in environmentally sensitive areas. Furthermore, biological control of aquatic weeds has a proud history in Senegal with the successful biological control of *P. stratiotes* in 1995.

The Government of Senegal pledged the aid of the United Nations Food and Agriculture Organization (FAO) which materialized its support with the Technical Cooperation Project -

TCP/SEN/0067 on February 21, 2001 which formulated a regional programme of 167 000 US dollars for Senegal and Mauritania under the project TCP/RAF/0173. This contribution covered numerous technical assistance missions, official journeys, national and international consultant services, training expenses, facilities and materials purchase, as well as the general and direct functioning expenses. The MDRE of Mauritania and the Ministry of the environment of Senegal were designated by FAO to carry out the project. The TCP focused to help Governments of Senegal and Mauritania to set up a biological control program against *S. molesta* in an integrated management scheme associating physical and biological controls.

## **1.8. Project rationale and aims of the study**

### **1.8.1. Rationale**

Van Driesche *et al.*, (2002) in citing the USA National Invasive Species Council (2001) reported that invasive aquatic weeds are species that, after they have been moved from their native habitat to a new location, spread on their own. Thus, some invasive plants reach high densities and cause economic or environmental harm or harm to humans. In Senegal, two major invasive aquatic weeds, *P. stratiotes* and *S. molesta*, were of great concern respectively in 1993 and 2000. Thus, thick mats interfered with transportation, agricultural irrigation, water supply and fishing. They provided habitats for vectors of human disease like malaria and schistosomiasis with serious socio economic impacts, mostly to the riverside communities. The invasion also threatened habitat for the rich bird life of the Senegal River Delta where a large population of resident breeding birds and some three million migrant birds coming from Europe over the winter season could not recognize or stop at some water bodies entirely covered with salvinia mats (Anonymous; www.gisp.org, 2006). Recently in 2005, a minor resurgence of water lettuce was observed in some areas of the Senegal River Delta.

### **1.8.2 Aims of the study**

The integrated management of the two aquatic weeds water lettuce and salvinia was based on physical removal and mainly on biological control with their specialized natural enemies, *N. affinis* for water lettuce and *C. salviniae* for salvinia.

There are four approaches towards of addressing the aims of this work:

- i) to quantify the impact of *N. affinis* and *C. salviniae* and their host weeds during pre-release studies to determine their potential for biocontrol in the field;
- ii) to conduct additional laboratory host range tests on *N. affinis* and *C. salviniae*, and confirm that it is safe to use in Senegal;

- iii) to conduct post-release evaluations of both agents at selected field sites to confirm that the results of i) are reflected in the field;
- iv) to discuss these results in the context of integrated aquatic weed management in which public awareness and community participation play significant roles.

The above aims form the basis for all chapters.

## Chapter 2

### Laboratory exclusion experiments with *Neohydronomus affinis* Hustache (Coleoptera: Curculionidae) on *Pistia stratiotes* Linnaeus (Areaceae)

#### 2.1. Introduction

Insect and plant populations are influenced by many factors in complex ways, for example abiotic environmental factors like temperature, moisture, light and wind (White, 1997). To date it has only been possible to understand all of these effects and all of this complexity for any insect/plant combination once the relationship has been established and observed over many years in the field. According to White (1997), the introduction and release of a weed biological control agent is an experiment with an unpredictable outcome and many significant questions may be asked: 1) Will the insect feed on the plant? 2) Will the insect increase in numbers under conditions in the field, or will density-independent factors limit its increase? 3) Will parasites and/or predators limit the population of the insect? 4) At densities achieved in the field, will damage inflicted on the plants significantly reduce the plant population?

One of the difficult aspects of assessing biological control is defining and describing success or failure. Outcomes of biotic interactions over the range in which the organisms (weed and agents) exist are usually variable, hence describing the results can be complex (Julien, 1997). Hoffmann (1990) comments that success in weed biological control can only be claimed when it is shown through suitable evaluation that the agents have caused a decrease in weed density or have inhibited the spread of the weed. It is erroneous to equate establishment of agents and demonstrable damage with success because the impact of herbivore damage on the dynamics of plants is often not apparent.

Studies of the effects of herbivorous insects on plants usually only consider losses to photosynthetic capacity or seed production (Lonsdale *et al.*, 1995). It is one thing to measure the effect of an herbivorous insect on plant performance, but it is another to demonstrate that the herbivory is affecting the plant population dynamics (Crawley, 1989). For example, the bud-feeding weevil *Trichapion lativentre* (Coleoptera:Apionidae) reduced seed production in the weed *Sesbania punicea* (Cav.) Benth (Fabaceae) by more than 98%, but failed to cause a corresponding decline in the density of mature plants because the seed loss only removed plants that would have died from competition anyway (Hoffmann and Moran, 1991). This example demonstrates that simple measures of damage alone may not be sufficient to indicate

the success or otherwise of an agent. The range of approaches that may be taken to determine the impact of biological control agents on the target weed include experimental manipulation, studies quantifying population dynamics before and after the release of the natural enemy, correlation, or before-and-after photography. The principles of experimental design are applicable to some degree regardless of the approach used (Farrell and Lonsdale, 1997).

The advantage of experimental manipulation is that it allows for rigorous statistical analysis, and thus yields more reliable information than other methods. Nevertheless, the disadvantage is that costs in time and resources are higher than for other methods. Farrell and Lonsdale (1997) emphasize that experimental manipulation as a basic requirement should apply biological control of weeds in such a way that their effects can be quantified. At the simplest level the hypothesis is that biological control agents will reduce the impact of the weed. The rates of change of population density, or in growth rate and/or survival of the weed, are compared between the treatment, in which the control agent is present on the weed, and the control, from which the control agent is absent. According to Farrell and Lonsdale (1997), there are three basic methods to ensure that control agents are excluded from experimental units to be used as controls: exclusion by insecticides and other means, including cages or controlled releases: 1) Exclusion by insecticides: insects can be excluded from control plants by spraying them at regular intervals with a contact insecticide or by sprinkling granular formulations of systemic insecticides on the soil. 2) Exclusion by cages: insects can be excluded from control plants by caging them before the agents establish on those plants, or by spraying them with a non-residual insecticide after they have been caged. The reverse approach may also be made of adding insects to some cages but not to control cages. 3) Controlled releases: release of agents at some sites, but not others, allows the impact of the agents to be assessed by comparing performance of plants at the release and no-release (control) sites.

The general public is often unconvinced about the use and efficacy of the biological control method to combat pest problems, particularly with striking invasive water weeds. Senegal has experienced this in 1995 with the release ceremony of *N. affinis* with villagers at Keur Momar Sarr/Lake Guiers where a person told us “There is no way that this tiny insect can overcome this huge infestation of water lettuce!”. This idea is shared in general by many people who are not aware of what biological control is all about.

Hence, doubt must be set aside to demonstrate the usefulness of a biological control approach to provide sustainable and environmentally safe solutions to invasive water weeds. The aim of

the exclusion trials was to demonstrate the damage potential of the agent or see weed's response to herbivory.

### **2.1.1. Aim**

The main aim of this chapter was to determine the impact of *N. affinis* feeding damage on water lettuce growth under controlled conditions.

The null hypothesis (**H<sub>0</sub>**) assumes that there are no differences between the treatments and the control.

The alternative hypothesis (**H<sub>a</sub>**) is that feeding damage by the weevil causes negative impact on plant growth or fitness.

## **2.2. Materials and Methods**

### **2.2.1. Importation of natural enemy**

Under a quarantine permit issued by the Plant Protection Directorate of Senegal, 300 *Neohydronomus affinis* weevils were imported in August 2005 from the Plant Protection Research Institute, Pretoria, South Africa.

### **2.2.2. Laboratory study**

#### **2.2.2.1. Plant material**

Insect-free water lettuce plants weighing 15 to 20 g of approximately the same size (15 to 20 cm diameters) were collected from Lake Guiers in Mbane village (16°16'N153 – 15°48'W068) and were grown under laboratory conditions as supply plants for the experiment.

#### **2.2.2.2. Experiment design**

On September 23, 2005, twenty five plastic tubs (diameter: 40 cm, depth: 20 cm) were set up with 15 litres of tap water with a pH of 7.47 and a conductivity of 560  $\mu$ s. A nutrient solution with nitrate (2mg/l) and phosphate (0.01 mg/l) was prepared and added to the water. Five plants were added to each tub. The plants were left for two weeks to become accustomed to the laboratory and the cover net. The inoculation of weevils (pre-sexed in copula) was initiated on October 6, 2005. Five replicates of five treatments (1 pair *N. affinis* + 5 plants + cover net; 2 pairs *N. affinis* + 5 plants + cover net; 3 pairs *N. affinis* + 5 plants + cover net; 5 plants + cover net; 5 plants without cover net) were used in this experiment (Table 2.1). The cover net was white gauze curtaining, attached around the tubs with an elastic cord to maintain weevils either in or out the tubs. The laboratory experiment was set up in a randomized complete block design (Table 2.2).

**Table 2.1:** The five different combinations of treatments used, each with five water lettuce plants, in the laboratory experiment.

Treatment (abbreviations)	Treatment (in full)
1PRCN	1 pair <i>N. affinis</i> , 5 plants, cover net
2PRCN	2 pairs <i>N. affinis</i> , 5 plants, cover net
3PRCN	3 pairs <i>N. affinis</i> , 5 plants, cover net
CN	5 plants, cover net (control <sub>1</sub> )
WCN	5 plants, without cover net (control <sub>2</sub> )

**Table 2.2:** The five replicates of each treatment in twenty-five plastic tubs set randomly in a complete block design in the laboratory.

<b>16</b> 5 <i>Pistia</i> plants + net	<b>21</b> 5 <i>Pistia</i> plants	<b>9</b> 2 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>13</b> 3 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>17</b> 5 <i>Pistia</i> plants + net
<b>20</b> 5 <i>Pistia</i> plants + net	<b>5</b> 1 pair <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>12</b> 3 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>22</b> 5 <i>Pistia</i> plants	<b>8</b> 2 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net
<b>11</b> 3 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>10</b> 2 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>25</b> 5 <i>Pistia</i> plants	<b>4</b> 1 pair <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>18</b> 5 <i>Pistia</i> plants + net
<b>23</b> 5 <i>Pistia</i> plants	<b>3</b> 1 pair <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>15</b> 3 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>7</b> 2 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>14</b> 3 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net
<b>2</b> 1 pair <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>19</b> 5 <i>Pistia</i> plants + net	<b>6</b> 2 pairs <i>N. affinis</i> + 5 <i>Pistia</i> plants + net	<b>24</b> 5 <i>Pistia</i> plants	<b>1*</b> 1 pair <i>N. affinis</i> + 5 <i>Pistia</i> plants + net

\*: tub number and setting in the laboratory

### 2.2.2.3. Temperature and pH

Inside the laboratory, the maximum temperatures and relative humidity were recorded daily with a pocket-sized thermo-hygrometer. The tub water pH was recorded at the beginning of the experiment.

### 2.2.2.4. Monitoring

Six response variables of the water lettuce plants were considered: wet weight, rosette diameter, length of the longest root, number of leaves, number of daughter plants, and weevil feeding damage score. Response variables were recorded 3 times on October 6, 20 and 31,

2005. A scoring system (1 to 6) was used to rate the impact of the weevil on water lettuce (Table 2.3). Results were recorded on a data sheet .

**Table 2.3.** Scoring weevil feeding damage on water lettuce.

Score	Comments
1	No adult feeding scars and larval mines
2	Evidence of feeding scars, larval mines and healthy bud leaves
3	Bud leaves start decomposing. Larval mines on 25-50% of the leaves
4	Older leaves start decomposing, and 25% of the leaves affected
5	Decomposing of leaves, 25-50% of the leaves affected
6	All plants are dead

### 2.2.3. Statistics

Data were analyzed and discussed using an ANOVA by groups ( $\alpha$  level for critical range = .05 and p level for significance = .05) and post hoc Tukey HSD (honest significant difference) test, to investigate for differences between the 3 treatments with insects (1, 2 and 3 pairs), and the 2 controls without insects (cover net and without cover net). The non-parametric Kruskal Wallis (KW-H) ANOVA by ranks and median test was used to compare the feeding score data. Levene's Test of homogeneity of Variances at  $p < .05$  was run to test the two controls: cover net and without control net. The Statistica software (Version 7.0) package was used.

### 2.3. Results

The laboratory temperature and relative humidity means recorded at 8 am, noon and 5 are listed in Table 2.4.

**Table 2.4.** Temperature and relative humidity means ( $\pm$ S.D and S.E), N=39, during the experiment in the laboratory at 8, 12 and 17h.

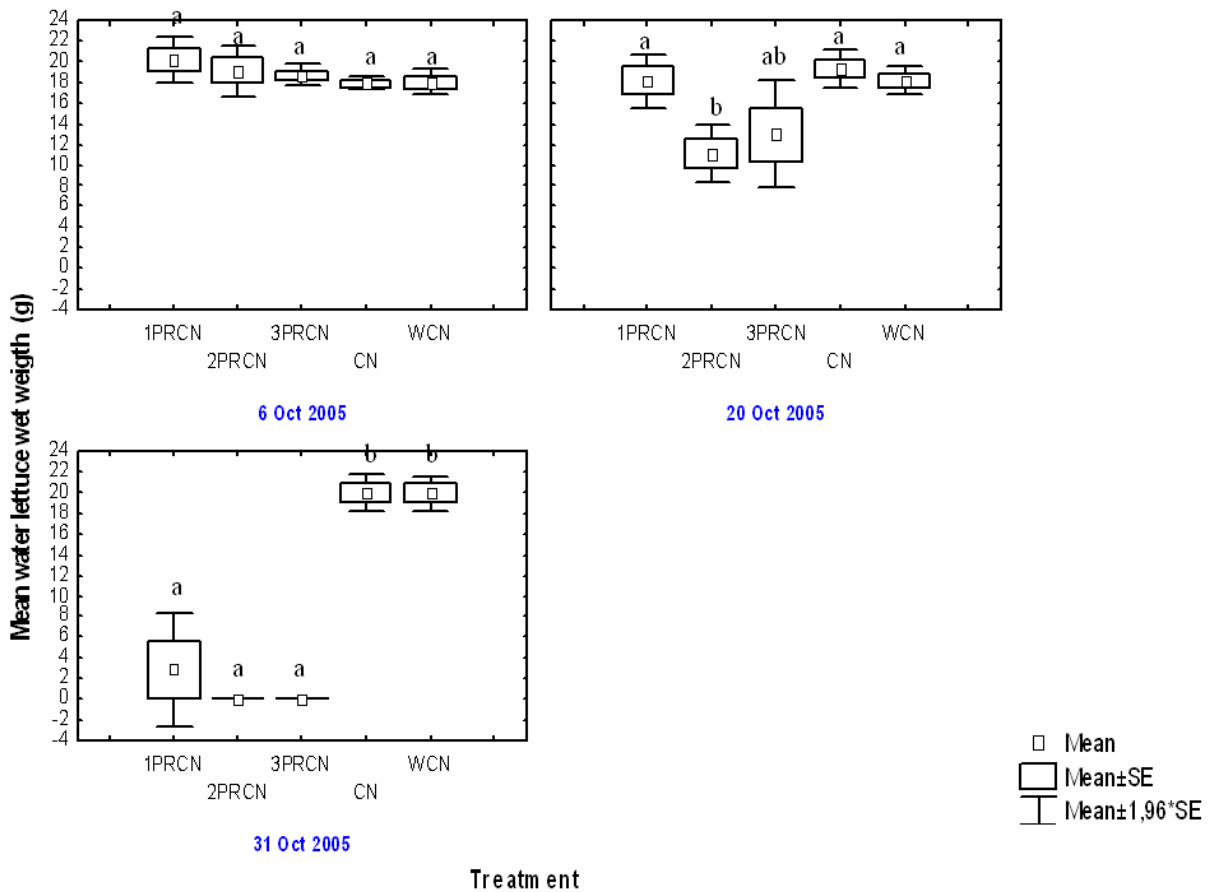
Date	Temperature °C (max)			Relative humidity % (max)		
	8h	12h	17h	8h	12h	17h
Mean	29.01°	38.10°	31.69°	83.21	51.67	65.28
Std. Dev.	1.22	4.05	2.1	5.16	10	5.69
Std. Err.	0.96	0.64	0.33	0.82	1.6	0.91

The temperature and the relative humidity did not negatively impact on the 6-week duration of this experiment, as plants placed in watered tubs two weeks before inoculation became accustomed to the conditions and no dead weevils were recorded during the experiment.

Because of the rate at which the condition of the treatment plants deteriorated due to intense feeding damage, the experiment was terminated much earlier than expected. It was hoped to run the trial for at least 6 weeks after weevil inoculation, but, as many of the plants were starting to die, it was decided that the monitoring would end after 4 weeks (October 31, 2005). The weevil *N. affinis* negatively impacted on the five parameters measured, contrasting with the control plants that remained healthy at the end of the experiment. Visual observation, notably that the plants were yellow and smaller, showed the negative impact of the weevils on treated plants (1PRCN, 2PRCN and 3PRCN) compared to the undamaged control plants (CN and WCN). The Tukey HSD test showed significant differences between weevil treatments and controls. All measured plant growth parameters were affected during the three recording periods: wet weight, rosette diameter, root length, number of leaves and daughter plants.

### **2.3.1. Mean water lettuce wet weight**

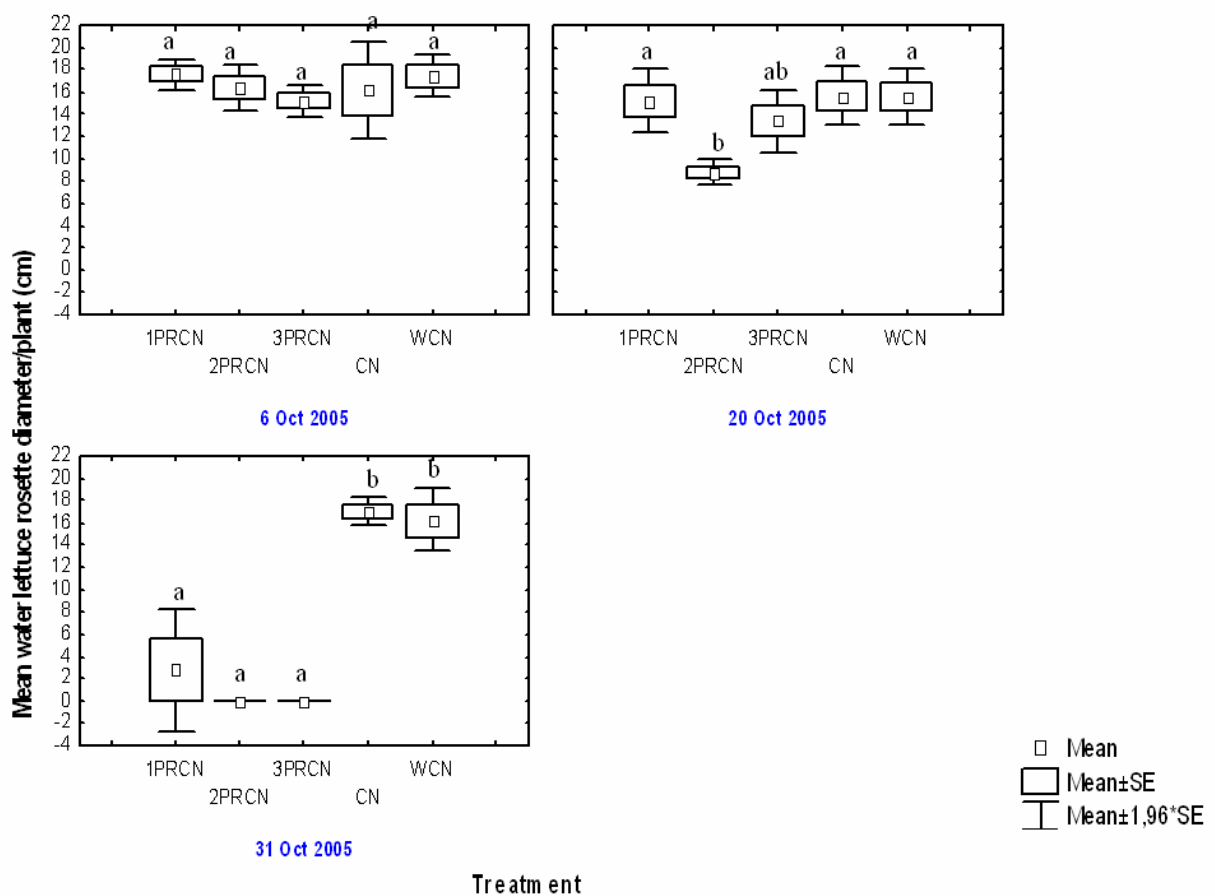
When weevils were absent from water lettuce plants, plant fresh weight means were significantly higher than plants that had been subjected to weevil herbivory at the end of the experiments. However, initially there were no significant differences in wet weight between any of the treatments on October 6, 2005 ( $F=1.19$ ;  $p>.05$ ), but as the experiment progressed, significant differences in wet weight became apparent. The Tukey HSD test indicated a significant difference on October 20, 2005 in wet weight between 1PRCN and 2PRCN, but no difference between 2PRCN and 3PRCN, and 1PRCN and 3PRCN ( $F=5.60$ ;  $p>.05$ ). At the end of the experiment (October 31), there were no significant differences in wet weight between any of the weevil herbivory treatments, nor between the control treatments, but the control plants were significantly heavier than plants that had been fed upon ( $F=56.88$ ,  $p<.05$ ). There were no plants to weigh in the 2PRCN and 3PRCN treatments because they were completely destroyed by the weevils and 1PRCN had a fresh weight mean less than 4 g (Figure 2.1).



**Figure 2.1.** Mean water lettuce plant wet weight compared by one-way ANOVA during the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). [October 6 2005:  $F_{(3,16)} = 1.19$ ;  $p > .05$ ], [October 20 2005:  $F_{(3,16)} = 5.6$ ;  $p < .05$ ], [October 31 2005:  $F_{(3,16)} = 56.88$ ;  $p < .05$ ]. Letters show mean difference following the Tukey HSD test for homogeneous groups. Means followed by the same letter are not significantly different.

### 2.3.2. Mean water lettuce rosette diameter

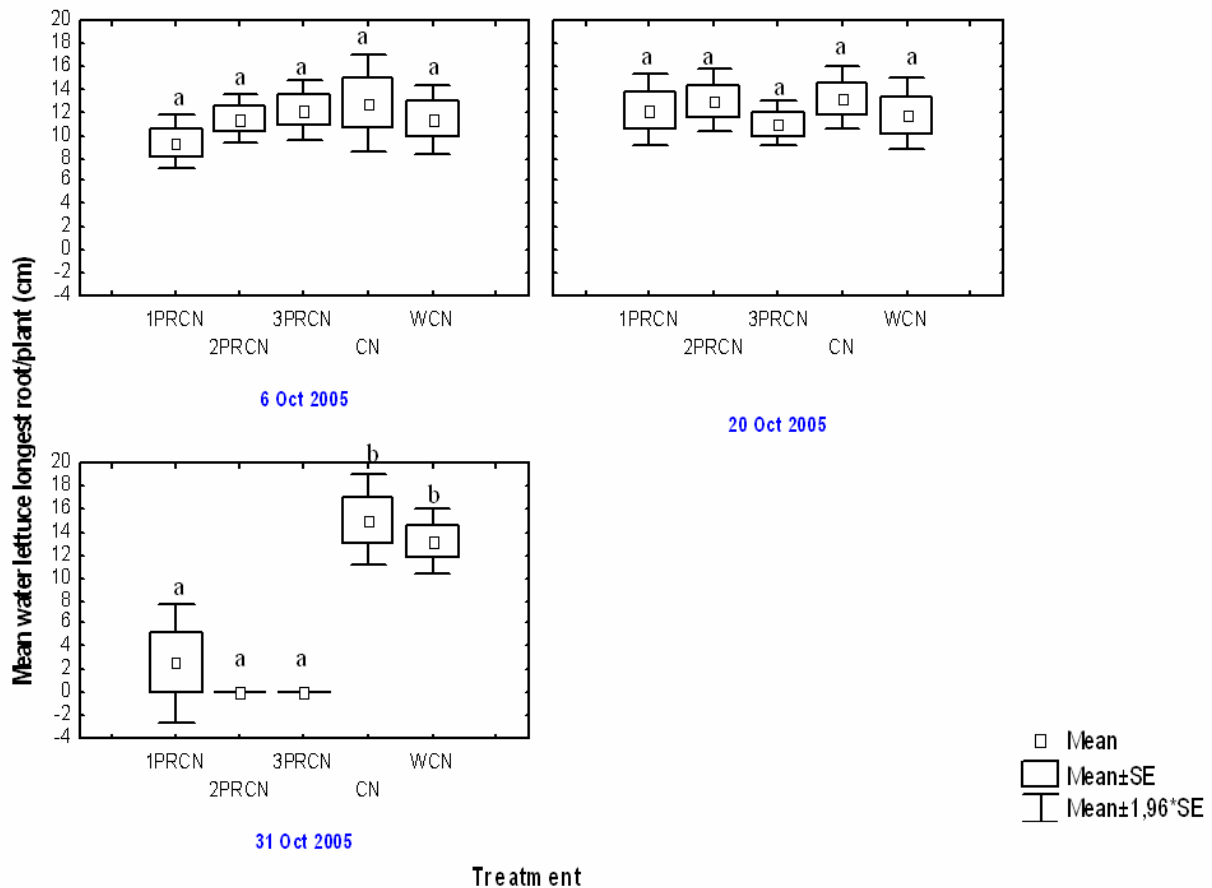
Similar patterns were observed for rosette diameter as for wet weight. Initially, there were no significant differences in rosette diameter between any of the treatments on October 6, 2005 ( $F=0.57$ ;  $p>.05$ ). On the other hand, as the experiment advanced, significant differences in rosette diameter became visible. There were significant differences with the Tukey HSD test between 1PRCN and 2PRCN on October 20, 2005 ( $F=5.33$ ;  $p<.05$ ), but no difference between 2PRCN and 3PRCN. By the end of the experiment on October 31 2005, there were no significant differences in rosette diameter between any of the weevil herbivory treatments, nor between the control treatments ( $F=36.48$ ,  $p<.05$ ). There were no rosettes to measure in the 2PRCN and 3PRCN treatments because the plants were destroyed by the weevils (Figure 2.2).



**Figure 2.2.** Mean water lettuce plant rosette diameter compared by one-way ANOVA during the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). [October 6 2005:  $F_{(3,16)} = 0.57$ ;  $p>.05$ ], [October 20 2005:  $F_{(3,16)} = 5.33$ ;  $p<.05$ ], [October 31 2005:  $F_{(3,16)} = 36.48$ ;  $p<.05$ ]. Letters show mean difference following the Tukey HSD test for homogeneous groups. Means followed by the same letter are not significantly different.

### 2.3.3. Mean water lettuce longest root

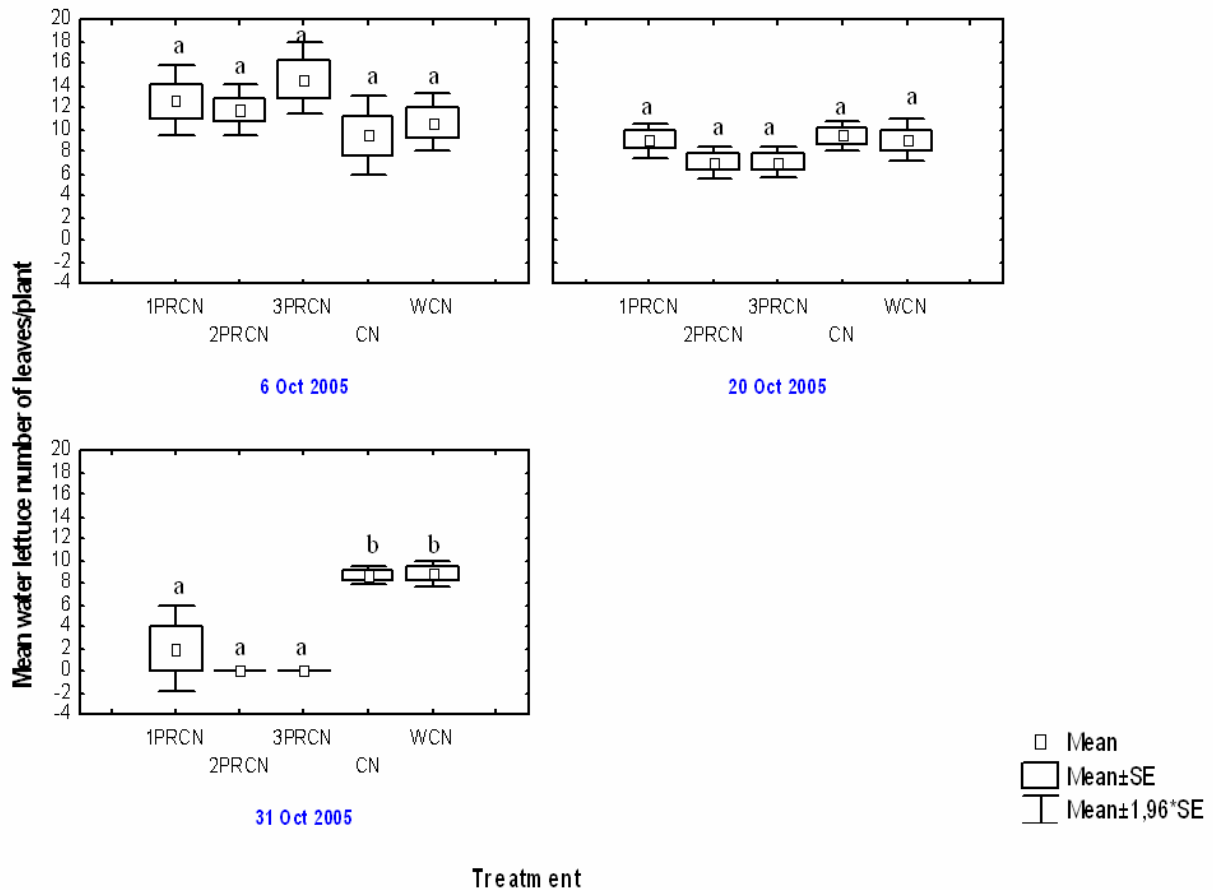
Different patterns were observed for longest root compared with wet weight and rosette diameter. There were no significant differences in longest roots between any of the treatments on October 6, 2005 ( $F=0.71$ ;  $p>.05$ ) and October 20, 2005 ( $F=0.39$ ;  $p>.05$ ). However, the Tukey HSD test indicated significant differences between the controls and the treated plants on October, 31 2005 ( $F=21.12$ ;  $p<.05$ ) due to the fact that plants felt and roted. Only control plants were floating and treated ones were dead (Figure 2.3).



**Figure 2.3.** Mean water lettuce plant length of longest root compared by one-way ANOVA during the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). [October 6 2005:  $F_{(3,16)} = 0.71$ ;  $p>.05$ ], [October 20 2005:  $F_{(3,16)} = 0.39$ ;  $p>.05$ ], [October 31 2005:  $F_{(3,16)} = 21.12$ ;  $p<.05$ ]. Letters show mean difference following the Tukey HSD test for homogeneous groups. Means followed by the same letter are not significantly different.

### 2.3.4. Mean water lettuce number of leaves

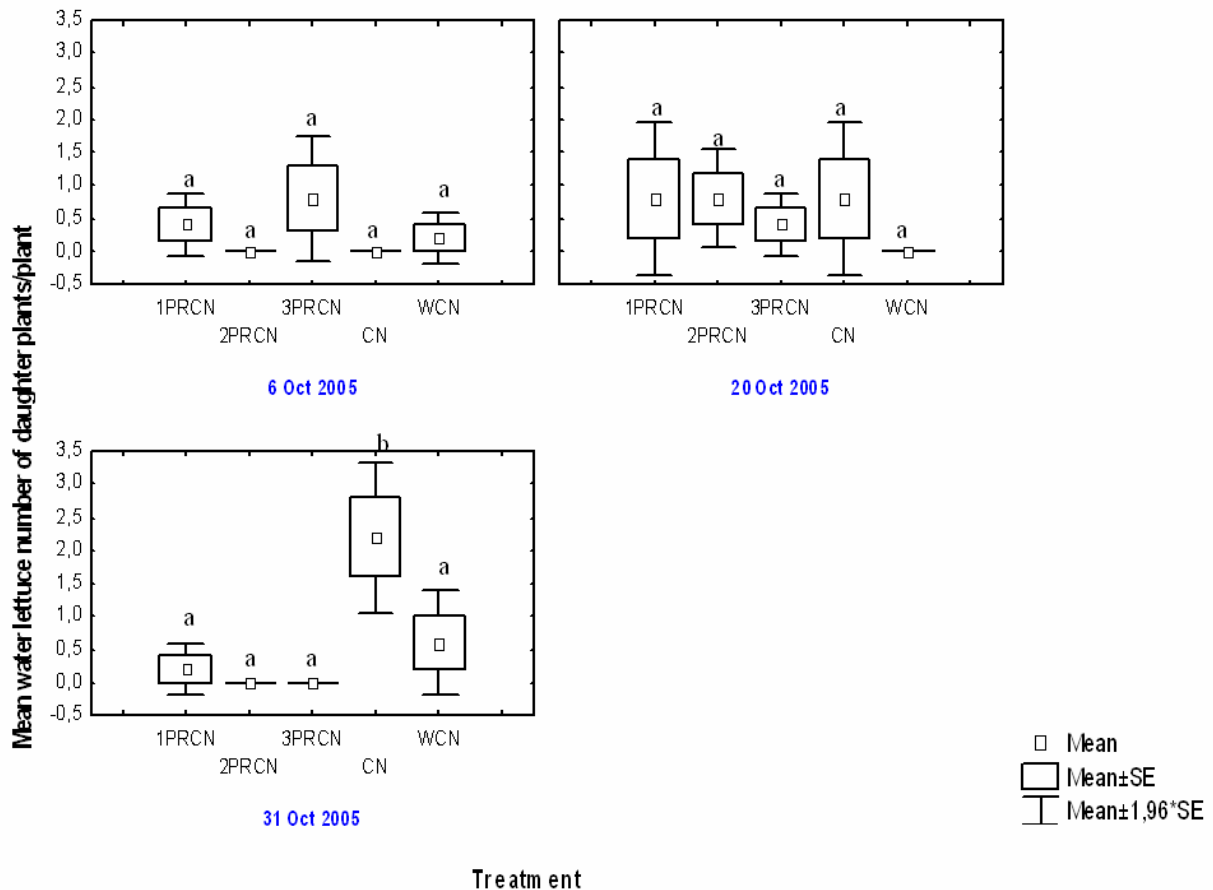
Similar patterns were observed for number of leaves as for root length. The Tukey HSD test indicated no significant differences in number of leaves across treatments on October 6, 2005 ( $F=1.64$ ;  $p>.05$ ) and October, 20 2005 ( $F=2.20$ ;  $p>.05$ ). However, by the end of the experiment on October 31 2005, control plants had significantly more leaves than treated plants ( $F=22.25$ ,  $p<.05$ ). The 2PRCN and 3PRCN plants were destroyed preventing monitoring (Figure 2.4).



**Figure 2.4.** Mean number of water lettuce plant leaves compared by one-way ANOVA during the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). [October 6 2005:  $F_{(3,16)} = 1.64$ ;  $p>.05$ ], [October 20 2005:  $F_{(3,16)} = 2.2$ ;  $p>.05$ ], [October 31 2005:  $F_{(3,16)} = 22.25$ ;  $p<.05$ ]. Letters show mean difference following the Tukey HSD test for homogeneous groups. Means followed by the same letter are not significantly different.

### 2.3.5. Mean water lettuce number of daughter plants

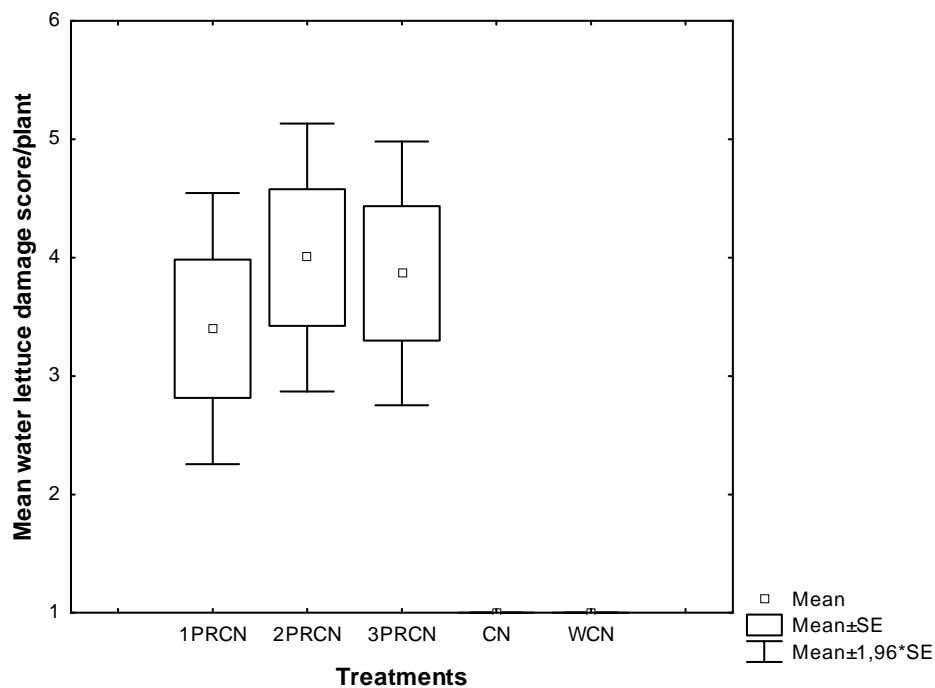
There was no significant difference in the number of daughter plants produced across treated and control plants by the time of weevil inoculation October 6, 2005 ( $F=1.64$ ;  $p>.05$ ) and two weeks later on October, 20 2005 ( $F=0.72$ ;  $p>.05$ ). However, by the end of the experiment on October 31 2005, the CN control produced more daughter plants than any treatments and the Tukey HSD test indicated significant differences between CN vs.WCN, 1PRCN, 2PRCN, and 3PRCN.(Figure 2.5).



**Figure 2.5.** Mean number of water lettuce daughter plants compared by one-way ANOVA during the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). [October 6 2005:  $F_{(3,16)} = 1.64$ ;  $p>.05$ ], [October 20 2005:  $F_{(3,16)} = 0.72$ ;  $p>.05$ ], [October 31 2005:  $F_{(3,16)} = 7.96$ ;  $p<.05$ ]. Letters show mean difference following the Tukey HSD test for homogeneous groups. Means followed by the same letter are not significantly different.

### 2.3.6. Mean water lettuce damage

The Kruskal-Wallis test showed that the highest rank sum for weevil damage appears in the 2PRCN (740) followed by the 3PRCN (726) and the 1PRCN (679) treatments. The lowest rank sums (CN=352.5, WCN=352.5) appear in the control conditions. There were no significant differences for the different experimental damage scores between the three herbivory treatments (1PRCN, 2PRCN, 3PRCN) ( $H_{4,75}=29.50$ ;  $P<.05$ ). Obviously, damage was significantly higher for the 3 herbivory treatments (2PRCN, 3PRCN) since feeding was excluded on controls (CN, WCN) (Figure 2.6).

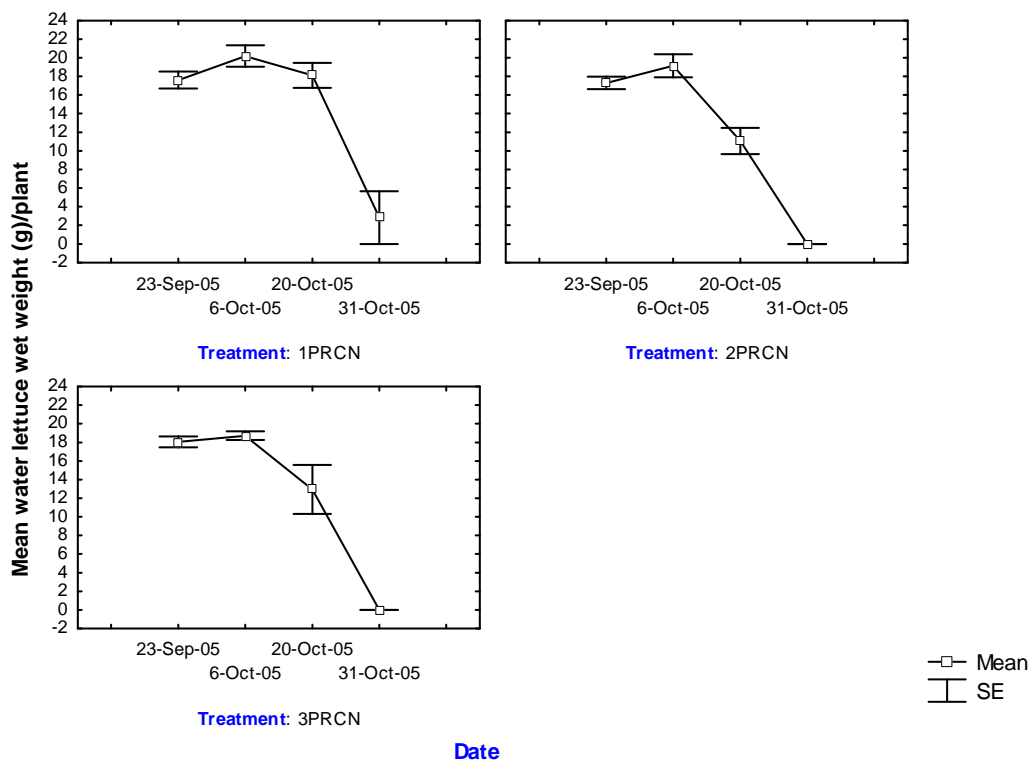


**Figure 2.6.** Median water lettuce plant damage scores for the laboratory experiments with weevils either present (1PRCN, 2PRCN, 3PRCN) or absent (CN, WCN). Medians were compared using a Kruskal-Wallis test:  $H_{4,75}=29.50$ ;  $p<.05$ .

### 2.3.7. Weevil treatment performances on water lettuce growth factors

#### 2.3.7.1. Weevil treatment performances vs. wet weight

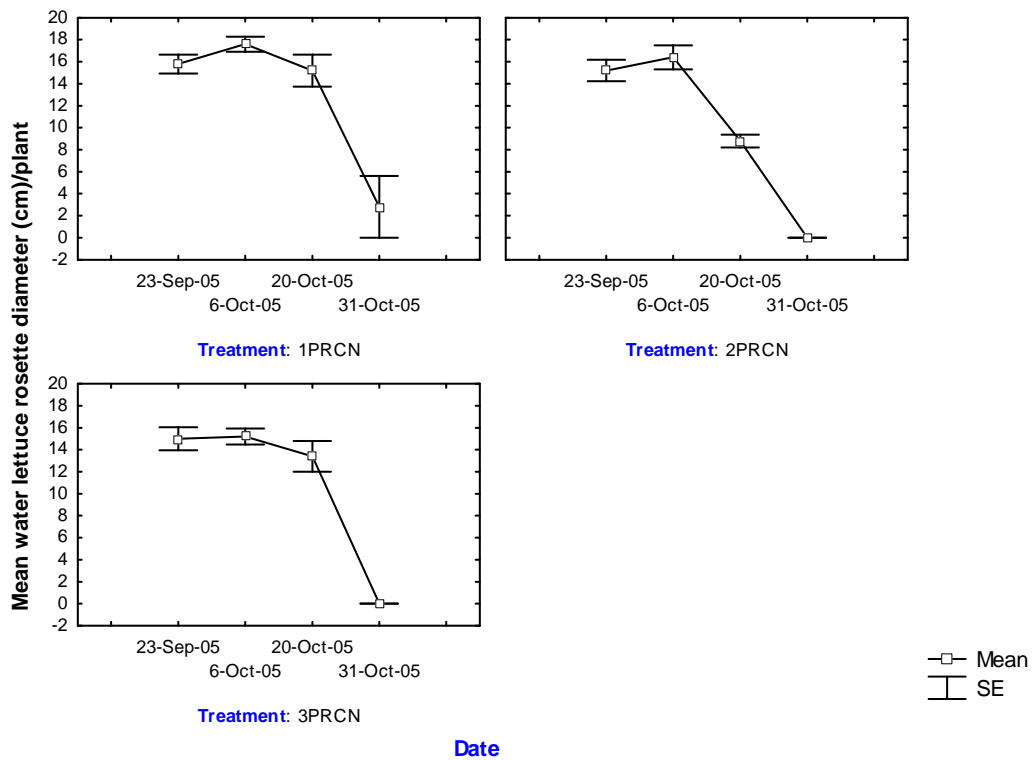
A similar pattern can be seen for 1PRCN, 2PRCN and 3PRCN weevil treatments (Figure 2.7). Two weeks after weevil inoculation (October 20, 2005), the three different treatments were all very similar with respect to wet weight with only the 1PRCN which was variable, as can be seen by the standard error in October 31. The comparison of the three means (1PRCN, 2PRCN and 3PRCN) did not detect significant differences in October 20 and in October 31 2005. However, for the same periods, there were significant differences within treatments at  $p < .05$ .



**Figure 2.7.** Mean of water lettuce wet weight at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN). 1PRCN:  $F_{(3,16)} = 21.11$ , 2PRCN:  $F_{(3,16)} = 74.34$ , 3PRCN:  $F_{(3,16)} = 40.15$ ; and  $p < .05$ .

### 2.3.7.2 Weevil treatment performances vs. rosette diameter

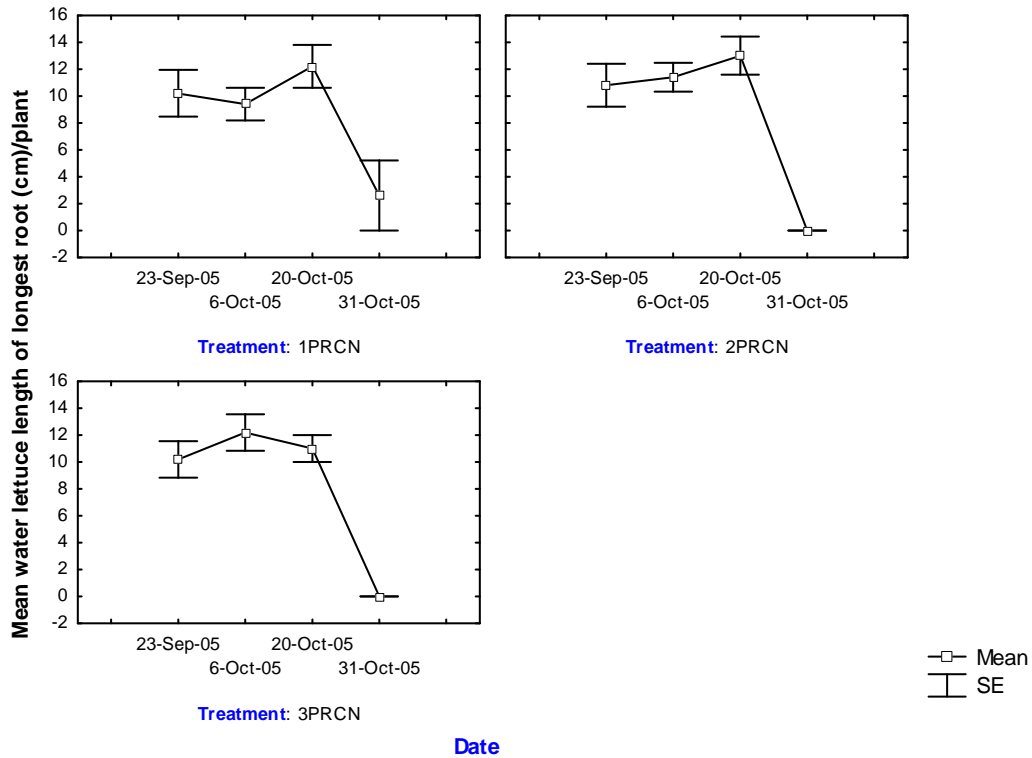
The impact of the three treatments on rosette diameter was apparently the same (Figure 2.8). There were no significant differences between 1PRCN, 2PRCN and 3PRCN regarding the weevils' performance on rosette diameter by October 20 and on October 31, 2005. However, for the same periods, there were significant differences within treatments at  $p < .05$ .



**Figure 2.8.** Mean of water lettuce water lettuce rosette diameter at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN). 1PRCN:  $F_{(3,16)} = 16.43$ , 2PRCN:  $F_{(3,16)} = 92.56$ , 3PRCN:  $F_{(3,16)} = 59.39$ ; and  $p < .05$ .

### 2.3.7.3. Weevil treatment performances vs. longest root length

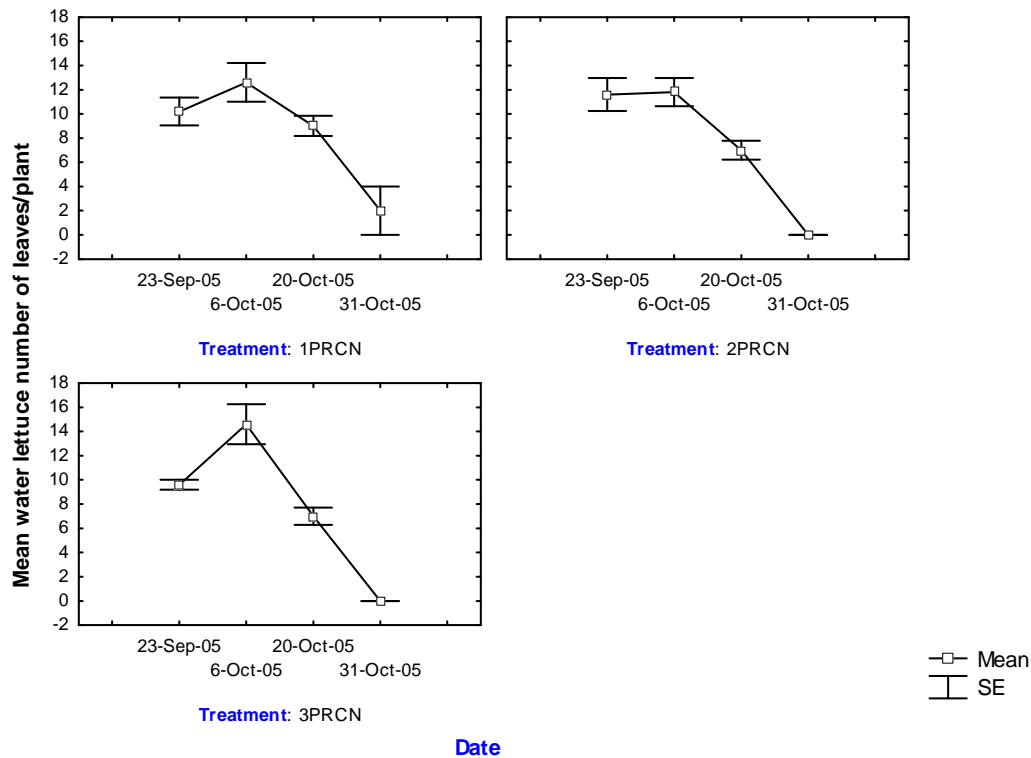
Mean length of longest root was a factor highly variable within 1PRCN, 2PRCN and 3PRCN treatments (Figure 2.9). However, there was no statistical significance detected between the three weevil treatments at  $p < .05$  (Table 2.5). The dramatic reduction in longest root length between 20 and 31 October indicates the damage that the weevils were inflicting on the water lettuce plants.



**Figure 2.9.** Mean of water lettuce length of longest root at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN). 1PRCN:  $F_{(3,16)} = 5.03$ , 2PRCN:  $F_{(3,16)} = 24.75$ , 3PRCN:  $F_{(3,16)} = 27.06$ ; and  $p < .05$ .

### 2.3.7.4. Weevil treatment performances vs. number of leaves

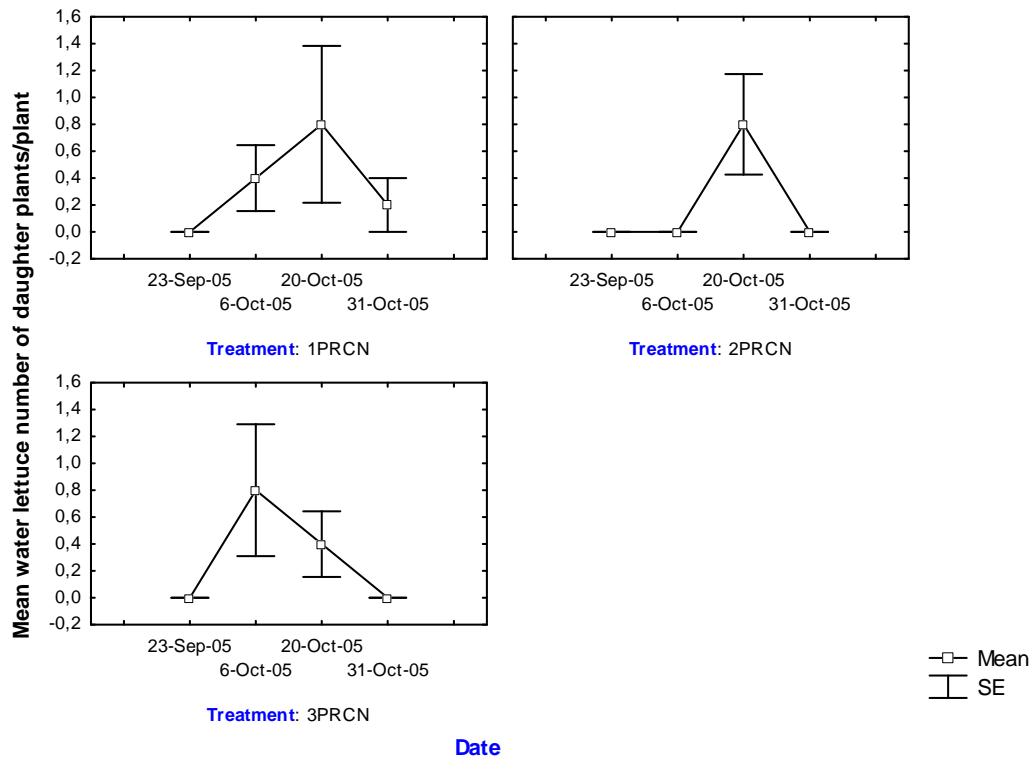
As in the other variable graphs, there were little differences in the mean number of leaves two weeks after inoculation (October 20) from weevil treatment (Figure 2.10). Thereafter, as damage to the water lettuce plants increased, mean number of leaves decreased to zero. No significant differences were obtained between treatments at all insect post inoculation evaluations at  $p < .05$ .



**Figure 2.10.** Mean of water lettuce number of leaves at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN). 1PRCN:  $F_{(3,16)} = 9.64$ , 2PRCN:  $F_{(3,16)} = 32.19$ , 3PRCN:  $F_{(3,16)} = 43.25$ ; and  $p < .05$ .

### 2.3.7.5. Weevil treatment performances vs. number of daughter plants

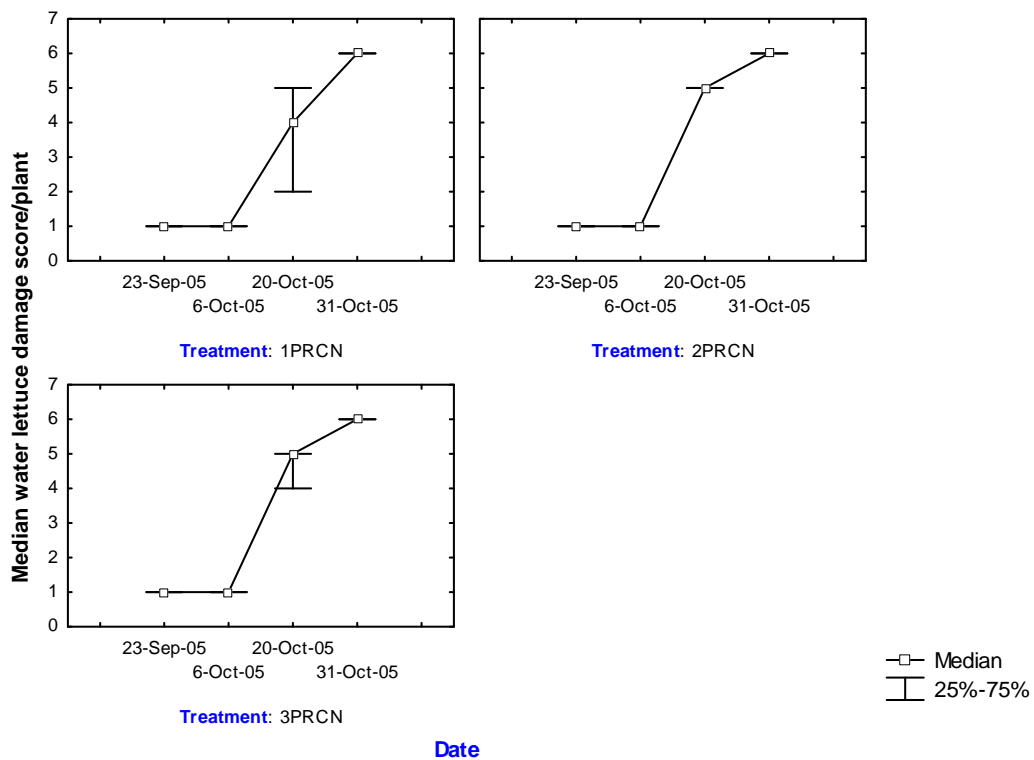
Two weeks after inoculation, the standard errors related to the occurrence of daughter plants, showed variations between 1PRCN and 2PRCN weevil treatments (October 20) (Figure 2.11). However, no statistical significance was recorded between weevil treatments at  $p < .05$ .



**Figure 2.11.** Mean of water lettuce number of daughter plants at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN). 1PRCN:  $F_{(3,16)} = 1.06$ , 2PRCN:  $F_{(3,16)} = 4.57$ , 3PRCN:  $F_{(3,16)} = 1.95$ ; and  $p < .05$ .

### 2.3.7.6. Weevil treatment performances vs. damage

Even though, the experiment lasted only four weeks, heavy damage was apparent only two weeks after insect inoculation in plant tubs and general collapse of many of the plants was observed at the end with regard to all three weevil treatments. The percentile error bar showed high variation for 1PRCN at October 20 and less variation was observed by October 31 for the same treatment (Figure 2.12). Nevertheless, there were no significant differences between the weevil treatments at  $p < .05$ .



**Figure 2.12.** Median of water lettuce damage score at different sample dates, after the three different weevil treatments (1PRCN, 2PRCN, 3PRCN):  $KW-H(3;20) = 16.76$ ,  $KW-H(3;20) = 19$ ,  $KW-H(3;20) = 18.75$ ; and  $p < .05$ .

### 2.3.8. Cover net influences on the experiment (procedural control)

The net did not influence the plant growth or the action of the weevils on water lettuce plants, as reported in previous sub-paragraphs (2.3.1 to 2.3.7). No significant differences were recorded for all tested variables between the two controls, one with gauze and the other without gauze. However, on October 20, the Levene Test of Homogeneity of Variances showed a significant difference at  $p < .05$  for the number of daughter plants between CN and WCN (Figure 2.5 and Table 2.5). But, over the whole experiment, no significant differences were reported.

**Table 2.5.** Levene Test of Homogeneity of Variances for water lettuce plant growth parameters on October 20 2005 for tubs with cover nets (CN) and without cover nets (WCN). Stars indicate significant differences at  $p < .05$ .

Plant variable	SS	df	MS	F	p
Wet Weight (g)	0.256	1	0.256	0.285370	0.607724
Rosette Diameter (cm)	0.144	1	0.144	0.058018	0.815715
Length of Longest Root (cm)	0.256	1	0.256	0.158220	0.701204
Number of Leaves	0.256	1	0.256	0.329897	0.581506
Number of Daughter Plants	2.304	1	2.304	8.408759	0.019898*

The comparison of the different parameters revealed that plant tubs with nets (CN) produced more daughter plants and the Tukey HSD test confirmed significant differences at  $p < .05$ . Consequently, the occurrence of daughter plants was the only factor which illustrated noticeable disparity between the CN control and the WCN control (Table 2.6).

**Table 2.6.** Post hoc Tukey HSD test with the variable: Number of daughter plants. CN plant tubs were significantly different from other treatments. Stars indicate significant differences at  $p < .05$ .

Treatment	1PRCN	2PRCN	3PRCN	CN	WCN
1PRCN		0.992344	0.992344	0.002944*	0.907862
2PRCN	0.992344		1.000000	0.001174*	0.699550
3PRCN	0.992344	1.000000		0.001174*	0.699550
CN	0.002944*	0.001174*	0.001174*		0.019420*
WCN	0.907862	0.699550	0.699550	0.019420*	



**Figure 2.13a.** Water lettuce 1PRCN treatment after 2 weeks.



**Figure 2.13b.** Water lettuce 1PRCN after 4 weeks.



**Figure 2.14a.** Water lettuce 2PRCN treatment after 2 weeks.



**Figure 2.14b.** Water lettuce 2PRCN treatment after 4 weeks.



**Figure 2.15a.** Water lettuce 3PRCN treatment after 2 weeks.



**Figure 2.15b.** Water lettuce 3PRCN treatment after 4 weeks.



**Figure 2.16a.** Water lettuce CN control after 2 weeks.



**Figure 2.16b.** Water lettuce CN control after 4 weeks.



**Figure 2.17a.** Water lettuce WCN control after 2 weeks.



**Figure 2.17b.** Water lettuce WCN control after 4 weeks.



**Figure 2.18a.** Control tubs (CN, WCN) show healthy water lettuce plants.



**Figure 2.18b.** Treated tubs (1PRCN, 2PRCN, 3PRCN) show feeding damage by weevil on water lettuce plants and mining by larvae produces characteristic tunnels.

## 2.4. Discussion

### 2.4.1 Laboratory experimental design

Moderately little use has been made of cages in considering the effect of herbivores on pest plants, while cages have been widely used in the biological control of insect pests (Van Driesche & Bellows, 1996). Despite the negative attributes of field-cages, they have been successfully implemented in weed biological control to aid in the establishment of agents (Thomas & Room, 1984; Wright, 1997), and to investigate the effects of temperature and nutrients on biological control agents and their hosts (Julien *et al.*, 1987; Room & Fernando, 1992). The confined area of a cage allows for close observation and a rapid build up of agents. In addition, cages facilitate the manipulation of various experimental variables and the ease and consistency with which populations can be sub-sampled during an experiment. However, elements such as lack of predators and an altered microclimate may confound the accuracy of the data obtained through the use of cages (McConnachie, 2004).

The use of tubs in a laboratory can be compared to field-cages in evaluating the impact of *N. affinis* on *P. stratiotes*. This experiment facilitated the controlled exploration of weevil impact on water lettuce. The laboratory experimental manipulation allowed the exclusion of weevils from control tubs by using a gauze cover. This approach is meticulous for exploring the impact of the biological control agent *N. affinis* on *P. stratiotes*. Recorded laboratory mean temperature and relative humidity seemed to be well-matched with the weevils and water lettuce plants development and growth. No mortality due to those two parameters was recorded for the weevil and the plant.

On the other hand, a number of shortcomings were encountered in the laboratory experiment. Firstly, the test was restricted on a spatial scale with regard to sample size and could not be extended as much as it would be in the field. Secondly, the two factors namely length of longest root and the number of leaves were difficult to standardize at the start of the experiment. The experiment was run during the heat of summer time with high temperatures and relative humidity leading to excessive evapotranspiration in the laboratory and provoking frequent water and fertiliser adjustment in the tubs. So, regular top up of water and nutrients was needed.

#### 2.4.2 Weevil treatment and damage to water lettuce

An extensive scientific literature discusses the attributes of a successful insect biological control agents should acquire (Harris, 1973; Beddington and Lawton, 1978; Goeden, 1983; Hokkanen and Pimental, 1984; Dennill, 1988; Myers *et al.*, 1989; Waage, 1990). Harris (1973), cited by Marohasy (1997), was the first to propose a formal system for prioritising insects. This system was based on biological attributes including phenology of attack, number of generations per year, feeding behaviour and size. However, this system and subsequent revisions (Goeden, 1983; Hokkanen and Pimental, 1984) are rarely used.

It seems that there are no proven scientific principles which can be used to determine in advance which biological control agents are going to establish and become abundant (Marohasy, 1997). Cullen (1992) comments that “ this is a continual source of frustration and a waste of resources, yet attempts to do better are notoriously difficult and make little progress, to the extent that many workers feel it is not worthwhile, preferring to rely on release of the agent as the only valid test of finding whether it will be successful.’’. According to Marohasy (1997), successful biological control agents should fulfil the following three criteria, they must be: 1) adequately host specific, 2) potentially damaging, and 3) able to build up to large populations to realise their potential to damage.

In this experiment, *N. affinis* damaged the leaves of water lettuce by feeding on the leaf surface and within the leaf, and the larvae caused damage by mining within the leaf. Plants were eventually killed by a combination of larval and adult feeding. The weevil treatment plants were severely damaged after only two weeks, rotted and totally collapsed after four weeks, whereas control plants were healthy. Detailed scientific literature has described similar symptomatic damages provoked by *N. affinis* on water lettuce plants either in the laboratory or in the field (DeLoach *et al.*, 1976; Thompson and Habeck, 1989, Chikwenhere and Forno, 1991; Dray and Center, 2002).

Weevil impact on treated plants was clear compared to the undamaged insect free plants (Figures 2.13a to 2.18b). In treated tubs, the weevil strongly depressed plant performance as measured by the plant growth parameters: mass, rosette diameter, root length, number of leaves and daughter plants. This concurs with findings by Moore (2005), based upon his experiment on the efficacy of *N. affinis* on *P. stratiotes* under different nutrient regimes.

There were no daughter plants at the start of the experiment but they showed up as the experiment progressed. Plants would more likely avoid suppression from *N. affinis* through their ability to continue to produce daughter plants, which would increase their likelihood of escape from the weevils but not for long, as in their turn they were destroyed by the weevils. What was noticeable from the experiment was that there were few statistical differences between the different weevil treatments related to growth factors, except for the factor ‘‘rosette diameter’’ which showed significant differences between 1PRCN and 2PRCN two weeks after insect inoculation (Figure 2.8).

No differences were found with regard to the number of weevils used; one, two or three pairs of weevils produced the same result, and were equally efficient in controlling the weed. The most stimulating facet about the study, was how speedily one, two or three pairs of weevils per tub induced severe damage to the plants, with many plants starting to die, just two weeks after inoculation of the weevils and two more weeks later, the weevils provoked a complete collapse of the plants as seen in figures 2.13a to 2.18b.

These results have practical application. A goal of exclusion experiments is to demonstrate the effectiveness of a biological control agent and so provide an intermediate link between the laboratory and the field by providing helpful insight into the use of *N. affinis* on *P. stratiotes*.

## **2.5. Conclusion**

Once the choice of the best natural enemies has been met, tub or cage experiment should be undertaken to look at closer interactions between the target water weed and the biological control agent and its level of efficiency. These studies should be done prior to release to answer the question: is the agent suitably damaging?

The weevil *Neohydronomus affinis* was highly destructive to *Pistia stratiotes* in the laboratory experiment and turned out to be a particularly effective biological control agent of water lettuce. The question that we needed to answer from the start, as to whether the weevil is successful on water lettuce, would appear to have been positively answered. In this experiment, the number of weevil pairs, i.e. one, two or three did not represent an obstacle to effective biological control. The three different treatments destroyed successfully water lettuce plants within less than one month while the plants in the control tubs were still in excellent condition. These studies demonstrated that *N. affinis* is a first-rate control agent for biological control of water lettuce.

## Chapter 3

### **Quantitative post-release evaluation of biological control of water lettuce, *Pistia stratiotes* Linnaeus (Araceae) with the weevil *Neohydronomus affinis* Hustache (Coleoptera: Curculionidae) at Lake Guiers.**

#### **3.1. Introduction**

According to Julien *et al.* (1999), as part of any biological control post-release evaluation on aquatic weeds the following information should be recorded: whether the agent established following release in a particular area; the rate of natural spread of the agent; the time taken for the agent to reach a damaging population; and the progressive impact on the weed infestation and eventual level of control achieved. In addition, Blossey (1996) stated that without scientific evaluation, the safety of biological control will remain subject to doubt and if public concerns are not taken seriously, biocrol will suffer further restrictions. Further, Blossey (1996) pointed out that conflict resolution will always be a part of biological control, and only sound scientific analysis can offer guidance to necessary decisions. Hence, increased attention must be given to follow-up studies to monitor target plant and control agent populations. The post-release evaluation of a biological control agent, however, is the real test of the success of a programme (McConnachie, 2004). However, post-release evaluations of biological control programmes are often neglected (Blossey, 1995); primarily because funding agencies take the view that it is unnecessary (McFadyen, 1998) or because of the lack of interest at national level.

Biological control of water lettuce has been highly successful in most areas around the world where the weed is present, mainly due to the weevil *Neohydronomus affinis*, which has been introduced widely along with the weed. *Neohydronomus affinis* has been officially released in at least ten countries; Australia, Benin, Botswana, Ghana, Papua New Guinea, South Africa, United States of America, Zambia, and Zimbabwe (Julien & Griffiths, 1998) and successful results have been recorded in Australia (Harley *et al.*, 1984, 1990), South Africa (Cilliers, 1987; Cilliers *et al.*, 1996), Zimbabwe (Chickwenhere and Forno, 1991), Côte d'Ivoire (Zebeyou Mesmer, pers. com.), Ghana (DeGraft Johnson, pers. com.), Benin (Ajuono and Neuenschwander, 2003) and the Republic of Congo (Mbatu and Neuenschwander, 2005).

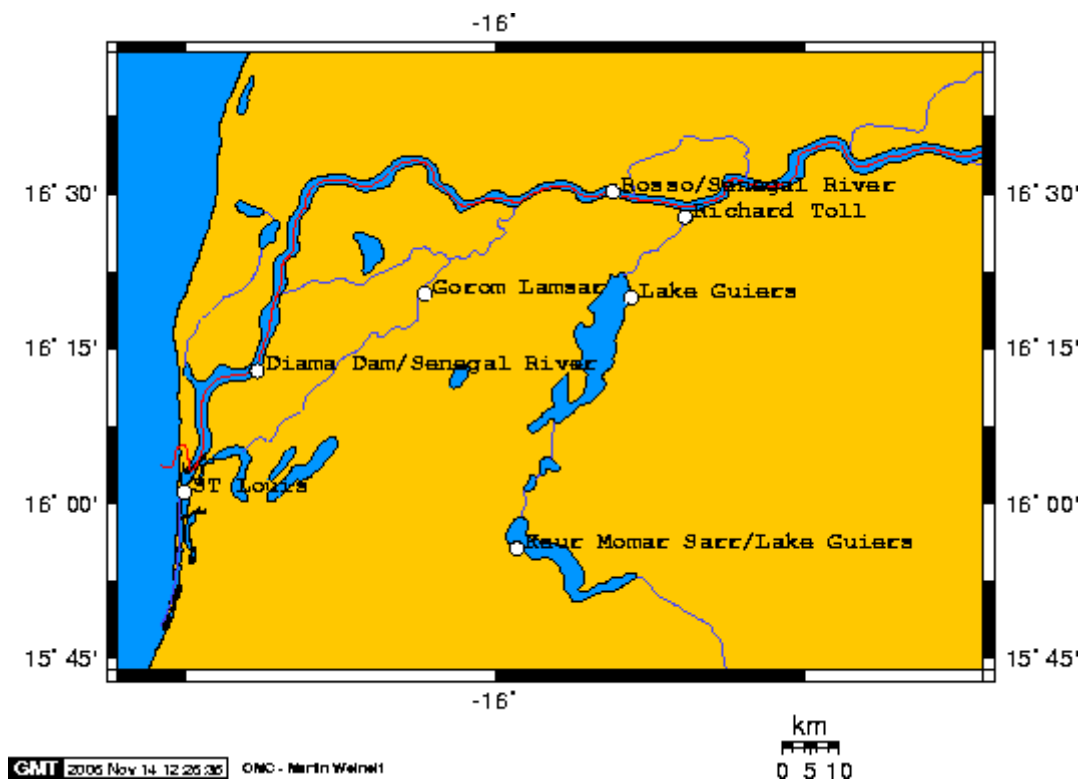
In Senegal, from 1993 to 1994, water lettuce covered important areas on Lake Guiers. Thus a biological control programme was launched for the control of water lettuce.

This chapter reviews the quantitative post release evaluation of *N. affinis* on *P. stratiotes* in Senegal and the following aims were addressed:

- 1) Pre-release surveys to select strategic sites for release.
- 2) *Neohydronomus affinis* mass rearing and release.
- 3) Biocontrol efficacy after several years of unsuccessful physical removal.

### 3.2. Materials and methods

In addition to the terrestrial surveys, information on the distribution of water lettuce was obtained from aerial surveys. Waterways surveys concerned the Senegal River and Lake Guiers. They started from Diama Dam (16°12N 521 – 16° 24W 544) to Rosso (16° 30N098 – 15°48W359) and from Richard Toll (16°27N480 – 15° 41W 340) towards Keur Momar Sarr (15°55N329 – 15°57W541) (Figure 3.1).



Map source: [http://www.aquarius.ifm-geomar.de/make\\_map.html](http://www.aquarius.ifm-geomar.de/make_map.html)

**Figure 3.1.** Pre-release surveys along the Senegal River: from Diama Dam (16°12N 521 – 16° 24W 544) to Rosso (16° 30N098 – 15°48W359) and at Lake Guiers: from Richard Toll (16°27N480 – 15° 41W 340) to Keur Momar Sarr (15°55N329 – 15°57W541).

### 3.2.1. Importation of the natural enemy *Neohydronomus affinis*

A starter colony of 1037 weevils was supplied in July 1994 by the International Institute for Tropical Agriculture (IITA)/Biological Control Station at Cotonou/Benin following the Senegalese Plant Protection Directorate's official request and import permit. These beetles were progeny of a founder colony that had been obtained in May 1994 from the Plant Protection Research Institute-Zimbabwe.

### 3.2.2. Mass rearing

The tub-rearing technique used in June 1994 was initially developed by IITA in Benin. Weevils were reared in tubs measuring about 40 cm diameter and 19 cm deep with a 20 L capacity. Rearing was carried out at two stations; in a laboratory at the Plant Protection Directorate Km15 Rufisque road and outdoors in semi-shade at the Phytosanitary Base of Richard Toll (Figure 3.1). A total of 75 plastic tubs were filled with tap water and a commercial concentrated plant food 'Nitrophoska Foliar' with N (10%) P (4%) and K (7%); 2 teaspoons were added to 15 L. Tubes were stocked with 6 to 8 water lettuce plants 10 to 17 cm diameter; leaf length between 11 to 13 cm and leaf width between 4.5 to 6 cm. Seven to 10 adult weevils were placed on the plants. The water was changed every two weeks. One tub produced more than 100 weevils in 4 weeks.

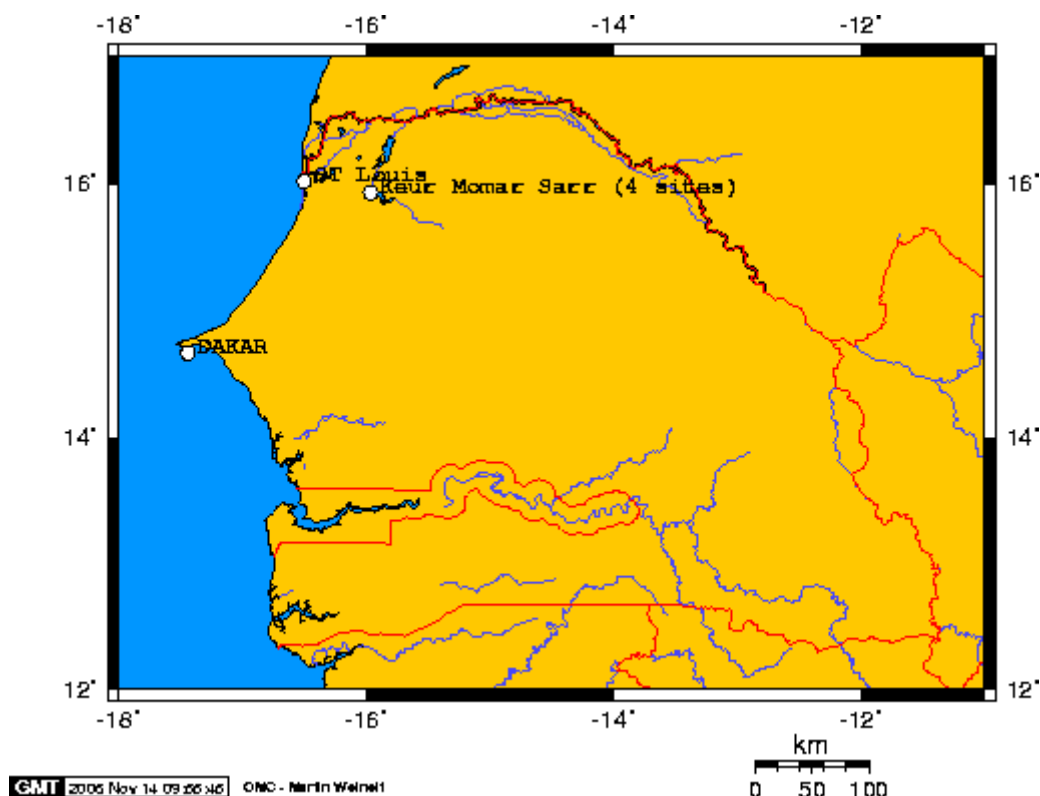
After one month, adults were harvested daily by hand and were stored in plastic jars with water lettuce leaves until required for release.

### 3.2.3. Releases

On the first day of the release a ceremony gathered local authorities and the population at Keur Momar Sarr square to participate in the first ever biological control programme for an invasive water weed in Senegal. Releases were made at four sites in this area following this scheme (Table 3.1 and Figure 3.2):

**Table 3.1** Releases of the weevil *Neohydronomus affinis* in Senegal in 1994 and 1995.

Release date	Sites	Number of released weevils and tubs of plants
September 30, 1994	Niossor	375 adults + 11 tubs with infested plants
November 23, 1994	Dounou Keur Momar Sarr	3 tubs with infested plants
March 22, 1995	Bountou Gaale You Mac Yi	800 adults
April 24, 1995	Dounou Digue Dekh	850 adults
	<b>Total</b>	2025 adults and 14 tubs with infested plants



Map source : [http://www.aquarius.ifm-geomar.de/make\\_map.html](http://www.aquarius.ifm-geomar.de/make_map.html)

**Figure 3.2.** Releases of the weevil *Neohydronomus affinis*: Keur Momar Sarr-Lake Guiers (15°55'N329 – 15°57'W541)-4 sites: Niissor, Dounou Keur Momar Sarr, Bountou Gaale You Mac Yi and Dounou Digue Dekh.

### 3.2.4. Monitoring

Monthly post release surveys were conducted to monitor the number of healthy and damaged water lettuce plants per square metre. The wooden quadrat measured 0.30 m on one side, which gives 0.09 m<sup>2</sup>, thrown 10 times onto the mat of water lettuce, gives about 1 m<sup>2</sup> sample. So, a sample of 50 m<sup>2</sup> was monitored monthly and the number of damaged and healthy plants was recorded. Adult feeding scars and larval tunnels were observed from released and non released sites and their presence or absence recorded. In addition, the percentage coverage of water lettuce was estimated and photographs taken. Water physical parameters: pH, hardness, conductivity, temperature at 10 cm above the water, temperature at 50 cm below the water surface; the relative humidity, the wind speed, the water height and the Lake Guiers water coverage; were recorded at one site the first day of release from the Senegalese Society of Waters (SONEES) at Nguith Station located at Lake Guiers.

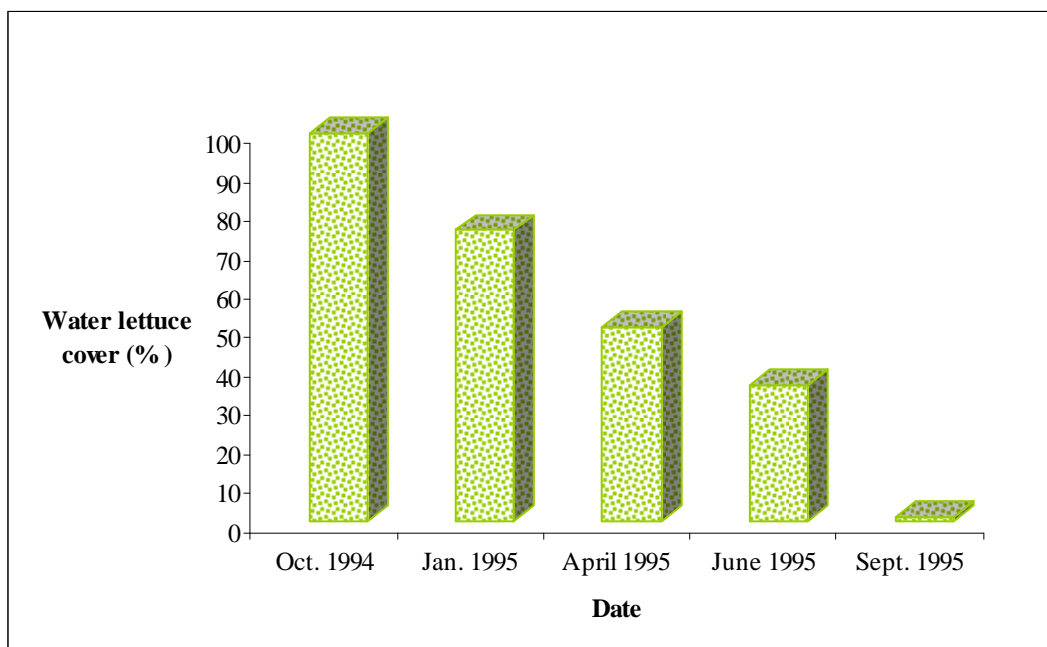
### 3.2.5. Statistics

Two variables healthy vs damaged water lettuce plants were monitored at field; analysed and plotted using ANOVA at p level for significance = .05 (Software Statistica ver.7).

### 3.3. Results

Physical parameters were measured on the first day of release at site Niossor: pH (7.8), hardness (7), conductivity (328  $\mu\text{s.cm}^{-1}$ ), temperature at 10 cm above the water (24°C), temperature at 50 cm below the water (20°C); the relative humidity (75%), the wind speed (3 to 4.5m/s), the water depth (2.15m), the monitored conductivity (328  $\mu\text{s.cm}^{-1}$ ) and the Lake Guiers coverage (270  $\text{km}^2$ ).

Water lettuce mats were impressive in Keur Momar Sarr at Lake Guiers (15°56N068 – 15°58W098). The area covered by *P. stratiotes* had been evaluated before releases to cover 2,034 ha. Following the first release in October 1994 and onwards, in all sampled sites at Lake Guiers, the coverage was visually estimated in percentage. So, the overall percentage incidence of water cover by *P. stratiotes* decreased by about 25% every two months causing the water lettuce mats to crash by the end of September 1995 at Lake Guiers (Figure 3.3). Media reporting on the success of biological control against water lettuce are indicated in Appendix 3.1.



**Figure 3.3.** Change in water lettuce cover (%) after release of *Neohydronomus affinis* at Lake Guiers from October 1994 to September 1995.

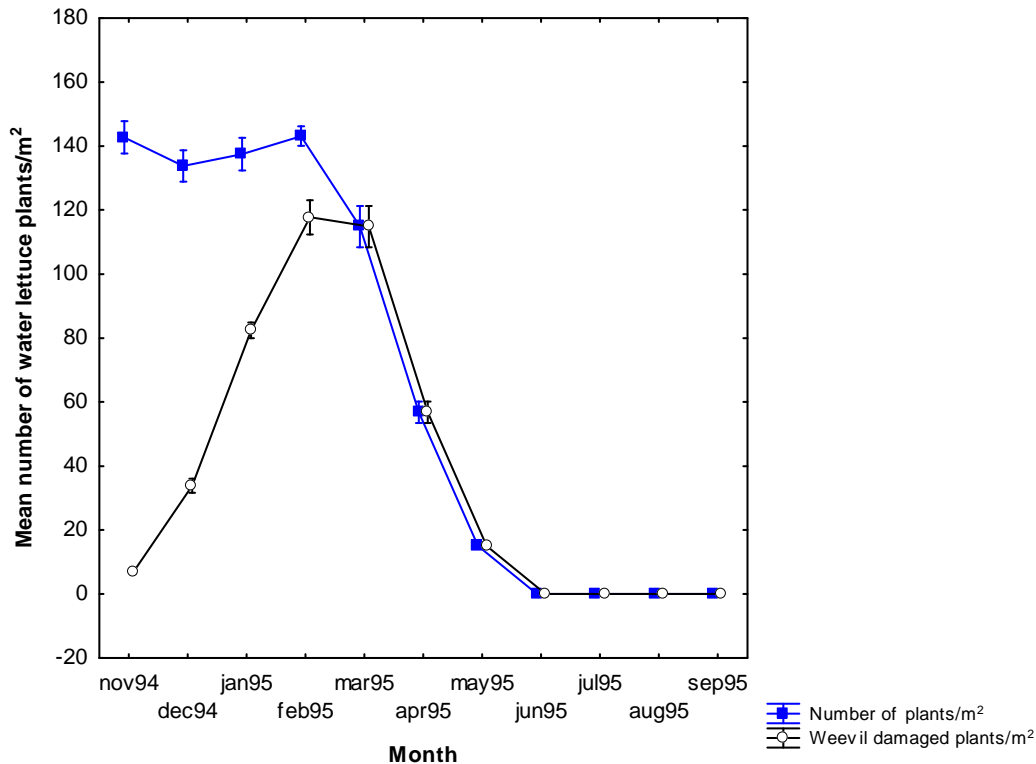
Monitoring at Lake Guiers revealed the presence of the weevils and feeding activity at the five released sites: Dounou Keur Momar Sarr, Dounou Digue Dékh, Bountou Gaal You Mac Yi and Nioissor but also the weevils colonized on their own two other sites: Dounou Keur Cheikh and Golfamerina. By August 1995, all sites were cleared of water lettuce (Table 3.2).

**Table 3.2.** Observations on *Neohydronomus affinis* at several field sites in Lake Guiers.

		<b>Dounou Keur Momar Sarr</b>	<b>Dounou Digue Dékh</b>	<b>Bountou Gaal You Mac Yi</b>	<b>Nioissor</b>	<b>Dounou Keur Cheikh</b>	<b>Golfamerina</b>
<b>Date of release</b>		23 Nov. 1994	24 Apr. 1995	22 Mar. 1995	30 Sep. 1994	No release made	No release made
<b>Date of observation</b>	Nov. 94	0	0	0	F, T, A	0	0
	Dec. 94	0	0	0	F, T, A	0	0
	Jan. 95	F, T, A	0	0	F, T, A	0	0
	Feb. 95	0	0	0	F, T, A	0	0
	Mar. 95	F, T, A	0	0	F, A	F	F, T, A
	Apr. 95	F, T, A	0	0	0	F, T, A	F, T, A
	May. 95	F, T, A	F, T, A	F, T	0	F, T, A	F, T, A
	Jun. 95	0	F, T, A	0	0	F, T, A	0
	Jul. 95	0	F, T	F, T	0	F, T, A	0
Aug. 95	0	0	0	0	0	0	

F: adult feeding scar  
T: larval tunnel  
A: adult observed  
0: none observed

Damaged water lettuce plants were visible from November 1994, and were obvious thereafter up to February 1995. By March 1995, all monitored plants were damaged as the mean number of plants sharply decreased from 140 plants in November 1994 to 5 plants/m<sup>2</sup> in May 1995 (Figure 3.4). Significant differences over time in mean number of plants and damaged plants were found respectively at  $F(10;539) = 1416.08$  and  $F(10;539) = 1041.40$  at  $p < .05$ .



**Figure 3.4.** Mean number of water lettuce plants/m<sup>2</sup> vs. weevil damaged plants/m<sup>2</sup> during the post release monitoring from November 1994 to September 1995 at Lake Guiers.

Plants/m<sup>2</sup>:  $F_{(10;539)} = 1416.08$ ;  $p < .05$ ; Weevil damaged plants/m<sup>2</sup>:  $F_{(10;539)} = 1041.40$ ;  $p < .05$ .

### 3.4. Discussion

The spread and distribution of *N. affinis* started two months after release. It was important to notice that, even though releases were not made at Djoudj Park which is located more than 150 km by water northwards of the release sites, adult weevils were recovered there four months later. Lake Guiers and Djoudj Park waterbodies are tributaries of the Senegal River which may explain this situation. Similar spread of *N. affinis* without deliberate human effort supports the results in Benin (Ajuonu and Neuenschwander, 2003), Zimbabwe (Chikwenhere and Forno, 1991) and Australia (Harley *et al.*, 1990).

Water coverage by water lettuce at Lake Guiers declined by 25 % in January 1995 and 50% in April 1995. Many plants were severely damaged. By June 1995, a general decline of 65% in water coverage by water lettuce was observed and it was concluded that biological control was being successful (Figure 3.3). Eight months after releases of the weevil at Lake Guiers, the green mats of water lettuce that persisted prior to biological control, turned brown dark, died and the mats started to sink by August 1995. These good results exemplify the ones recorded out in Australia (Harley *et al.*, 1984), South Africa (Cilliers, 1987; Cilliers *et al.*, 2003; Moore,

2005), Zimbabwe (Chikwenhere and Forno, 1991), Côte d'Ivoire (Zebeyou Mesmer, pers. Communi., 2000), Benin (Ajuonu and Neuenschwander, 2003), and more recently the Republic of Congo (Mbatu and Neuenschwander, 2005). In addition, without further *N. affinis* releases, all water lettuce mats were destroyed by the natural enemy at Djoudj Park water bodies, 150 km from the release site within 18 months. This indicates the potential of the weevil to spread long distances from strategically selected release sites.

The biological control was effective at Lake Guiers. *Neohydronomus affinis* has reduced the large area covered by water lettuce to very low infestations, less than 1% in September 1995. Since then, the water lettuce population has been stable and no longer poses a great problem in Senegal. However, water lettuce resurgence has recently been observed in 2005 in the Senegal River Delta and in the Niayes (area located between Saint Louis and Dakar). As stated by Cilliers *et al.* (1996), in biological weed control there is no eradication of the target plant but the aim is to bring the weed population down to an environmentally/ecologically acceptable level. Consequently, new releases of the biological control have been prompted (Chapter 4).

### **3.5. Conclusion**

Good numbers of the weevil *N. affinis* were reared and released leading to successful biological control of water lettuce in Senegal. Several factors have contributed to the success of this programme, including the tropical climate of Senegal, which allowed rapid increases in *N. affinis* populations. Again, the benefits of exploiting biological control agents against water lettuce that have succeeded elsewhere in the world has been verified. However, vigilance does need to be maintained on the situation throughout the waterbodies in the country for enforcement of surveillance and an early warning system.

## Chapter 4

### **Evaluation of biological control of *Pistia stratiotes* Linnaeus (Araceae) at three additional sites in the Senegal River Delta and in the Niayes, and reasons for its appearance and subsequent control**

#### **4.1. Introduction**

Since 1995, water lettuce has not been considered problematic in Senegal as it was normally kept under control by the biological control agent, *Neohydronomus affinis*, which was first mass released in 1994 (Chapter 3). Since the successful control of water lettuce at Lake Guiers and Djoudj Park, no other severe infestations were reported around the country. However, in 2005 resurgence of the weed was noticed in a few parts of the Senegal River Delta and outside in the Niayes, an area located northwest between the capital Dakar and Saint Louis with an economy based on horticulture and vegetable crops.

The areas infested were located in Ndiawdoune Bridge on the Gorom Lamsar River, the Thiagar Pumping Station on the Senegal River, the Richard Toll Bridge on the Taouey River and in a reservoir at Passe 77-ICS Mboro in the Niayes. Even though the control agent *N. affinis* had been recovered during our survey in September 2005 in some areas of the Senegal River, these infested areas did not show signs of the weevil being there. In the case of Passe 77-ICS Mboro, the newly introduced aquaculture and horticultural activities were threatened. People could not use chemical control because of its bad side effects on the ecosystems and their environment, nor manual removal, which was considered too costly and ineffective. So, they called for biological control. Thus, these considerations have prompted a course of action to manage the weed as early as possible with biological control.

What are the reasons for water lettuce appearance? The resurgence of the weed ten years after control could be explained by the absence or low population levels of the weevil at the infested sites. Will new releases be able to control the weed again? We have seen that under eutrophic conditions in the laboratory (Chapter 2) and in previous field work (Chapter 3) that the weevil *N. affinis* has demonstrated its ability to control water lettuce. Therefore, this chapter reviews post release evaluation of biological control of water lettuce at three infested sites:

Ndiawdoune Bridge, Passe 77-ICS Mboro and Thiagar Pumping Station.

#### **4.1.1 Aim**

The aim of this study was to verify that the negative impacts on plant fitness, which were shown in the laboratory trial, are being realized in the field.

## **4.2. Materials and Methods**

#### **4.2.1. The natural enemy *Neohydronomus affinis***

The weevil *Neohydronomus affinis* was again imported from the Plant Protection Research Institute, Pretoria, South Africa as described in Chapter 2.

#### **4.2.2. Mass rearing**

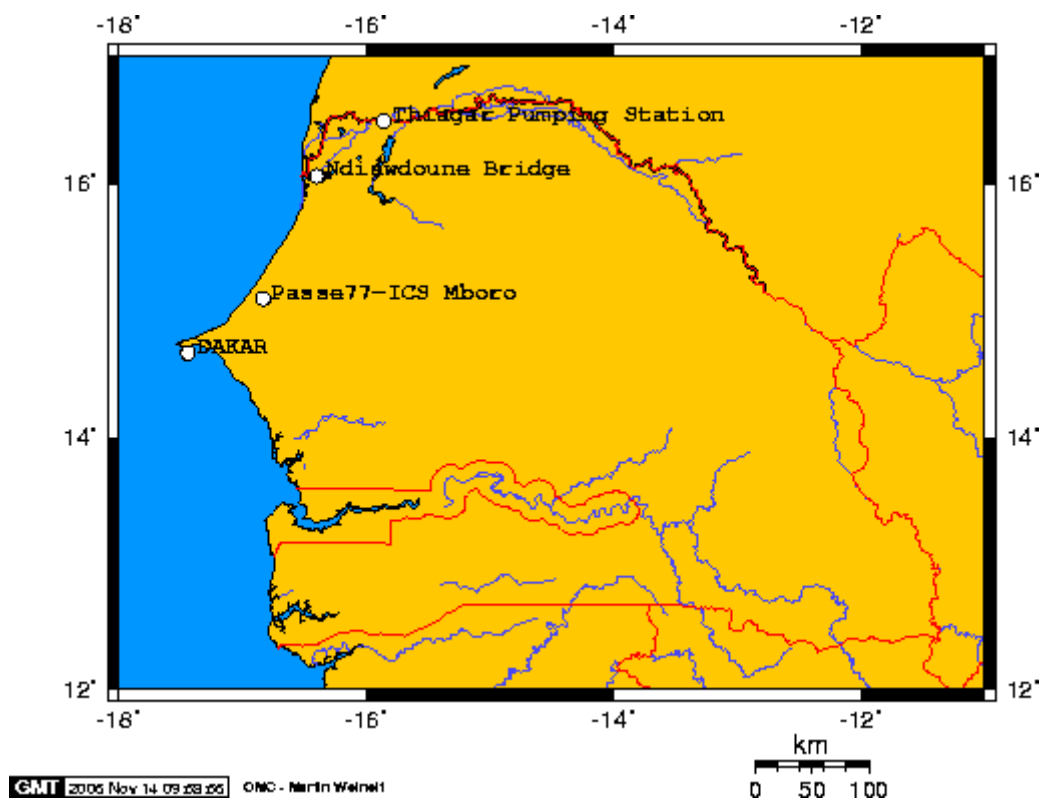
Mass rearing started in September 2005 with a start-up colony of 240 *N. affinis* weevils in the Plant Protection Directorate's greenhouse. They were reared in 15 plastic tubs (diameter 40 cm, depth 19 cm), filled with tap water with a pH of 7.47 and a conductivity of 560  $\mu\text{s}$ . During the mass rearing period, ambient temperature and relative humidity varied between 29°C and 83% (8am), 38°C and 52% (noon) and 32°C and 65% (5pm). Each tub contained 8 to 10 water lettuce plants, which were inoculated with 16 adult weevils. Fresh plants were added as needed. Water and nutrients (same as Chapter 3) were added to ensure good development of the plants. Adults started emerging 25 days after inoculation. A week before the releases, adult weevils were collected daily by hand, with the aid of fine hair brushes and stored in small plastic boxes with fresh water lettuce leaves, covered with a fine nylon fabric. For the purpose of this study, 561 weevils were collected by November 2005.

#### **4.2.3. Pre-release field surveys**

Extensive field surveys were completed between September and November 2005 in the Senegal River and Lake Guiers to map areas where water lettuce is of concern and to choose the 4 stations at which the weevils would be released. The areas covered by the weed were calculated by using a Global Positioning System (GPS XL 12 Garmin).

#### **4.2.4. Field release**

In November 2005, 553 weevils were released at four sites with 100 at Ndiawdoune Bridge (16°03'N245-16°24'W068), 100 at Thiagar Pumping station (16°29'N046-15°51'W313), 153 at Taouey/Richard Toll Bridge (16°27'N480-15°41'W340) and 200 at Passe 77-ICS Mboro (15°05'N493-16°50'W181) (Figure 4.1).



Map source: [http://www.aquarius.ifm-geomar.de/make\\_map.html](http://www.aquarius.ifm-geomar.de/make_map.html)

**Figure 4.1.** Release sites of the natural enemy *Neohydronomus affinis* at Ndiawdoune Bridge (16°034N245-16°24W068), Thiagar Pumping station (16°29N046-15°51W313) and Passe 77-ICS Mboro (15°05N493-16°50W181).

#### 4.2.5. Monitoring

Monthly monitoring started in December 2005 for three of the sites: Ndiawdoune Bridge, Thiagar Pumping station and Passe 77-ICS Mboro. The 4<sup>th</sup> site, Taouey/Richard Toll Bridge, could not be monitored because the mat of water lettuce was washed away.

For sampling, the number of water lettuce plants was counted per square meter by randomly throwing a PVC quadrat (a quadrat is one tenth of a square meter and is made from a PVC piping to make a frame which is 33cm x 33 cm to give 0.1 m<sup>2</sup> in the inner measurement) ten times onto the mat of water lettuce giving about 1 m<sup>2</sup>. In the meantime, 4 plants were sampled per thrown quadrat giving a total of 40 plants per site for the quantification of six parameters: wet weight, length of longest leaf, length of roots, number of leaves, number of daughter plants, number of adults and damage score using the same scale described as with the laboratory exclusion experiment test in Chapter 2. In addition, the total water surface and the area covered by the water lettuce were determined with a GPS. Temperature and relative

humidity were measured using a pen-type thermo-hygrometer; water conductivity and pH using a digital pH-meter. Photographs were also taken to assess the biological control progress.

#### **4.2.6. Statistics**

A General Linear Models GLM-ANOVA and post hoc Tukey HSD test were used to investigate insect damage and water lettuce growth rate variables over time at p level for significance = 0.05. The STATISTICA software (Version 7.0) package was used to conduct the analysis.

#### **4.3. Results**

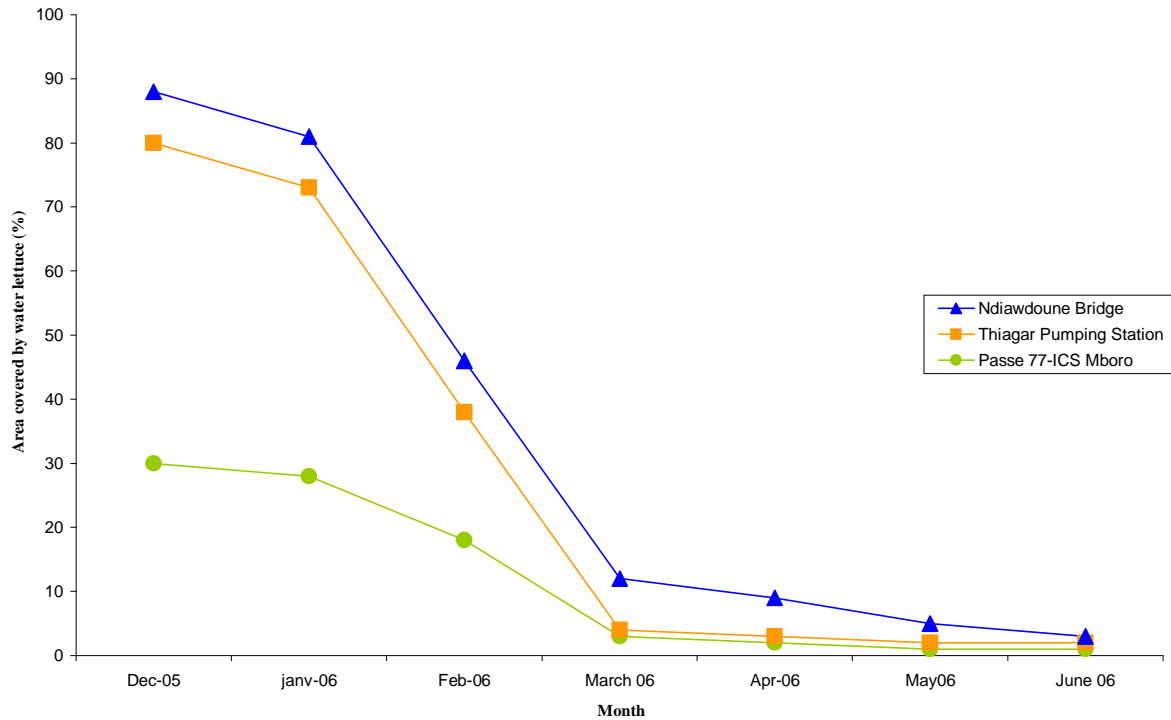
Seven periods separately for each of the parameters and locations were calculated. The introduction of the weevil to all three sites resulted in a significant reduction in all of the plant growth parameters measured. Thus, the ANOVA showed significant differences for all the parameters at Ndiawdoune Bridge, Passe77 ICS Mboro and Thiagar Pumping station (Table 4.1).

**Table 4.1.** Post release results ANOVA on water lettuce plant variables from December 2005 to June 2006 at Ndiawdoune, Passe77 ICS Mboro and Thiagar sites (stars indicate differences at  $\alpha=0.95$  level of significance).

<b>NDIAWDOUNE</b>					
<b>Variable</b>	<b>SS</b>	<b>df</b>	<b>MS</b>	<b>F</b>	<b>p</b>
Wet Weight (g)	976107.1	6	162684.5	30.2202	0.00*
Longest Leaf Length (cm)	3010.1	6	501.7	182.9355	0.00*
Root Length (cm)	39234.0	6	6539.0	218.5472	0.00*
Number of Daughter Plants	984.3	6	164.1	68.2088	0.00*
Number of Adults	874.7	6	145.8	57.6560	0.00*
Damage Score	909.8	6	151.6	937.6121	0.00*
<b>PASSE77 ICS MBORO</b>					
<b>Variable</b>	<b>SS</b>	<b>df</b>	<b>MS</b>	<b>F</b>	<b>p</b>
Wet Weight (g)	381285.9	6	63547.65	147.746	0.00*
Longest Leaf Length (cm)	4224.2	6	704.04	557.555	0.00*
Root Length (cm)	26891.8	6	4481.97	411.733	0.00*
Number of Daughter Plants	978.1	6	163.03	92.499	0.00*
Number of Adults	974.5	6	162.42	53.710	0.00*
Damage Score	885.5	6	147.59	1455.871	0.00*
<b>THIAGAR PUMPING STATION</b>					
<b>Variable</b>	<b>SS</b>	<b>df</b>	<b>MS</b>	<b>F</b>	<b>p</b>
Wet Weight (g)	951330.6	6	158555.1	123.493	0.00*
Longest Leaf Length (cm)	4915.9	6	819.3	263.189	0.00*
Root Length (cm)	23612.0	6	3935.3	234.065	0.00*
Number of Daughter Plants	1190.7	6	198.4	91.188	0.00*
Number of Adults	190.8	6	31.8	38.017	0.00*
Damage Score	933.7	6	155.6	1218.151	0.00*

#### 4.3.1. Percentage coverage of water lettuce

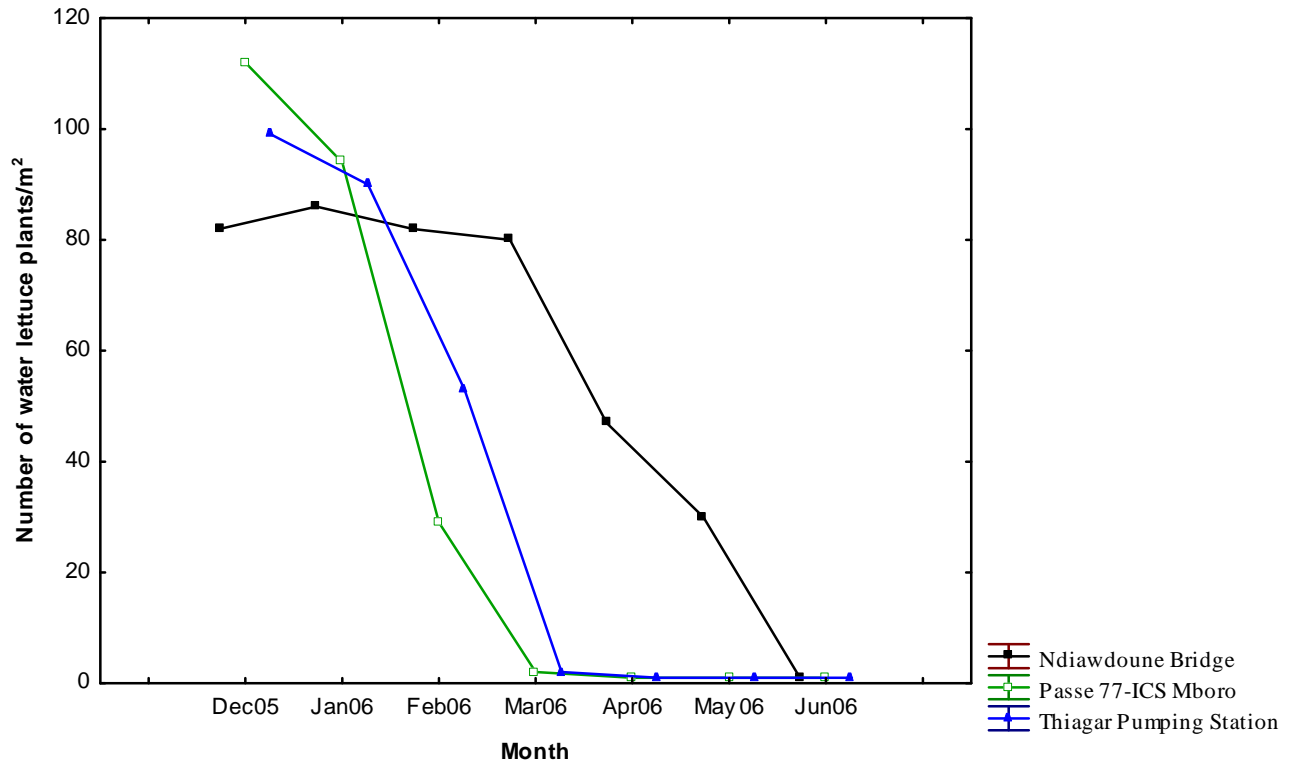
Prior to the release of the weevil, the areas covered by the water lettuce were: Thiagar Pumping Station (0.4038 ha = 80% of the total water surface area = 0.5048 ha); Passe 77-ICS Mboro (2.9625 ha = 30% of the water surface area = 9.875 ha); Ndiawdoune Bridge (16.6624 ha = 88% of the total water surface area = 18.9346 ha). After release, all sites showed a marked decrease in the surface area covered by the weed over the duration of the monitoring (Figure 4.2).



**Figure 4.2.** Percentage water covered by water lettuce after weevil release in November 2005 at the 3 sites: Ndiawdoune Bridge, Thiagar Pumping Station and Passe 77-ICS Mboro from December 2005 to June 2006.

#### 4.3.2. Number of plants per square metre

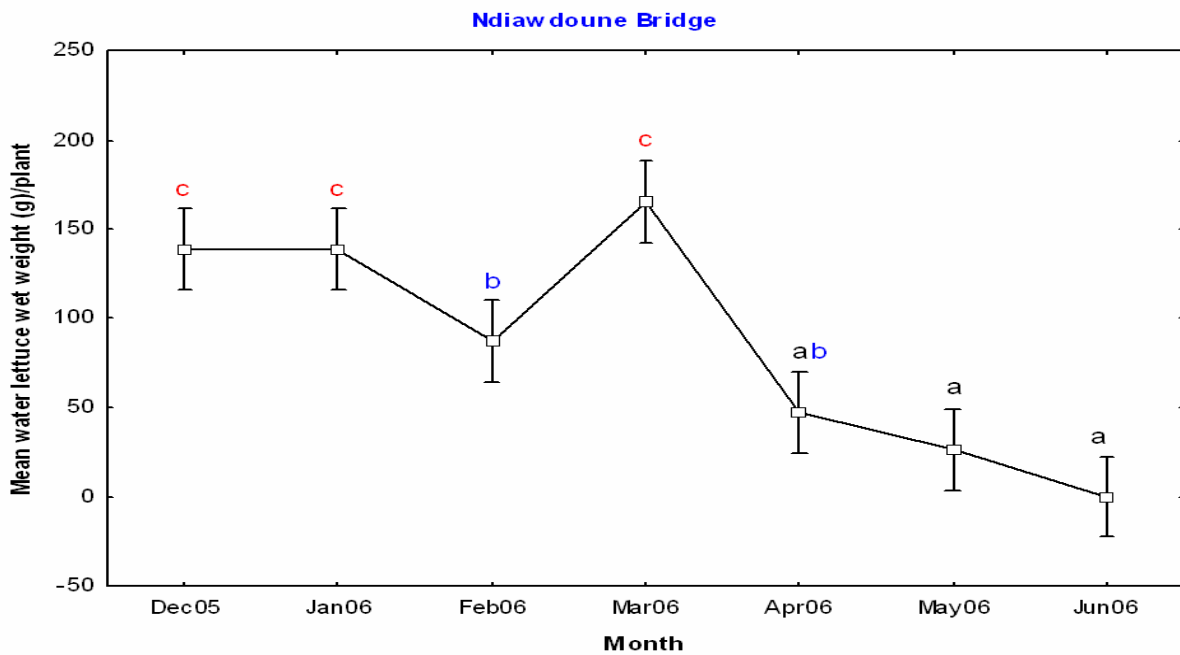
The number of plants per square metre decreased sharply between January and February 2006 at Passe 77-ICS Mboro ( $M = 34.2857143$ ;  $SD = 48.3036033$ ) and Thiagar Pumping Station ( $M = 35.2857143$ ;  $SD = 44.7240215$ ). Meanwhile, at the third site Ndiawdoune Bridge (Mean =  $58.2857143$ ; Standard Deviation =  $33.0994173$ ), the number of plants per square metre remained unchanged (80 to 86) up to March and then rapidly decreased until there were no plants left at the site by June (Figure 4.3). The problem encountered with the fixed quadrat sampling technique was that as soon as most of the mat had collapsed, most of the quadrats recorded zero plants although there were still plants at the sites and thus the number of plants per area was underestimated by this technique. However, at all sites there was a massive reduction in the percentage cover of water lettuce in a very short period of time.

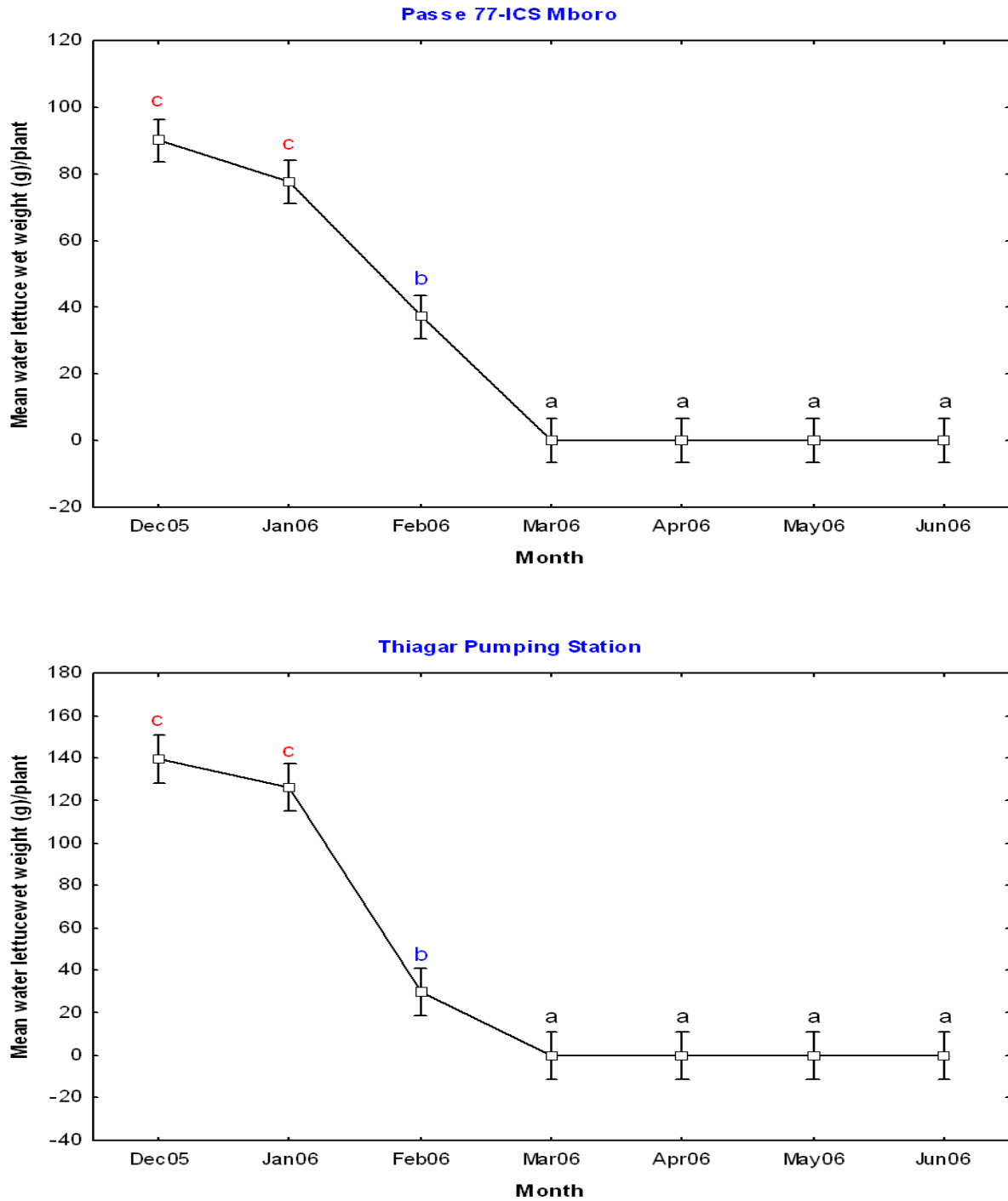


**Figure 4.3.** Number of water lettuce plants per square metre after weevil release in November 2005 at the 3 sites: Ndiawdoune Bridge, Passe 77-ICS Mboro, and Thiagar Pumping Station from December 2005 to June 2006.

### 4.3.3. Wet weight

Water lettuce wet weight was one of the best indicators of the impact of the weevils. The ANOVA and the post hoc Tukey test showed significant differences for the variable wet weight from February 2006 at the 3 sites (Figure 4.4). The wet weight progressively declined as the plants were damaged by the weevil at the two sites Passe 77-ICS Mboro and Thiagar Pumping Station. At those 2 sites a general water lettuce mass decrease was observed from January 2006 and the monitoring was stopped by March 2006 because the biocontrol gave successful results (Figure 4.4). Instead, a decrease, followed by an increase of the wet weight was observed in February and April 2006 at Ndiawdoune Bridge. This situation could have been explained by the exceptional cool temperatures (not recorded) at the site from November 2005 to February 2006 preventing good performance of the weevils. However, in June 2006, the mat of water lettuce was destroyed by the weevils (Figure 4.4).

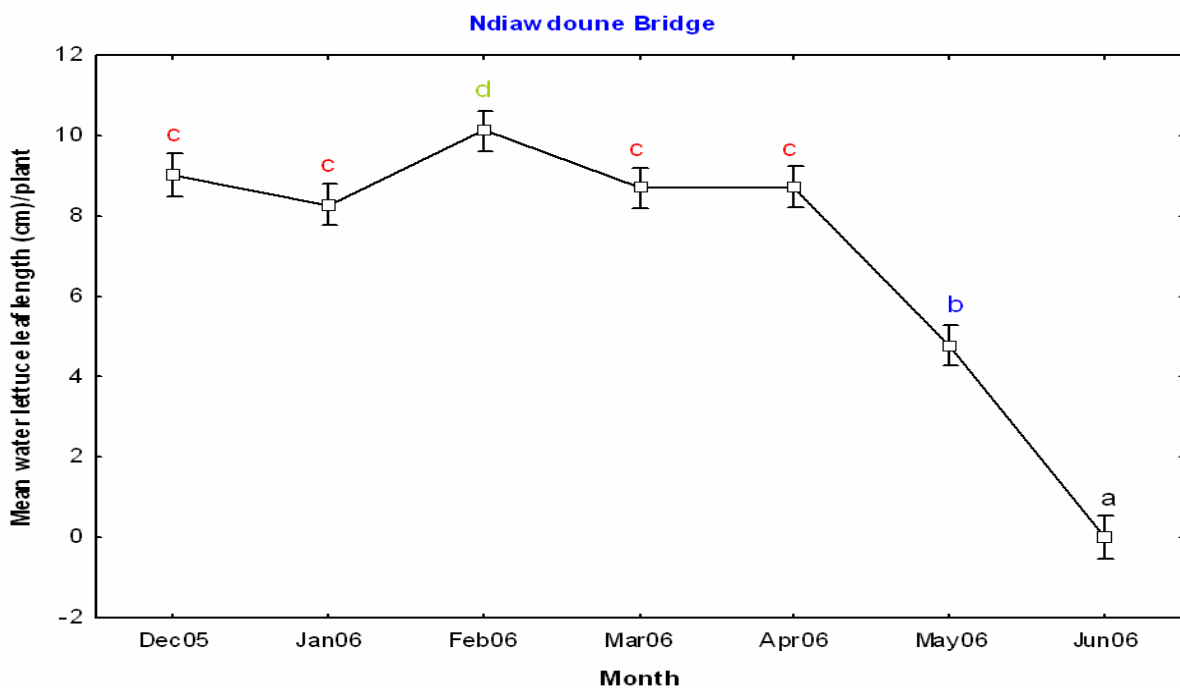


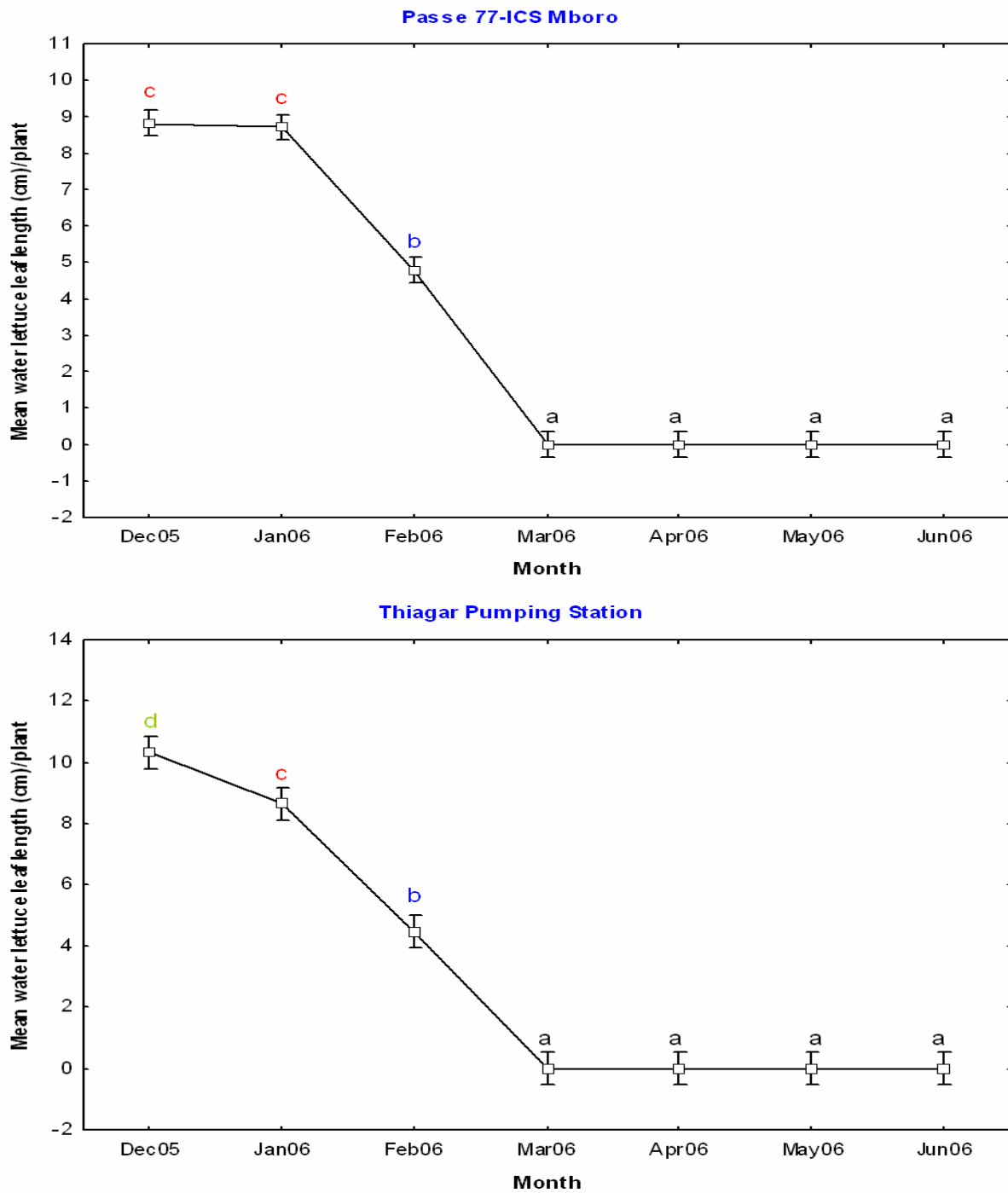


**Figure 4.4.** Mean water lettuce wet weight per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=30.2202$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=147.746$ ;  $df=6$ ) and Thiagar Pumping Station ( $F=123.493$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.

#### 4.3.4. Leaf length

The longest leaf within the water lettuce rosette was measured. Fluctuation of this parameter was observed at Ndiawdoune Bridge where instead of a decrease 2 months after release, an increase was observed in February 2006 (Figure 4.5). In January 2006 the mean length of leaf reached as much as 8 cm at Passe 77-ICS Mboro and Thiagar Pumping Station, but become far smaller thereafter. Mean leaf size declined as plant growth was affected by the weevil feeding damage. The ANOVA and the post hoc Tukey test showed significant differences for the variable longest leaf length from February 2006 for Ndiawdoune Bridge and Passe 77-ICS Mboro and in January for Thiagar Pumping Station (Figure 4.5).

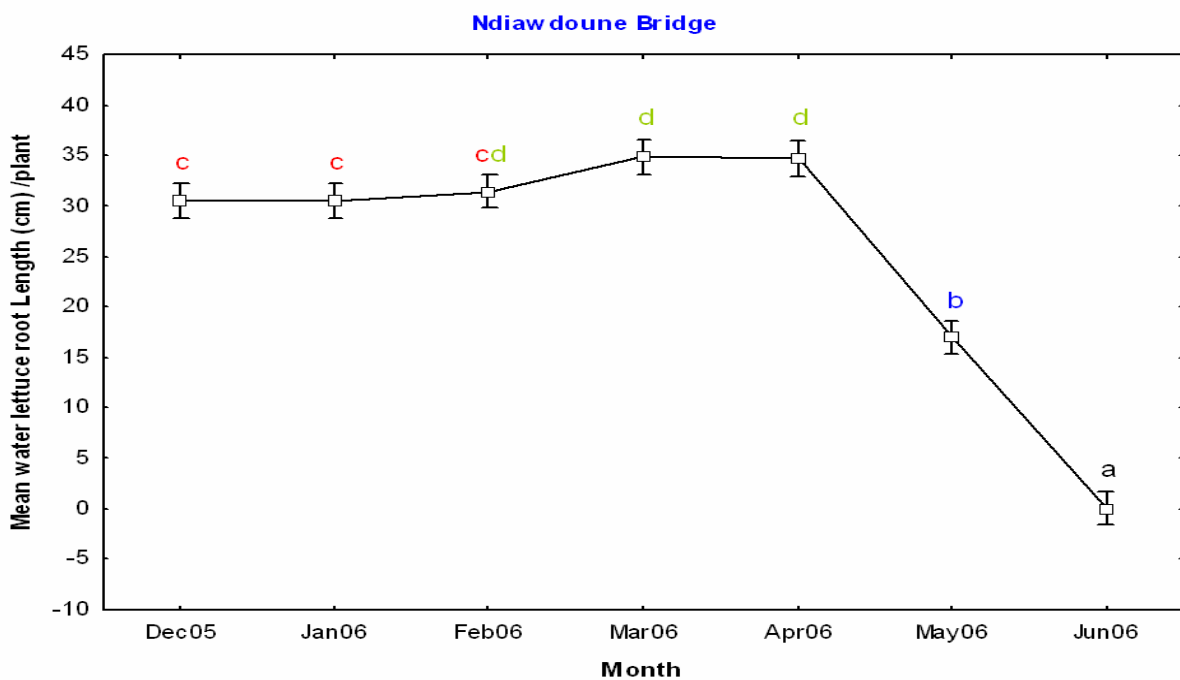


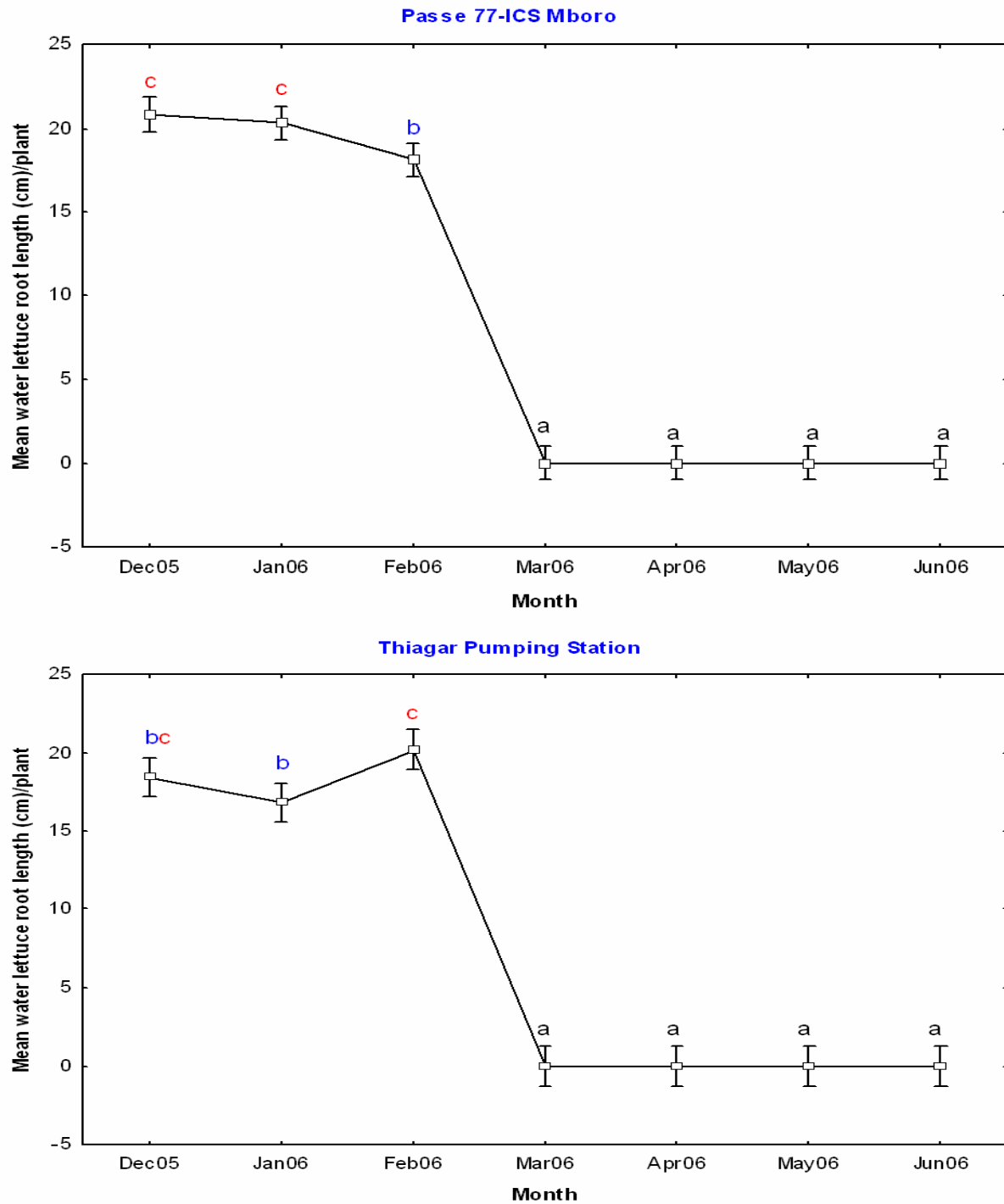


**Figure 4.5.** Mean water lettuce leaf length per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=182.9355$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=557.555$ ;  $df=6$ ), and Thiagar Pumping Station ( $F=263.189$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.

### 4.3.5. Root length

The ANOVA and the post hoc Tukey test showed significant differences for the variable root length at the 3 sites (Figure 4.6). Prior to the sinking of the upper part of water lettuce plants, many roots were progressively detached and sunk to the bottom of the water body. The length of roots was the factor which appeared to have the least variation over the monitoring period, particularly at Ndiawdoune Bridge where from December 2005 to April 2006, the roots all averaged 30 to 35 cm in length (Figure 4.6). The monitoring was stopped for the variable root length as the water lettuce mats were destroyed in March 2006 at Passe 77-ICS Mboro and Thiagar Pumping Station and later in June 2006 at Ndiawdoune (Figure 4.6).

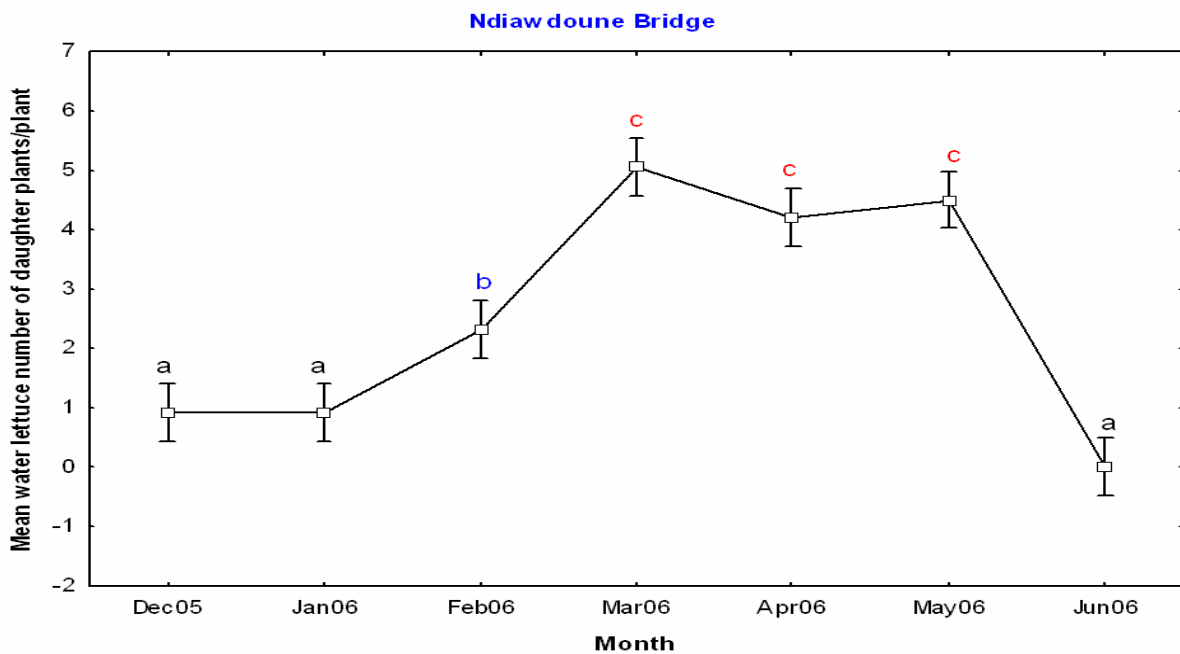


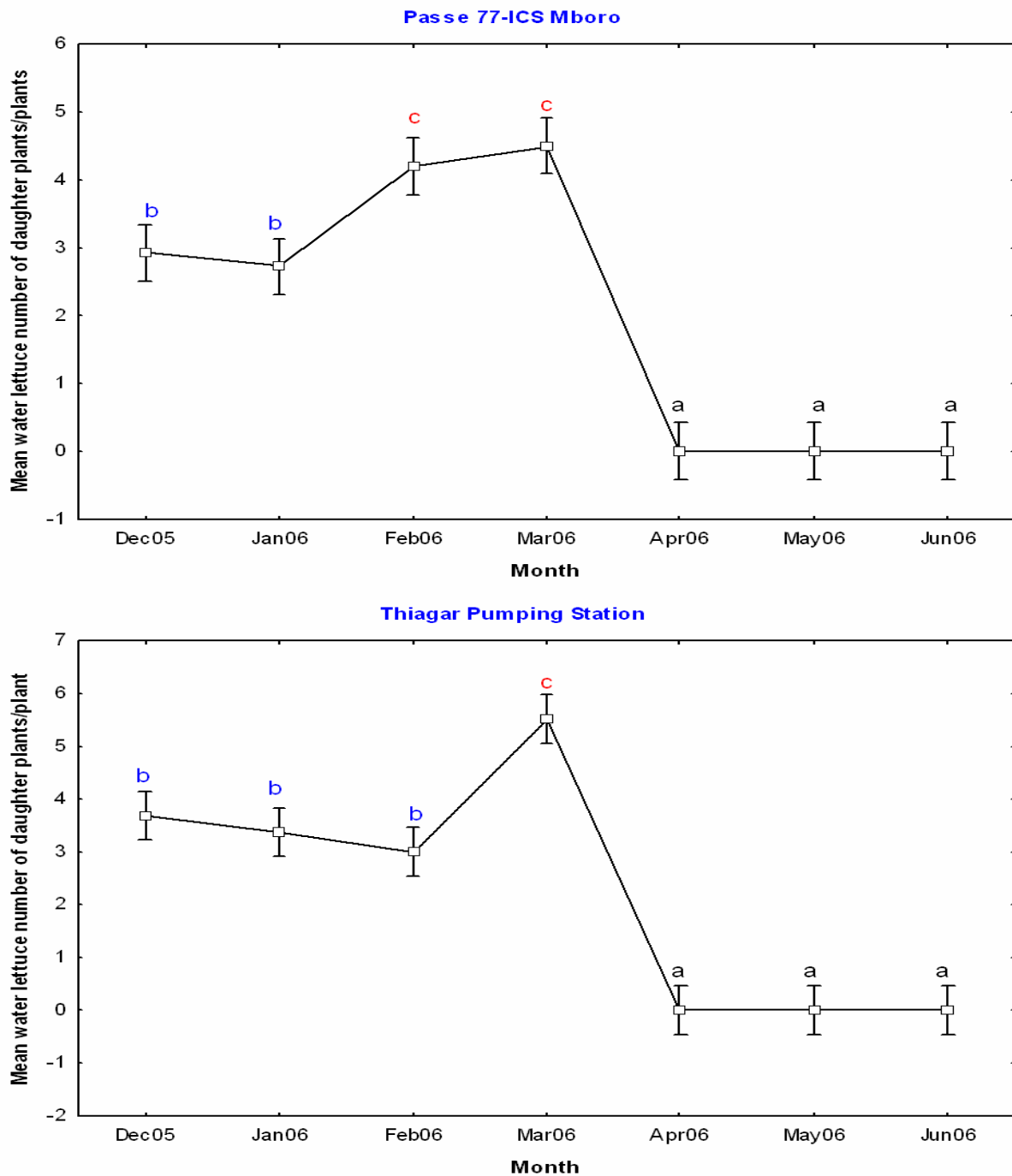


**Figure 4.6.** Mean water lettuce root length per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=218.5472$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=411.733$ ;  $df=6$ ) and Thiagar Pumping Station ( $F=234.065$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.

#### 4.3.6. Number of daughter plants

The ANOVA and the post hoc Tukey test showed significant differences for the daughter plants at the 3 sites as early as from February 2006 for Ndiawdoune Bridge, Passe-77-ICS Mboro and one month later for Thiagar Pumping Station (Figure 4.7). Daughter plants heavily damaged by the weevils failed to grow to the size of normal parent plants. A high number of daughter plants per plant was observed at Passe-77-ICS Mboro in January and in March 2006 at Thiagar Pumping Station. At all sites, parent plants produced more daughter plants by March 2006 before the plants crashed but they did not survive as they were severely damaged by the weevils. The number of daughter plants decreased to zero as the water surface was cleared of water lettuce at all sites (Figure 4.7).

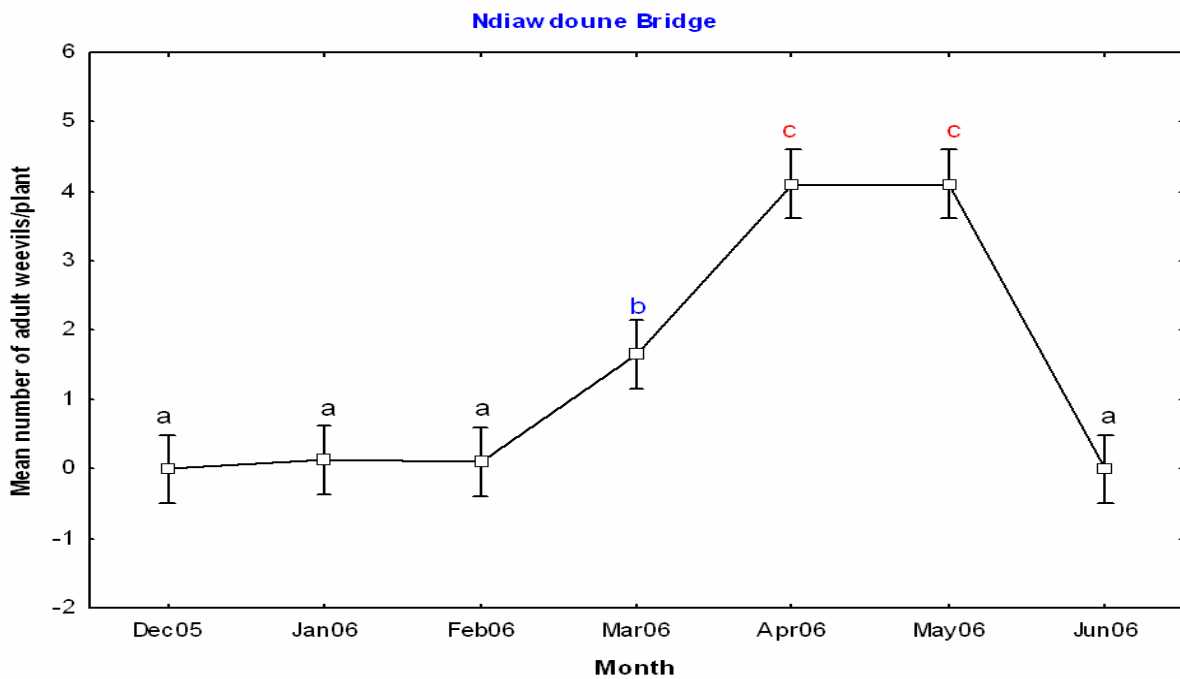


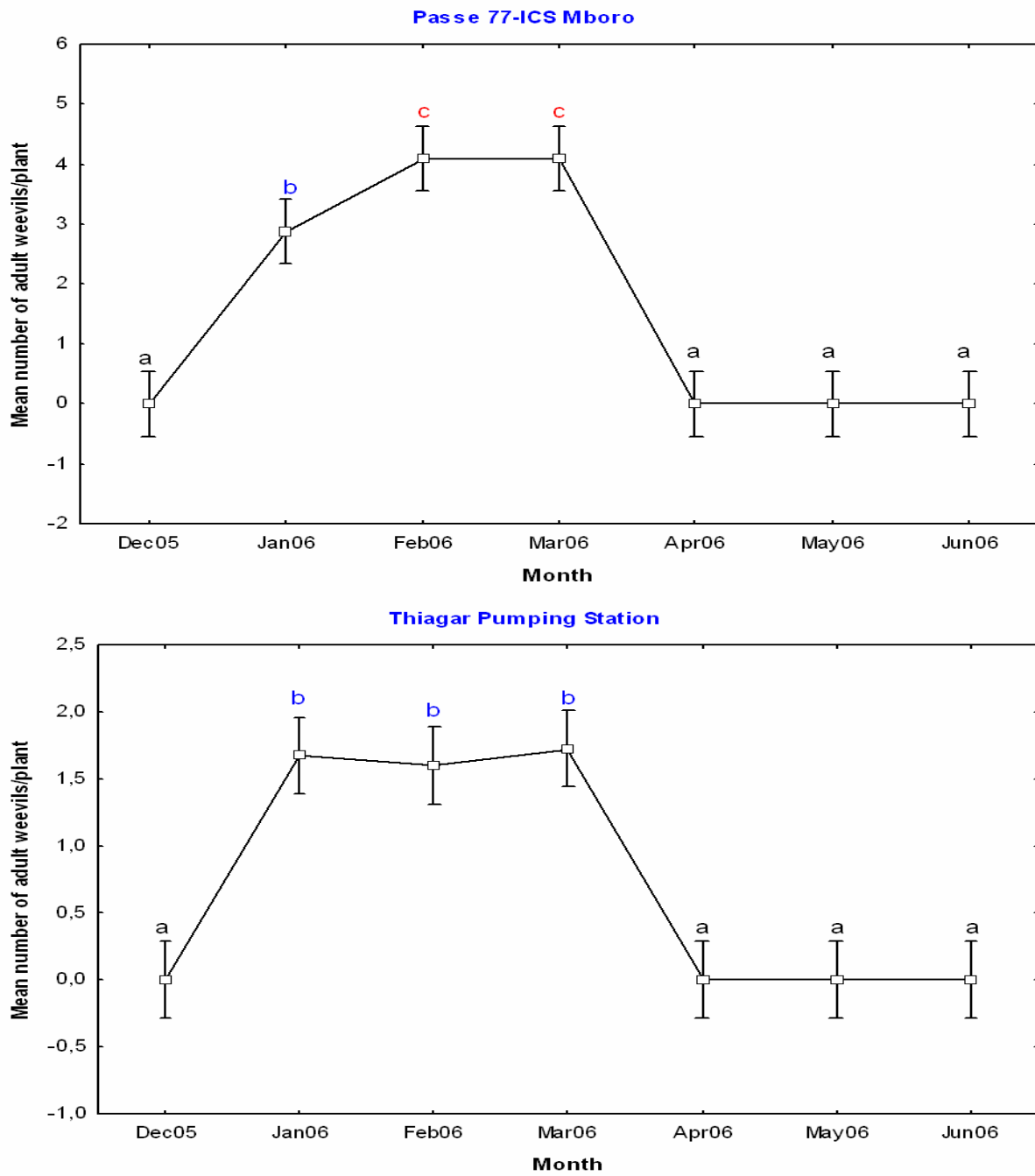


**Figure 4.7.** Mean water lettuce number of daughter plants per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=68.2088$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=92.499$ ;  $df=6$ ) and Thiagar Pumping Station ( $F=91.188$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.

#### 4.3.7. Adult weevil populations

The ANOVA and the post hoc Tukey test showed significant differences for the weevil numbers at the 3 sites (Figure 4.8). The number of adult weevils per plant was a good indicator of the establishment and spread of *N. affinis* at the release sites. The adult weevils were recovered at all three sites. By January 2006, a mean of 3 adults/plant  $\pm$ SE=0.108 was recorded at Passe 77-ICS Mboro. At Thiagar Pumping Station the weevil was less abundant at around 1 adult/plant  $\pm$ SE=0.108. However, at Ndiawdoune Bridge, weevil-free plants were observed up to February 2006 (Figure 4.8) but number increased to high number by April. The weevil populations were found to follow very similar trends over time to those of the plant populations. The drop off observed in April 2006 at Passe 77-ICS Mboro, Thiagar Pumping Station and in June 2006 at Ndiawdoune Bridge was due to the fact that there were no plants left for the weevils.

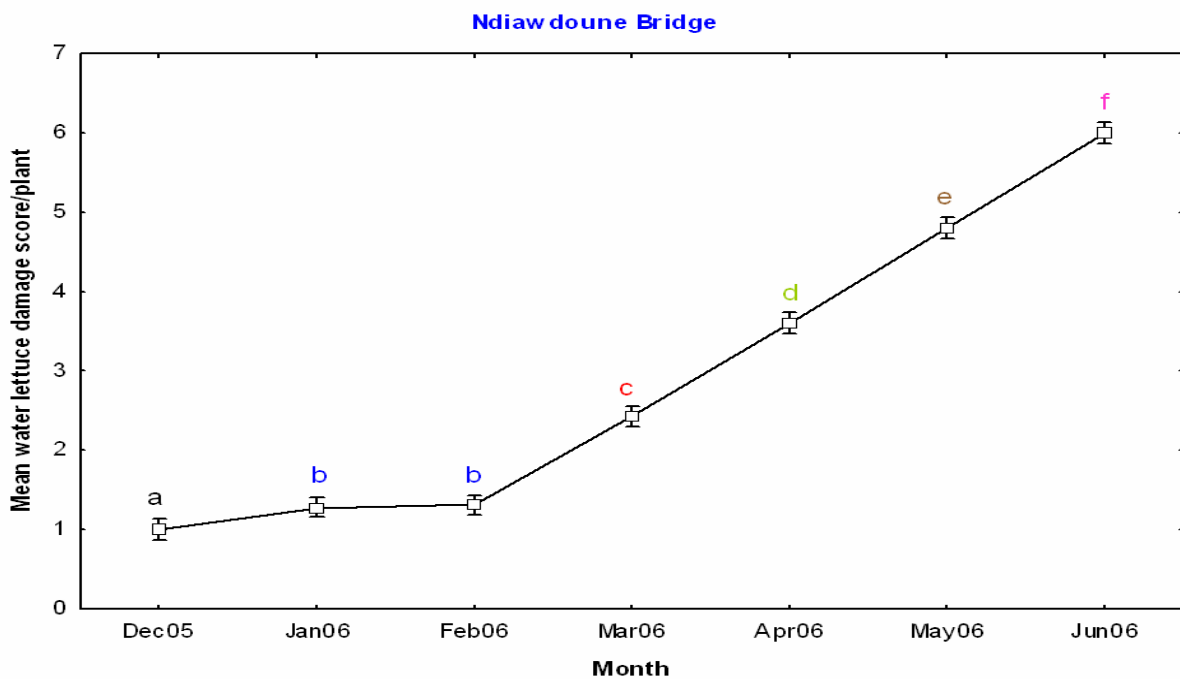


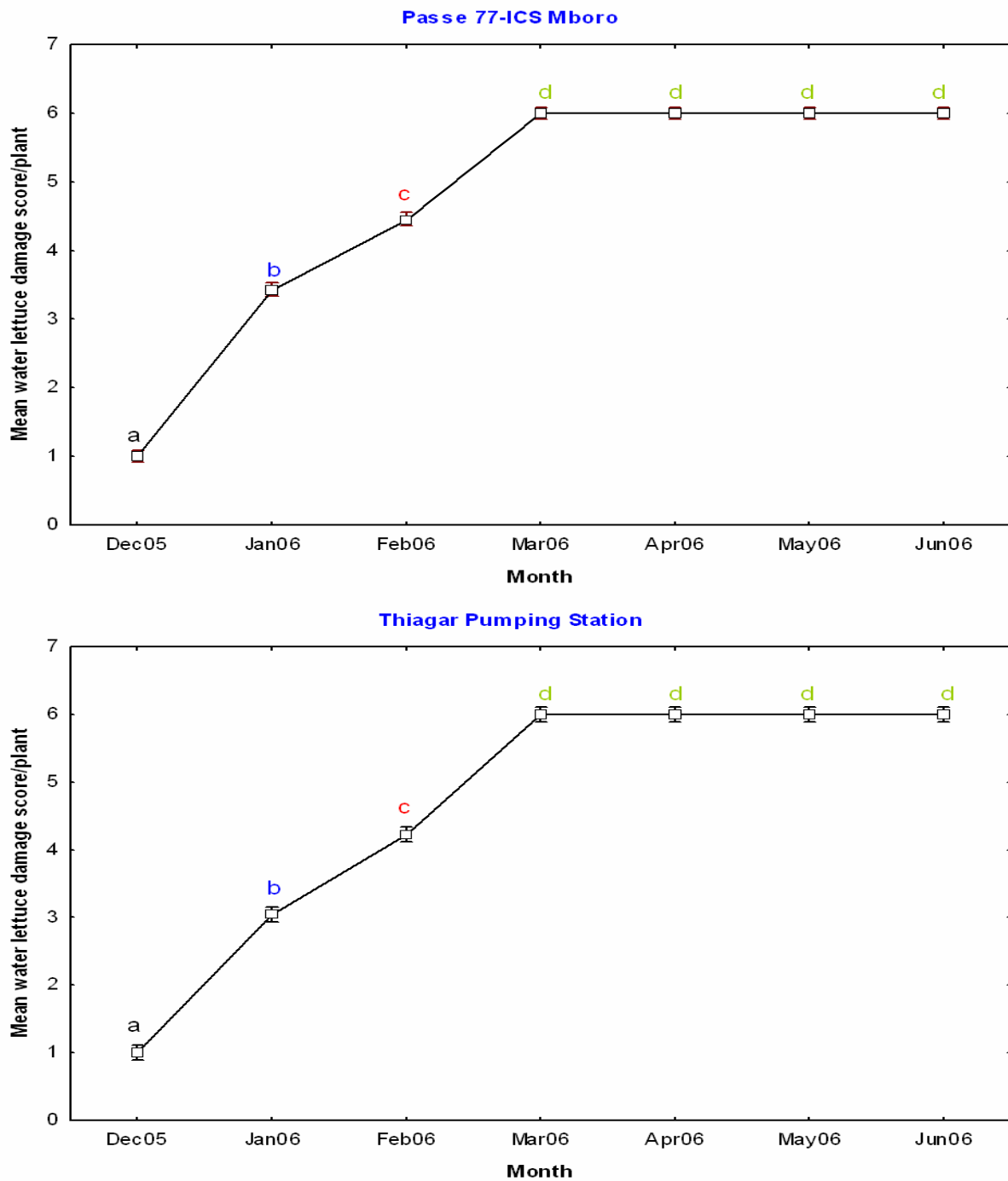


**Figure 4.8.** Mean number of adult weevils per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=57.6560$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=53.710$ ;  $df=6$ ), and Thiagar Pumping Station ( $F=38.017$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.

#### 4.3.8. Adult and larval weevil damage

Tunnelling activity and adult damage by *N. affinis* were high on water lettuce plants just two months after releases, notably at sites Passe 77-ICS Mboro and Thiagar Pumping Station where some plants were severely damaged by January 2006. Later on, very high damage scores (4 – 5) were reached prior to the death of water lettuce plants (Figure 4.9). At Ndiawdoune Bridge site, the weevil damage was much less up to April 2006 and, the weevils did not have the same rapid impact on water lettuce plants as they did at Passe 77-ICS Mboro and Thiagar Pumping Station. Highest score (6) indicating plant death was reached by March 2006 for Passe 77-ICS Mboro, Thiagar Pumping Station and in June 2006 for Ndiawdoune (Figure 4.9). The post hoc Tukey test showed significant differences for the adult weevil damage at the 3 sites (Figure 4.9). Therefore, the monthly post release evaluations were terminated because the water surface was cleared of water lettuce mats in March 2005 at Passe 77-ICS Mboro, Thiagar Pumping Station and in June 2006 at Ndiawdoune Bridge (Figures 4.10 and 4.11).





**Figure 4.9.** Mean water lettuce damage scores (from 1 to 6) per plant from monthly (December 2005 to June 2006) sampling of 40 plants at the 3 sites Ndiawdoune Bridge ( $F=937.6121$ ;  $df=6$ ), Passe 77-ICS Mboro ( $F=1455.871$ ;  $df=6$ ) and Thiagar Pumping Station ( $F=1218.151$ ;  $df=6$ ). Error bars denote standard deviation. Letters show mean difference following the Tukey HSD test for homogeneous groups.



**Figure 4.10.** A stand of water lettuce plants before the release of the weevil *Neohydronomus affinis* at Passe 77-ICS Mboro (November 2005).



**Figure 4.11.** After the release of the weevil *Neohydronomus affinis* at Passe 77-ICS Mboro (March 2006).

#### 4.4. Discussion

Lake Guiers and Djoudj Park experienced the first invasion of water lettuce in Senegal in 1993 (Chapter 3). Although the weed has not returned at these two sites, the resurgence of the weed at other sites may be explained by the fact that the water bodies are interconnected between the Senegal River and the Delta of the Senegal River. The infestation at Ndiawdoune Bridge on the Djeuss River may have been possible because it is a tributary of Senegal River. Meanwhile, the onset of the aquaculture programme may have resulted in the appearance of water lettuce at Passe 77-ICS Mboro. In effect, the starter population of tilapia fish brought from the Taouey River at Richard Toll may have carried seeds or plantlets of *P. stratiotes* without the natural enemy *N. affinis* and consequently infested the reservoir of Passe 77-ICS Mboro. The Taouey River connects the Senegal River and the Lake Guiers water bodies where insignificant patches of *P. stratiotes* can still be seen. Furthermore, another source of reinfestation by water lettuce may be by seeds. *Pistia stratiotes* has produced seeds in Senegal, agreeing with Holm *et al.* (1977) who reported that seed production occurs in Africa even though water lettuce populations expand mainly by vegetative propagation (Sculthorpe, 1967). Sexual reproduction of water lettuce occurred during the laboratory experiment in tubs where seed capsules, germinated seeds and seedlings were observed.

In Senegal there is no research institution or group of researchers specially dedicated to aquatic weeds as for terrestrial weeds. Only the Plant Protection Directorate (DPV) has an extension structure that deals with aquatic weeds and is responsible for importing, rearing and releasing natural enemies and evaluating biocontrol post-release of invasive weeds, notably water lettuce and salvinia that have so far infested the Senegal River and Lake Guiers. It was advantageous that DPV personnel who conducted the 1993/95 biological control project were in place since they already had acquired skills in this field. Furthermore, riverine human populations were sensitized to biological control and so it was easy to get them involved with the new programme. For instance, in the case of Passe 77-ICS Mboro, routine surveys could have not led to the detection of the invasion by water lettuce because the site is isolated and far from the main source of invasion, the Senegal River Delta. However, because the ICS plant technical manager was aware of the biocontrol success on water lettuce at Lake Guiers ten years ago, he called on DPV for biological control action. In addition, in Senegal, policy-makers are conscious that with exotic invasive aquatic weeds, only biological control can deliver long-term and environmentally safe results. All these considerations have made the reintroduction of

the weevil *N. affinis* to control water lettuce easy in terms of setting up the mass rearing unit, releases and monitoring.

The weevil *N. affinis* quickly established at all sites 2 to 3 months after the releases were made. It is essential to note that from a single release at each infested site, *N. affinis* spread to cover the whole infested area. Biological control was achieved within three months at Passe 77-ICS Mboro (Figures 4.10-4.11) and Thiagar Pumping Station; and seven months at Ndiawdoune Bridge Station. The rate of control was slower at Ndiawdoune Bridge where low temperatures are usually recorded in the area from November to February. Thus, the counts for insect-damaged plants may have been lower because the weevils were still spreading or sampling may have been between generations or because of slower breeding of the weevils in the cool season of the year. Similar observations were reported in South Africa by Cilliers (1987). Another explanation could have been that the waterbodies where *N. affinis* was released were eutrophic and so, the nutrient-enriched impoundment could have supported vigorous plant growth and permitted the plants to more than equilibrate for the disadvantageous effects of weevil damage. In South Africa, Cilliers (1991) reported that the proliferation of water lettuce, in the face of extensive weevil activity, was attributed to the high nitrogen content of the water which supposedly supported vigorous plant growth and permitted water lettuce plants to more than compensate for the detrimental effects of *N. affinis* damage. However, the activity of the weevil became apparent on water lettuce plants as the warm season progressed. Finally, the 3 sites had been totally cleared and monitoring terminated at the end of June 2006.

When comparing the results of the field experiments (weevil impact on wet weight, damage score, leaf length, root length, daughter plants and adult weevils) with those previously recorded in the laboratory (Chapter 2), they show that the negative impacts on water lettuce plants fitness which were shown in the lab trial were effectively realized in the field, making the two studies (laboratory and field) support each other.

#### **4.5. Conclusion**

The damage by water lettuce and the later alleviation of the problem was perceptible from observations and, more expressively, from declaration of staff members of the Chemical Industries of Senegal at Passe 77-ICS Mboro. Also, the restoration of the water body was well acknowledged by the villagers as rice farmers and fishermen at Thiagar Pumping Station and Ndiawdoune, who viewed the success of the biological control of water lettuce allowing them to return to their navigation, farming and fishing activities.

The biological control programme against *P. stratiotes* with *N. affinis* has been initiated and conducted successfully in Senegal. Once again, as reported from many parts of the world, the benefits of exploiting biological control have been clearly demonstrated. However, in view of the resurgence of *P. stratiotes* ten years after its first invasion in Senegal, further investigation will probably have to focus on in-depth biological and physical parameter studies of the water bodies to increase our knowledge of the succession of invasive aquatic weeds in the Senegal River and its tributaries.

## Chapter 5

### Laboratory studies on the control of the floating fern *Salvinia molesta* D.S. Mitchell (Salviniaceae) with the weevil *Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae)

#### 5.1. Introduction

In 1999, populations of *Salvinia molesta* invaded the Senegal River and other water bodies in the Senegal River Delta. The invasiveness of the weed was a cause for alarm because it grew very fast, forming dense mats that blocked water bodies, interfered with agricultural irrigation, fishing activities, water supply and waterways for transportation. The subsequent biological control with the release of *Cyrtobagous salviniae* allowed effective control of *S. molesta*. The situation called for urgent control measures.

*Salvinia molesta* is a free-floating fern that inhabits still and slow-moving freshwater bodies. It is sterile and reproduces by vegetative growth of the rhizomes (Forno and Julien, 2000).

*Salvinia molesta* can fairly easily be controlled with the use of herbicides (Hill and Julien, 2004). However, concerns over the use of chemicals in the aquatic environment prompted the search for a more sustainable control option. Among the agents released against *S. molesta* in Africa the weevil *Cyrtobagous salviniae* has been the most successful and has now been released in many countries in Africa (Julien and Griffiths, 1998). The adults feed on the growth tips of *S. molesta*, stunting its vegetative growth. The larvae feed on the buds and the roots and then burrow into the rhizome of the plant, causing the plants to rot and sink (Julien *et al.*, 1987). Although this insect is not a particularly good disperser (Forno and Julien, 2000), it has been a successful biological control agent wherever it has been introduced in the world. In South Africa, *Salvinia molesta* is under complete biological control and no longer requires any manual removal or herbicide application (Cilliers, 1991).

Host range tests to assess feeding by *Cyrtobagous salviniae* were carried out in Australia on 46 species (Table 5.1) from six families of Pteridophyta (ferns), eleven families of Monocotyledons, and sixteen families of Dicotyledons (Forno *et al.*, 1983). Host specificity tests indicated that this weevil was restricted to *S. molesta*. It has never been observed attacking plants other than *Salvinia* species in the field in South America, including those that grew in association with *S. molesta* such as water fern (*Azolla* sp.), water hyacinth and water lettuce (Forno *et al.*, 1983). Importantly, the weevil has not been found to attack any other

plants even when huge populations were starving following population crashes of *S. molesta* (Julien *et al.*, 2002).

**Table 5.1.** Plants previously tested in Australia by Forno *et al.* (1983).

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<i>Adiantum hispidulum</i>	<i>Eichhornia crassipes</i>	<i>Gossypium hirsutum</i>
<i>Azolla pinnata</i>	<i>Potamogeton tricarlinatus</i>	<i>Nymphoides indica</i>
<i>Pteridium esculentum</i>	<i>Typha orientalis</i>	<i>Eucalyptus tereticornis</i>
<i>Marsilea drummondii</i>	<i>Zingiber officinale</i>	<i>Eucalyptus maculata</i>
<i>Schizaea dichotoma</i>	<i>Carica papaya</i>	<i>Nymphaea gigantea</i>
<i>Christella dentata</i>	<i>Beta vulgaris</i>	<i>Ludwigia peploides</i>
<i>Sagittaria graminea</i>	<i>Spinacia oleracea</i>	<i>Polygonum lapathifolium</i>
<i>Allium cepa</i>	<i>Lactuca sativa</i>	<i>Polygonum hydropiper</i>
<i>Pistia stratiotes</i>	<i>Ipomoea batatas</i>	<i>Polygonum sp.</i>
<i>Ananas comosus</i>	<i>Ipomoea aquatica</i>	<i>Rumex brownii</i>
<i>Zea mays</i>	<i>Cucurbita maxima</i>	<i>Rumex crispus</i>
<i>Orzya sativa</i>	<i>Nasturtium officinale</i>	<i>Fragaria x ananassa</i>
<i>Saccharum officinarum</i>	<i>Brassica oleracea var. botrytis</i>	<i>Citrus sinensis</i>
<i>Asparagus officinalis</i>	<i>Medicago sativa</i>	<i>Citrus limon</i>
<i>Musa x paradisiaca</i>	<i>Trifolium subterraneum</i>	<i>Citrus reticulata</i>
		<i>Lycopersicon esculentum</i>

---

Precautions must be taken against the introduction of organisms that may attack not only the target, but also crop plants or other economically important plants. Furthermore, it is equally important to guard against introducing organisms that will attack elements of the native biota, and an argument has arisen about whether or not there exist adequate safeguards against this potential danger (Futuyma, 2000). For instance, the weevil *Rhinocyllus conicus* (Frölich), released in the United States to control several Eurasian thistles, is severely reducing seed production of several native thistles as well (Louda *et al.*, 1997). It is well understood that in order to avert such disaster, potential biological control agents must be tested for specificity. The ideal biocontrol agent will attack only the target pest species and no others (Futuyma, 2000). However, most practitioners would allow strictly stenophagous insects (attacking a few closely related hosts of the same genus) to be imported (Peter Neuenschwander, Pers. com.).

Louda (2000) stated that for future biocontrol control efforts, the re-examination of some of the most fundamental assumptions of biological control is crucial. These assumptions include: 1) the target weed species poses major economic and environmental problems, 2) no less risky alternatives exist, 3) control by introduced natural enemies is predicted, 4) significant harm to native species is unlikely, and 5) release involves known risks acceptable to the public.

Prior to the release of the weevil *C. salviniae* in Senegal, it was deemed necessary to undertake laboratory studies on host specificity and impact tests to confirm that the agent *C. salviniae* would be specific to and damage *S. molesta* in field.

The main aims of these laboratory studies were to monitor:

- 1) The action of the weevil *C. salviniae* on *S. molesta* and 13 cultivated plant species.
- 2) The impact of *C. salviniae* on *S. molesta* at different treatment levels (1 pair + 12 plants; 8 pairs + 12 plants; 16 pairs + 12 plants; 24 pairs + 12 plants).

## **5.2. Materials and Methods**

### **5.2.1. Insects and plant material**

The first starter colony of 300 weevils was received from the Plant Protection Research Institute, Pretoria, South Africa in June 2000 by the Plant Protection Directorate (DPV). The second colony of weevils was imported in October 2001 from Côte d'Ivoire by FAO TCP/RAF/0173 (T) for Senegal and Mauritania in which each country received a healthy colony of 1250 weevils. For the purpose of the experiment, weevils were collected from the TCP mass rearing unit at Djoudj Park. Insect-free salvinia plants weighing 15 to 20 g were collected from the Senegal River in Diama village (16°12N 645 - 16°24W106).

### **5.2.2. Host specificity tests**

Indigenous aquatic plant species were not tested because the host-specificity of *C. salviniae* is well documented, based on information gathered from Australia, USA and South Africa. This species feeds only on members of the genus *Salvinia*. The high degree of host-specificity indicated that establishment of this weevil in Australia is without risk to non target plant species (Forno *et al.*, 1983). This high level of specificity has been confirmed by researchers in several other countries, at least 11 countries of which have introduced the weevil without any adverse consequences (Julien and Griffiths, 1998). However, there was a political requirement to test economically important crops against the weevil to demonstrate that no host range extension was possible. Thus, the intention was to conduct host range testing of *C. salviniae* on cultivated plants found in the Senegal River Delta. Host specificity testing was conducted in June 2000 with 13 species of plants representing 9 families (Table 5.2). Methodology was similar to that carried out by Scharzlander (2000) with specific methods on the same agent and the same target derived from Forno *et al.*, (1983).

Specificity and impact tests were conducted at FAO-TCP-Headquarters in Saint Louis, 260 km NW from Dakar. Both choice and non-choice trials were performed in the laboratory at 28°C daily mean temperature. Weevils used were brought from the mass rearing pool at the courtyard of the hotel Hostellerie du Djoudj in Djoudj Park and starved for one day before the test started. To monitor the specificity, feeding damage to the salvinia plant's leaf buds, feeding scars on test plants and the number of dead weevils were determined over a 10 day period. Each replicate was observed daily.

**Table 5.2.** List of 13 economically important crops representing 9 families tested with *Cyrtobagous salviniae*.

Family	Common name	Botanical name
<i>Solanaceae</i>	eggplant	<i>Solanum melongena</i> L.
	red pepper	<i>Capsicum anuum</i> L
	tomato	<i>Lycopersicum esculentum</i> L.
<i>Gramineae</i>	rice	<i>Oryza sativa</i> L.
	corn	<i>Zea mays</i> L
	sugar-cane	<i>Saccharum officinarum</i>
<i>Umbellifereae</i>	carrot	<i>Daucus carota</i> L.
<i>Brassicaceae</i>	cabbage	<i>Brassica oleracea</i> L.
<i>Asteraceae</i>	lettuce	<i>Lactuca sativa</i> L.
<i>Euphorbiaceae</i>	cassava	<i>Manihoi esculenta</i> Crantz
<i>Cucurbitaceae</i>	melon	<i>Cucumis melo</i> L.
<i>Liliaceae</i>	onion	<i>Allium cepa</i> L
<i>Convolvulaceae</i>	sweet potato	<i>Ipomea batatas</i> Poir.

For the no-choice tests, four mature adults of *C. salviniae* were placed in rectangular plastic containers (about 500 ml) containing water (half container) either one of the test plants or salvinia each test species was tested on three separate occasions.

For the choice tests, the containers simultaneously received one of the test plants with *S. molesta* and 4 mature adults were placed an equal distance from the tested plant and *S. molesta*. A total of 13 plant species were tested with the weevil *C. salviniae* (Table 5.2). Entire plants were tested (leaves, stems and roots). Three replicates were made.

### 5.2.3. Impact test

#### 5.2.3.1. Experiment design

On October 20, 2005 (Period - P<sub>0</sub>), 20 plastic tubs filled with 12 litres of water from the Senegal River and 12 plants each were set up and inoculated six days later (P<sub>1</sub>) with pairs of

weevils pre-sexed in copula. No fertilizer was added in the water, nor was ambient temperature recorded. Tubs were set up in a randomized complete block design outdoors under a shaded area. Control tubs were covered with a gauze lid to prevent weevil infestation.

The experiment lasted 4 weeks. One response variable, number of dead plants, was measured every five days from October 26, 2001 to November 20, 2001.

Four replicates were made for the control and each level of treatment: 1, 8, 16, and 24 pairs of weevils. These numbers of weevils were chosen to monitor how long it would take from the time of inoculation to salvinia plants' death, in relation to different weevil treatment levels.

#### **5.2.3.2. Statistics**

Data were analyzed using an ANOVA statistics by groups ( $\alpha$  level for critical range = 0.05 and p level for significance = 0.05) and Kruskal-Wallis test significant at  $p < .05$  to determine differences between the 4 weevil treatment levels (0, 1, 8, 16, and 24 pairs). The Statistica software (Version 7.0) package was used.

### **5.3. Results**

#### **5.3.1. Laboratory host range testing**

In the choice tests involving each of the 13 test plants and a salvinia plant, all *C. salviniae* ended up on salvinia plants within few hours. They thus showed a strong preference for the target plant *S. molesta*. This was confirmed in the no-choice test where no feeding damage was observed on any of the 13 test crop plants and weevils only fed on salvinia.

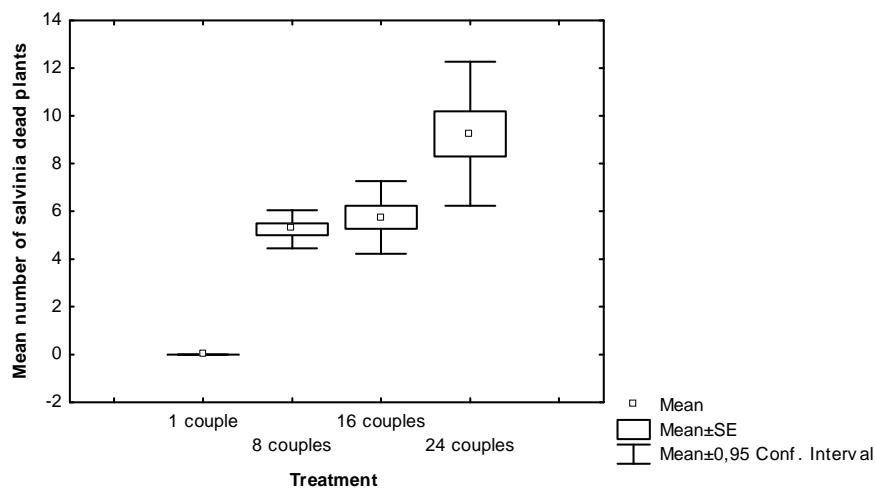
Weevil mortality in the no choice tests started on the second day of monitoring and the daily maximum insect death was recorded on the seventh day with 29 *C. salviniae* cadavers collected on the 13 test plants (Table 5.3). No weevil mortality was recorded on salvinia plants. In the no-choice containers with test plants alone, most of the cadavers were observed between the fourth and ninth day with a total of 140 weevil cadavers. The highest mortality was recorded on the seventh day and all weevils on the test plants died within 10 days (Table 5.3). By contrast, all weevils survived in the choice test causing noticeable damage to salvinia plants and no damage to the test plants.

**Table 5.3.** No-choice tests: daily monitoring of *Cyrtobagous salviniae* mortality on salvinia and the 13 test plants over 10 days trial.

Replicate	Test plants	Container	weevils/ container	Day of monitoring										Dead weevils
				1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	6 <sup>th</sup>	7 <sup>th</sup>	8 <sup>th</sup>	9 <sup>th</sup>	10 <sup>th</sup>	
<b>1</b>	eggplant	1	4	0	0	0	0	1	2	0	1	0	0	4
	red pepper	2	4	0	0	0	0	1	0	1	1	1	0	4
	tomato	3	4	0	0	0	1	0	2	1	0	0	0	4
	rice	4	4	0	0	0	1	0	1	1	1	0	0	4
	corn	5	4	0	0	0	1	1	0	1	1	0	0	4
	sugar-cane	6	4	0	0	0	0	0	1	1	2	0	0	4
	carrot	7	4	0	0	0	1	1	0	0	0	1	1	4
	cabbage	8	4	0	0	0	0	0	1	1	0	2	0	4
	lettuce	9	4	0	0	0	1	0	1	1	0	0	1	4
	cassava	10	4	0	0	0	1	0	1	1	1	0	0	4
	melon	11	4	0	0	0	0	1	0	1	0	1	1	4
	onion	12	4	0	0	0	0	0	1	0	1	2	0	4
	sweet potato	13	4	0	0	0	0	0	1	1	0	2	0	4
	<i>Salvinia</i>	14	4	0	0	0	0	0	0	0	0	0	0	0
<b>2</b>	eggplant	1a	4	0	0	1	0	0	1	1	1	0	0	4
	red pepper	2a	4	0	1	0	0	1	1	0	0	0	1	4
	tomato	3a	4	0	0	0	1	0	1	1	0	1	0	4
	rice	4a	4	0	0	0	1	1	0	1	0	0	1	4
	corn	5a	4	0	0	0	1	0	1	1	1	0	0	4
	sugar-cane	6a	4	0	0	1	0	1	0	0	2	0	0	4
	carrot	7a	4	0	0	0	2	0	0	1	1	0	0	4
	cabbage	8a	4	0	0	0	0	0	2	1	0	1	0	4
	lettuce	9a	4	0	0	0	1	2	0	0	0	0	1	4
	cassava	10a	4	0	0	1	0	1	0	0	1	1	0	4
	melon	11a	4	0	1	0	0	0	0	1	2	0	0	4
	onion	12a	4	0	0	1	0	1	0	0	1	1	0	4
	sweet potato	13a	4	0	1	0	1	0	0	1	0	1	0	4
	<i>Salvinia</i>	14a	4	0	0	0	0	0	0	0	0	0	0	0
<b>3</b>	eggplant	1b	4	0	0	1	0	0	0	1	0	2	0	4
	red pepper	2b	4	0	0	1	0	2	0	0	1	0	0	4
	tomato	3b	4	0	0	1	0	0	1	1	1	0	0	4
	rice	4b	4	0	0	0	1	1	1	0	1	0	0	4
	corn	5b	4	0	0	0	1	0	1	1	0	1	0	4
	sugar-cane	6b	4	0	0	0	1	1	1	1	0	0	0	4
	carrot	7b	4	0	0	0	1	0	1	1	1	0	0	4
	cabbage	8b	4	0	0	0	1	0	1	1	0	1	0	4
	lettuce	9b	4	0	0	0	1	1	0	1	0	1	0	4
	cassava	10b	4	0	0	0	1	1	0	1	1	0	0	4
	melon	11b	4	0	0	0	1	0	1	1	0	1	0	4
	onion	12b	4	0	0	0	1	1	0	1	0	1	0	4
	sweet potato	13b	4	0	0	0	1	1	0	1	1	0	0	4
	<i>Salvinia</i>	14b	4	0	0	0	0	0	0	0	0	0	0	0
<b>Total dead weevils</b>				0	3	7	23	20	24	29	23	21	6	<b>156</b>

### 5.3.2. Impact test

The first dead *S. molesta* plants were observed on 10 November, two weeks after inoculation of the experiment. Salvinia plants in control tubs were healthy. Only senescent leaves were observed and plants continued their normal growth. The ANOVA showed significant differences among treatments (1, 8, 16 and 24 weevils) at  $F= 49.03509$  and  $p=0.000001$  (Table 5.4). Furthermore, on November 10, 2001 comparison between treatments showed only one significant difference: between the 24 pair and the 1 pair treatment; Kruskal-Wallis test:  $H(3, N= 16) =13.47801$  and  $p =.0037$  (Table 5.5). After November 10, 2001 it was not possible to continue collecting data because all plants were destroyed in the 24 pair weevil treatment followed by the 16 pair weevil treatment in which plants in 3 tubs out of 4 were destroyed. However, the 1 pair treatment did not record any dead plants for the same period. The 4 tubs with plants treated with 8 pairs of weevil were destroyed by November 20. The experiment was terminated once all plants in the 8, 16 and 24 weevil pair treatments were destroyed, leaving only the 1 weevil pair treatment and the control tubs. Ten days later, the 1 weevil pair treatment tubs were destroyed leaving only the control tubs where plants were thriving. The impact test showed that the greater the number of placed weevils, the quicker the damage to salvinia plants and the higher the mortality (Figure 5.1).



**Figure 5.1.** Mean number of dead salvinia plants for the four insect treatments (1 pair, 8 pairs, 16 pairs, and 24 pairs) on November 10, 2001.

**Table 5.4.** Analysis of Variance of the number of dead salvinia plants between the 4 treatment levels during the last 3 recording periods (5 Nov., 10 Nov. and 15 Nov. 2001). Stars indicate significant differences at  $p < .05$ .

Variable	Date	SS	df	MS	F	p
Number of dead plants	5 Nov. 2001	5.2	3	1.7	0.6860	0.577663
	10 Nov. 2001	174.69	3	58.23	49.03509	0.000001*
	15 Nov. 2001	76.19	3	25.40	6.518717	0.007277*

**Table 5.5.** By Group Analysis - Multiple comparisons p values (2-tailed) of the 4 treatment levels: 1 couple, 8 couples, 16 couples, and 24 couples of *Cyrtobagous salviniae* on salvinia at 10 Nov. 2001. Stars indicate significant differences at  $p < .05$ .

Variable	1 pair	8 pairs	16 pairs	24 pairs
1 pair		0.662112	0.294465	0.002187*
8 pairs	0.662112		1.000000	0.294465
16 pairs	0.294465	1.000000		0.662112
24 pairs	0.002187*	0.294465	0.662112	

Number of dead plants: Kruskal-Wallis test:  $H(3, N=16) = 13.47801$   $p = .0037$

#### 5.4. Discussion

Other Senegalese native aquatic plant species could have been tested against *C. salviniae*. However, attention was only paid to crop plants. Thus, 13 cultivated plants were tested because of their commercial importance in the areas infested by *S. molesta*, and mostly because of them being cultivated in aquatic conditions e.g. rice. Previous host specificity results of Forno *et al.* (1983) who tested 46 plant species, confirmed that the weevils developed and reproduced only on *S. molesta*. So, laboratory host range testing of *C. salviniae* demonstrated a high specificity of the weevil *C. salviniae* for *S. molesta*. The results from the host-specificity testing conducted in our experiment concur with the results of Forno *et al.*, (1983). Their host-specificity tests on other crop plants included rice, onion, tomato, corn, sugar-cane, ginger, papaya, beet, spinach, lettuce, asparagus pumpkin, cauliflower, lucerne, sub-clover, cotton, strawberry, orange, banana, lemon, mandarin, and pineapple: no feeding was observed on any of them.

In the USA, Flores and Wendel (2001) reported that due to the documentation of previously tested host plants, a list of only four plant species was generated to supplement the list of plants previously tested by Forno *et al.* (1983) (Table 5.1). Previous host specificity results are *Marsilea vestita* Hook and Grev., hairy water-clover; *Azolla filiculoides* Lam., water fern; *Zizania aquatica* L., wild rice; and *Sagittaria sanfordii* E. Greene, Sanford's arrowhead. There was no feeding damage or oviposition observed on any of the test plants being studied, with the

exception of *S. molesta*, where feeding damage and oviposition were observed daily and longevity was much higher. This high degree of host-specificity indicates that the release and establishment of this weevil in Senegal would be without risk to nontarget plants specially to crop plants. The high level of specificity has been confirmed by researchers in several other countries, at least 11 of which have introduced the weevil (Julien and Griffiths, 1998) without any adverse consequences.

*Cyrtobagous salviniae* has an extremely voracious appetite (Flores and Wendel, 2001). This was confirmed by our impact test using four treatment levels of the weevil (1, 8, 16 and 24 pairs) where the insect showed intense voracity feeding on *S. molesta*. Typical behavior and activity of *C. salviniae* on *S. molesta*, includes them becoming weak and sluggish in the absence of *S. molesta*. When weevil populations rise and *S. molesta* infestation levels decline, *C. salviniae* will starve and die rather than switch host plants. In all reality, it just does not recognize other plants as food (Flores and Wendel, 2001).

## **5.5. Conclusion**

Host specificity tests are the best tool presently available to determine an agent's likely host range. Thus, the probability of feeding, oviposition, and development on a set of nontarget native species, at least under test conditions, can and should be estimated (Louda *et al.*, 2005).

*Cyrtobagous salviniae* has been widely used to control *S. molesta* in other countries and has been shown to have a high degree of host specificity (Forno *et al.*, 1983). It can be stated that *C. salviniae* is host specific to species within the genus *Salvinia*, with a strong preference for its field host, *S. molesta*. Test plants were never accepted by *C. salviniae*. In addition according to Flores and Wendel (2001), there is no evidence to indicate that *C. salviniae* can survive on any host other than *Salvinia* spp. Therefore, biological control of *S. molesta* offers the possibility of permanent control of this weed as it has already provided in other countries where *C. salviniae* has been released. Our laboratory specificity and impact test results show that *C. salviniae* can be a satisfactory means of effectively controlling *S. molesta* in Senegal because other test plants were never accepted.

## Chapter 6

### **Quantitative post-release evaluation of biological control of floating fern *Salvinia molesta* D.S. Mitchell (Salviniaceae) with the weevil *Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae) on the Senegal River and Senegal River Delta**

#### **6.1. Introduction**

Post-release evaluation is a very important stage in a biological control programme. It provides information on the effectiveness of an agent in establishing and reducing the weed problem, and allows assessments to be made of the potential effectiveness of the agent if introduced to other regions. In addition, observations on the interaction between agent and host provides important biological information and allows an evaluation of alternative or complementary management techniques if the level of control achieved is less than that desired (Julien *et al.*, 1999).

Senegal has experienced the second main outbreak of an invasive aquatic weed with *S. molesta*. In 2000, *S. molesta* covered a total surface of 18 694 hectares of which 10 854 hectares was in Senegal and 7 840 hectares in Mauritania. The development of irrigation for agriculture, which has involved important investments on behalf of State members of the Senegal River Organization Development (OMVS), was seriously affected because of blocked waterways. Transportation and fishing were also impaired.

The invasion also threatened habitat for the rich bird life of the Senegal River Delta, a World Heritage Site that has been designated a Wetland of International Importance under the Ramsar Convention. Senegal's Parc National des Oiseaux du Djoudj (Djoudj National Bird Sanctuary), and the adjacent Parc National du Diawling (Diawling National Park) on the Mauritania side of the Senegal River, provide protection for residents and migrating birds. However, due to the favourable conditions, excessive growth of *S. molesta* resulted in complete coverage of large water surfaces which degraded natural habitats in several ways at Djoudj and Diawling Parks where a large population of resident breeding birds and some three million migrant birds coming from Europe over the winter season could not recognize or stop at some water bodies entirely covered with salvinia mats (Anonymous; [www.gisp.org](http://www.gisp.org), 2006).

*Salvinia molesta* has been very effectively controlled in other parts of the world through biological control with the release of the weevil, *C. salviniae*, notably, Congo (Mbatu and

Neuenschwander, 2005); South Africa (Cilliers, 2003); Australia, Papua New Guinea and Namibia (Room *et al.*, 1981, 1985; Forno and Bourne, 1984, 1985, 1986; Forno, 1985; Room, 1983; Forno *et al.*, 1983; Thomas and Room, 1984, 1986). Furthermore, laboratory studies in chapter 5 showed that this weevil was host specific and damaging to the weed. As a result, the weevil was cleared for release in Senegal and Mauritania.

The aim of this study was to undertake a quantitative post release evaluation of *C. salviniae* on *S. molesta* in the Senegal River and its tributaries, and the following points were addressed:

- 1) The importance of public awareness and their involvement in the biocontrol programme.
- 2) The mass rearing technique of the natural enemy *C. salviniae*.
- 3) The post release evaluation of *C. salviniae* on *S. molesta*.

## **6.2. Materials and methods**

### **6.2.1. Riverine population awareness**

From mid November to mid December 2001, an awareness and training campaign on aquatic plant biological control was directed at local fishing and farmer communities (Table 6.1). For this purpose, emphasis was put on the following topics:

- Importance of public awareness for the biocontrol of aquatic weeds;
- Advantages of biological control of *S. molesta*;
- Recognition of the weevil and its damage to *S. molesta*;
- Demonstration of the weevil rearing method and release techniques.

### **6.2.2. Pre release surveys**

Intensive pre-release surveys were conducted in November 2001 along the Senegal River and at Lake Guiers and to locate ideal release sites.

### **6.2.3. Mass rearing**

On October 2001, the project set up a mass rearing facility with six ground metal pools in each country, one in Diawling Park /Mauritania and the other in Djoudj Park/Hostellerie du Djoudj/Senegal. Above-ground metal pools with plastic liners (3.05 m diameter, 76 cm deep, and 5000 L capacity) were set up and these allowed easy access to all areas of the water surface. These pools were large enough to moderate evapotranspiration and overheating.

Pools were filled with water to within approximately 20 cm of the top and this level was constantly maintained. 150 g of a soluble complete fertiliser containing nitrogen (10%),

phosphorus (10 %) and potassium (20 %) were added monthly to the pool water. Water temperature beneath the weed mat was between 20 and 25°C. Conductivity analysis was conducted regularly to monitor the salt content.

Each pool was inoculated with 200 weevils and salvinia plants covering 1/3 of the water surface. Regular and continued care of pools was done to ensure the continuity of the rearing process. For the pool maintenance, 25 plants were sampled by pool. If 60 % of salvinia plants were attacked by the natural enemy, fresh plants were added and mixed with old ones. Water levels were checked, plant contaminants (dead leaves, weeds, spiders and ants) removed and the density and condition of plants noted.

Two methods of harvesting were used, hand picking and submerging plants with a sheet of wooden mesh covering the entire pool surface. However, due to the fact that the wooden mesh was difficult to handle on the plastic rearing tubs, hand picking was mostly used. Adult weevils (brown immature and black mature) were harvested every week, stored, and transported in containers with Petri dishes that had fresh salvinia leaves and gauze covers for ventilation.

#### **6.2.4. Releases**

Releases were made away from critical locations where physical controls occurred to ensure establishment and spread of the weevils. Due to the extensive infestation, releases of large numbers of weevils were made into a number of well distribution sites. Weevils were released at source infestations as high up the water course as possible. Thus, they were tipped from containers directly into the infestation from a boat and sometimes from the water edges. Finally, records of the number of adult weevils released were kept in a consignment form.

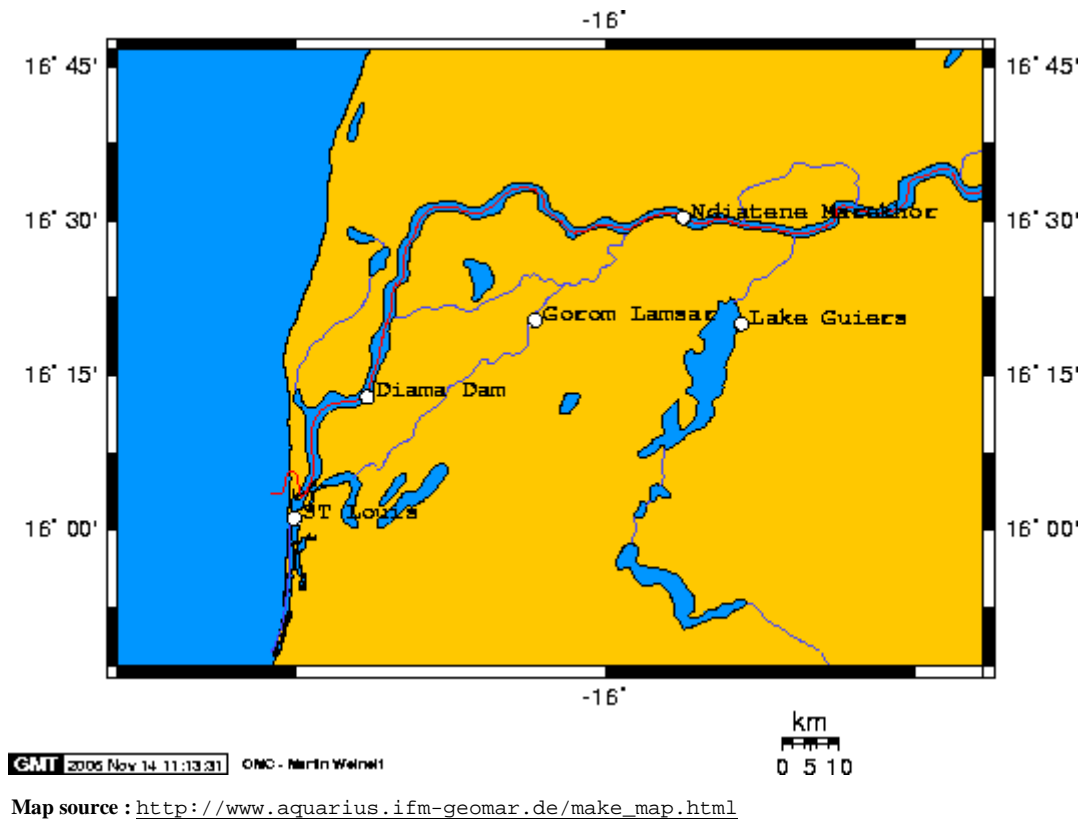
Three sequences of release were made:

1) In June 2000, an initial release of 200 adult weevils was made on the Senegal River in Ndiatene Marekhor (16°30N193 – 15°52W260) (Figure.6.1) locality which was the source infestation. Physical parameters were recorded as pH (8.2), water salinity (0), conductivity (130.6 µs), temperature (26.6°C), water height (1.5 m); RH (73%) and time of release: 7 pm.

2) In September 2000, a second release of 190 adults and 5 buckets of infested *Salvinia* plants was made in a tributary of the Senegal River, at Gorom Lamsar-Grande Digue Pumping Station (16°20N198 – 16°06W514) (Figure.6.1).

3) Inundative releases started with the FAO programme supporting Senegal and Mauritania. A total of 48 953 weevils was released at 270 sites from early January 2002 to August 2002. In

Senegal (Senegal River: Left Bank and tributaries), 27 153 weevils were released in 161 sites and in Mauritania (Senegal River: Right Bank) 21 800 weevils in 109 sites. Details of release sites are reported in Appendix 6.3.



**Figure 6.1.** Release of *Cyrtobagous salviniae*: Ndiatene Marekhor (16°30'N193 – 15°52'W260), Gorom Lamsar-Grande Digue Pumping Station (16°20'N198 – 16°06'W514).

### 6.2.5. Monitoring

Post release evaluation of the impact of *C. salviniae* on *S. molesta* was undertaken for the study case at Ndiatene Marekhor (16°30'N193 – 15°52'W260). This is a 100 ha area that was 100% covered by *S. molesta*. Monthly samples were taken from June 2000 to June 2002. During each sampling event, the surface area of the site covered by *S. molesta* was estimated and fixed point photography taken. Six quadrats (a quadrat is one tenth of a square meter and comprises a PVC pipe frame which is 33cm x 33 cm to give 0.1 m<sup>2</sup> in the inner measurement) were randomly thrown each month and the wet weight of plants per quadrat was measured. 100 plants were randomly selected from the sample area. For each plant, the apical ramet was inspected for damage and the numbers of immature or adult *C. salviniae* present were recorded.

Four other study sites: Debi Tiguet, Temeye, Gorom Lamsar and Gouer Sangfaye were also involved.

### **6.2.6. Statistics**

Data were analyzed with Software Statistica ver.7: using by Group Analysis/Breakdown and one-way ANOVA for the variables wet weight and adult weevil populations; and t-Test of means for dependent samples healthy vs. damaged buds.

## **6.3. Results**

### **6.3.1. Riverine population awareness**

In Senegal, about 26000 inhabitants from 23 local villages were involved in the awareness campaign. Local communities organized in village committees were initiated to the rearing and recognition of *C. salviniae*. In Mauritania, 13 riparian villages and 6 fishermen cantonments were sensitized (Table 6.1). The local rural communities familiarized themselves with damage caused to salvinia plants by the natural enemy, actively participated in mass releases and adopted the biological control method in which they committed to regularly carry out control actions.

**Table 6.1.** Awareness and training campaigns in localities invaded by *Salvinia molesta*

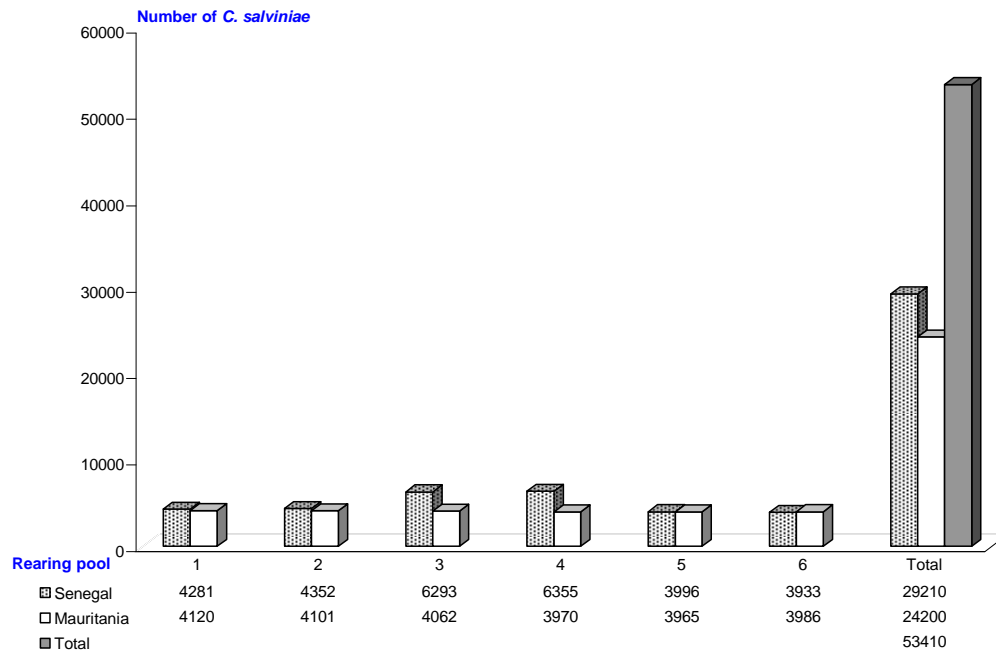
1) Senegal				
Locality invaded by <i>Salvinia</i>	Village	Session date	Number of sensitized people*	Main local activities
Senegal River	Rone	21/11/01	900	Fishing, farming, small business
	Diadieme 3	21/11/01	300	Fishing, farming, small business
	Diadieme 2	21/11/01	300	Fishing, farming, small business
	Debi	22/11/01	2700	Fishing, farming, small business
	Tiguet	22/11/01	2400	Fishing, farming, small business
	Fourarate	23/11/01	260	Fishing, farming, small business
	Diadieme 1	23/11/01	900	Fishing, farming, small business
	Ronkh	28/11/01	3600	Fishing, farming, small business
	Ndiatene	28/11/01	2240	Fishing, farming, small business
	Rosso Senegal	28/11/01	100	Fishing, farming, small business
	Thiagar	28/11/01	1855	Fishing, farming, small business
Kheune	29/11/01	2200	Fishing, farming, small business	
Gorom Lamsar	Mboundoume barrage	26/11/01	3000	Fishing, farming, small business
	Kassack Nord	26/11/01	3000	Fishing, farming, small business
	Kassack Sud	27/11/01	1109	Fishing, farming, small business
	Diawar	28/11/01	3500	Fishing, farming, small business
Lake Guiers	Temeye Toucouleur	03/12/01	250	Fishing, farming
	Mbane	05/12/01	500	Fishing, farming
	Sanene	07/12/01	100	Fishing, farming
	Malla	07/12/01	50	Fishing, farming
	Ndiakhaye	09/12/01	150	Fishing, farming
	Nder	10/12/01	50	Fishing, farming
Ngnith	12/12/01	20	Fishing, farming	
<b>Total</b>			<b>26444</b>	
2) Mauritania				
Locality invaded by <i>Salvinia</i>	Villages and Fishermen cantonments	Session date	Number of trained people	Main local activities
Senegal River	Birete	20/12/01	25	Fishing, farming
	Bou Hachra	21/12/01	12	Fishing, farming
	Keur Macen	22/12/01	12	Fishing, farming
	Ndiaga	23/12/01	12	Fishing, farming
	Ndielar	24/12/01	19	Fishing, farming
	Dar Salam	26/12/01	12	Fishing, farming
	Bouteydouma Est	27/12/01	9	Fishing, farming
	Bouteydouma Ouest	28/12/01	25	Fishing, farming
	N'Kheila	29/12/01	8	Fishing, farming
	Fishermen PK74Rosso	30/12/01	5	Fishing
	Fishermen PK71Rosso	30/12/01	22	Fishing
	Fishermen PK56Rosso	30/12/01	10	Fishing
	Fishermen PK47Rosso	3/1/02	6	Fishing
	Fishermen PK35Rosso	3/1/02	7	Fishing
	Fishermen PK21Rosso	3/1/02	4	Fishing
	Brun Darou	16/1/02	2	Fishing
	Brun Gouyare	17/1/02	3	Fishing, farming
Diaka	18/1/02	3	Fishing, farming	
Tekachkoumba	19/1/02	2	Fishing, farming	
<b>Total</b>			<b>198</b>	

\* In villages, people are organised in committees. Thus, awareness was pursued by those structures after main sessions. That is why the number of people is high.

### 6.3.2. Mass rearing

After 9 weeks the first generation of adults started to emerge and feed on plant buds, and harvesting could commence. By the end of the rearing process, about 60000 weevils were harvested from the two mass rearing facilities: in Senegal (29210) and in Mauritania (24200).

Details of mass rearing are reported in Figure 6.2 and Appendix 6.1.

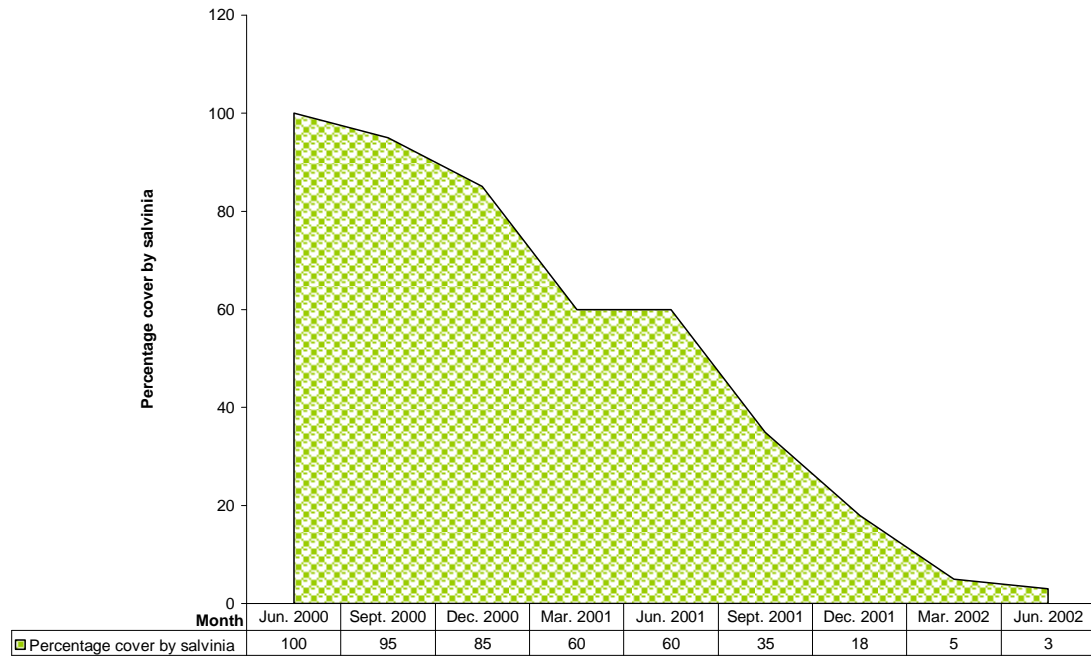


**Figure 6.2.** *Cyrtobagous salviniae* mass rearing productivity in Senegal and Mauritania.

### 6.3.3. Field observations

#### 6.3.3.1. Case study at Ndiatene Marekhor

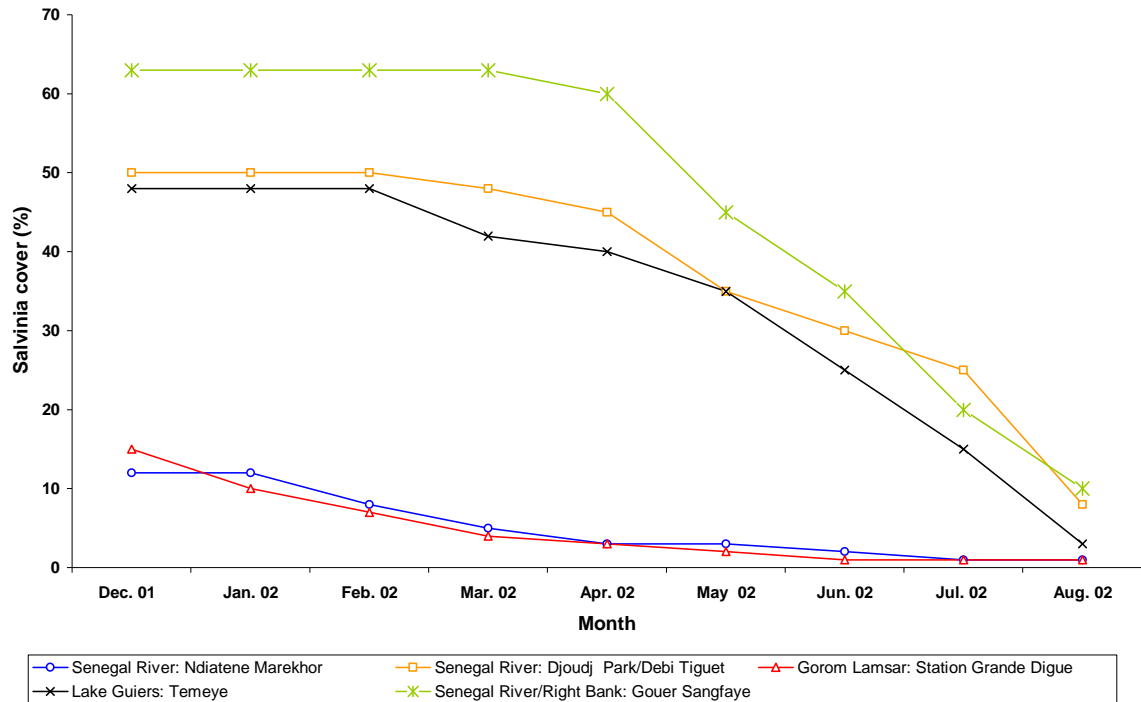
In June 2000, the area Ndiatene Marekhor was entirely covered with a thick mat of *S. molesta*, dense enough to support other weeds: Cyperaceae (*Scirpus cubensis*), Onagraceae (*Ludwigia repens*) and other unidentified grasses. By December 2000, six months after release, open patches of water were apparent and the mat of *S. molesta* decreased steadily by 15%. By September 2001, the area of open water increased as the green *S. molesta* mats turned brown, died and started to sink. The collapse of the weed continued steadily with time and by June 2002 the area was totally freed of *S. molesta* (Figure 6.3).



**Figure 6.3.** Change in salvinia cover (%) after release of *Cyrtobagous salviniae* at Ndiatene Marekhor-Senegal River from June 2000 to June 2002.

### 6.3.3.2. Percentage coverage of *S. molesta*

In 1999, *S. molesta* covered an estimated area of 18000 ha on the Senegal River Left Bank and tributaries (Senegal) and 7840 ha on the Senegal River Right Bank (Mauritania). From December 2001 to June 2002, the percentage coverage of *S. molesta* was heavy at Debi Tiguet, Temeye and at Gouer Sangfaye. However, during the same period there was very little weed at Ndiatene Marekhor and at Gorom Lamsar (Station Grande Digue) localities where releases had been made 25 and 23 months earlier respectively. As a consequence, the salvinia mat was found to decrease quickly by April 2002 at the latter 2 sites (Figure 6.4).



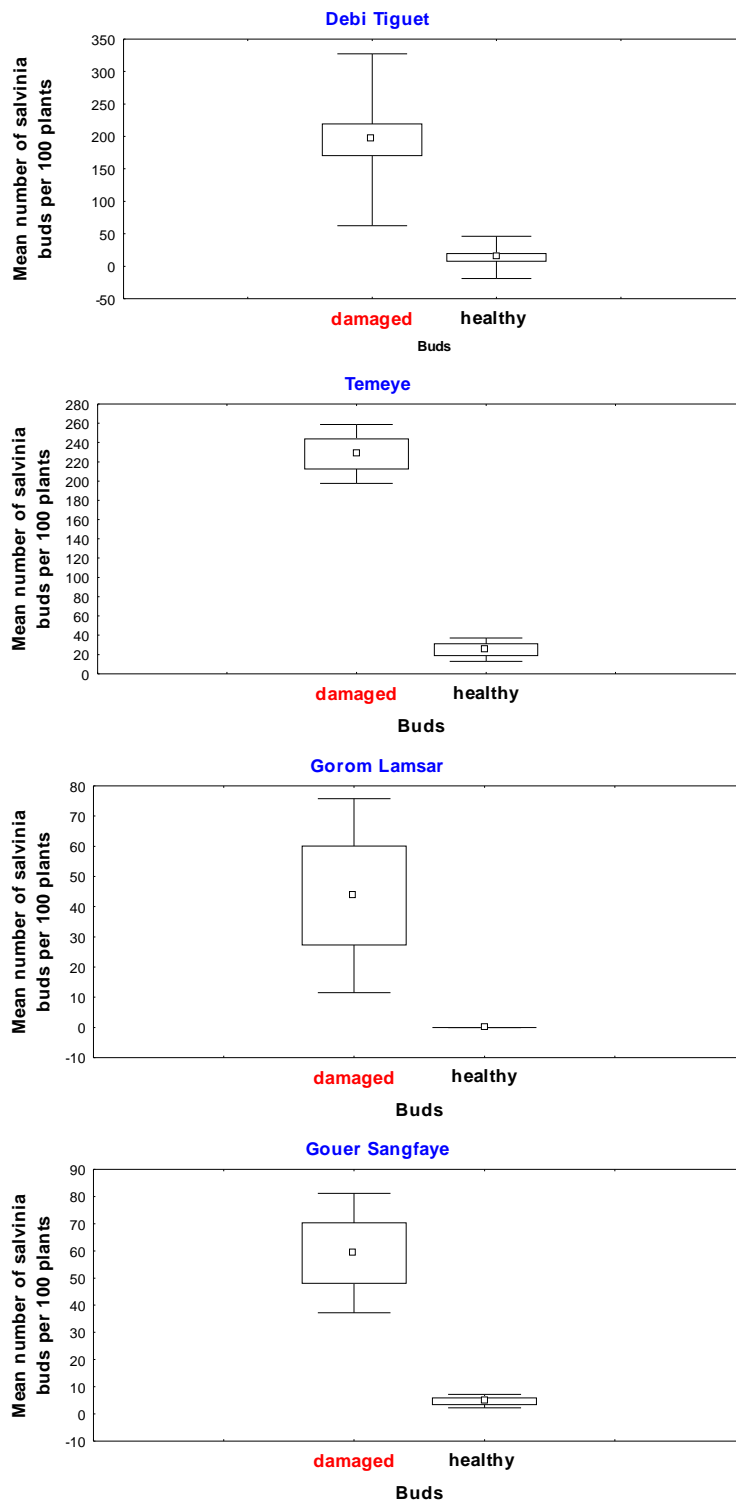
**Figure 6.4.** Decrease in percentage cover of salvinia per month from December 2001 to August 2002 at Ndiatene Marekhor, Debi Tiguet, Gorom Lamsar, Temeye and Gouer Sangfaye.

### 6.3.3.3. Adult weevil damage

Monthly post-release monitoring showed that there was a significant difference between the number of damaged and healthy buds at all four sites, namely Debi Tiguet ( $t = 7.28547$ ), Temeye ( $t = 10.47093$ ), Gorom Lamsar ( $t = 2.66502$ ) and Gouer Sangfaye ( $t = 5.41877$ ) (Table 6.2). The proportion of damaged buds was more evident in Gorom Lamsar where the release was made earlier in September 2000 (Figure 6.5). From June 2002 onwards, there were few undamaged ramets at all sites; consequently it was difficult to find a healthy bud. By August 2002, sampling was terminated when most *S. molesta* plants had sunk and the remaining plant material was water-logged and rotting.

**Table 6.2.** Results of t-test comparing healthy vs. damaged buds for monthly post-release monitoring on 100 sampled salvinia plants from April 2002 to August 2002 at Debi Tiguet, Temeye, Gorom Lamsar and Gouer Sangfaye. Stars indicate significance at  $p < .05$ .

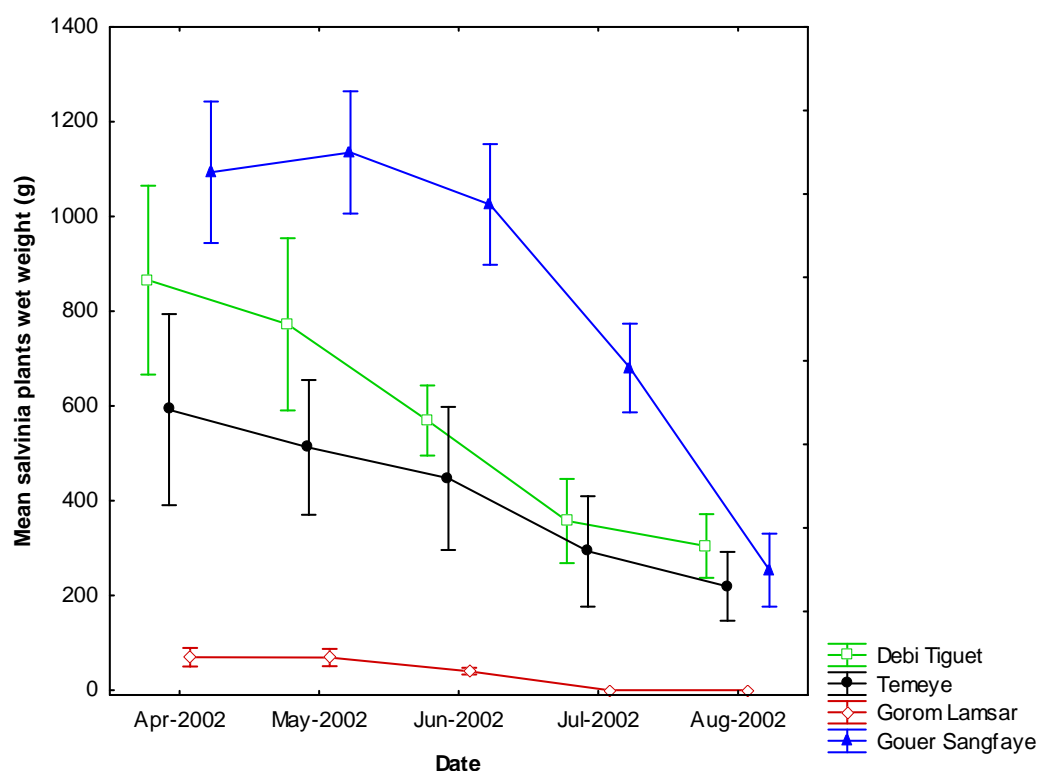
Site/variable	Mean	Std. Dv.	N	t	df	p
<b>Debi Tiguet :</b> damaged buds	194.9000	132.4575				
healthy buds	13.7000	32.4305	30	7.28547	29	0.000000*
<b>Temeye :</b> damaged buds	228.0333	85.5483				
healthy buds	24.9667	33.7143	30	10.47093	29	0.000000*
<b>Gorom Lamsar:</b> damaged buds	43.6667	89.7450				
healthy buds	0.0000	0.0000	30	2.66502	29	0.012446*
<b>Gouer Sangfaye:</b> damaged buds	59.2000	61.2234				
healthy buds	4.6667	6.8949	30	5.41877	29	0.000008*



**Figure 6.5.** Mean number of damaged and healthy buds for monthly post-release monitoring on 100 sampled salvinia plants from April 2002 to August 2002 at Debi Tiguet, Temeye, Gorom Lamsar and Gouer Sangfaye. Error bars denote standard error.

### 6.3.3.4. Plant wet weight

The mean wet weight of salvinia plants was significantly different in all 4 sites over time with  $F = 22.22268$  (Debi Tiguet);  $F = 7.64704$  (Temeye);  $F = 52.49988$  (Gorom Lamsar) and  $F = 65.47502$  (Gouer Sangfaye) at  $p < .05$  (Appendix 6.2). During the evaluation, plant wet weight at Gouer Sangfaye stood out from the other three sites. By April 2002, mean (M) salvinia wet weight was as high as  $M=1200$  g/quadrat followed respectively at the same period by Debi Tiguet ( $M=900$  g/quadrat), Temeye ( $M=600$  g/quadrat) and Gorom Lamsar ( $M=100$ g/quadrat). The sharp decline in mean salvinia wet weight was observed in June 2002 at all sites due to intense weevil feeding damage (Figure 6.6).

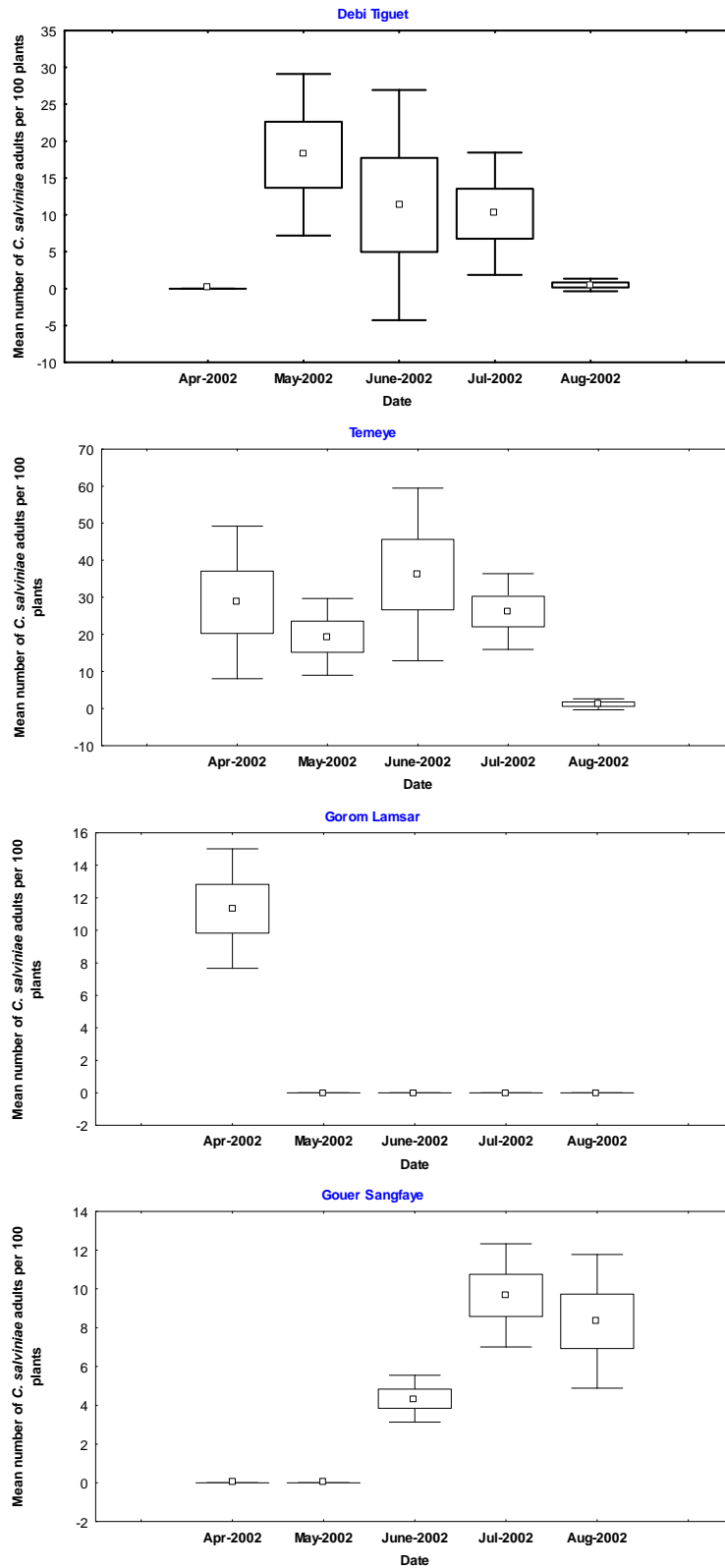


**Figure 6.6.** Mean wet weight of salvinia plants per month per  $0.1 \text{ m}^2$  on salvinia mat from April 2002 to August 2002 at Debi Tiguet, Temeye, Gorom Lamsar and Gouer Sangfaye.

### 6.3.3.5. Adult weevil population

The mean number of adult weevils over time was significantly different at all 4 sites with  $F = 4.14397$  (Debi Tiguet);  $F = 4.48373$  (Temeye);  $F = 57.22772$  (Gorom Lamsar) and  $F = 30.11438$  (Gouer Sangfaye) at  $p < .05$  (Appendix 6.2). In general, higher adult weevil populations were found on newly attacked plant buds than on old plants with apparent

symptoms. A high number of adult weevils was recorded from May to July 2002. The site Temeye at Lake Guiers had the highest weevil populations. The number of weevils was very variable, as can be seen by the standard deviations at Debi Tiguet and Temeye, notably in June 2002 (Figure 6.7). The May to August 2002 samples at Gorom Lamsar yielded no weevils. This was due to the fact that the biocontrol was complete and there were no more salvinia plants at the site. On the contrary, at Gouer Sangfaye several undamaged salvinia plants due to the late release at this site explained why the weevil was still observed in August 2002. In heavily damaged salvinia mats it was difficult to find weevils in damaged old ramets in the absence of newly attacked ones. By August 2002, weevil population decline corresponded to the decrease in salvinia percentage cover to zero (Figure 6.4.).



**Figure 6.7.** Mean of number of adult weevils recorded per month from a sample of 100 salvinia plants from April to August 2002 at Debi Tiguët, Temeye, Gorom Lamsar and Gouer Sangfaye. Error bars denote standard error.

## **6.4. Discussion**

### **6.4.1. Riverine population awareness**

The riverside people were conscious of the negative impact and dangers involved with the presence of salvinia in their environment. Therefore, it was easy to pass on information and get them involved in the control programme for *S. molesta*. The member committees in charge of the physical removal campaigns explained to the villagers, whom they live with, the dangers of spreading the weed from infested to uninfested places. For that purpose, t-shirts, hats, press, television, broadcasting services and other local means of communication were used extensively all over the Senegal River and the Delta to sensitize and educate people. A similar approach of public awareness was reported in Ghana by DeGraft-Johnson (1995) where print and electronic media such as newspapers, radio and television, have been used to inform the public on the dangers of handling, use and trade in aquatic weeds. Further, Navarro and Phiri (2000) suggested that riparian communities on infested water bodies should be involved in appropriate control strategies and recommended that particular attention should be given to community mobilization, access to information, and coordination of community-based activities. Media of the two countries covered activities of this project (Appendix 6.4).

Increased public awareness, notably the riparian communities of the Senegal River whose major income is closely linked to the water, derived improved activities of cropping, fishing and transportation. Participating community villagers have raised the level of understanding about biological control in the community. The general public is concerned about the safety and efficacy of biocontrol agents. Education about how biological control works, especially safety aspects and expectations, is vital if the riparian community is to lend its support.

### **6.4.2. Mass rearing**

The multiple pool mass rearing technique used is the same as the one described by Julien *et al.* (1999). Due to the very large area infested by *S. molesta* in Senegal/Left Bank (18000 ha) and Mauritania/Right Bank (7840 ha), only this rearing approach could result in such a high output in terms of the number of weevils to be collected for release. The aim of the mass rearing was achieved in that a large number of good quality weevils was produced, without encountering any difficulties.

### 6.4.3. Field observations

Within one year, weevils were established and were being recovered 50 km from release sites. Post-release sampling data from the five sites indicated a reduction in plant wet mass, and a significant increase in weevil feeding damage and the number of adult weevils per square metre. The rapid and excellent impact of the agent *C. salviniae* on the weed should be credited to the high number (48 953 weevils) of the natural enemy released in Senegal and Mauritania. Referring to the study case at Ndiatene Marekhor, a substantial decrease of 40% in salvinia cover was observed by March 2001, 8 months after release. Twenty four months after release, the salvinia cover was reduced to less than 3%. Only, a few patches of salvinia persisted, encrusted in *Typha australis*, from Djoudj Park Biological Station to Tiguet village.

The Senegal River and its main tributary, Lake Guiers, have experienced increased loadings of nutrients from the filling of the Diama Dam, drainage from agricultural land, discharge into the water of factory or urban waste and inadequately treated sewage runoff. Such nutrient enrichment greatly increases growth by aquatic weeds. Similar observations were reported by Hill and Olckers (2001) who found that many of the rivers in South Africa receive run-off which is highly polluted with fertilisers arising from agricultural activities. According to Heard and Winterton (2000) one of the issues that contribute to the invasiveness of aquatic weed species is the presence of nitrate- and phosphate- enriched waters, associated with urban, agricultural and industrial pollution. Even though the salvinia nitrogen content was not quantified during this study, the nutrient content of the water could have been relatively high and its eutrophic status was suspected by the blooming of excessive growth of aquatic weeds notably *S. molesta*. The development of *C. salviniae*, and hence its effectiveness as a biological control agent, is also affected by nitrogen levels within the host salvinia plant. The growth rates of both *S. molesta* and its herbivore, *C. salviniae*, are determined by the amount of available nitrogen and plants with nitrogen levels of less than 0.8%, by dry mass, are unsuitable hosts for *C. salviniae* (Cilliers, 1991). Thus, in nitrogen-deficient aquatic systems infested with *S. molesta*, the efficacy of *C. salviniae* can be enhanced by fertilizing the weed with nitrogen (Room *et al.*, 1981; Sands *et al.*, 1983; Forno, 1985; Forno and Bourne, 1985). This was demonstrated by Room and Thomas (1985) who reported that a population of 570 adult *C. salviniae* released into two field cages containing the host plant salvinia, declined to about forty adults over nearly 7 months, or about four generations, because there were low concentrations of nitrogen in the host plant. Eleven weeks after adding another 592 adults to

the cages, and starting weekly applications of urea fertilizer, there were approximately 3000 adults present.

Although physical removal of *S. molesta* has been attempted, the rate at which the floating fern grows makes this method of control impractical and expensive (Room, 1990). Early attempts at physical, chemical and mechanical control proved temporary and expensive, especially for developing countries (Madeira *et al.*, 2006). To this end, many countries have used biological control to clear blocked waterways. In Senegal and Mauritania, *C. salvinia* has successfully controlled *S. molesta*. These results repeat those obtained in Congo (Mbatu and Neuenschwander, 2005); Australia, Fiji, Ghana, India, Kenya, Malaysia, Namibia, Papua New Guinea, South Africa, Sri Lanka, Zambia, and Zimbabwe (Thomas and Room, 1986; Julien and Griffiths, 1998, Tipping and Center, 2005). In Zimbabwe, the weevil was established in two reservoirs comprising 16 ha in the northwest of the country (Chikwenhere and Keswani, 1997). Within two years after introduction in these reservoirs, the weevil provided 99% control of the weed at a cost-benefit ratio of 1:10.6 over a 4-year period. The cost of this biocontrol campaign was estimated at \$ 5 to \$ 6/ha, representing one fourth of the cost of chemical control and physical removal. The success of this weevil in Australia and Papua New Guinea, where the weed was completely controlled by *C. salviniae*, was reviewed by Thomas and Room (1986), who concluded that *C. salviniae* provides cost-effective, environmentally sound, and apparently permanent control of *S. molesta* in these two countries. The use of *C. salviniae* for the management of *S. molesta* is recognized as the leading and most frequently used strategy in all areas of the world due to its highly effective nature. In tropical areas, the time taken to control an infestation biologically is measured in terms of months instead of years, as is the norm with most insect biological control agents. It is highly cost effective since the impact is realized for years without reintroduction and there are no recorded risks associated with the release of *C. salviniae* (Flores and Wendel, 2001). In comparison with chemical control and physical removal, biocontrol is a more viable method for the long-term control of *S. molesta* (Charudattan, 2001).

## **6.5. Conclusion**

During early infestations, salvinia was difficult to manage due to the fact that physical removal was not effective because of the huge water bodies covered by salvinia. However, the biological control programme using *C. salviniae* against *S. molesta* was successful in Senegal and Mauritania. The effects of *C. salviniae* on the weed along the Senegal River and its

tributaries were visible three months after release. Establishment and subsequent population build-up were observed. Mats of *S. molesta* were totally destroyed by August 2002 leaving isolated plants or minor patches of the weed. As a result, the invasion of salvinia has effectively been solved with biological control in an environmentally safe manner and with very substantial economic savings.

The single most important factor contributing to the success of the biological control programme in Senegal and Mauritania was the involvement of dedicated individuals who understood the potential of biological control and who ensured that the programme progressed. On the accomplishment of the riparian community's awareness and participation, these people developed community involvement, another important factor in the success of the programme, in mass rearing and agent distribution. The mass media (radio and television), newspapers and journals, have also been used to educate people about the harmful effects of the uncontrolled spread of *S. molesta*. Riparian communities on infested water bodies that were trained by the programme were involved and actively participated in the rearing and releases of the weevils. The fishermen played an important role in the dissemination of the weevils by moving infested plants to sites where the weevils had not established.

## Chapter 7

### General discussion and conclusion

#### 7.1. Introduction

In 1985 the Diama Dam was built near the mouth of the Senegal River to regulate water flow during the rainy season and prevent the intrusion of seawater during the dry season. This created ideal conditions upstream of the dam wall for invasion by aquatic weeds.

Consequently, the Senegal River and Lake Guiers have been invaded successively in 1993 and 1999 by two invasive aquatic weeds, *Pistia stratiotes* and *Salvinia molesta* respectively. The lack of indigenous natural enemies and the presence of nutrient rich waters have contributed to their invasiveness. In a study of the impact and control of alien aquatic vegetation in South African aquatic ecosystems, Hill (2003) reported that the long-term management of alien aquatic vegetation relies on biological control of existing species, the prevention of other species entering in the country and, more importantly, the reduction of nutrients entering aquatic ecosystems.

The two weeds are of South American origin and are capable of developing dense mats, impeding fishing and boat transport, as well as constituting health problems by sheltering disease-carrying insects and snails. In this study, no analyses have been made of environmental or economic costs. However, *P. stratiotes* and *S. molesta* inevitably have impacted on the social and natural environments. Clearly *S. molesta* is capable of rapidly reducing a complex ecology to a monoculture (Doeleman, 1989). Thus, according to Doeleman (1989) as salvinia has spread in Sri Lanka, aquatic plants and animals as well as birds must have suffered even though this has not been quantified. The world-wide distribution, impact and control of water lettuce and salvinia have been described by Hill *et al.* (1998), Navarro and Phiri (2000) and Julien *et al.* (2001). In Africa, the focus was on Eastern, West, and particularly Southern Africa (Olckers and Hill, 1999).

Biological control is generally deemed successful when the target plant population is significantly reduced and no additional control methods are required (McConnachie *et al.*, 2003). Forno and Julien (2000) reported on methods for measuring the success of biological control agents that have been released on weeds. These range from simple descriptive methods proposed by Laing and Hamia (1976) and Hoffmann (1995), which rate success from negligible to complete, to the more complex methods of Moran and Zimmerman (1984), or a

combination of qualitative and quantitative methods (Julien, 1997). Long-term monitoring is still required to determine the dynamics of weed resurgence and agent location and so the findings of a post-release evaluation are important for other countries that have the same or similar aquatic weed infestations (McConnachie *et al.*, 2003).

Van Wyk and Van Wilgen (2002) reported that biological control has its drawbacks. It is often slow, especially initially, and this often leads to impatience and pressure to use herbicides to achieve quick control. Like other controls, biological control will not completely eliminate the weed, and so low levels of infestation, with occasional outbreaks from time to time, will remain a feature of systems under biological control. However, its relatively low cost should offset these disadvantages.

In this study, much of the emphasis has been put on the importance of quantitative post-release monitoring of biological control of *P. stratiotes* and *S. molesta*. Mass rearing and releases of host-specific weevils have been achieved with *Neohydronomus affinis* against *P. stratiotes* and *Cyrtobagous salviniae* against *S. molesta*. Further, exclusion experiments, host-specificity and impact tests were conducted in the laboratory.

## **7.2. The successful biological control of *Pistia stratiotes* and *Salvinia molesta* in Senegal**

### **7.2.1. Biological Control Programme background**

Why was biological control of aquatic weeds considered in Senegal? The acceptance of biological control in Senegal was probably due to a few historically successful programmes. In 1976 the invasion of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Homoptera: Pseudococcidae) in Senegal destroyed almost all the cassava crop around the country. The Plant Protection Directorate (DPV) unsuccessfully applied pesticides to control the pest due to the mealybug living underneath cassava's leaves. Up to 1991, there was no effective solution for controlling the pest. Facing much criticism due to the exclusive use of chemical pesticides in pest control, the DPV initiated a small biological control unit in 1990 to explore alternatives. The International Institute of Tropical Agriculture (IITA)/Biological Control Station in Benin was the ideal partner. In February 1989, after training two Senegalese technicians, IITA signed an agreement with the Senegalese Government; confirming the partnership in biocontrol. The Senegal Biological Control Project (PLB, French abbreviation) was thus born in 1990. Several biological control programmes were successfully conducted by the PLB. Firstly, the introduction and release of the parasitoid *Epidinocarsis lopezi* brought the cassava mealybug, *Phenacoccus manihoti* under control (Anonymous, 1994; Neuenschwander, 2001). This

success allowed new prospects in the adoption of biological control in Senegal. Subsequently, other successful biological programmes were applied: 1) in 1994, *Metharizium flavoviride* Gams & Rozypal, 'Green muscle' against grasshoppers (Anonymous, 1994; Lomer *et al.*, 2001) and 2) in 1995, two parasitoids, *Anagyrus mangicola* Noyes and *Geranusoiidea tebygi* introduced and released to control mango mealybug, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae) which posed a serious problem for mango orchards (Anonymous, 1995; Neuenschwander, 2003).

These successes sensitized not only the Senegalese Government, but also the general public to the theory, practice and potential of biological control. The programmes on water lettuce and salvinia were further supported due to great successes in controlling these weeds elsewhere in Africa (Hill *et al.*, 1998; Julien *et al.*, 2001).

### **7.2.2. Effective biological control of water lettuce and salvinia**

The lack of funding has often been a stumbling block in such projects and, the programme could have not been launched and conducted without specific funding from the Government of Senegal and IITA. The initial funding was not used for feasibility studies to elucidate the problem but to develop support for the programme with basic infrastructures: laboratory (plastic house) and rearing tubs.

An awareness campaign was conducted on the riverine people. They were reluctant at the beginning of the biological control activities but as saying of the Wolof (main ethnic group in Senegal) goes: "... if mum is not there, you suck grandma's breast..." In other words, as the physical control was not effective, they were eager to see the programme proposing a control alternative and they voluntarily adhered to it. Local fishing and farmer communities were trained on the importance of public awareness for the biocontrol of aquatic weeds, the advantages of biological control of water lettuce, recognition of the weevil and its damage on water lettuce and demonstration of the weevil rearing and release methods.

The quantitative post-release evaluation of biological control of *P. stratiotes* with the weevil *N. affinis* recorded that the area covered by *P. stratiotes* before releases amounted to 2,034 ha. Following the first release in October 1994 and onwards, at all sampled sites on Lake Guiers, the overall percentage water cover of *P. stratiotes* showed a decrease of about 25% every two months resulting in the water lettuce mat crashing by the end of September 1995. The spread

and distribution of *N. affinis* started two months after release. It was important to notice that, even though releases were not made at Djoudj Park which is located more than 150 km upstream and north of the release sites, adult weevils were recovered there four months later. This indicates the potential of the weevil to spread long distances (Chapter 3). The biological control was effective and the waterbodies cleared of water lettuce within 8 months. This success has had a great impact on a national level and the media played an important role in the broadcasting of the good results of the programme on water lettuce (Appendix 3.1).

After a break of about 6 years, a second aquatic weed, *Salvinia molesta* took over and infested large areas of the Senegal River and to a lesser extent on Lake Guiers. The success attained with the control of water lettuce paved the way for a biological control project on salvinia. Officially, DPV was appointed to conduct the biological control programme against salvinia. However, this project was slightly more complicated in that it involved the two countries, Senegal and Mauritania, sharing the Senegal River. A coordination unit was appointed by FAO.

A total of 48 953 *C. salviniae* weevils was released at 270 sites infested with salvinia from early January 2002 to August 2002. Within one year, weevils were established and were being recovered 50 km from release sites. Post-release sampling data from five study sites indicated a reduction in plant wet mass, and a significant increase in weevil feeding damage and adult weevils per square metre. The rapid and excellent impact of the agent *C. salviniae* on the weed should be credited in part to the high numbers (48 953) of the natural enemy released in Senegal and Mauritania. Referring to the case study at Ndiatene Marekhor, a substantial decrease of 40% in salvinia cover was observed by March 2001, 8 months after release. Twenty four months after release, the salvinia cover was reduced to less than 3%. Only a few patches of salvinia remained (Chapter 6).

Prior to the biological control programme, physical control had been applied to clear invaded boat access points and provide access to water bodies, and also to prevent salvinia infesting new areas. However, this was very difficult to achieve and was not sustainable due to rapid regrowth. Also, among other constraints was the very high financial costs and labour commitment associated with physical control. The physical removal of salvinia in Senegal has been estimated at  $1\,500 \text{ francs CFA/m}^2 = \$\text{US } 3/\text{m}^2 = \$\text{US } 30,000/\text{hectare}$  (Abdou Dia,

Coordinator Comité Civilo-Militaire d'Appui au Développement - CCMAD in St Louis, pers. comm.). The most detailed assessment of costs caused by *S. molesta* was conducted in Sri Lanka using 1987 as the base year (Doeleman, 1989). Paddy rice losses, fishing losses, other losses (power generation, transport, washing and bathing, etc.), health costs, abatement costs, and economic benefits were considered. No environmental costs were included, but they were recognised as important. There were no identified benefits from *S. molesta*. Total costs associated with *S. molesta* were estimated to be between 0.9 and 2.1 million Australian dollar (A\$) for 1987. This information was used to determine the benefits from biological control over the following 25 years. The benefits were A\$ 53 per A\$ 1 invested, or 1673 man-hours per man-hour invested. Using this information as a guide, Room and Julien (1995) estimated that the annual benefits gained from successful biological control of *S. molesta* worldwide were approximately US\$ 150 million.

The biological control of the two aquatic weeds has been successful in Senegal and these two weeds no longer pose as much of a problem. However, in 2005 a resurgence of water lettuce was observed in some areas of the Senegal River Delta and in a reservoir in Mboro. Additional releases of the weevil again achieved effective control.

### **7.3. Why such good results with biological control of aquatic weeds in Senegal?**

In the light of our studies, it took less than one year for the successful biological control of water lettuce and less than two years for salvinia. Our results support the ones obtained in South Africa by Cilliers (2003) who reported that, depending on climate and the extent of a *S. molesta* infestation, mats sink within 1-3 years. Also, similar results were reported in Zimbabwe by Chikwenhere and Forno (1991) with water lettuce. The biological control of aquatic weeds world-wide has been highly successful, more so than the programmes on terrestrial weeds. Hill and Julien (2004) listed several factors that have contributed to the successful biological control of water weeds world-wide and these hold true for the programmes in Senegal:

- Reliance on fundamental research from developed countries. Researchers, notably in the USA, South Africa, and Australia have done much of the basic work relating to the specific natural enemies of the three important aquatic weeds in Africa: water hyacinth, water lettuce and salvinia; notably host-specificity tests. The biocontrol project in Senegal took advantage of these results and was able to implement the

programmes, considerably faster than if the country had been required to undertake the fundamental research.

- Simple mass rearing and release techniques. The easy, improved mass-rearing techniques with pools used in developed countries like Australia and South Africa were found to be innovative and practical. These gave our programme the opportunity to harvest for release large numbers of healthy natural enemies, notably in the case of *C. salviniae* in Senegal and Mauritania.
- Standard post-release monitoring techniques. The standardization of the post release monitoring sheets, among countries affected by water weeds, permitted the recording and analysis of salvinia data for Senegal and Mauritania. The technicians have been trained to fill out the forms properly and it was easy to make data comparisons between different control sites from the two countries. Furthermore, as these techniques are standardized internationally, global comparisons became possible.
- Stakeholder participation. The awareness campaigns and the community participation in training, agent rearing and agent distribution in the two countries were innovative and successful. Political support from the respective governments was also effective. In addition, the media relayed the news of success, notably where impacts were observed in Lake Guiers and the Senegal River. Without public participation the programmes would not have been as successful.
- Involvement of dedicated individuals. Support from international organizations, NGOs, state departments has been good and eased any administrative constraints that could have negated the programme's progress in the two countries.
- Any control strategy must be affordable and sustainable. This is what biological control is all about. Indeed, the success achieved has saved a lot of money for the agriculture, fishing, and transportation sectors which could have been better elaborated in socio-economic studies. Furthermore, biocontrol is environmentally safe and long-lasting. The weevils will always be present in Senegal even though re-inoculations may be needed from time to time.

#### 7.4. Integrated management of invasive aquatic weeds

In some cases, once biocontrol has been introduced, an integrated management focusing on the low application of selected herbicides could be undertaken to enhance the weevil strategy effects. This possibility has been studied mainly with water hyacinth. Many herbicides have adverse effects on biocontrol agents (Ueckermann and Hill, 2000) which are important when integrated control is being considered. Wright and Bourne (1990) investigated the effect of 2,4-dichlorophenoxy acetic acid (2,4-D), on the quality of water hyacinth as foods for insects. They found that the use of 2,4-D could favour attack by the leaf weevils *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae) and *Neochetina bruchi* Hustache (Coleoptera: Curculionidae), and the moth, *Niphograpta albiguttalis* Warren (Lepidoptera: Pyralidae) (= *Sameodes albiguttalis* Warren) as the chemical induced a softening of the leaf and petiole epidermis and it was therefore easier for the insects to enter the plants. However, in all their experiments, the herbicide was applied without its surfactant which Wright and Skilling (1987) had found to be toxic to the insects. Wright and Bourne (1990) therefore suggested that integrating biological control of water hyacinth with low applications of 2,4-D without its surfactant, could enhance the control of the weed.

Hill and Olckers (2001) reported that in South Africa the control of water hyacinth relies heavily on the application of herbicides, and that this policy has been antagonistic to biological control for two reasons. Firstly, certain herbicide formulations used on the weed in South Africa, especially those with high surfactant content, cause high mortality of the natural enemies. Although *N. eichhorniae* was resistant to most herbicide applications, those that contained diquat as an active ingredient were toxic to the weevil (Ueckermann and Hill, 2000). These authors also found that all herbicides tested, with the exception of one glyphosate-based product that contained no surfactants, were toxic to the mirid *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae). Secondly, herbicidal destruction of water hyacinth populations, especially in impounded systems causes extensive mortality of the sessile immature stages and dispersal of the adult stages, when the weed mats start to sink. Re-infestation of these treated sites occurs via seed germination and isolated plants that were left unsprayed and the water hyacinth populations proliferate in the absence of natural enemies (Center *et al.* 1999).

The impact of other herbicides and their surfactants on natural enemies released as biological agents for water hyacinth is poorly understood and requires further investigation before the

compatibility of herbicide and biological control can be confirmed or refuted (Hill, 1999). Solutions to these problems, currently under investigation, include: (i) using herbicide formulations that are less toxic to the natural enemies; (ii) re-inoculating plants that are overlooked during herbicidal application; and (iii) accepting the concept of leaving untreated 'reserves' to act as refuge for the agents (Hill and Olckers, 2001).

## 7.5. Conclusion

The availability of biological control data on the two natural enemies utilised in our studies, *N. affinis* and *C. salviniae*, and on their respective hosts, water lettuce and salvinia, was of key importance when we were planning mass rearing, releases and quantitative post-release evaluations. For example, data on the biology of the weeds (growth and reproduction) and on the natural enemies (biology and ecology) were useful in running the two biological control programmes. These considerations were stressed by Stocker (2000) i.e. that the known ecological impacts of weeds and control methods gathered from other regions should be taken into consideration when assessing the potential local impacts of control methods.

*Pistia stratiotes* and *Salvinia molesta* are under control in the water bodies of Senegal, notably Senegal River and Lake Guiers. However, with their disappearance other aquatic plant species mainly *Typha australis* have taken over. The long-term control of weeds in such systems will require an integrated management approach utilising all appropriate control methods, with special emphasis on the need to look at the eutrophication of water ecosystems by clarifying the nitrate and phosphate pollution in the aquatic environment. This is why it is crucial that biological control of an aquatic weed forms part of an integrated control approach, which has at its base the control of nutrients. Future studies on the succession of invasive aquatic weeds in the Senegal River and Lake Guiers should be focused on elucidating the issue of eutrophication with nitrates and phosphates.

Finally, Senegal should not hesitate in raising public awareness and training local communities about invasive water weeds. This is a predominantly pressing task, given that the world's worst aquatic weed is poised to take over as the primary aquatic problem. Water hyacinth *Eichhornia crassipes* has already been introduced as an ornamental plant for garden water features in the capital city of Dakar, and it is only a matter of time before it escapes into the Senegal River.

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**Appendix 2.1.** The laboratory tub experiment design.



**Appendix 3.1.** Media report on the biological control of water lettuce *Pistia stratiotes* in Senegal.

1. "SPORE Bulletin bimestriel du Centre de Coopération Agricole et Rurale. N°62 Avril 1996.  
Un charançon dans la salade."

# SPORE



Bulletin bimestriel du Centre Technique de Coopération Agricole et Rurale

N° 62  
AVRIL 1996

## Un charançon dans la salade

La laitue d'eau, *Pistia stratiotes* pour les scientifiques, « panau » en peuhl et « teumbelane » en ouoloff, est une calamité, notamment dans la vallée du fleuve Sénégal. Il y a quelques années, le lac de Guiers, au nord de Dakar, ressemblait par endroit à une prairie, l'eau étant recouverte d'un épais tapis de verdure. En empêchant la remontée d'eau salée dans le fleuve, la construction du barrage de Diama en 1985 a favorisé la prolifération de cette plante aquatique. Depuis, elle envahit les canaux d'irrigation, obstrue les crépines des moto-pompes et prive les poissons d'oxygène.

C'est un chercheur sénégalais, Ousseynou Diop, à la tête d'une modeste équipe qui a relevé le défi en appliquant un procédé de lutte biologique déjà testé au Zimbabwe : le charançon d'eau *Neohydronomus affinis*, ennemi naturel du pistia. Le charançon pond à la base des feuilles de laitue et ses larves s'attaquent à la plante avec des perforations d'un millimètre de diamètre environ. Les feuilles jaunissent et l'affaire est réglée en quinze jours. Pistia affaiblie se ratatine puis meurt. Trois mois après les premiers lâchers d'insectes, les salades ont disparu.

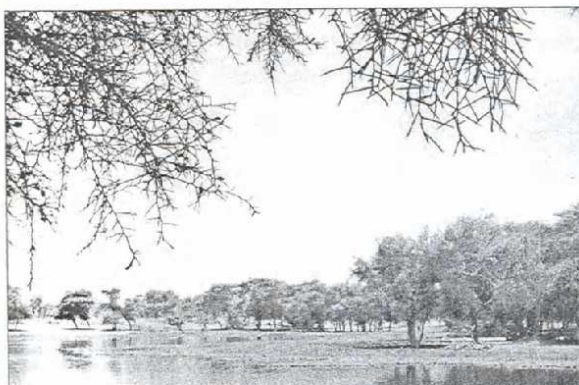


PHOTO PERISCOOP

*Pistia*, la calamité des eaux tropicales, peut recouvrir un plan d'eau d'un épais tapis de verdure.

Mais comme dans toute lutte biologique, on a au préalable vérifié si le charançon était susceptible de s'attaquer à des plantes utiles car dans ce cas, le remède peut être pire que le mal. Fort heureusement, les études menées sur une quarantaine de plantes ont révélé que notre charançon n'aimait guère d'autre plante que le Pistia.

↳ Ousseynou Diop - Projet de lutte biologique - Service de la protection des végétaux  
BP 20084 - Thiaroye - Dakar - SENEGAL

## Appendix 3.1. (continued)

### 2. "Lutte contre la pollution des cours d'eau. Un insecte dans la salade. Par Madieng SECK. Syfia."

**Lutte contre la pollution des cours d'eau**

*La laitue d'eau qui prolifère à la surface des lacs a trouvé son maître : un charançon originaire d'Amérique du Sud. L'insecte vient de gagner un premier round très spectaculaire.*

## Un insecte dans la salade

Par Madieng SECK\*

SAMEDI 7 août 1995 : jour de marché forain à Keur Momar Sarr, au bord du lac de Guiers (250 km au nord de Dakar). A quelques mètres de la berge, un éleveur peulh lave son cheval dans l'eau. Plus loin, des femmes, sans doute des gargotières rurales, remplissent leurs bassines. Scènes apparemment banales si ce n'est que cette année l'eau est accessible et claire, enfin débarrassée de son épais tapis de salades qui, depuis quelques années, flottait à la surface. *«Avant, à pareille époque, il était impossible de s'aventurer ici pour chercher de l'eau»,* remarque joyeusement une villageoise, un seau d'eau sur la tête. L'année dernière, par endroit, le lac ressemblait en effet à une prairie.

*«Incroyable mais vrai !»,* s'exclame Abdou Ndiaye, chef de secteur des Eaux et Forêts. *«C'est le charançon d'eau qui a détruit la salade !».* Ce forestier qui, en juin dernier, avait participé aux opérations de lâcher de ces insectes dans la partie sud du lac, s'étonne des résultats fulgurant de la lutte biologique. La «bête» est un coléoptère brun jaune de 2 mm de long, originaire d'Amérique du Sud.

La laitue d'eau, *Pistia stratiotes* pour les scientifiques, «panau» en peulh et «teumbelane» en wolof, est une calamité dans cette localité et jusque dans la moyenne vallée du fleuve Sénégal. La construction, en 1985, du barrage de Diamana en empêchant la remontée d'eau salée dans le fleuve, a favorisé la prolifération de cette plante aquatique. Depuis, elle envahit les canaux d'irrigation, obstrue les crépines des moto-pompes, prive les poissons d'oxygène... Elle pose aussi un sérieux problème à Ngnith où se trouve l'usine de traitement des eaux du lac de Guiers qui alimente en eau potable l'agglomération dakaroise.

Un peu plus au nord, dans le parc de Djoudj, classé «patrimoine mondial» par l'Unesco, cette peste empêche les oiseaux migrateurs, venus d'Europe pour hiverner, de se poser et de pêcher leur nourriture. Les racines flottantes de *Pistia*, où s'empêtrent leurs pattes, forment des pièges souvent mortels pour eux. A l'approche de l'hivernage, l'odeur fétide des salades en putréfaction se dégage de ces eaux stagnantes où prolifèrent mouches, moustiques et mollusques indésirables. Et qui dit moustiques dit paludisme. En septembre 1994, trois cas mortels ont été enregistrés.

Comment rendre la santé aux eaux, à leurs hôtes et à leurs riverains ? La lutte chimique contre cette maudite laitue est impossible sans polluer l'eau.

La destruction mécanique a été expérimentée, mais sans grands résultats. Les efforts des villageois mobilisés pour ramasser ces tapis flottants gorgés d'eau ont été vains. *«Un plant de laitues enlevé la veille revient en force le lendemain»,* affirme à sa manière un paysan. En fait, chaque tronçon donne naissance à un nouveau pied qui à son tour émet des pousses qui à leur tour, etc. Un cycle infernal. Méthode radicale, l'assèchement des lits des rivières a été tenté, mais n'a pas mieux réussi.

Finalement, c'est un chercheur sénégalais à la tête d'une modeste équipe (deux techniciens et trois laborantins) qui va relever le défi en appliquant un procédé de lutte biologique déjà testé au Zimbabwe. Sans grands espoirs au départ, ce jeune entomologiste, Ousseynou Diop, responsable du projet de lutte biologique au service de la protection des végétaux, a cherché à *«contenir et de maintenir à un niveau acceptable l'infestation de Pistia stratiotes par un ennemi naturel, le charançon d'eau (Néohydronomus affinis)».*

(Suite en page 5)

WALFADJIRI N°1098  
Sam. Dim. 11 Nov. 1995

## Lutte contre la pollution des cours d'eau

### Un insecte dans la salade

(Suite de la page 4) - Dès juin 1994, un an avant les premiers lâchers dans la nature, des essais sont menés en serre à Richard-Toll et à Dakar avec 1 037 insectes adultes provenant du programme de lutte biologique de l'Institut international d'agriculture tropicale installé au Bénin, partenaire financier du projet avec l'Etat sénégalais.

Le charançon pond dans les grosses côtes à la base des feuilles de laitue et ce sont ses larves qui vont s'attaquer à la plante. Des perforations d'un millimètre de diamètre environ, «signes évidents de trous de nourriture», ont été observées sur les feuilles qui jaunissent puis brunissent, explique M. Diop dans un rapport. En quinze jours, l'affaire est réglée. *Pistia* affaibli, se ratatine puis meurt. Mais comme dans toute lutte biologique, on a au préalable étudié si le charançon était susceptible de s'attaquer à des plantes «utiles», car dans ce cas le remède peut être pire que le mal. Des études menées au Zimbabwe en 1990 ont montré qu'une quarantaine de plantes, comestibles ou non, n'intéressaient guère notre charançon. Sorgho, mil, riz, maïs, coton, niébé, canne à sucre, pommes de terre, etc., assistent donc en spectateurs au combat aquatique entre l'insecte et la plante. Des études menées en 1988 en Australie puis en Floride

avaient d'ailleurs montré que *Pistia* était la seule espèce attrayante pour la ponte et l'alimentation de ce charançon *Néohydronomus* ne manifeste qu'un intérêt très modéré pour d'autres plantes aquatiques dont l'Azolla.

Cheick Guèye, responsable du volet arboriculture à l'Association sénégalaise d'études et d'appui au développement (Asread), une Ong installée à Keur Momar Sarr, se félicite de l'expérience. Lui aussi est formel : «Trois mois après les premiers lâchers d'insectes, les salades ont disparu et il n'y a plus de panes de crépine dans les motopompes.» Massamba Diagne, le chef du centre de santé, note une baisse du taux de prévalence des maladies diarrhéiques (de 25 % en 1994 à 5% cette année) et de celui de nombreuses allergies cutanées constatée après les baignades. Seule fausse note dans ce concert d'applaudissements, le scepticisme du président du conseil rural, Djouméroù Kâ. Pour lui, seul les vents ont déplacé les laitues, le reste n'est qu'obscur saladier politique.

En tout cas, dopés par leur éblouissant succès, Ousseynou Diop et son équipe se disent prêts à étendre la lutte biologique partout où cela sera nécessaire dans le pays. A condition, bien sûr, qu'on leur en donne les moyens.

M. SECK\*  
\*Syfia

**Appendix 6.1.** *C. salviniae* weevils collected from the mass rearing in Senegal (Senegal River–Left Bank).

Date	Rearing pool 1	Rearing pool 2	Rearing pool 3	Rearing pool 4	Rearing pool 5	Rearing pool 6	TOTAL
19.12.2001	110	83	60				253
20.12.2001	12	23	21	69	165	111	401
21.12.2001	26	10		16	29	34	115
22.12.2001			1301				1301
24.12.2001	8	9	443	12	8	8	488
30.12.2001		5	179	3	13	4	204
31.12.2001				327			327
1.1.2002				1045			1045
5.1.2002				246			246
7.1.2002				157	549		706
8.1.2002					32		32
11.1.2002					432		432
13.1.2002					71		71
14.1.2002					61		61
15.1.2002		274	28	30	23		355
18.1.2002		352					352
20.1.2002		30					30
21.1.2002	746					828	1574
27.1.2002	154						154
29.1.2002	119			326	155	200	800
30.1.2002		452	535				987
1.2.2002	86	75	144	166	46	84	601
13.2.2002	101	131	188				420
14.2.2002				114	72	82	268
16.2.2002	177	145	461	361	79	210	1433
20.2.2002	107	152	255	430	152	206	1302
1.3.2002	143	93	165	245	120	81	847
4.3.2002			158				158
6.3.2002	121	71	80	184	124	158	738
9.3.2002	57	49	80	79	53	34	352
13.3.2002	22	23	46	39	17	51	198
27.06.2002	381	463	444	427	385	362	2462
1.07.2002	370	480	470	390	360	410	2480
7.07.2002	384	395	313	306	317	320	2035
10.7.2002	419	377	292	647	151	141	2027
13.7.2002	626	536	504	566	468	502	3202
25.7.2002	112	124	126	170	114	107	753
<b>TOTAL</b>	<b>4281</b>	<b>4352</b>	<b>6293</b>	<b>6355</b>	<b>3996</b>	<b>3933</b>	<b>29210</b>

**Appendix 6.1.** (continued) *C. salviniae* weevils collected from the mass rearing in Mauritania (Senegal River - Right Bank).

<b>Date</b>	<b>Rearing pool 1</b>	<b>Rearing pool 2</b>	<b>Rearing pool 3</b>	<b>Rearing pool 4</b>	<b>Rearing pool 5</b>	<b>Rearing pool 6</b>	<b>TOTAL</b>
15.3.2002	235	234	229	234	233	235	1400
18.3.2002	241	232	222	225	240	240	1400
21.3.2002	245	239	226	230	229	231	1400
24.3.2002	200	196	201	202	200	201	1200
26.3.2002	190	203	203	202	201	201	1200
28.3.2002	189	204	200	202	202	203	1200
29.3.2002	175	174	180	155	153	163	1000
30.3.2002	176	173	180	158	149	164	1000
31.3.2002	98	98	100	100	103	101	600
31.4.2002	98	99	100	101	102	104	600
14.6.2002	180	188	186	181	182	183	1100
16.6.2002	182	170	180	178	176	174	1060
18.6.2002	173	170	170	172	172	173	1030
20.6.2002	170	168	169	171	168	169	1015
22.6.2002	148	150	151	147	150	149	895
24.6.2002	128	129	126	129	127	126	765
26.6.2002	123	126	123	121	122	120	735
26.7.2002	125	130	126	124	123	132	760
27.7.2002	124	128	127	122	124	126	751
28.7.2002	122	126	125	120	122	125	740
29.7.2002	120	123	122	121	120	123	729
30.7.2002	118	122	120	119	117	120	716
31.7.2002	116	118	117	116	115	118	700
1.8.2002	114	115	114	114	112	113	682
2.8.2002	110	111	98	96	89	92	596
3.8.2002	90	85	94	70	68	48	455
4.8.2002	80	60	45	35	36	30	286
5.8.2002	50	30	28	25	30	22	185
<b>TOTAL</b>	<b>4120</b>	<b>4101</b>	<b>4062</b>	<b>3970</b>	<b>3965</b>	<b>3986</b>	<b>24200</b>

**Appendix 6.1** (continued) Above-ground metal pools with plastic liners for *Cyrtobagous salviniae* mass rearing at Hotel Hostellerie du Djoudj courtyard-Djoudj Park-Senegal



**Appendix 6.2.** Analysis of variance of two monitored variables of *Salvinia molesta* over time: wet weight and number of adult weevils.

**1) Wet weight** - Stars indicate significance at  $p < .05$

Site	SS	df	MS	F	p
DebiTiguet	1464444	4	366111.1	22.22268	0.000000*
Temeye	569971	4	142492.7	7.64704	0.000362*
GoromLamsar	28914	4	7228.5	52.49988	0.000000*
Gouer Sangfaye	3331020	4	832755.0	65.47502	0.000000*

**2) Number of adult weevils** - Stars indicate significance at  $p < .05$

Site	SS	df	MS	F	p
Debi Tiguet	1436.467	4	359.117	4.14397	0.010368*
Temeye	4219.133	4	1054.783	4.48373	0.007211*
Gorom Lamsar	616.533	4	154.133	57.22772	0.000000*
Gouer Sangfaye	491.467	4	122.867	30.11438	0.000000*

**Appendix 6.3.** *Cyrtobagous salviniae* release sites in Senegal and Mauritania.

**1. Senegal** (Senegal River Left Bank)

Date	Locality	Release Site	GPS latitude & longitude	Number of released weevils		
4.1.02	Temeye	S1	16°20 N 648 15°46 W 305	200		
		S2	16°20 N 651 15°46 W 315	200		
		S3	16°20 N 701 15°46 W 385	200		
		S4	16°20 N 570 15°46 W 268	200		
		S5	16°20 N 405 15°46 W 248	200		
		S6	16°20 N 177 15°46 W 369	200		
		S7	16°20 N 179 15°46 W 329	200		
		S8	16°20 N 101 15°46 W 243	200		
08.1.02	Richard Toll	S9	16°27 N 404 15°41 W 652	200		
		S10	16°27 N 405 15°41 W 652	200		
	Temeye	S11	16°21 N 113 15°46 W 663	200		
		S12	16°20 N 823 15°46 W 447	200		
	Temeye Taouweye	S13	16°20 N 644 15°46 W 298	200		
	Temeye village	S14	16°20 N 213 15°46 W 273	200		
		S15	16°20 N 181 15°46 W 291	200		
		S16	16°20 N 175 15°46 W 291	200		
		S17	16°20 N 161 15°46 W 296	200		
		S18	16°20 N 071 15°46 W 283	200		
		S19	16°20 N 066 15°46 W 276	200		
		S20	16°20 N 049 15°46 W 242	200		
S21		16°20 N 182 15°46 W 329	200			
19.1.02	Gde Digue Keur Demba	S22	16°22 N 022 16°05 W 058	200		
	Diambar bridge	S23	16°25 N 948 15°58 W 329	200		
05.2.02	Djoud Park: Debi village	S24	16°25 N 949 15°58 W 786	200		
		S25	16°28 N 882 16°16 W 529	200		
		S26	16°28 N 845 16°16 W 550	200		
		S27	16°28 N 805 16°16 W 575	200		
		S28	16°28 N 745 16°16 W 613	200		
		S29	16°28 N 707 16°16 W 634	200		
		Djoudj Park: Tiguet village	S30	16°28 N 138 16°17 W 065	200	
			S31	16°28 N 173 16°17 W 105	200	
			S32	16°28 N 119 16°17 W 070	200	
	S33		16°28 N 136 16°17 W 083	200		
	S34		16°28 N 175 16°17 W 121	200		
			S35	16°28 N 176 16°17 W 121	200	
			S36	16°28 N 180 16°17 W 122	200	
			S37	16°28 N 181 16°17 W 122	200	
08.2.02			Temeye	S38	16°20 N 113 15°46 W 055	200
				S39	16°19 N 979 15°46 W 529	200
				S40	16°20 N 039 15°46 W 482	200
				S41	16°20 N 224 15°46 W 353	200
	Wassoule / Senegal River	S42		16°28 N 910 16°01 W 623	200	
	Ndigue bridge	S43		16°18 N 583 16°18 W 756	200	
	13.2.02	Ndigue bridge		S44	16°18 N 603 16°18 W 746	200

18.2.02	Senegal River: Diakhar	S45	16°18 N 854 16°19 W 270	200
		S46	16°18 N 845 16°19 W 322	200
		S47	16°19 N 084 16°19 W 186	200
		S48	16°19 N 138 16°19 W 167	200
		S49	16°19 N 332 16°19 W 139	200
		S50	16°19 N 466 16°19 W 065	200
		S51	16°19 N 317 16°19 W 091	200
		S52	16°19 N 313 16°19 W 161	200
		S53	16°19 N 134 16°19 W 157	200
		S54	16°18 N 835 16°18 W 901	200
27.2.02	Senegal River: Diama village	S55	16°12 N 645 16°24 W 106	200
		S56	16°12 N 650 16°24 W 200	200
		S57	16°12 N 651 16°24 W 173	200
		S58	16°12 N 652 16°24 W 032	200
	Senegal River:Cpt Maka Mirador	S59	16°12 N 905 16°23 W 173	200
	Senegal River: Maka village	S60	16°12 N 969 16°23 W 042	200
15.3.02	Senegal River:Rawette	S61	16°15 N 536 16°21 W 361	200
		S62	16°15 N 503 16°21 W 394	200
		S63	16°15 N 618 16°21 W 429	200
		S64	16°15 N 530 16°21 W 472	200
		S65	16°15 N 507 16°21 W 453	200
		S66	16°15 N 465 16°21 W 482	200
		S67	16°15 N 578 16°21 W 251	200
		S68	16°15 N 490 16°21 W 237	200
		S69	16°15 N 410 16°21 W 287	200
		S70	16°15 N 354 16°21 W 284	200
		S71	16°15 N 187 16°21 W 293	200
		S72	16°15 N 083 16°21 W 105	200
14.3.02	Senegal River:Diama Dam	S73	16°12 N 708 16°24 W 444	3 tubs of infested plants
		S74	16°12 N 703 16°24 W 433	3 tubs of infested plants
		S75	16°12 N 705 16°24 W 441	3 tubs of infested plants
		S76	16°12 N 723 16°24 W 466	3 tubs of infested plants
		S77	16°12 N 724 16°24 W 468	3 tubs of infested plants
		S78	16°12 N 726 16°24 W 469	3 tubs of infested plants
		S79	16°12 N 730 16°24 W 472	3 tubs of infested plants
		S80	16°12 N 795 16°24 W 523	3 tubs of infested plants
		S81	16°12 N 797 16°24 W 528	3 tubs of infested plants
28.6.02	Djoudj Park / Embarcadere	S82	16°23 N 190 16°16 W 451	200
		S83	16°23 N 205 16°16 W 450	200
		S84	16°23 N 227 16°16 W 449	200
		S85	16°23 N 236 16°16 W 450	200
		S86	16°23 N 256 16°16 W 451	200
		S87	16°24 N 545 16°18 W 074	200
		S88	16°24 N 548 16°18 W 081	200
		S89	16°24 N 550 16°18 W 093	200
		S90	16°24 N 554 16°18 W 106	200
		S91	16°24 N 557 16°18 W 121	200
		S92	16°24 N 248 16°17 W 681	200
		S93	16°24 N 261 16°17 W 698	200
2.7.02	Djoudj Park / Debi village	S94	16°28 N 887 16°16 W 528	200

		S95	16°28 N 868 16°16 W 536	200
		S96	16°28 N 854 16°16 W 543	200
		S97	16°28 N 778 16°16 W 588	200
		S98	16°28 N 772 16°16 W 592	200
		S99	16°28 N 763 16°16 W 597	200
		S100	16°28 N 758 16°16 W 600	200
		S101	16°28 N 475 16°16 W 775	200
	Djoudj Park / Poste Ndouth	S102	16°25 N 192 16°18 W 217	200
		S103	16°25 N 188 16°18 W 217	200
		S104	16°23 N 425 16°16 W 618	200
		S105	16°23 N 422 16°16 W 614	200
11.7.02	Temeye	S106	16°20 N 539 15°46 W 209	200
		S107	16°20 N 546 15°46 W 215	200
		S108	16°20 N 576 15°46 W 239	200
		S109	16°20 N 587 15°46 W 250	200
		S110	16°20 N 590 15°46 W 252	200
		S111	16°20 N 617 15°46 W 274	200
		S112	16°20 N 622 15°46 W 278	200
		S113	16°20 N 657 15°46 W 341	200
		S114	16°20 N 714 15°46 W 376	200
		S115	16°20 N 713 15°46 W 377	200
	Temeye	S116	16°20 N 350 15°46 W 325	200
		S117	16°20 N 352 15°46 W 324	200
		S118	16°20 N 358 15°46 W 322	200
		S119	16°20 N 449 15°46 W 237	200
		S120	16°20 N 520 15°46 W 260	200
		S121	16°20 N 523 15°46 W 259	200
	Ross Béthio / Grande Digue	S122	16°21 N 835 16°05 W 194	200
	Senegal River / Djoudj Park	S123	16°28 N 462 16°16 W 785	200
		S124	16°28 N 459 16°16 W 788	200
		S125	16°28 N 455 16°16 W 790	200
13.7.02	Senegal River / Djoudj Park	S126	16°22 N 609 16°16 W 435	200
		S127	16°22 N 611 16°16 W 436	200
		S128	16°22 N 613 16°16 W 436	200
		S129	16°22 N 628 16°16 W 436	200
		S130	16°22 N 629 16°16 W 436	200
		S131	16°22 N 631 16°16 W 436	200
		S132	16°22 N 634 16°16 W 436	200
		S133	16°22 N 637 16°16 W 436	200
		S134	16°22 N 992 16°16 W 444	200
		S135	16°22 N 994 16°16 W 444	200
		S136	16°23 N 000 16°16 W 444	200
		S137	16°23 N 002 16°16 W 444	200
		S138	16°23 N 055 16°16 W 446	200
		S139	16°23 N 064 16°16 W 445	200
		S140	16°23 N 065 16°16 W 445	200
		S141	16°23 N 071 16°16 W 445	200
28.7.02	Senegal River / RIM / Keur Macene	S142	16°31 N 748 16°14 W 298	100
		S143	16°31 N 750 16°14 W 306	100
		S144	16°31 N 751 16°14 W 317	100

		S145	16°31 N 753	16°14 W 327	100
		S146	16°31 N 753	16°14 W 330	100
		S147	16°31 N 753'	16°14 W 335	100
		S148	16°31 N 749	16°14 W 293	100
		S149	16°31 N 757	16°14 W 294	53
29.7.02	Senegal River / Djoudj Park	S150	16°22 N 235	16°28 W 087	2 tubs of infested plants
		S151	16°23 N 068	16°16 W 444	2 tubs of infested plants
		S152	16°23 N 206	16°16 W 448	2 tubs of infested plants
		S153	16°23 N 228	16°16 W 449	2 tubs of infested plants
		S154	16°23 N 236	16°16 W 448	2 tubs of infested plants
		S155	16°23 N 259	16°16 W 449	2 tubs of infested plants
		S156	16°23 N 345	16°16 W 519	2 tubs of infested plants
		S157	16°28 N 455	16°16 W 789	2 tubs of infested plants
		S158	16°28 N 460	16°16 W 786	2 tubs of infested plants
		S159	16°28 N 463	16°16 W 784	2 tubs of infested plants
		S160	16°28 N 449	16°16 W 792	2 tubs of infested plants
		S161	16°28 N 856	16°16 W 538	2 tubs of infested plants
<b>Total</b>					
<b>27153 weevils and 41 tubs infested plants</b>					

**Appendix 6.3.** (end) *C. salviniae* release sites in Senegal and Mauritania.

**2. Mauritania** (Senegal River Right Bank)

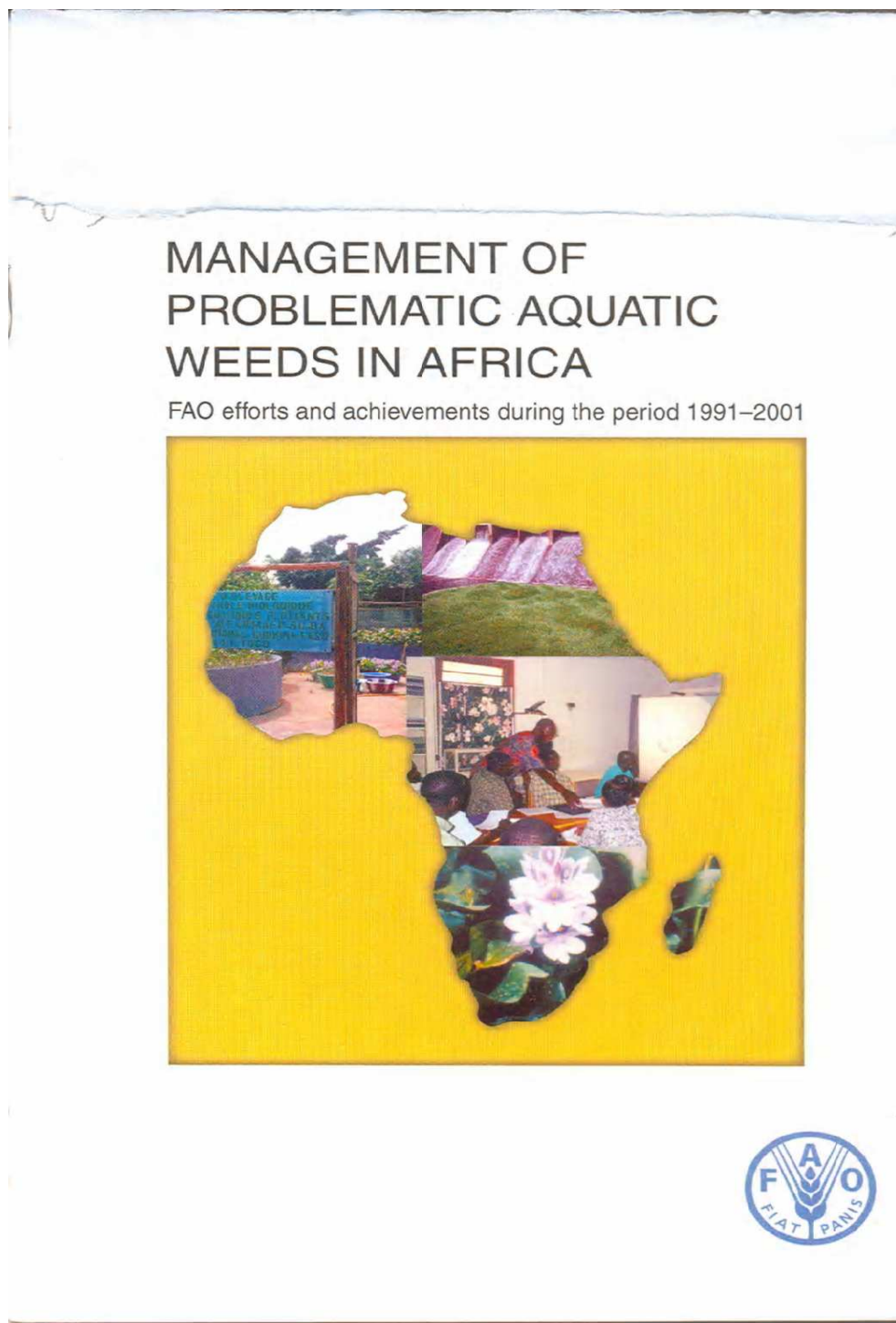
Date	Locality	Release Site	GPS latitude & longitude	Number of released weevils
22/03/02	Gouer Sangfaye	S1	16°31 N 373 16°05 W 167	200
		S2	16°31 N 144 16°04 W 582	200
		S3	16°30 N 511 16°05 W 127	200
		S4	16°31 N 538 16° 03W 541	200
		S5	16° 31 N 421 16° 04 W 087	200
		S6	16° 31 N 396 16° 04 W 207	200
		S7	16° 31 N 371 16° 04 W 331	200
		S8	16° 31 N 326 16° 04 W 548	200
		S9	16° 31 N 316 16° 05 W 048	200
		S10	16° 31 N 334 16° 05 W 151	200
25/03/02	Khaira	S11	16° 29 N 354 16° 00 W 422	200
		S12	16° 29 N 465 16° 00 W 514	200
		S13	16° 29 N 358 16° 01 W 221	200
25/03/02	Breun Darou	S14	16° 30 N 593 15° 53 W 315	200
		S15	16° 30 N 294 15° 52 W 229	200
		S16	16° 30 N 270 15° 55 W 404	200
25/03/02	Rosso M'Pourie	S17	16° 30 N 205 15° 40 W 091	200
		S18	16° 30 N 269 15° 40 W 186	200
		S19	16° 30 N 504 15° 52 W 011	200
29/03/02	Ibrahima	S20	16° 31 N 542 16° 05 W 503	200
		S21	16° 32 N 552 16° 06 W 058	200
		S22	16° 33 N 109 16° 00 W 114	200
29/03/02	Dalagoma	S23	16° 33 N 207 16° 06 W 164	200
		S24	16° 33 N 171 16° 08 W 464	200
		S25	16° 31 N 105 16° 09 W 057	200
29/03/02	Goup	S26	16° 32 N 526 16° 19 W 399	200
		S27	16° 31 N 322 16° 13 W 050	200
		S28	16° 31 N 317 16° 13 W 057	200
31/03/02	Keur Macene	S29	16° 31 N 387 16° 13 W 565	200
		S30	16° 31 N 407 16° 14 W 152	200
		S31	16° 31 N 484 16° 14 W 210	200
31/03/02	Aftout El san	S32	16° 31 N 140 16° 16 W 185	200
		S33	16° 30 N 484 16° 16 W 517	200
		S34	16° 30 N 130 16° 17 W 317	200
31/03/02	Seyal	S35	16° 28 N 057 16° 18 W 203	200
		S36	16° 25 N 006 16° 19 W 434	200
		S37	16° 24 N 267 16° 20 W 011	200
01/04/02	Lemer	S38	16° 24 N 162 16° 20 W 064	200
		S39	16° 22 N 531 16° 20 W 228	200
		S40	16° 22 N 348 16° 20 W 244	200
01/04/02	Tekech	S41	16° 31 N 545 15° 55 W 407	200
		S42	16° 31 N 404 15° 57 W 326	200
		S43	16° 31 N 353 15° 58 W 020	200
01/04/02	Moushaib	S44	16° 32 N 158 16° 03 W 002	200
		S45	16° 32 N 179 16° 03 W 133	200
		S46	16° 32 N 183 16° 03 W 281	200
		S47	16° 32 N 104 16° 03 W 520	200
		S48	16° 31 N 064 15° 59 W 073	200
		S49	16° 31 N 128 15° 58 W 569	200
18/06/02	Gouer Sangfaye	S50	16° 31 N 471 16° 05 W 492	200

		S51	16° 31 N 566 16° 05 W 382	200
		S52	16° 32 N 090 16° 05 W 438	200
18/06/02	Khaira	S53	16° 29 N 162 16° 02 W 121	200
		S54	16° 29 N 465 16° 00 W 514	200
		S55	16° 30 N 169 16° 59 W 526	200
		S56	16° 30 N 169 16° 59 W 526	200
18/06/02	Breun Darou	S57	16° 29 N 594 15° 59 W 526	200
		S58	16° 29 N 594 15° 59 W 085	200
22/06/02		S59	16° 31 N 135 15° 54 W 750	200
		S60	16° 31 N 025 15° 55 W 144	200
		S61	16° 30 N 484 15° 56 W 027	200
		S62	16° 30 N 400 15° 56 W 194	200
		S63	16° 30 N 379 15° 56 W 415	200
		S64	16° 30 N 249 15° 56 W 875	200
22/06/02	Rosso	S65	16° 30 N 356 15° 51 W 371	200
		S66	16° 30 N 244 15° 51 W 171	200
		S67	16° 30 N 490 15° 51 W 503	200
		S68	16° 30 N 507 15° 52 W 071	200
		S69	16° 30 N 244 15° 51 W 271	200
24/06/02	Ibrahima	S70	16° 32 N 211 16° 05 W 492	200
		S71	16° 32 N 341 16° 05 W 558	200
		S72	16° 33 N 201 16° 06 W 164	200
24/06/02	Dalagoma	S73	16° 32 N 487 16° 09 W 443	200
		S74	16° 33 N 281 16° 06 W 276	200
31/06/02	Keur Macene	S75	16° 33 N 525 16° 03 W 089	200
		S76	16° 32 N 323 16° 14 W 101	200
28/07/02	Gouer Sangfaye	S77	16° 31 N 554 16° 01 W 384	200
		S78	16° 31 N 554 16° 01 W 315	200
		S79	16° 31 N 313 16° 04 W 505	200
		S80	16° 32 N 476 16° 05 W 343	200
		S81	16° 32 N 341 16° 05 W 558	200
		S82	16° 21 N 211 16° 05 W 492	200
28/07/02	Keur Macene	S83	16° 31 N 517 16° 16 W 103	200
		S84	16° 31 N 849 16° 16 W 396	200
		S85	16° 31 N 904 16° 15 W 339	200
		S86	16° 31 N 754 16° 14 W 296	200
01/08/02	Tekech	S87	16° 31 N 507 15° 55 W 507	200
		S88	16° 31 N 411 15° 56 W 104	200
		S89	16° 31 N 394 15° 57 W 184	200
		S90	16° 31 N 336 15° 37 W 538	200
		S91	16° 31 N 056 15° 58 W 526	200
01/08/02	Gouer	S92	16° 32 N 038 16° 02 W 267	200
		S93	16° 32 N 136 16° 02 W 446	200
		S94	16° 31 N 340 15° 58 W 201	200
		S95	16° 30 N 357 15° 59 W 517	200
03/08/02		S96	16° 32 N 014 16° 01 W 767	200
		S97	16° 31 N 483 16° 00 W 644	200
		S98	16° 31 N 360 16° 00 W 512	200
		S99	16° 31 N 324 16° 00 W 445	200
		S100	16° 30 N 382 15° 59 W 914	200
03/08/02	Moushaib	S101	16° 30 N 371 16° 04 W 305	200
		S102	16° 30 N 414 16° 00 W 143	200
		S103	16° 30 N 467 16° 00 W 167	200
		S104	16° 30 N 528 16° 00 W 169	200
05/08/02		S105	16° 31 N 594 16° 00 W 151	200
		S106	16° 31 N 056 16° 00 W 139	200
		S107	16° 31 N 108 16° 00 W 186	200

		S108	16° 30 N 281 16° 00 W 035	200
		S109	16° 30 N 249 15° 59 W 587	200
<b>Total</b>	<b>21 800 weevils</b>			

**Appendix 6.4.** Media report on the biological control of *Salvinia molesta* in Senegal and Mauritania.

1. “Management of Problematic Aquatic Weeds in Africa. **FAO**-efforts and achievements during the period 1991-2001. Control of Water Fern in Mauritania and Senegal.”



### **Control of Water Fern in Mauritania and Senegal**

Water Fern was officially recorded in the Senegal River in September 1999, near the villages Khor and Rosso, about 60 km from the Diama dam. This plant was originally introduced for cultivation in Khor for its use in integrating poultry feed. Unfortunately floods allowed the plant to escape cultivation and invade both sides of the Senegal River for a distance of about 70 km. Water Fern then also invaded the canals in the region and the Lampsar and Gorom Rivers. In 2000, Water Fern and *Typha australis* were estimated to infest altogether an area of 18 694 ha, 10 854 ha of which were on the Senegalese side and 7 840 ha on the Mauritanian side.

A regional project was started in February 2001 in **Mauritania** and **Senegal** to (a) build two units for the rearing of the weevil *Cyrtobagous salviniae* (one unit in each country); (b) release the weevil in the field; and (c) establish a surveillance system for the fern and the weevil. To date the following tasks have been accomplished: (a) The weevil has been introduced, the rearing is in place and the weevil has been released; (b) *Cyrtobagous salviniae* has been established at the release sites, where it is effectively controlling the weed; local authorities and rural communities (about 26 000 people in 23 villages in the area invaded) have been sensitized about the importance to control aquatic weeds. Following the excellent results obtained with biological control, parts of the Senegal River, where previously dense mats of Water Fern occurred, have been completely cleared.

Appendix 6.4. (continued)



Infestation of Water Fern in Senegal River, BEFORE (Top) and AFTER (Bottom) release of *Cyrtobagous salviniae*



## Appendix 6.4. (continued)

### 2. "Tambalaye le monstre recule. Madieng SECK, Abdou S. DIAGANA. Syfia. Walfadjri, Lundi 19 Aout 2002."

#### PARC DU DJOUDJ

**On a souvent besoin d'un plus petit que soi. Dans la vallée du fleuve Sénégal, les insectes sont de précieux alliés contre les pestes aquatiques venues d'ailleurs.**

### Tambalaye le monstre recule

**SYFIA** - «Un marron ! trois attaqués ! Deux marrons ! Quatre attaqués !...». La chaleur de midi est accablante, en ce jeudi de mai. A Débi, non loin du parc des oiseaux de Djoudj, à 300 km au nord de Dakar, les techniciens du service de la protection des végétaux (Dpv) récitent des heures durant cette litanie. Dans leur jargon, «un marron» est un jeune insecte brun, né de la dernière génération de charançons, ces tueurs à gages utilisés dans la guerre biologique contre *salvinia molesta*. Les «attaqués», ce sont les bourgeons de cette fougère d'eau envahissante qui menace toute la région.

**Ousseynou Diop**, l'ingénieur qui coordonne cette lutte au Sénégal et en Mauritanie, dispose de tout un arsenal : balances, fiches d'enregistrement remplies avec soin par les agents de l'équipe. Ces derniers, assis sur une vieille pirogue échouée, comptabilisent le nombre de *salvinia* touchés. Un travail de Sisyphe que n'arrêtent même pas les vents de sable venus du désert mauritanien, sur l'autre rive du fleuve. Depuis août 2001, avec l'appui de la Fao, cette modeste équipe de cinq personnes cherche à évaluer par échantillonnage le recul de cette plante conquérante, dans le parc du Djoudj, trois mois après les lâchers d'insectes censés les tuer.

Aller dans le fleuve en déchirant les épais tapis de plantes polluantes n'est pas une mince affaire. La plante, une fois terrassée, ressemble à un fraisier épuisé, aux feuilles fanées. Dans l'eau, ses racines noires forment de longues mèches. «*Ici tous les plants sont attaqués !*», s'exclame Ousseynou, ravi de voir que ses troupes ont pris le dessus sur *salvinia*, appelée *tambalaye* en wolof. Côté mauritanien, pareil. Le charançon s'attaque aux

bourgeons de *salvinia* qui «meurt d'une belle mort», à en croire Ahmed, un ingénieur agronome engagé dans l'opération.

Selon les riverains, tout est parti, en septembre 1999, des villages voisins du parc de Djoudj. Un chercheur de l'université de Dakar y a introduit cette plante originaires d'Amérique du sud afin de la tester comme aliment pour la volaille. Expérimentation très hasardeuse, car cette plante double de volume chaque semaine. Elle et classée seconde derrière la jacinthe d'eau sur la liste des végétaux aquatiques les plus envahissants. L'erreur de ce biologiste a valu aux producteurs de la vallée du fleuve Sénégal leur «septembre noir».

Bloqués par l'épais tapis vert, le long des berges des rivières et des plans d'eau, piroguiers, pêcheurs, cultivateurs et éleveurs n'avaient plus accès à l'eau, polluée de surcroît par les racines et les plantes pourries. Insectes et moustiques se sont mis à proliférer, causant paludisme, bilharziose, etc. «*J'ai vu salvinia pour la première fois à l'embarcadere du parc. Quelques jour après, elle était déjà envahissante*», témoigne Ibrahima Kane, président du comité de gestion de l'environnement des villages de Djoudj.

En moins de trois mois cette peste avait envahi une grande partie du delta. Pour enrayer le fléau, populations, militaires, agents du parc et du projet allemand de la Gtz, la coopération allemande, unissent leurs efforts pour enlever ce qu'ils peuvent. Estimés à plus de 100 millions de francs, ces combats épiques n'ont pas fait que limiter les dégâts. «*S'il n'y avait pas eu la lutte mécanique, les paysans allaient la trouver à l'intérieur des casiers rizicoles*», soutient le colonel Christophe Sagna, coordonnateur de

cette lutte et fondateur du parc en 1972.

Seulement contenue, la fougère continuait à prospérer. Grâce à la Fao, 1 250 charançons, *Cyrtobagous salviniae*, ses ennemis naturels, originaires eux aussi d'Amérique du Sud, furent alors importés de Côte d'Ivoire puis élevés à l'Hostellerie du Parc de Djoudj. Composés de six bacs de 5 000 litres d'eau chacun, cette unité d'élevage produit, tous les trois mois, 10 à 15 000 charançons. C'est dans les sites de Marékhor, Ndiatène/Khor et sur l'axe Gorom Lamsar qu'eurent lieu les premiers lâchers en juin-septembre 2000, avec l'appui de l'Union mondiale pour la conservation de la nature (Uicn).

Il y a sept ans, la lutte biologique avait déjà fait ses preuves à Keur Momar Sarr, sur le lac de Guiers qui alimente Dakar en eau. La salade d'eau (*Pistia stratiotes*) avait envahi le lac, menaçant l'approvisionnement de la capitale. Contre *Salvinia*, la méthode est en passe de connaître le même succès. «*Il y a deux ans, on ne voyait pas l'eau, mais un tapis vert. Avec les insectes, on a eu la baraka*», dit en souriant un agent du parc. «*On jette nos filets n'importe où*», affirme Daouda Bâ, un pêcheur du Pont Ndigueu qui se souvient des angoisses de toutes ces journées de pêche perdues.

Difficile de mesurer les conséquences économiques de ces pollutions vertes dans la vallée où l'Union européenne a injecté, depuis plus de vingt ans, plus de 400 milliards de francs pour soutenir l'agriculture. Sans compter les menaces sur le parc, classé patrimoine mondial avec ses millions d'oiseaux, et où de nombreux touristes viennent chaque année. En Mauritanie comme au Sénégal, les techniciens se

réjouissent de ce succès. «*La lutte biologique est lente, mais une fois que l'ennemi naturel s'établit et se disperse, elle devient efficace et durable*», rassure Ousseynou, satisfait d'avoir atteint les objectifs assignés par la Fao, à trois mois du bouclage du projet d'Appui à la lutte contre *Salvinia*, qui a coûté 109 millions de francs au profit de deux pays.

Mais l'expert en végétaux aquatiques a déjà de nouveaux soucis. D'autres pestes végétales sont prêtes à prendre le relais le long du fleuve Sénégal. En témoigne la présence massive de roseaux *Typha australis* sur des dizaines de milliers d'hectares. Une bataille a été gagnée mais la guerre contre les envahisseurs n'est pas finie.

Madieng SECK  
Abdou S. DIAGANA

Walfadjri

LUNDI 19 AOUT 2002

19 Aout  
2002

## Appendix 6.4. (continued)

### 3. "Saint-Louis : L'antidote de l'insecte venu d'Afrique du Sud. La *Salvinia molesta* mise hors d'état de nuire. Reportage de Mohamadou SAGNE. Le Soleil du Jeudi 22 Août 2002."

**ENVIRONNEMENT & CADRE DE VIE**

**SAINT-LOUIS : L'ANTIDOTE DE L'INSECTE VENU D'AFRIQUE DU SUD**

**La salvinia molesta mise hors d'état de nuire**

**REPORTAGE DE MOHAMADOU SAGNE**

**190 adultes a suivi dans le cours d'eau Lampsar en septembre 2000, au niveau de la station pompage Grande Digue à 7 km de Rosso Béthio. Le choix de ces sites s'explique par la nature de l'envahissement, la direction des vents dominants, la position en amont d'importantes superficies envahies et surtout, le point de Ndiatène qui constituait la limite haute de la présence de Salvinia dans le Fleuve. Six mois après ces lâchers, certains sites sont bien nettoyés par l'ennemi naturel, notamment à Marekhor-Ndiatène et Khor et le long du Lampsar en amont de la station Grande Digue. On peut constater que l'insecte s'est bien établi et s'est dispersé sur des dizaines de kilomètres à partir des deux points de lâchers.**

**D'autres lâchers à l'actif de la Direction des Parcs Nationaux (DPN), ont suivi dans le Parc de Djoudj, avec un second lot d'insectes importé d'Afrique du Sud. Ces lâchers ont débuté à partir d'Avril 2002, dans les limites du parc et ont concerné six sites au niveau du Gorom, du Djoudj et du Marigot Ndeupelou (Débi-Tiguet). Six mois après, l'ennemi naturel s'est bien établi au niveau de ces sites, surtout au niveau de l'ouvrage du Gorom où les symptômes de déprédation étaient bien visibles. Avec le temps, la dispersion sera effective un peu partout dans les différentes zones infestées.**

**Temey Toucouleur, Thiagar, Ndiatène, Ronkh, Wassul, ces différents villages parmi tant d'autres, ont été envahis par la plante aquatique dite "Salvinia molesta" depuis la date de son introduction dans la vallée, en Septembre 1999. Une lutte farouche y est menée par les autorités et les populations, avec l'appui des bailleurs de fonds contre ce phénomène inquiétant qui a défrayé la chronique ici. Près de trois ans après la prolifération, les choses semblent maîtrisées. La plante a été mise hors d'état de nuire par un insecte venu d'Afrique du Sud. "D'ici quelques mois, voire un an, on n'entendra plus parler de Salvinia molesta" nous lance Ousseyou Diop, le coordonnateur du projet d'appui à la lutte contre ce végétal aquatique du Sénégal, financé par la FAO avec qui nous avons sillonné toute cette zone.**

**Le vieux Habib Thiam, originaire du village de Ndiatène, dans la communauté rurale de Rosso Béthio, ne manque pas de nous faire un bref rappel historique sur l'introduction dans la vallée de la plante dite : "Salvinia molesta". Ce végétal aquatique envahissant, supposé très dangereux, a été cultivé dans son village, non loin de Rosso Sénégal, 50 km en aval du parc des oiseaux du Djoudj, par un fermier que lui-même a beaucoup aidé dans son œuvre. "L'homme, un certain Sanokho m'avait dit qu'il voulait utiliser**

**cette plante comme ingrédient dans l'alimentation des volailles" révèle le vieux Thiam.**

**Cette plante inquiétante est sortie de sa parcelle de Ndiatène, cette partie frontalière avec la Mauritanie, le long du fleuve Sénégal, où le climat est chaud et poussiéreux. Mais le vieux Habib dit n'avoir plus de nouvelles de cet homme qu'il considère comme le responsable de cette catastrophe naturelle. C'est ainsi qu'une prospection a été menée dans la première semaine d'octobre de la même**

**année selon Ousseyou Diop le coordonnateur du projet d'appui à la lutte contre le Salvinia molesta. "Ceci a montré que la plante était présente sur de grandes superficies, le long de la rive gauche, sur le Fleuve Sénégal. Elle fut repérée ensuite au niveau du Barrage de Diana situé à 70 km environ du village de Khor, point d'introduction de la plante qui a proliféré à l'intérieur des roseaux (I ypha australis) qui croissent le long du fleuve où des tapis épais de salvinia sont aujourd'hui observés. Ils servent de substrat à d'autres végétaux aquatiques."**

**Ousseyou Diop d'ajouter que : "L'envahissement concerne les ouvrages d'admission d'eau connectés au Fleuve Sénégal, notamment : les ouvrages du Djoudj et de Crocodile pour le Parc National des oiseaux du Djoudj et ceux de Gorom et Ndeupelou pour l'alimentation en eau des villages, ainsi que le point de débarquement des pêcheurs et les stations de pompage de Débi et Tiguet, Ronkh et de Diawar pour les périmètres rizicoles. Et lors de la crue de 1999, la plante a été rencontrée à 15 km en amont de Khor faisant planer l'inquié-**

**de. Il fallait alors prendre des mesures adéquates pour empêcher les crues de remonter la Salvinia à hauteur du Taouéy, cette rivière qui relie le fleuve Sénégal au lac de Guiers. Ce qui exposerait ce lac qui assure l'essentiel de l'alimentation en eau de la région de Dakar."**

**Une situation très préoccupante qui mettra en branle les autorités de notre pays en l'occurrence le Ministère de l'Environnement à travers la Direction des Parcs Nationaux. Plusieurs réunions assorties de visites des lieux de prolifération au niveau du Fleuve Sénégal ont été tenues et des commissions de lutte physique et biologique sont chargées alors de mener le travail sur le terrain. La lutte mécanique qui a été appliquée par le comité civilo-militaire d'appui au développement avec la participation des populations riveraines concernées. Elle a permis de dégager et de protéger certains ouvrages hydro-agricoles aussi bien à l'intérieur qu'à l'extérieur du Parc de Djoudj. La lutte biologique a mis à contribution un ennemi naturel, "Cyrtobagus salvinia", un insecte qui a été importé d'Afrique du Sud grâce au concours financier de l'Union Mondiale pour la Conservation de la Nature. La Direction de la Protection des Végétaux (DPV) étant la structure d'exécution technique a procédé au premier lâcher de 200 adultes en juin 2000 au niveau de Marekhor-Ndiatène. Un second lâcher de**

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## Une réelle menace sur la biodiversité

L'envahissement des plans d'eau dans le Delta du Fleuve Sénégal par le *Salvinia* est une réelle menace pour la biodiversité, l'agriculture irriguée et l'approvisionnement en eau potable des populations riveraines. Ces considérations font que la *salvinia* est classée plante aquatique envahissante nuisible de premier ordre qu'il faut combattre partout où elle se trouve.

C'est précisément le 25 Septembre 1999 que *Salvinia molesta* a été identifiée dans le Fleuve Sénégal. La *salvinia* a été localisée dans le voisinage du Parc National du Djoudj. D'autres prospections complémentaires effectuées dans la première semaine d'octobre 1999 ont montré que la plante était présente sur de vastes étendues dans le Fleuve Sénégal. Les conditions d'introduction de la *salvinia* sont connues contrairement à celles de la salade (*Pistia stratiotes*) qui avait envahi le Parc du Djoudj et le Lac de Guiers entre 1993 et 1995. En effet, la *Salvinia* était cultivée dans une parcelle débarrassée des roseaux (*Typha Australis*) dans le Fleuve Sénégal et jouxtant un jardin maraîcher à Ndiatène-Khor. C'est au cours de la saison des pluies de 1999, que la plante y a échappé pour envahir et coloniser le fleuve. Elle prolifère principalement à l'intérieur des roseaux (*Typha Australis*) qui croissent le long du fleuve. Des tapis vastes et épais de *salvinia* étaient observés à partir de la berge.

Sur les plans environnementaux, économiques et sanitaires, la *salvinia* est classée second derrière la jacinthe d'eau sur la liste des végétaux aquatiques les plus envahissants à travers le monde. Des insectes vecteurs de maladie hydrique (moustique) sont abrités par la plante. Parfois d'autres plantes peuvent se développer au-dessus des tapis épais de *salvinia* rendant davantage impossible la navigation des embarcations légères. La *salvinia* empêche la pénétration de la lumière dans les eaux entraînant une eutrophisation du milieu sans oxygène qui tue les poissons. Aussi, lorsque la *salvinia* se décompose, il se forme une sédimenta-

tion organique qui pollue la qualité des eaux.

L'envahissement de ce végétal aquatique est aujourd'hui une contrainte pour le tourisme (Parc Djoudj) et le développement rural de l'ensemble de la vallée du fleuve Sénégal. Entre autres conséquences, on peut citer : l'accès difficile des abords des cours d'eau pour l'abreuvement des populations et du bétail, le déplacement en pirogue devenant difficile. La prolifération de la *salvinia* a créé des conditions propices pour le développement des maladies hydriques. Le pourrissement sur place des feuilles altère la qualité de l'eau et les populations sont contraintes de se déplacer sur de longues distances pour puiser de l'eau. Cela constitue également une véritable entrave à la pêche et à l'agriculture. La présence de *salvinia* freine les écoulements hydrauliques, relève les lignes d'eau et en conséquence, augmente les risques d'inondations lors des crues. Les grands axes hydrauliques pour l'irrigation et les collecteurs de drainage sont envahis. Les écoulements dans ces canaux sont freinés et de ce fait l'efficacité hydraulique générale des aménagements est de plus en plus mauvaise. La biodiversité est menacée avec l'absence d'oxygène en dessous des plans d'eau recouverts de tapis de *salvinia*, entraînant une eutrophisation du milieu aquatique.

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#### Appendix 6.4. (continued)

4. "Environnement. Les bons "plants" des Africains. Sénégal. Lutte biologique contre les envahisseurs verts p75-80. Madieng SECK, Abdou Salam DIAGANA. *Syfia*, Juillet 2002."

#### Sénégal

#### Lutte biologique contre les envahisseurs verts

*On a souvent besoin d'un plus petit que soi.  
Dans la vallée du Fleuve Sénégal, les insectes  
sont de précieux alliés contre les pestes  
aquatiques venues d'ailleurs.*

« Un marron ! Trois attaqués ! Deux marrons ! Quatre attaqués !... ». La chaleur de midi est accablante, en ce jeudi de mai. A Débi, non loin du Parc des oiseaux de Djoudj, à 300 km au nord de Dakar, les techniciens du Service de la protection des végétaux (Dpv) récitent des heures durant cette litanie macabre. Dans leur jargon, « un marron » est un jeune insecte brun, né de la dernière génération de charançons, ces tueurs à gages engagés dans la guerre biologique contre *Salvinia molesta*. Les « attaqués » ce sont les bourgeons de cette fougère d'eau envahissante qui menace toute la région. Pour compter les morts, Ousseynou Diop, l'ingénieur qui coordonne cette lutte biologique au Sénégal et en Mauritanie dispose de tout un arsenal : balances, fiches d'enregistrement remplies avec soin par les agents de l'équipe. Ces derniers, assis sur une vieille pirogue échouée là depuis belle lurette, comptabilisent les pertes : le nombre de *Salvinia* touchées. Un véritable travail de Sisyphe que n'arrêtent même pas les vents de sable venus du désert mauritanien, sur l'autre rive du fleuve. Depuis août 2001, avec l'appui de la Fao, cette modeste équipe de cinq personnes travaille d'arrache-pied. Elle cherche à évaluer par échantillonnage le recul de cette

#### Appendix 6.4. (continued)

plante conquérante, ici dans le parc du Djoudj, trois mois après les lâchers d'insectes censés les tuer. Aller dans le fleuve en déchirant les épais tapis de plantes polluantes, faire des pesées de *Salvinia*, identifier les morts et en faire le décompte n'est pas une mince affaire. La plante, une fois terrassée, ressemble à un fraisier épuisé, ses feuilles se fanent. Dans l'eau, ses racines noires forment de longues mèches, semblables à une chevelure de femme au sortir de la douche.

« Ici tous les plants sont attaqués ! », s'exclame Ousseynou, ravi de voir que ses troupes ont pris le dessus sur *Salvinia*, appelée *tambalaye* en Ouloff. Côté Mauritanien, pareil. Le charançon s'attaque aux bourgeons de *Salvinia* qui « meurt d'une belle mort », à en croire Ahmed, un ingénieur agronome engagé dans l'opération.



## Appendix 6.4. (continued)

### « Septembre Noir »

Selon les riverains, tout est parti, en septembre 1999, des villages voisins du Parc de Djoudj. Un chercheur de l'université de Dakar y a introduit cette plante originaire d'Amérique du Sud afin de la tester comme aliment pour la volaille. Expérimentation très hasardeuse, car cette plante double de volume chaque semaine. Elle est classée seconde derrière la jacinthe d'eau sur la liste des végétaux aquatiques les plus envahissants. L'erreur de ce biologiste a valu aux producteurs de la Vallée du Fleuve Sénégal leur « Septembre noir ».

En déroulant rapidement son épais tapis vert le long des berges des rivières et des plans d'eau, *Salvinia* a fini par bloquer l'activité des riverains. Piroguiers, pêcheurs, cultivateurs et éleveurs n'avaient plus accès à l'eau, polluée de surcroît par les racines et les plantes pourries. Insectes et moustiques se sont mis à y proliférer, causant paludisme, bilharziose et autres maladies. « *Quand j'ai vu Salvinia pour la première fois à l'embarcadère du Parc je l'ignorais totalement. Quelques jours après, elle était déjà devenue envahissante* », témoigne Ibrahima Kane, de Débi, président du Comité de gestion de l'environnement des villages de Djoudj. De fait, en à peine trois mois cette peste avait envahi une grande partie du delta du fleuve.

Pour enrayer le fléau, populations, militaires, agents du Parc et du projet allemand de la Gtz, la Coopération allemande, unissent leurs efforts. Ils enlèvent ce qu'ils peuvent, nettoient les conduites d'eau, dressent des barrages. Estimés à plus de 100 millions de F cfa, ces combats épiques n'ont fait que limiter les dégâts. « *La plante est arrivée en catastrophe. S'il n'y avait pas eu la lutte mécanique, les paysans allaient la trouver à l'intérieur des casiers rizicoles* », soutient le colonel Christophe Sagna, coordonnateur de cette lutte et fondateur du Parc en 1972.

#### Appendix 6.4. (continued)



#### L'ennemi vaincu

Mais même contenue, la fougère malfaisante continuait à prospérer. Grâce à la Fao, 1250 charançons, *Cyrtobagous salviniae*, ses ennemis naturels, originaires eux aussi d'Amérique du Sud, furent alors importés de Côte d'Ivoire puis élevés à l'Hostellerie du Parc de Djoudj. Composée de 6 bacs de 5000 litres d'eau chacun, contenant des plants de *Salvinia*, cette unité d'élevage produit, tous les trois mois, 10 à 15 000 charançons. C'est dans les sites de Marékhor, Ndiatène/Khor et sur l'axe Gorom Lamsar qu'eurent lieu les premiers lâchers en juin-septembre 2000, avec l'appui de l'Union mondiale pour la conservation de la nature (Uicn). Dans ces villages, la lutte mécanique n'avait pas suffi à venir à bout de cette plante.

#### Appendix 6.4. (continued)

Il y a sept ans, la lutte biologique avait déjà fait ses preuves à Keur Momar Sarr (260 km au nord de Dakar), sur le lac de Guiers qui alimente la capitale sénégalaise en eau. Comme la *Salvinia* aujourd'hui, la salade d'eau (*Pistia striatotes*) avait envahi ce lac, menaçant même l'approvisionnement de Dakar. Elle avait été combattue avec succès grâce à un autre charançon (*Neohydronomus affinis*) lâché par Ousseynou Diop, le même technicien de la Dpv qui lutte aujourd'hui contre *Salvinia*. De nos jours, « le lac est devenu propre et les pêcheurs ont du poisson », s'émerveille Abdourakhmane Cissé, de l'Ong Asraed, qui s'occupe de développement durable dans cette localité.

Contre *Salvinia*, la lutte biologique est en voie de connaître le même succès. « Il y a deux ans, on ne voyait pas l'eau, mais un tapis vert. Avec les insectes, on a eu la baraka », dit en souriant un agent du Parc. « On jette nos filets n'importe où », affirme Daouda Bâ, un pêcheur du Pont Ndigueu qui se souvient des angoisses de toutes ces journées de pêche perdues.

Difficile de mesurer toutes les conséquences économiques de ces pollutions vertes dans la Vallée où l'Union européenne a injecté depuis plus de 20 ans, plus de 600 millions d'euros, soit plus de 400 milliards de F cfa pour soutenir l'agriculture. Sans compter les menaces sur le Parc, classé patrimoine mondial avec ses millions d'oiseaux de différentes espèces et les nombreux touristes qui y viennent chaque année.

En Mauritanie comme au Sénégal, les techniciens se frottent les mains d'avoir gagné cette guerre. Dans son bureau aux murs remplis de photos d'insectes, d'oiseaux et de plantes aquatiques, Ely Mohamed, biologiste mauritanien est euphorique : « Nous avons gagné ! *Salvinia* ne sera bientôt plus qu'un mauvais souvenir. » Au parc du Diawling, sur la rive mauritanienne, cette joie est partagée par ses collègues naturalistes et agronomes.

#### Appendix 6.4. (end)

« *La lutte biologique est lente, mais une fois que l'ennemi naturel s'établit et se disperse, elle devient efficace et durable* », rassure Ousseynou, satisfait d'avoir atteint les objectifs assignés par la Fao, à trois mois du bouclage du projet d'« Appui à la lutte contre *Salvinia* », qui a coûté 109 millions de F cfa au profit des deux pays. L'expert en végétaux aquatiques a cependant de nouveaux soucis. D'autres pestes végétales sont prêtes prendre le relais le long du fleuve Sénégal. En témoigne la présence massive de roseaux *Typha australis* sur des dizaines milliers d'hectares. Une bataille a été gagnée mais la guerre contre les envahisseurs verts n'est pas finie.

Madieng Seck  
Abdoul Salam Diagana  
Juillet 2002