Biological control and monitoring of water hyacinth, *Eichhornia crassipes*, Marts. Solms-Laubach (Liliales: Ponteridiaceae) during the post-resurgence period in Lake Victoria basin, Kenya

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Abstract

The paper presents recent results from an ongoing classical biological control programme for water hyacinth, implemented by Kenya Agricultural Research Institute under the Lake Victoria Environmental Management Project. Approximately 5600 adult *Neochetina* spp. (Coleoptera: Curculionidae) weevils, biological control agents for water hyacinth *Eichhornia crassipes* (Liliales: Ponteridaceae) were harvested, between November 2000 and June 2001, from the Kibos rearing facility, Namba-Okana "field insectary" and community weevil rearing units. Weevils were released on water hyacinth at thirteen sites in Berkeley, Nyakach, Osodo, Kendu, Homa and Karungu and Muhuru Bays, at Kuja-Migori river tributaries and upstream of Nzoia, Yala and Sondu-Miriu rivers. Post-release sampling of water hyacinth plants indicated that the mean number of rametes ranged from 1.4±0.2 to 3.3±0.4, while fresh weight ranged from 290.0±40.0 to 770.0± 73.0 grammes. Leaf length ranged from short 21.4± 2.1 to medium, 50.7±1.5 cm while leaf laminar area ranged from 50.6±4.4 to 154.9±4.1 cm^2. Mean number of adult weevils ranged from 0.0±0.0 to 5.5±1.4. Once the critical threshold of five weevils $plant^{-1}$ has been achieved, releases are no longer necessary. Mean number of petioles damaged by weevil larvae, ranged from 2.9±2.7 to 8.6±5.4. In general, reproductive and growth potential (number of daughter plants, petiole length and laminar area) of the weed was suppressed. There was a gradual increase in insect population levels (number of weevils $plant^{-1}$) and damage to plants by weevil larvae. Visual observations showed that between October and November 2000, most of the water hyacinth resurgence was concentrated at Kusa, Nyakach bay, with a resident mat covering 300 hectares. Fresh growth was evident in the Nzoia and Sio river-mouths during the last quarter of 2000. From January to March 2001, the water hyacinth infestation was still concentrated at Kusa, Nyakach bay with a resident mat covering 400 hectares. However, fresh growth was evident in the tributaries of Kuja-Migori riverine system. Between April and June 2001, the stationary mat at Kusa broke off and was moved by wind and water currents southwest to Sango-Rota, Nyakach bay and onwards to Rakwaro in Osodo bay. By the end of May, a floating mat estimated at 400 hectares was observed at Rakwaro while Kusa and Sango-Rota were free from water hyacinth. Water hyacinth infestation pattern during the resurgence period was similar to the one at peak infestation in 1998. However, Kisumu bay has remained free of water hyacinth for the last three years. There is an urgent need to carry out an aerial survey to verify the visual estimates of water hyacinth cover and to intensify mass rearing and releases of weevils in hotspot areas and to concentrate releases in riverine systems.

Key words: *Neochetina* weevils, rearing, releases, monitoring, impact, water hyacinth, resurgence

Introduction

Lake Victoria (circa. 69 000 $kilometres^2$), shared by the three East African countries, Kenya, Uganda and Tanzania, is the world's second largest fresh water lake. It has a 3 450km shoreline and a catchment area of 258 700 km^2. In the early 1990s, it was invaded by the water hyacinth *Eichhornia crassipes* (Mart.) Solms-Laubach (Ponteridiaceae). The tropical free-floating perennial aquatic shrub of South American origin, presented an enormous challenge for biological control in East Africa. Socio-economic impact of the weed in East Africa has included the disruption of commercial and artisanal fishing and boat transport. Water hyacinth has affected infrastructural facilities including water supply intake points, port facilities and the hydroelectricity power generation plant at Owen Falls, Uganda (Harley *et al.*, 1996). The weed is also associated with increased incidence of water-borne diseases.

In Lake Victoria, environmental degradation, ideal environmental conditions and the lack of biological control agents such as phytophagous insects, mites and microbial pathogens were responsible for rapid growth and spread of the water hyacinth for the better part of the 1990s. In the Kenyan portion of Lake Victoria (circa. 4 200 square kilometre^2), less than 1.0% was covered by water hyacinth at the mid-1998 peak infestation of 6000 hectares.

Water hyacinth: biological control and monitoring in Lake Victoria, Kenya

Biological control using insects, mites and pathogens is considered the long-term environmentally sustainable control method for floating aquatic weeds (FAWs). Three main FAWs in Kenya include water hyacinth (*E. crassipes*), Kariba fern (*Salvinia molesta* Mitchell) and water lettuce (*Pistia*
stratiotes L).

The host-specific weevils *Neochetina bruchi* Hustache and *N. eichhorniae* Warner (Coleoptera: Curculionidae) are the most important agents used against the water hyacinth, with notable success outside East Africa (Harley, 1990; Julien *et. al*, 1998, Julien *et. al.*, 1999). Attempts at biological control of the water hyacinth in Africa using *Neochetina* weevils are from South Africa (Cilliers, 1991), Benin (van Thielen *et al.*, 1994) and Zimbabwe (Chikwenhere, 1994). The introduction of *Neochetina* spp. into Lake Kyoga, Uganda in 1993 led to the successful control of water hyacinth (Ogwang' and Molo, 1997, 1999).

More recently, biological control attempts have started in Lake Victoria (Mailu *et. al*, 1999, Ochiel *et. al*, 1999, Mallya, 1999), in Shire River in Malawi (Hill *et. al*, 1999), in riverine systems and lagoons in Nigeria (Farri and Borrofice, 1999), Burkina Fasso (Ouedrago *et al.*, 1999) and Côte d' Ivoire (Koffi-Koffi *et. al*, 1999).

New biological control agents for water hyacinth have been tested in Australia (Julien and Stanley, 1999), United States (Centre and Hill, 1999) and South Africa (Hill, 1999) and include a hemipteran bug and moths. A search for additional biological control agents has been going on in South America (Cordo, 1999).

Interactions between three fungal pathogens, *Acremonium zonatum*, *Alternaria eichhorniae* and *Cercospora piaropi* and the weevil *Neochetina eichhorniae* in South Africa showed larger lesion diameters with pathogen-insect combination than with pathogen alone (van Breeyen, 1999). The initial expectations of a feasible mycoherbicide for water hyacinth has been frustrated by the lack of commercial interest in promising pathogens *Acremonium zonatum*, *Cercospora piaropi* and *C. rodmanii*. The pathogen *Uredo eichhorniae* has also been researched on as a potential mycoherbicide (Charudattan, 1999).

Due to obvious environmental concerns, chemical control of water hyacinth using 2,4-D and glyphosate has not been recommended in East Africa. However, use of herbicides has been reported Sudan, South Africa and Zimbabwe. Mechanical, physical and chemical control methods have been used to manage aquatic weeds, including water hyacinth, in Zimbabwe (Chikwenere *et al*. 1999). Mechanical harvesting and barrier construction was donen Uganda (Nyeko, pers. comm.) while mechanical chopping and shredding of the weed was control has been done in Kenya (Robertson, pers. comm.).

Satellite images (RADARSAT) and Geographical Information Systems (GIS) mapping estimated the mid-1998 peak infestation of water hyacinth, *Eichhorniae crassipes* at 5000-6000 hectares in the Winam gulf of Lake Victoria. By February 2000, a reduction of 85 percent of the water hyacinth cover to an all-time low of 200 hectares was documented (Clean Lakes Inc., unpublished report).

Virtually all bays in the Winam Gulf of Lake Victoria were clear, including Kisumu, Nyakach, Osodo, Kendu and Homa bays, all of which had been infested for three years. The dramatic reduction in water hyacinth was mainly attributable to damage by the host-specific biological control agents, *Neochetina* weevils and fungal pathogen attack after weevil damage. Hydrological changes during the El Niño floods were also implicated in the reduction of the weed.

After the ecological succession of degraded water hyacinth by secondary vegetation, Nyakach bay was the first to experience the weed's resurgence between August and September 2000. The resurgence was attributed to low weevil populations, nutrient loading and flushing of fresh hyacinth from upstream of the riverine systems draining into the lake.

The objectives of this study were to evaluate the reproductive and growth parameters of water hyacinth, to evaluate the impact of weevils on water hyacinth and to determine the spatio-temporal distribution and cover of water hyacinth.

Materials and Methods

Mass rearing and releases of *Neochetina weevils*

Thirteen thousand weevils were imported from Australia, Uganda and South Africa in 1997 and used for mass rearing and direct releases on water hyacinth in Lake Victoria. Julien *et al*. (1999) describe in detail rearing and harvesting techniques for *Neochetina* weevils from plastic tubs, rearing pools and galvanized corrugated iron (GCI) sheet tanks, which have been used at the Kibos rearing facility. Additionally, "Technotank" PVC tanks (230 L and 500 L), are also currently used to rear the weevils at community-based rearing facilities near the lakeshore. Fertilizer (NPK 17:17:17) and dried cow dung were added to the rearing containers once a month to maintain plant vigour.

Weevils were harvested for field releases as described by Julien *et al*., 1999. Hyacinth plants with weevil life stages and adult weevils were used for releases. Adult weevils were fed on fresh leaves and petioles in plastic jars before transporting them to release sites. There were no specific release techniques. Host plants infested with weevil life stages were scattered among water hyacinths and adult weevils tipped from the plastic containers onto hyacinth plants. Weevils were released early morning or late evening to avoid the intense midday heat. Waders were used to release weevils to more than 50 meters from the shoreline. Canoes were used to release at sites that were inaccessible by motor vehicle or on foot, particularly at upstream sites in rivers draining into Lake Victoria.

Determination of spatio-temporal distribution and cover of water hyacinth

Spatio-temporal distribution and cover of water hyacinth was determined and visual estimates of water hyacinth cover were made from the northern part, Berkeley bay down to the eastern part (Kisumu Bay) and southwards to Nyakach, Kendu, Osodo, Homa, Karungu and Muhuru bays. The health status of water hyacinth plants was observed, whether it was fresh healthy growth, flowering or stunted due to weevil damage.

Water hyacinth: biological control and monitoring

Evaluation of the impact of *Neochetina spp.* weevils on water hyacinth

Using a modified sampling protocol developed at Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia, the impact of *Neochetina* spp. on water hyacinth was evaluated. A 0.5 metre x 0.5 metre quadrat was thrown randomly on mats of hyacinth plants. For each of ten randomly selected plants per quadrat, the following parameters were recorded: fresh weight, leaf laminar area, leaf length, number of feeding scars, number of weevils plant^{-1} and number of petioles plant^{-1} damaged by weevil larvae.

Results and Discussion

Mass rearing and releases of *Neochetina* weevils

Between October 2000 and June 2001, the Kibos rearing facility, Namba-Okana "field insectary" and community rearing facilities produced a total of nearly 5,600 adult weevils (Table 1). This figure was equivalent to 1,000 weevils per m

Evaluation of the impact of *Neochetina spp.* weevils on water hyacinth

Approximately 5600 adult weevils were released from November 2000 to June 2001, at thirteen discrete sites in Berkeley, Nyakach, Osodo, Kendu, Homa, Karungu and Muhuru bays. Releases were also carried out in tributaries of Kuja-Migori riverine system and upstream of Nzoia, Yala and Sondu-Miriu riverine systems (Table 2). Releases were carried out on both stationary and floating mats. The release strategy will continue to concentrate on upstream sites where fresh growth is observed. Water transport has been a major limiting factor in optimizing the release of weevils in areas inaccessible by ground transport. Releases in the littoral sites will also be intensified where low weevil populations are present. The critical threshold of five weevils per plant will be the target population.

Table 2. Releases of *Neochetina* at sites along lake Victoria shoreline, Kenya, November 2000-June 2001

Site	Release date	No. adult weevils
Berkeley bay		
Nakhoba/Bulwani Island	17.11.00	200
Sio Port	18.11.00	60
Nakhoba/Bulwani Island	23.2.01	160
Sio Port	8.3.01	200
Sango Camp, upstream of Nzoia estuary	8.3.01	131
Osieko	8.3.01	260
Nyakach bay		
Sango-Rota Beach	19.11.00	170
Kusa Beach	23.3.01	300
Kusa Beach	19.5.01	600
Muhuru bay		
Mugabo	20.11.00	50
Karungu bay		
Luanda Konyango	20.11.00	260
Kendu bay		
Kendu Bay Pier	21.11.00	40
Homa bay		
Homa bay Pier	21.11.00	70
Osodo bay		
Rakwaro/Kamwala	21.11.00	50

Table 2. (contd). Releases of *Neochetina* at sites along lake Victoria shoreline, Kenya, November 2000-June 2001

Site	Release date	No. adult weevils
Osodo bay		
Rakwaro/Kamwala	23.3.01	250
Karungu bay		
Angugo seasonal river near Aneko beach	23.5.01	85
Kuja-Migori main tributary	23.5.01	462
River Yala		
Daraja Market Bridge	24.5.01	60
Kisumu bay		
Seasonal river near Usare Beach	13.6.01	153
	Total	**5580**

Evaluation of the impact of *Neochetina* spp. weevils on water hyacinth

Post-release sampling data collected between October 2000 and December 2000 (Table 3) at Berkeley, Nyakach, Osodo and Karungu bays indicated that average number of rametes ranged from 1.4± 0.2 to3.3±0.4. Fresh weight ranged from 290.0±40.0 to 595.0±95.0 grammes. Petiole length ranged from 21.4±2.1 to 36.5±1.6 cm while leaf laminar area ranged from 50.6±4.4 to 109.8±9.6 $cm^{2,}$ Mean number of adult weevils was low, ranging from 0.1±0.1 to 0.6±0.2, Number of petioles damaged by weevil larvae ranged from medium, 3.8± 0.7 at Luanda Konyango, to high, 6.8±0.9 at Vusijo, near Sio Port.

During the period, the plants were not as prolific as during the peak infestation period and a considerable decline in biomass was experienced. Leaf petiole length and laminar area, classified as low to medium was due to suppressed growth of hyacinth plants. Despite the low weevil populations, there was a high population of immature stages (larvae and pupae). The adult weevil populations were expected to steadily increase with time.

Table 3. Post-release sampling data to evaluate the impact of *Neochetina* weevils on water hyacinth at sites along Lake Victoria shoreline, November 2000-May 2001

Site	Sampling date	Rametes	Fresh weight (gram)	Leaf length (cm)	Leaf laminar area (cm²)	V p
Kusa	11.12.00	2.6±3.9	455.0±88.0	36.5±1.6	109.8±9.6	1
Luanda Konyango	12.12.00	1.4±0.2	290.0±40.0	33.7±2.2	72.5±6.1	0 .
Kamwala	13.11.00	3.1±0.5	575.0±106. 0	34.4±1.2	98.3±7.2	0 .
Vusijo,	14.11.00	1.7±0.2	490.0±83.3	21.4±2.1	50.6±4.4	0 .
Bukoma	14.11.00	3.3±0.4	595.0±95.0	31.5±1.0	74.9±6.2	0 .
Kusa	8.3.01	1.5±0.2	445.0±72.5	39.7±4.2	88.7±5.3	3
Luanda Konyango	8.3.01	1.6±0.3	415.0±69.9	31.8±3.7	68.9±8.2	0
Kusa	8.4.01	1.4±0.2	450.0±113.5	50.0±2.3	116.5±7.1	5
Rakwaro	8.4.01	2.8±0.4	570.0±112.8	50.7±1.5	154.9±4.1	4
Modi	24.5.01	1.5±0.2	300.0±59.2	25.7±1.7	62.2±6.8	0
Luanda Konyango	24.5.01	2.3±1.0	446.0±96.2	39.8±4.7	87.1±15.0	1
Rakwaro	24.5.01	2.7±0.3	700.0±73.0	48.8±1.9	141.5±8.9	3

Post-release sampling at Nyakach and Karungu bays during the period January to March 2001 (Table 3) indicated that the average number of rametes at Kusa and Luanda K' Onyango was the same 1.6±0.3. Fresh weight was comparable at the two sites (Kusa 415.0±69.9 grammes; Luanda K'Onyango 445.0±72.5 grammes). Leaf length at Kusa was 39.7±4.2 while that one at Luanda K'Onyango was 31.8±3.7. Leaf laminar area was 88.7±5.3 cm² at Kusa, while that at Luanda K'Onyango it was 68.9±8.2 cm². Although the mean number of adult weevils was low at Luanda K'Onyango (0.1±0.1 weevil plant^{-1}), the weevil populations had steadily increased to 3.6± 0.2 weevils plant^{-1} at Kusa. Kusa had a higher number petioles damaged (5.9±0.7) compared to 3.6±0.5 at Luanda K'Onyango, meaning that there was considerable damage to the plants by the immature or larval stages at both sites sampled. As in the preceding period, the mean fresh weight indicated a considerable reduction in biomass. Stunted growth of hyacinth was responsible for the short leaf petioles and small leaf laminar area. Although the mean number of adult weevils was low at Luanda K'Onyango (0.1±0.1 weevil plant^{-1}), the weevil populations had steadily increased to 3.6± 0.2 weevils plant^{-1} at Kusa. Kusa had a higher number petioles damaged

Table 4. Estimates of water hyacinth cover and observations on nature of infestation and status of water hyacinth

Locality	**Date**	**Area covered, nature of infestation**	**Health status of water hyacinth**
Kusa	11.11.2000	280 ha; resident/floating mats	Extensive damage by weevil larvae, plants stunted and partially submerged, no flowering
	9.3.2001	400 ha; resident/floating mats	Extensive damage by weevil larvae, short bulbous and medium petioles, plants stunted and partially submerged, no flowering
	15.4.2001	300 ha.; resident mat	
	23.5.2001	Clear	
Kamwala/Rakwaro	11.11.2000	2 ha; floating mat	
	9.3.2001	Scattered mats; 1-10 metre²	
	23.5.2001	400 ha.; floating scattered mats	
Luanda Konyango	12.11.2000	5 ha.; 1-5 m² floating mats	
	9.3.2001	Scattered mats; 1-10 metre²	
Modi	12.11.00	Floating mats, 1-10 m²	
Nzoia estuary	14.12.2000	1 metre fringing mat up to 1 km upstream	Healthy plants, few feeding scars, no flowering
Sio Port	14.12.2000	Plants growing in mud Along the passageway into the lake	Fresh growth; no flowering
Nakhoba/Bulwani	14.12.2000	Fringing mat; 1-2 metres	Fresh growth; no flowering
Sango-Rota	15.4.2001	200-250 ha.; resident mat	Extensive damage by weevil larvae, plants stunted and partially submerged, no flowering
	23.5.2001	Clear	-

(5.9±0.7) compared to 3.6±0.5 at Luanda K'Onyango, meaning that there was considerable damage to the plants by the immature or larval stages at both sites sampled.

Between March and June 2001, post-release sampling at Karungu, Nyakach and Osodo bays (Table 3) indicated that rametes ranged from 1.4±0.2 to 2.8±0.4, indicative of low reproductive potential and growth rate. Fresh weight ranged from 300.0±59.2 to 700.0±73.0 grammes. Reduce biomass is a function of low reproductive potential and growth rate. Leaf length ranged from 25.7± 1.7 to 50.7±1.5 while laminar area ranged from 87.1± 15.0 to 141.5± 8.9cm². Mean number of adult weevils ranged from 0.3±0.2 at Modi to 5.5±1.4 at Kusa, which was above the critical threshold. Petioles damaged by weevil larvae ranged from 4.9±0.6 to 8.4±0.4.

During the period, the reproductive potential of water hyacinth plants was still low while the biomass was considerably reduced. Short leaf petioles and low leaf laminar area were considered a function of low reproductive potential and growth rate. At some sites, weevil populations were still low but the weevil populations at Kusa had increased to the critical threshold of five weevils plant^{-1}. Once the critical threshold is achieved, releases of weevils are no longer necessary.

Determination of spatio- temporal distribution and coverage of water hyacinth

Table 4 shows spatio-temporal distribution and visual estimates of water hyacinth cover, nature of infestation and health status of hyacinth plants. In the last quarter of the year 2000, most of the water hyacinth infestation was concentrated at Kusa, with a resident mat covering 300 hectares. Fresh growth was evident in the Nzoia and Sio river-mouths during the period. During the first trimester of 2001, the infestation was still concentrated at Kusa, with a resident mat covering 400 hectares. Fresh growth was observed in the tributaries of Kuja-Migori riverine system. During the second quarter of 2001, the stationery mat at Kusa broke off and was moved by wind/water currents to Sango-Rota and onwards to Rakwaro in Osodo bay. By the end of May, a floating mat estimated at 400 hectares was observed at Rakwaro while Kusa and Sango-Rota were free from water hyacinth infestation. By August 2001, the water hyacinth had move further west to Kendu and Homa bays but not more than 500 hectares have been estimated as the area covered by the weed. Water hyacinth infestation and movement pattern remained the same as at peak infestation and wind and water currents played a major role in the spatio-temporal distribution of the weed. However, the return northeasterly movement to Kisumu bay has not been experienced for the last three years. What is urgently required is an aerial survey using digital videography to determine the location and amount of water hyacinth in the Winam gulf of Lake Victoria, Kenya. A national water hyacinth surveillance system will ensure regular and reliable information on water hyacinth infestation.

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