The impact on biodiversity, and integrated control, of water hyacinth, *Eichhornia crassipes* (Martius) Solms-Laubach (Pontederiaceae) on the Lake Nsezi – Nseleni River System.

Thesis

Submitted in fulfillment of the requirements for the degree of Master of Science - *Ad Eundem Gradum* at Rhodes University.

By

Roy William Jones

Department of Zoology and Entomology
Rhodes University
P.O.Box 94
Grahamstown
6140

Date: January 2009

Frontispiece

Nseleni River choked with water hyacinth in 1983, when *ad hoc* control was being implemented.

Nseleni River after successful implementation of an integrated control programme. (2000)

IN MEMORY OF THE LATE

IZAK GERHARDUS OBERHOLZER

Agricultural Research Council – Plant Protection Research Institute,
Pretoria. South Africa.

"A colleague to a few. A friend to ALL."

Abstract

Water hyacinth, *Eichhornia crassipes* (Martius) Solms-Laubach (Pontederiaceae), a free floating aquatic plant was discovered by C. von Martius in 1823 in Brazil. It is believed to have been introduced into South Africa, as an ornamental plant, in 1908 to the Cape Province and Natal. Since its introduction, water hyacinth has spread throughout South Africa to the detriment of all aquatic systems that it has been introduced to directly or indirectly. The weed was first positively identified on the Nseleni and Mposa rivers on the Nseleni Nature Reserve which is a protected area near Richards Bay in KwaZulu-Natal in 1982 and formed a 100% cover of the river by 1983. An integrated management plan was implemented in 1995 and resulted in a reduction of the weed from a 100% cover to less than 20% cover in 5 years. The keys to success of the water hyacinth integrated management plan, presented here, were finding the source of the weed, mapping the extent of the water hyacinth infestation, identifying sources of nutrient pollution, appointing a champion to drive the programme, dividing the river into management units, consultation with interested and affected parties, judicious use of herbicides and biological control and a commitment to follow-up. This study further showed that water hyacinth on the Nseleni and Mposa river systems had a negative impact on the biodiversity of the protected area and the control of water hyacinth resulted in the recovery of the benthic invertebrate, amphibian, reptile, fish and avian fauna. The implementation of this integrated management plan was very cost-effective and serves as a model approach to the control of water hyacinth in both South Africa and the rest of the world.

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Acknowledgements

I am sincerely grateful to my supervisor, Professor Martin Hill for his advice, comments, encouragement and meticulousness during this study. Your exceptional patience, guidance and ardour are noted. I am grateful to Rhodes University for taking me on as a student.

I acknowledge Dr. Julie Coetzee's (Rhodes University) patience and guidance with the statistical analyses of this study. It brought all the field work to an understandable conclusion and helped me to understand science from a different perspective.

I thank the staff of the Department of Zoology and Entomology (Rhodes University) for their assistance, as well as Mrs. Kate Benyon for assisting with the arrangements for my trips to Grahamstown.

I wish to record my sincere thanks to both Dr. Carina Cilliers and Professor Martin Hill (formally of ARC-PPRI, Pretoria), who I got to know and respect in 1994 / 1995. Dr. Cilliers and Professor Hill made sure that the "bug" bit me when I was busy floundering in the waters of the Nseleni and Mposa rivers. You both gave me the support and direction that I required at that time.

The Integrated Control Committee is acknowledged for their input and persistence in the early years. It made my job easier. Kwambo Conservancy has remained enthusiastic and persistent in assisting with the control of water hyacinth and particular thanks to Mr.Dave Davidson who has been on board since 1995.

I would like to acknowledge financial support from the Department of Water Affairs (Working for Water) via the Rhodes University.

To my wife, Sonia, and family who edged me on at my "ripe old age" to do something that I have seen for many years as more than just a job**,** my sincere thanks.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Aquatic weed problems in South Africa

Water resources in South Africa are extremely important for the environment, industry, domestic and agricultural purposes. South Africa's rainfall is highly erratic and variable. So while much of the country is arid, other parts are subjected to frequent flooding. In an attempt to alleviate this situation, numerous dams, weirs and inter-basin transfer schemes have been constructed to ensure sufficient water resources for domestic, agricultural and industrial use. Further, aquatic resources in South Africa have become increasingly polluted through urban runoff, incorrect agricultural practices, informal development and the products of industrial wastes (Hill and Olckers 2001). The alteration of flow regimes and the enrichment of South Africa's water bodies have made them susceptible to biological invasion (MacDougall and Turkington 2005). Indeed, 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. At present there are five aquatic weeds that are especially problematic in Africa (Cilliers *et al.* 2003). *Azolla filiculoides* (Lam.) (red water fern) is native to North and South America and was first recorded in South Africa in 1948 and has the potential to form large dense mats that negatively impact on the aquatic systems. Biological control using the weevil, *Stenopelmus rufinasus* (Gyllenhal) has successfully controlled this weed to the point that it is no longer considered problematic in South Africa (Cilliers *et al*. 2003) *Myriophyllum aquaticum* (Vell.)Verdc. (parrot's feather) is native to the Amazon River in South America. Unlike the other problematic weeds, this plant is attached to the substratum. It has become a troublesome aquatic weed in southern Africa. Since the introduction of the leaf beetle, *Lysathia* sp. in 1991 in South Africa, this weed has successfully been brought under control (Cilliers, 1999). *Pistia stratiotes* L.(water lettuce) is also from South America. The weevil, *Neohydronomus affinis* (Hustache), has been successful as a biological control agent throughout the world (Julien, 2001). *Salvinia molesta* (Mitchell) (salvinia) is another South American native free-floating aquatic fern species which is invasive throughout the world and has been present in South Africa since the 1960s. The weevil, *Cyrtobagous salviniae* (Calder and Sands) was introduced and has since controlled the weed (Cilliers *et al.* 2003).

The most widespread and damaging aquatic plant species in Africa is *Eichhornia crassipes* (Mart.) Solms (water hyacinth) (Hill, 2003). This plant was introduced to Africa from South America in the late 1800s. Despite successful biological control of water hyacinth in a number of countries in Africa (Cilliers *et al.* 2003), it is still regarded as problematic in regions of South Africa (Hill and Olckers 2001) and is the topic of this thesis.

1.2 Taxonomy, morphology and ecology of water hyacinth – *Eichhornia crassipes*.

Taxonomy

Kingdom	- *Plantae*	Plants
Subkingdom	- *Tracheobionta*	Vascular plants
Superdivision	- *Spermatophyta*	Seed plants
Division	- *Magnoliophyta*	Flowering plants
Class	- Liliopsida	Monocotyledons
Subclass	- *Commelinidae* [*Liliidae*]	
Superorder	- *Commelinanae*	
Order	- *Pontederiales* [*Philydrales*]	
Family	- *Pontederiaceae*	
Genus	- *Eichhornia*	
Species	- *Eichhornia crassipes*	water hyacinth

The family Pontederiaceae contains 5 genera and 21 accepted taxa overall (Gopal, 1987), of which the following genera are recognized, namely,

Genus *Eichhornia* Kunth – water hyacinth

Genus	*Heteranthera*	Ruiz & Payon – mudplantain
Genus	*Monochornia*	K.Presl – monochornia
Genus	*Pontederia*	L. – pickerelweed
Genus	*Reussia*	Endl. - reussia

and the genus *Eichhornia* contains 6 accepted species (Gopal, 1987), namely:-

Species	*azurea*	Kunth – anchored water hyacinth
Species	*crassipes*	(Mart.) Solms – common water hyacinth
Species	*diversifolia*	(Vahl) Urban – variable water hyacinth
Species	*paniculata*	(Spreng) Solms – Brazilian water hyacinth

The distribution of the above four species is as follows (Gopal, 1987), namely: *E.azura*, first reported from Jamaica, is widely distributed with its range overlapping (almost completely) that of *E.crassipes*. *Eichhornia crassipes*, is widely distributed in South America. *E.diversifolia*, is largely distributed in Brazil and extends to Surinam, Cuba, Haiti, Puerto Rico and Santo Domingo and *E. paniculata*, occurs mainly in northern Argentina and Brazil.

There are two other species of *Eichhornia*, namely *E.natans* (Beauv.) Solms, which is endemic to Africa (Senegal, Sudan, Nigeria and Mali) and *E. paradoxa* Solms which is endemic to Brazil and possibly Caracas in Venezuela (Gopal, 1987).

Morphology

Water hyacinth is a perennial, aquatic plant, free-floating or anchored in shallow water. Usually 100 – 200mm high, it can extend to 1 meter when growing in dense mats. Roots of floating plants are long and feathery. Leaves of water hyacinth are shiny dark green in colour, in rosettes with distinctive erect swollen bladder-like petioles (Fig. 1.1). Flowers are pale violet or blue, in flowered spikes with each flower measuring about 50mm in diameter. The upper petal has a prominent dark blue, yellow-centered patch. Fruit consists of capsules with very fine seed (Henderson, 2001). The root structure of the plant gives it a feathery appearance, due to it being adventitious and fibrous. As much as 50% of a single plant's biomass could be made up of the root structure (Gopal, 1987).

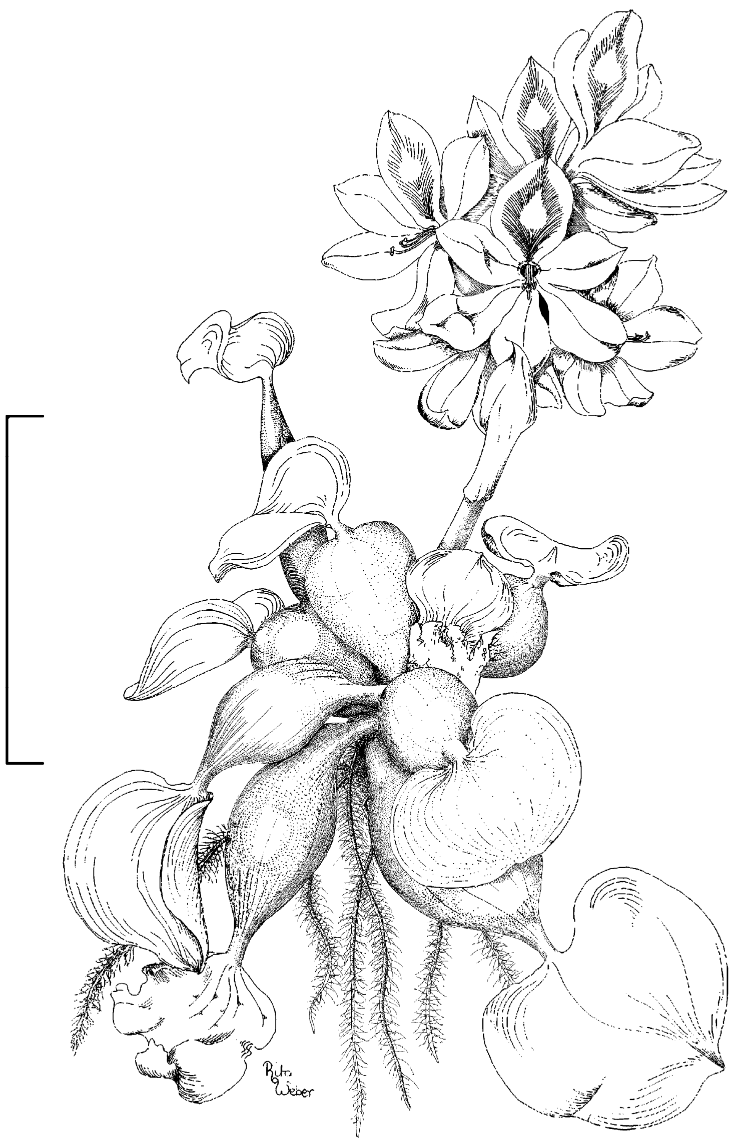

Fig. 1.1 Water hyacinth, *Eichhornia crassipes (*Martius*)* Solms-Laubach (Drawn by Rita Weber, SANBI). Scale bar = 10cm.

Ecology

Water hyacinth occurs in both highly acidic and alkaline waters but more luxuriant growth is observed in near neutral water bodies. The water may be clean and poor in major nutrients as in most rivers and reservoirs, or may be highly polluted with large amounts of nutrients and organic matter as in sewerage lagoons (Gopal, 1987) and many aquatic systems in South Africa. One hectare of water hyacinth plants under optimum conditions could absorb the average daily nitrogen and phosphorus waste production of over 800 people (Rogers and Davis, 1972).

Invasive species are widely accepted as one of the leading causes of biodiversity loss and can have significant effects on resource availability and can suppress or enhance the relative abundance of native species, without necessarily being the driving force behind community change (Didham *et al.* 2005). A dense cover drastically reduces and may prevent light penetration of water. Without light, phytoplankton and submerged plants can not photosynthesize. Oxygen levels decrease and carbon dioxide increases, with catastrophic effects on the aquatic fauna (Howard and Harley, 1998). Populations of fish can be reduced or eliminated, as well as other animals (Gratwicke and Marshall, 2001; Timmer and Weldon, 1966). Few invaded ecosystems are free from habitat loss and disturbance, leading to uncertainty as to whether dominant invasive species are driving community change or are passengers along for the environmental ride (MacDougall and Turkington, 2005).

Water hyacinth has a direct impact on aquatic systems water flow by slowing it by 40 to 95% in irrigation channels (Bogart 1949, Guscio *et al.* 1965, in: Gopal 1987), which may cause severe flooding. This could have a detrimental effect on the ecology of the system. In addition it is suggested that mats of water hyacinth lower temperatures, pH, bicarbonate alkalinity and dissolved oxygen content and increase the free carbon dioxide content, and nutrient levels (Wahlquist 1972, McVee and Boyd 1975, Rai and Datta Munshi 1979 all in: Gopal, 1978).

Dense mats of water hyacinth reduce light to submerged plants and thereby reduce oxygen levels in aquatic communities (Ultsch, 1973). Invertebrate community composition is altered (McVea and Boyd, 1975). During periods of strong winds, mats of water hyacinth drift and scour indigenous vegetation. This in turn destroys both plant and wildlife habitats (Gowanloch, 1944). Exotic species (water hyacinth) that invade systems represent a threat to that ecosystem and could directly modify an ecosystem, causing a cascading effect for resident biota e.g. space (Crooks, 2002).

Habitat

Water hyacinth can be located worldwide in a variety of different habitats. These include habitats varying from shallow ponds, possibly temporary, to large lakes and even fairly fast flowing rivers (Gopal, 1987). Where the plant is situated in shallow water bodies it does not have to contend with excessive wave action and varying depths of water. The velocity of water also plays a significant role in the plant's habitat. Climatic conditions vary within a system and will have an affect on the ecology of the plant itself. Water hyacinth can be located in both natural water and artificially made aquatic systems. However, it does not occur in aquatic systems with an average salinity greater than 15% of sea water (Penfound and Earle, 1948).

Water hyacinth is able to remove high levels of nutrients from water, which then influences the plant's growth form eg. plant's established in or near to a sewage outlet, compared to those plant's established in a low nutrient habitat. The plant grows prolifically in nutrient enriched waters and new plant populations form from rooted parent plants. Wind and current assists to distribute them. Excessively large mats can be formed. The root system, as well as the above water structures of the plant, forms a habitat for organisms. However, large mats of water hyacinth are capable of negatively affecting the original habitat.

The feathery roots of water hyacinth provide a suitable habitat and substrate for specific periphytic microphytes. In addition, a large variety of invertebrates are particularly associated with the roots hanging in the water as they provide a habitat, and may possibly trap them from the water column. In some cases a few organisms have been reported to be specifically associated with water hyacinth mats. Water hyacinth mats also provide a suitable habitat for germination and establishment of the seedlings of a number of emergent species (Gopal, 1987).

Growth and reproduction

Water hyacinth, growing in ideal situations, has an incredible mechanism to outgrow any native species occurring in the system. It is capable of reproducing vegetatively, which is its primary reproductive method. This is carried out from the 'mother' plant via stolons. During periods of high wind and wave action, plants are able to disperse and colonize other areas of the system. Penfound and Earle (1948), further record that 10 adult plant's are capable of producing some 655 360 daughter plants in a single growing season. Gopal (1987) reports that water hyacinth has the capacity to increase sevenfold in 50 days, that the edge of mat extends by 60cm per month, that 2 plants can multiply to 1 200 plants in 120 days, that the surface area increases by an average of 8% per day and that the surface mat can double every 6.2 days.

Another method used by water hyacinth to reproduce, is sexually. Sexual reproduction is reported to be limited (Gopal, 1987; Penfound and Earle 1948). Plant's are capable of flowering throughout the year, should environmental factors be suitable. Penfound and Earle (1948), reported that a water hyacinth ovary may produce up to 500 ovules, but rarely sets more than 50 seeds per capsule in trials that they performed. Barrett (1980), performed trials and concluded that 44.2 seeds per capsule were the average, with a high seed germination rate of 87.5% on average.

Penfound and Earle (1948), further recorded that upwards of 900 00 capsules have been counted in an area of one hectare. This equates to 45 million seeds per hectare. Of interest is the fact that they further suggest that pollination by insects rarely occurs, but that self-pollination is a common phenomenon during the wilting stage. Water hyacinth seed can lay dormant for many years, until the correct climatic condition arise, when it may then germinate. Seed can remain dormant for up to 20 years (Gopal, 1987). Very few seeds germinate on the mat, as they are lost in the detritus build-up, or sink due to being heavier than water.

1.3 Origin of water hyacinth (*Eichhornia crassipes*) and distribution

In 1823, the German naturalist C. von Martius discovered the species, while carrying out floral surveys in Brazil. He named it *Pontederia crassipes*. Solms included it in the *Eichhornia* genus, 60 years later, as had previously been described by Kuntz in 1829. However, a collector by the name of von Humbolt had already collected specimens from Colombia in 1801, together with the species *azurea* (Gopal, 1987). The reason for the world-wide distribution of this weed varies, but generally it has coincided with the plant's ornamental properties or as feed (Ding *et al*. 2001).

The native range of *E.crassipes* (Gopal, 1987) in South America includes Argentinia, Brazil, Paraguay, Uruguay, Bolivia, Ecuador, Colombia, Chile, Guyana, Surinam and Venezuela. It has spread to Panama, Nicaragua, Honduras and El Salvador in Central America. There appears to be several schools of thought when it comes to the actual point of origin / dispersal of *Eichhornia crassipes*. Many authors refer to the neotropics as being the native range (Fig. 1.2).

In North America, it is believed to have been introduced in 1884 at the Cotton States Exposition in New Orleans, Louisiana. It subsequently spread across the southeastern United States to Florida in 1895 and California in 1904 (Center *et al.* 2002). Water hyacinth is most prolific in the south-eastern states, as well as being recorded in Hawaii (Center *et al.* 2002). Water hyacinth has, since its introduction to Louisiana, spread to Alabama, Arkansas, Arizona, California, Colorado, Florida, Georgia, Hawaii, Kentucky, Louisiana, Missouri, Mississippi, North Carolina, New York, Oregon, South Carolina, Tennesse, Texas, Virginia and Washington, (USDA–NRCS, www.USDA.gov) in other words to about 50% of the State in the U.S.A (Fig. 1.2).

It was introduced into Asia towards the end of the 19th Century via Japan and Indonesia (Ueki *et al.* 1975) where it naturalized in rice fields in Indonesia (Backer, 1951), where it was grown as an ornamental plant in the Botanical Gardens. In India it first appeared in Bengal at the beginning of 1890. It has also established in Taiwan and China, as early as

1901 as a good fodder plant (Ding *et al.* 2001). It was first noticed in Australia in Brisbane, Sydney and Grafton in the 1890's (CSIRO Fact Sheet, undated) and has since spread to all mainland States and Territories. As in other countries, here to it is believed to have been introduced as an ornamental plant. In Australia it was introduced as an aquarium plant. It has in addition spread to Papua New Guinea, where it was first recorded from dredge ponds in old gold fields of Bulolo in 1962 (Harley *et al.* 1996). Holm *et al.* (1969) record the fact that both New Zealand and Bangladesh also have water hyacinth infestations (Fig. 1.2). Burton (2005) records that many islands in the Pacific Ocean also have infestations of the plant. Europe has also been affected by water hyacinth, where it was introduced as an ornamental plant in Portugal. The first record of it was made in 1939. First documented records for Spain are for 1989 (Têllez *et al.* 2008). Potter (2000), in an editorial quotes that water hyacinth has also been observed in the wild in Britain by Gates (2000) and Harper (2000) and states that: " Invasive species, particularly those associated with aquatic habitats are out competing many of Britain's native plants and the law is doing nothing to stop them …".

Water hyacinth was originally introduced outside of its home range, due to the lack of understanding of the plant's invasive properties and the immense ecological negative impacts that it would have on fresh water ecosystems. In more modern times, lack of enforcement of relevant legislation or in some cases the lack of any relevant legislation has assisted in the degradation of freshwater systems. The lack of general public awareness has also been a factor.``` The lack of political will-power has also played its role in allowing weeds to disperse.

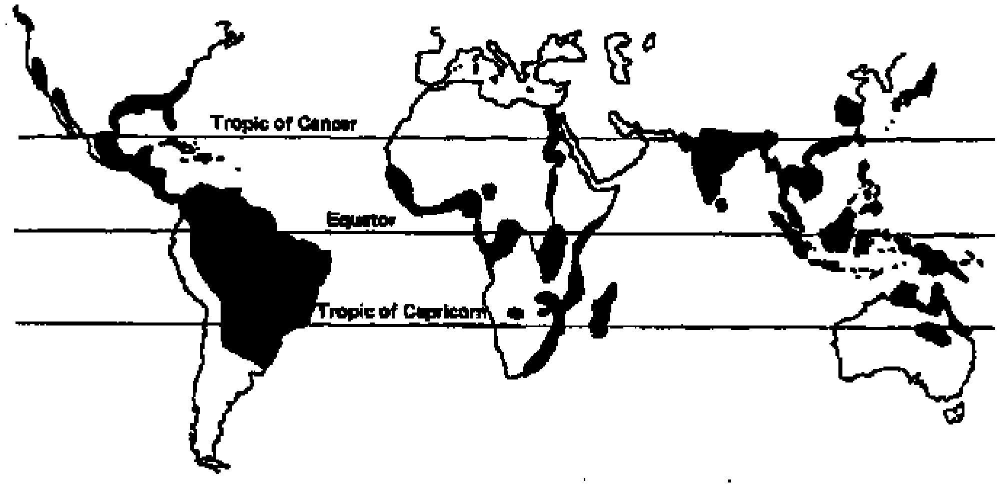

Fig. 1.2 Distribution of the three different style lengths of water hyacinth throughout the world, including its native distribution (after Barrett, 1989)

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). Africa has been particularly affected by the introduction and spread of water hyacinth (Table 1.1).

Climatic suitability modeling suggests that, with the exception of the drier areas of the continent (Sahara and Kalahari deserts), water hyacinth would be able to infest most of the continent and the fact that it does not occur in all countries in Africa is more due to it not having being recorded or not having spread there, rather than it not being able to establish (Wise *et al.* 2007).

The first recorded introduction of water hyacinth onto the continent was for Egypt in the period 1889 – 1892, during the reign of Khevede Tawfiq (Gopal, 1987). It is believed to have been introduced as an ornamental plant. Water hyacinth occurs throughout the Nile Delta and is believed to spreading southwards, due to the construction of the Aswan Dam, which has slowed the river down (Obeid, 1975 in: Gopal 1987).

The second record for the continent is for South Africa in 1908 (Stent, 1913). Water hyacinth is believed to have been introduced as an ornamental aquatic plant for garden ponds and aquaria, owing to its attractive flowers (Ashton *et al.* 1979). In the case of water hyacinth, a warning of what was likely to happen, was printed as early as 1913 (Jacot Guillarmod, 1979).

Thirdly, Zimbabwe recorded water hyacinth infestations in 1937. The first record was from the Mukuvisi River in Harare and the plant only attained its pest status in the early 1950's on Lake Chivero (Chikwenhere *et al.* 1999).

In the period 1941 to 1960, a further ten African countries (Table 1.1) recorded water hyacinth infestations, namely: Angola (1942), Benin (1942), Burundi (1957), Congo (1950-1951), the Democratic Republic of Congo (1952), Ethiopia (1956), Mozambique (1942), Rwanda (1957), Sudan (1954) and Tanzania (1955).

There appears to be a slump in water hyacinth introductions, in the period from 1961 to 1980, and this is due to the fact that a further eight countries are recorded to have water hyacinth infestations but no accurate data are available to ascertain when the first recordings were made and the data have not been included in Figure 1.3. It is, however, acknowledged that some of these infestations could have taken place in the period 1981 to 2000. However, a further four African countries, published their first records of water hyacinth infestations during 1961 - 1980, namely: Central African Republic (1970), Malawi (1960's), Senegal (1963) and Zambia (1965). Nine African countries recorded water hyacinth infestations in the period 1981 to 2000, namely: Burkina Faso (1989), Cote d' Ivoire (1980's), Ghana (1984), Kenya (1982), Mali (1987), Niger republic (1987), Nigeria (1982), Togo (1987) and Uganda (1988).

Both intentional introductions (ornamental) and unintentional introductions (rivers flowing from one country to another) of water hyacinth have occurred throughout Africa, since the first intentional introduction into Egypt.

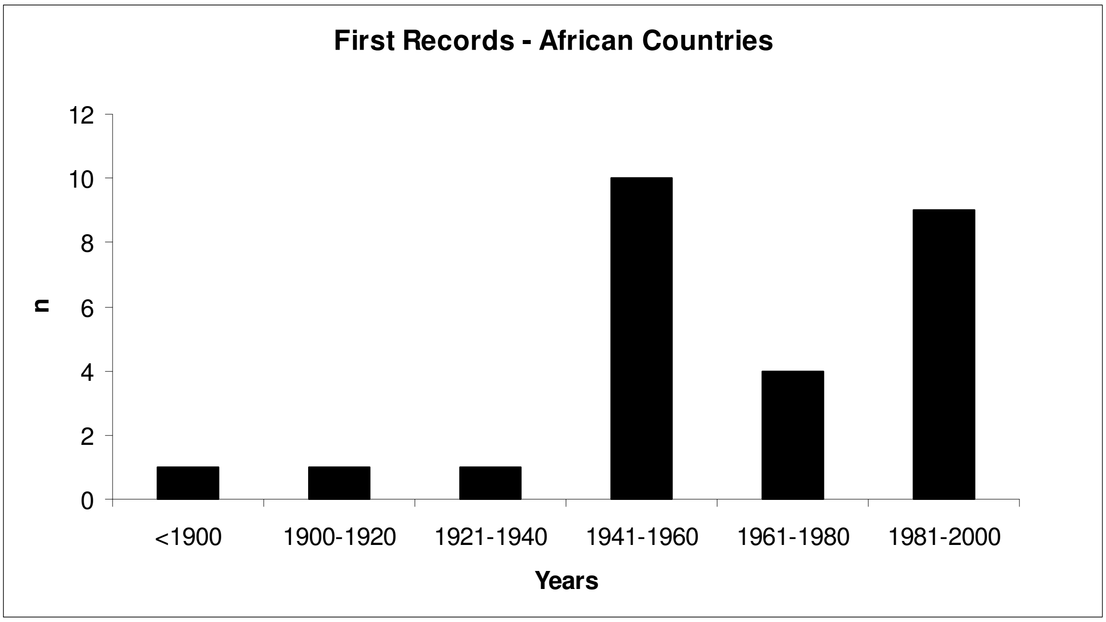

Fig. 1.3 Introduction of water hyacinth to African countries. [Excludes eight countries where no positive date of identification exists, as per Table 1.1].

Table 1.1 Water hyacinth distribution in African countries.

Country	First Recorded	Reference
Angola	1942	Gopal, 1987.
Benin	1942	Gopal, 1987.
Burkina Faso	1989	Ouedraogo *et al.* 1999.
Burundi	1957	Navarro & Phiri, 2000.
Cameroon	?	Barrett, 1989.
Central African Republic	1970	Gopal, 1987.
Congo	1950 - 51	Gopal, 1987.
Côte d' Ivoir	1980's	Koffi Koffi *et al.* 1999.
Democratic Republic of Congo	1952	Greathead & de Groot, 1993.
Egypt	1879 – 1892.	Fayad, 1999.
Equitorial Guinea	?	Barrett, 1989.
Ethiopia	1956	Navarro & Phiri, 2000.
Gabon	?	Barrett, 1989.
Ghana	1984	Greathead and de Groot, 1993.
Guinea-Bissau	?	Barrett, 1989.

Kenya	1982	Ochiel *et al.* 1999.
Liberia	?	Barrett, 1989.
Malawi	1960's	Navarro & Phiri, 2000.
Mali	1987	Navarro & Phiri, 2000.
Mozambique	1942	Gopal, 1987.
Niger Republic	1987	Ouedrago *et al*. 1999.
Nigeria	1982	Charudattan *et al*. 1995.
Rwanda	1957	Navarro & Phiri, 2000.
Senegal	1963	Gopal, 1987.
Sierra-Leone	?	Barrett, 1989.
South Africa	1908	Stent, 1913.
Sudan	1954	Navarro & Phiri. 2000.
Swaziland	?	* Swaziland Alien Plants Database
Tanzania	1955	Mallya, 1999.
The Gambia	?	Barrett, 1989.
Togo	1987	Ouedrago *et al*. 1999.
Uganda	1988	Ogwang & Molo, 1999.
Zambia	1965	Mailu *et al*. 1999.
Zimbabwe	1937	Chikwenhere *et al*. 1999.

* Swaziland Alien Plants database merely records the fact that water hyacinth has been reported, without further details.

1.4 Introduction to South Africa

Water hyacinth appears to have been introduced into South Africa as an ornamental plant in 1908 – Cape Province and Natal (now KwaZulu-Natal). No records have been found as to where the plants originated from. Since the introduction of water hyacinth to South Africa, it has invaded 9 provinces, in varying degrees of infestation (Fig. 1.4).

Stent (1913) reports that water hyacinth was first recorded in South Africa on the Cape Flats in 1908 and in Natal at approximately the same time. Du Toit, (1938) and Edwards and Musil, (1975) (in: Gopal 1987), reports that water hyacinth was first introduced to South Africa, in the Natal Province in 1910 and that it then spread to other parts of South Africa.

In South Africa, water hyacinth has become a serious pest plant in both fresh and brackish water systems and, as early as 1913, a warning was raised as to the consequences of this introduced aquatic weed. Further to this, it appeared that as far back as the mid 1970's there was a lack of awareness of the dangers pertaining to water hyacinth. An additional warning was raised, concerning the availability of fresh water Resources, in particular that South Africa could be using all available water supplies by 1995 and that there could be a 30% deficit by 2000 (Jacot Guillarmod, 1979).

Since the introduction of water hyacinth in South Africa, (Jacot Guillarmod, 1979), it has spread throughout numerous provinces. The lack of natural enemies and the presence of enriched waters have contributed to its establishment on water bodies, where it degrades aquatic ecosystems and limits their utilization and its main distribution occurs from low-lying subtropical areas to high elevations where frost occurs in winter (Cilliers, 1991).

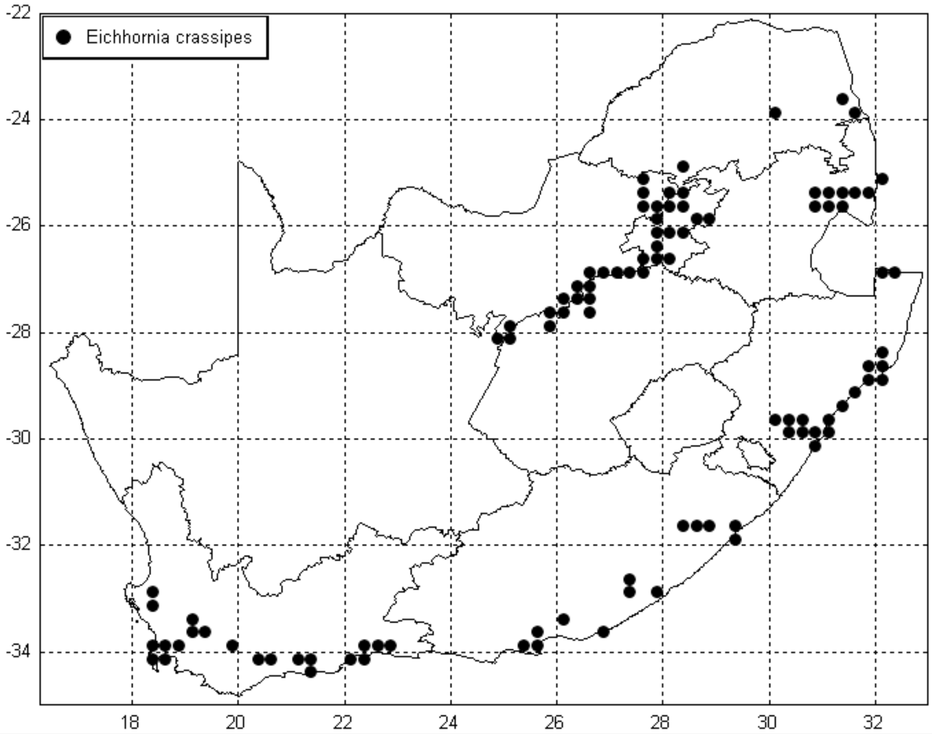

Fig. 1.4 Distribution of water hyacinth in South Africa. (SAPIA Database, ARC – PPRI).

1.5 History of water hyacinth on the Nseleni River

The Nseleni and Mposa rivers in the Enseleni Protected Area are the subject of this study (see chapter 2 for full site description). No records have been located to indicate when water hyacinth was first observed on either the Nseleni or Mposa rivers, however by 1983 the rivers were 100% covered by the weed. Neither have any records been located to assist in determining where exactly water hyacinth was first recorded on the river system. There are three large lakes and two large rivers in the region that could have been the source of infestation on the Nseleni River and Lake Nsezi. Neither Lake Nhlabane nor Lake Mzingazi had a water hyacinth infestation, and the third lake in the region, namely Lake Cubhu, only became infested in the 1990's, well after Lake Nsezi and the Nseleni River became infested. The Mfolozi River has no record of any water hyacinth infestation. As with Lake Cubhu, the Mhlathuze River only became infested with water hyacinth in the 1990's.

It is, however, believed to have been introduced for ornamental purposes onto a private land holdings dam adjacent to either the Nseleni or Mposa rivers and was possibly flushed into one of the rivers during a period of heavy rain or flood. In discussing the issues with many of the surrounding farmers that have farmed in the area since the turn of the century, all are of the same opinion that it first became evident in the early 1970’s but was not a problem. No attempts were carried out to eradicate it, or even attempt to control it. Further discussions with farmers in the area, indicate that the plant was collected for its ornamental attraction by nursery owners, aquarium enthusiasts and the general public to put in their ponds.

2. Aims of the study

2.1 To develop and implement an integrated programme for water hyacinth control on the Nseleni river system and Lake Nsezi.

2.2 To quantify the impact of water hyacinth on the aquatic biodiversity in the Nseleni river and Lake Nsezi.

CHAPTER 2

SITE DESCRIPTION

2.1 Enseleni Nature Reserve

Ezemvelo KZN Wildlife is the Provincial mandated conservation authority for the KwaZulu-Natal Province of South Africa, in terms of Nature Conservation Ordinance 15 of 1974.

The Enseleni Nature Reserve, situated inland from Richards Bay and north-west of Richards Bay (Fig. 2.1), on the north coast of the province was established on 22 January 1948 - Proclamation P4/48. This proclamation was amended on 16 October 1958 – Proclamation P72/58. The reserve is approximately 300ha in size and is commonly known as the gateway to Zululand. It is a popular venue for outdoor enthusiasts for many reasons. It is a well known area for birding enthusiasts and boasts many rare or unusual species, many of which are aquatic species.

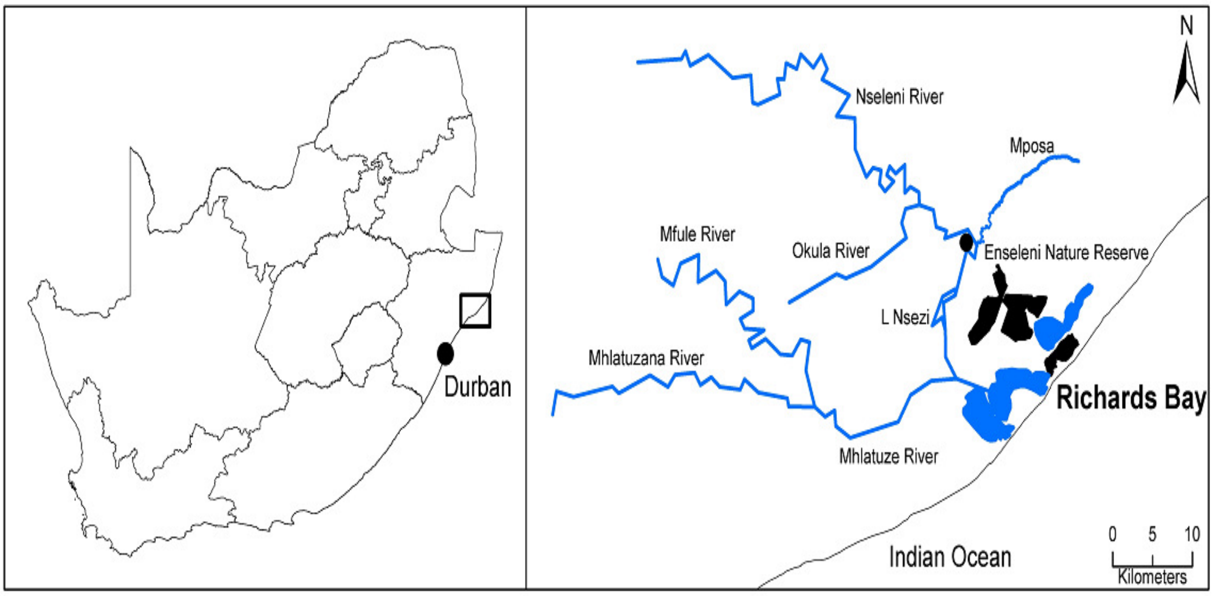

Fig. 2.1 Location of the Enseleni Nature Reserve, KwaZulu-Natal, South Africa

A reason for the proclamation of this nature reserve in KwaZulu-Natal, was the formal protection of the biodiversity of the immediate area. At that stage in the history of the area, more and more of the coastal grasslands / forests were being converted into sugar cane and timber farms, due to the national and international demand for these products. Prior to proclamation, the area was classified as Crown Land and used by the surrounding farming community as grazing land, which caused serious damage to the vegetation due to over grazing.

In this instance it is important to note that the Enseleni Nature Reserve's eastern and northern boundary is the Nseleni River, which flows into Lake Nsezi. There has been an increase in farming, industrial and urban development in the area, increasing the pressure on the biodiversity. There are numerous rivers, lakes and wetlands in this region of the coast and all experience the same pressure from development. With the increase in industrial and urban development in the Richards Bay, Empangeni and Nseleni township area, the water in the area is being placed under severe pressure from extraction and nutrient input and is placing severe pressure on the biodiversity of the area.

The Enseleni Nature Reserve's further importance is that it has, within the approximate 300ha, five distinct habitats namely: coastal grassland, coastal forest, riverine forest, swamp forest and an aquatic habitat. The most noteworthy terrestrial habitat is the riverine forest. This is possibly one of the rarest types of habitat in the province. The riverine forest habitat is characterized by large canopies of *Barringtonia racemosa* and *Ficus* species. The fauna of the reserve is diverse in nature. Of importance, is the fact that the rare Cape clawless otter (*Aonyx capensis* Schinz) has been recorded and requires an open aquatic environment, free of aliens, to survive. Fish species that have been recorded in the Nseleni River are: oxeye tarpin (*Megalops cyprinoids* Broussonet,1782), estuarine round-herring (*Gilchristella aestuaria* Gilchrist,1913), bulldog (*Marcusenius macrolepidotus* Peters,1852), straightfin barb (*Barbus paludinosus* Peters,1852), Johnson's topminnow (*Aplocheilichthys johnstoni* Günther,1983) and the southern mouthbrooder (*Pseudocrenilabrus philander* Weber, 1897) (Skelton, 2001). All game occurring within the reserve depend on the Nseleni River, and access to the water, as there are no man-made drinking points.

Another important factor about the Enseleni Nature Reserve and its geographical location, is that it is seen as a nucleus for biodiversity dispersal in the sub-region and region.

2.2 Rivers and Lakes

The two main rivers that supply water to the City of uMhlathuze, are the Mhlathuze River (indirectly) and the Nseleni River. Lake Nsezi is fed directly from the Nseleni River, while water is transferred via a weir on the Mhlathuze River to Lake Nsezi, to supplement water that is extracted from the lake for industrial and domestic use. Lake Mzingazi does not have any large rivers that feed it, but relies on a couple of small streams and precipitation (Fig. 2.2).

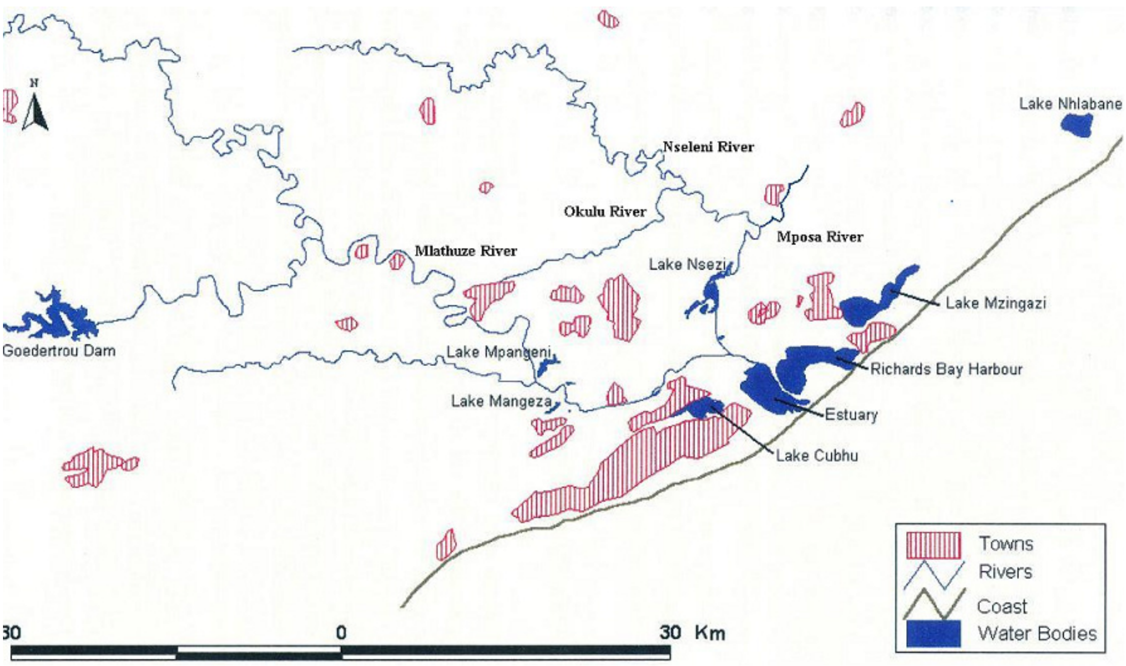

Fig. 2.2 Rivers and Lakes in the vicinity of Richards Bay and Empangeni (Adapted from WRC Report No.720/1/01)

2.3 Nseleni River Catchment

The catchment of the Nseleni River is relatively small compared to that of the Mhlathuze River, which is fed from the Goedetrouw Dam. The Nseleni River has two small rivers that fall within its catchment, namely the Mposa River that reaches as far as Kwambonambi (this catchment covers a large area of rural land and private timber and sugar cane farms with a high nutrient run-off) and the Okulu River (this catchment covers the area to the west of the N2 Highway and Enseleni Nature Reserve and comprises mainly of sugar cane farms with a high nutrient run-off). (Fig. 2.3).

The catchment of Lake Mzingazi is even smaller than that of Lake Nsezi and comprises of a couple of small streams that rely on precipitation to feed them. Commercial forestry and informal settlements surround the streams.

Lake Nsezi and Lake Mzingazi are presently unable to cope with the demand from industrial and domestic use in the area, from natural flow of water into these two lakes. Additional water is transferred to Lake Nsezi, from a weir on the Mhlathuze River, which is controlled by the Mhlathuze Water Board situated in Richards Bay. Additional water requirements for the Mhlathuze Water Board (Lake Nsezi) is released from the Goedetrouw Dam. This, therefore, makes Lake Nsezi and the Nseleni River unique in the area in as much as the Nseleni River's natural flow is from west to east, but during times of water transfer from the Mhlathuze River into Lake Nsezi, water pushes back upstream ie. east to west. This is done in an attempt to have a constant level of water at the Umhlathuze Water Board extraction point on Lake Nsezi. This causes further problems in that water hyacinth flows in both directions and can re-infest cleared sections of the Nseleni River.

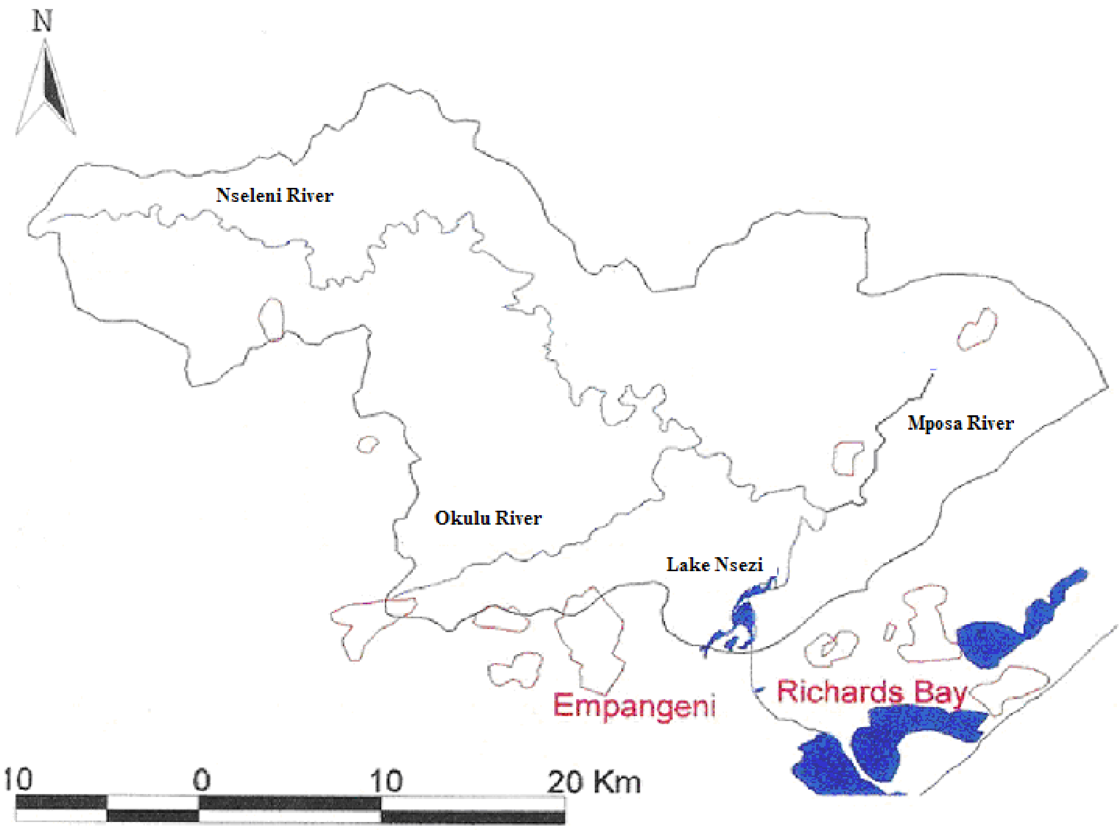

Fig. 2.3 Catchment of the Nseleni River. (Adapted from WRC Report No.720/1/01)

2.4 Sources of possible infestation of water hyacinth

Aerial surveys have been carried out over the years, since water hyacinth first became established, of water bodies between the Umfolozi River and the Mhlathuze River, with the use of a helicopter, to determine the extent of aquatic weed infestations in an attempt to locate present infestations, as well as levels of infestations.

Areas surveyed include; Lake Eteza Nature Reserve, Lake Mavuya, Lake Nhlabane and river/estuary, Lake Mzingazi and Richards Bay Golf Course, Lake Nsezi, Lake Cubhu, Umfolozi river, Nseleni River, Mposa River, Mhlathuze River, Okulu River and numerous un-named private dams (Table 2.1).

Results of survey

Table 2.1 Results of aerial surveys carried out in 1983, 1995 and 1998 by KZN Wildlife.

Water Body	Aquatic Alien Species Identified		
	Azolla filliculoides	*Eichhornia crassipes*	*Pistia stratiotes*
Lake Cubhu		√	-
Lake Eteza Nature Reserve	-	-	-
Lake Mavuya	-	-	-
Lake Mzingazi	-	-	√
Lake Nhlabane	√	-	√
Lake Nsezi	√	√	-
Okhulu River	-	√	-
Mhlathuze River	-	√	-
Mposa River	√	√	-
Nhlabane River/Estuary	-	-	√
Nseleni River	√	√	-
Umfolozi River	-	-	-
*Other water bodies	√	√	√

* - Private dams and Richards Bay golf course.

Subsequent to the aerial survey, ground truthing was undertaken and biological control agents were observed on all of the weed infestations of all species. The largest infestation of water hyacinth has been located on Lake Nsezi, and the Nseleni and Mposa rivers, a possible indication that the origin of water hyacinth in the area originates from the Nseleni and Mposa river system (Table 2.1).

2.5 Water Consumption in the area

Potable water in the area is under severe threat from development in the area. There are two sources of water for extraction for industrial and domestic use, for the City of uMhlathuze, namely Lake Nsezi and Lake Mzingazi. There are in addition, extraction points along the Nseleni River, that supply Richards Bay Minerals, the rural township of Nseleni and private agricultural farms (Fig 2.4). Table 2.2 is an indication of water requirements for the City of uMhlathuze, with special reference to the transfer of water from the Mhlathuze River weir into Lake Nsezi, an indication that Lake Nsezi is unable to cope with demand from a natural inflow situation.

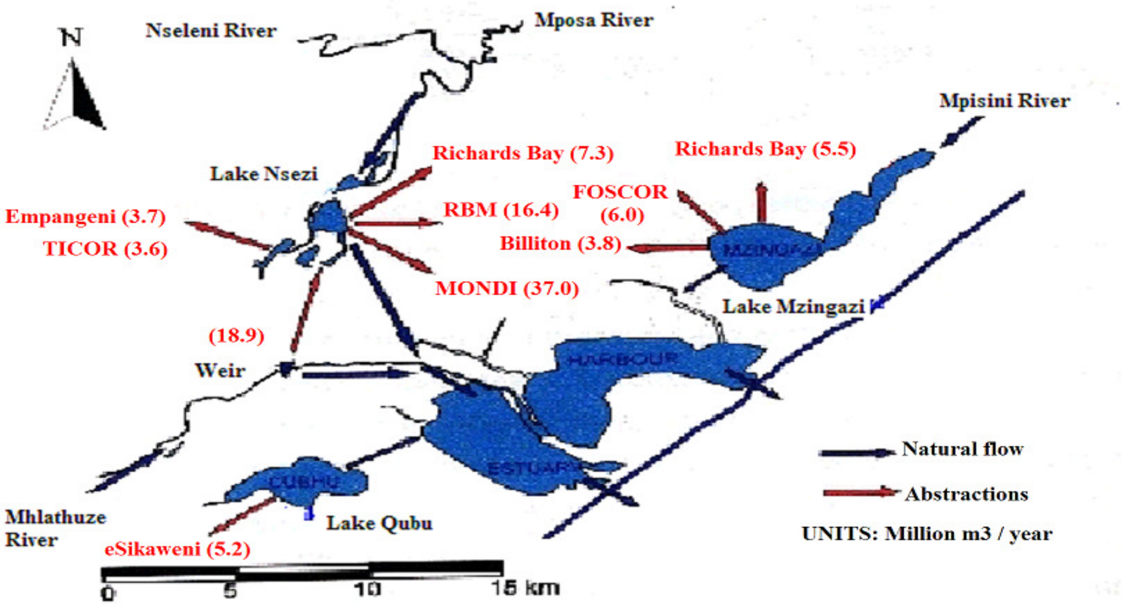

Fig. 2.4 Water extraction – City of uMhlathuze (2001). (Adapted from WRC Report No. 720/1/01).

Table 2.2 Comparison of water extraction and transfer – City of uMhlathuze for 2001 & 2007.

Source	**Authority**	**2001 Million m³/year**	**2007 Million m³/year**
Lake Qubu [1]	Richards Bay Municipality	5.2	9.4
Lake Nsezi [2]	Mhlathuze Water Board	51.6	46.4
Nseleni River [2] (*RBM)	Mhlathuze Water Board	16.4	1.2
Mhlathuze River Weir [2]	Mhlathuze Water Board	18.9	24.0
Lake Mzingazi [1]	Richards Bay Municipality	15.3	19.0
	BHP Billiton (Bayside)	1.2	0.81

[1] - 2007 information supplied by Mr.S.Hlongwa [Water & Sanitation SA]

[2] - 2007 information supplied by Mr.V.Botes [Operations Manager, Mhlathuze Water Board]

* Richards Bay Minerals – During the period 2001 to 2007, additional water was extracted from Lake Nhlabane and a new extraction point was created with water from the Umfolozi River, hence the drop in extraction figures between 2001 and 2007 for the Nseleni River.

Total extraction from the Nseleni River at the Richards Bay Minerals and Mhlathuze Water Board extraction points for 2007 was 40.1 million m^3, whereas only 24.0 million m^3 was transferred from the Mhlathuze River weir to Lake Nsezi. This equates to 16.9 million m^3 being extracted during 2007 or 1,408 million m^3 / month, from the Nseleni river. The rainfall for the Nseleni river catchment is not known, however the natural inflow to Lake Nsezi is insufficient for the demand. Richards Bay receives on average 1,200mm of rainfall / annum.

2.6 Study site

Lake Nsezi, situated at the southern extreme of the Nseleni River, has over the years become silted up due to poor farming practices further inland. This has caused what used to be a single large lake to become fragmented. Lake Nsezi now consists of four "splintered" lakes due to aquatic vegetation (*Typha capensis* and *Eichochloa pyramidalis*) that has taken advantage of the siltation and encroached into the former large lake area.

The backwater prior to entering the main lake area, on the western side of the Nseleni River, was chosen as the study site for multiple reasons, namely:
Permanent mats of water hyacinth around the edges;
Permanent open water;
Depth from water surface to substrate was adequate;
Sampling would be easier;
Access was by boat only, and;
No chemical spraying is carried out in this particular area.

CHAPTER 3

INTEGRATED MANAGEMENT PLAN FOR WATER HYACINTH CONTROL ON THE NSELENI AND MPOSA RIVERS

3.1 Introduction

Water hyacinth is a declared weed in South Africa and is covered by legislation. This is the Conservation of Agricultural Resources Act (Act 43 of 1983) and is administered by the Directorate of Resource Conservation of the National Department of Agriculture. The Act states clearly that this weed must be controlled. The South African Department of Water Affairs and Forestry (DWAF) is mandated to co-ordinate the control of water hyacinth and to execute measures in situations where the weed threatens state water works. In other cases it becomes the responsibility of the provincial and local water authorities (Jones, 2001).

Ad hoc control efforts were practiced between the late 1970s and 1994 by various interested and affected parties on the Nseleni River. By 1982, stretches of the Nseleni and Mposa rivers were covered with water hyacinth (100% coverage) and KwaZulu-Natal Nature Conservation Service initiated control of the weed. In 1984, a heavy flood alleviated the problem, as most of the water hyacinth was washed away before an aerial spraying operation could be implemented. Thereafter, little was done to the remaining islands of water hyacinth, because the decreased level of infestation was no longer seen as a threat (Jones, 2001).

The aim of this chapter was to develop and implement an integrated management plan for water hyacinth on the Nseleni and Mposa river systems.

3.2 Management: Water Hyacinth Control

3.2.1 Background

During the early 1980's, concern was raised by Natal Parks Board staff, as well as members of the public and officials from the Empangeni Town Board, due to the fact that Empangeni had an extraction point on the western bank of Lake Nsezi, the only source of water for the town of Empangeni, and that the water hyacinth was becoming a threat to it.

Officials from the Department of Transport also voiced their concern, regarding the national road bridge that crosses the Nseleni River. Both the Empangeni and Richards Bay municipalities also raised concern about the road leading from Empangeni to Richards Bay that crosses the Nsezi River. In both cases the concern was that the bridges would be washed away, due to water hyacinth building up against them.

In 1982, Mr. P. J. Ashton was invited to carry out a study of the perceived aquatic weed problem (Ashton, 1982). By this stage, the infestation was of such a proportion that it was considered a threat to the entire infrastructure crossing the Nseleni, Mposa and Nsezi rivers, as well as any infrastructure situated along the river banks and the extraction points on Lake Nsezi. It was estimated that the infestation along the Nseleni River and Lake Nsezi had already reached approximately 150 hectares. This figure did not include the entire Mposa River, but only the section at the confluence with the Nseleni River. The report further suggested that habitat alteration was taking place and that there were no signs of nutrient deficiency. There were also no signs of hippopotamus utilizing the water hyacinth as a food source. The record indicated that no signs of damage to the water hyacinth by insects or fungal pathogens were observed. The report clearly stated, "The greatest threat posed by the present water hyacinth infestation is the large area of consolidated plants in the Nseleni and Mposa rivers upstream of the north coast road bridge. After heavy rains this mat of plants will dam up against the bridge pillars, obstructing the river flow, and may flood sugar cane fields along the river margin. The north coast road bridge would come under serious threat and that it would most probably break away, disrupting road traffic on this important highway. The abstraction of water supplies would also be threatened.” This statement confirmed the concerns that had previously been raised.

Shortly after this report was received by interested and affected parties of the time, a decision was made to chemically eradicate all the water hyacinth. However, due to bureaucratic incompetence this took a long time and by late 1983, the Nseleni and Mposa rivers still had high infestation levels.

At a meeting held on 11 January 1995, at the Enseleni Nature Reserve, a control programme was discussed and introduced. It was further decided that a formal Control Committee be established from important role players. It was further recognized that end users of water should start contributing financially towards the programme. A closing statement by Dr. C. Cilliers was recorded as “All present were thanked for their participation and assistance in controlling the water hyacinth problem. “Dr.C.Cilliers further stated that” this great effort will show good results in the future.” The minutes of this meeting, further recorded the fact that an integrated approach was seriously being considered by initiating management control units. The control efforts had to be initiated at the source/s of infestation and that the rest of the river system was to be merely monitored. Officials from the KwaZulu Bureau of Natural Resources investigated the sewerage works on the Mposa River to determine the effects of sewerage being pumped into the Mposa River. Finally, it was agreed that the officials from the Natal Parks Board (now Ezemvelo KZN Wildlife) formalize a working document to control water hyacinth and that meetings be held every three months, where possible. A meeting date was set for March 1995 to formally introduce a way forward to control water hyacinth.

3.2.2 Formalizing a control committee

Prior to March 1995, numerous meetings took place, concerning the control of water hyacinth on the Nseleni River system. Unfortunately, they were few and far between and only took place when the water hyacinth infestation threatened infrastructure. These *ad* *hoc* meetings, although important, did not amount to much at the time as they did not have widespread support from the surrounding community and end users of water. Realistically, no noticeable long lasting results were achieved.

In March 1995, an Integrated Water Hyacinth Control Committee was formed. The committee consisted of important identified role players from the surrounding community, namely:-

Conservation:	KZN Wildlife (Chair)
	Kwambo and Nseleni Conservancies
Research	ARC – PPRI (Pretoria)
Water authority	Mhlathuze Water Board (Local)
	Department of Water Affairs and Forestry (Provincial)
Community representatives	Rural Nseleni
	Forestry / Agriculture
	Industry
	Private landowners

It was recognized that unless surrounding communities and water users were included in having some form of input, the project was destined to fail. To ensure the success of control efforts, the conservation manager at the Enseleni Nature Reserve, was requested to champion the control of water hyacinth on the Nseleni river system. This was done due to the fact that he had been working on controlling water hyacinth since his arrival at the protected area in 1993. In addition, it was felt that there would be more stability and continuity if one person was driving the process. However, it is important to note that the conservation manager was not working in isolation, but had input from the control committee.

3.2.3 Objectives of committee

The first objective of the committee was to collate all the work that had previously been carried out on the water hyacinth infestation, secondly to formulate a holistic approach to use the various control options that were available; i.e. chemical, biological and mechanical, and thirdly to formulate a management plan, consisting of four main components, namely: Survey, Plan, Control and Record, as well as an action plan for floods.

3.2.3.1 Survey:

Identify problem

The infestation of water hyacinth had not been controlled and there was no plan in place to reach a long lasting solution to the problem of the threat to biodiversity, loss of water resources and infrastructure.

Identify source / cause

Nutrient enrichment is widely regarded as the main contributing factor to the proliferation of water hyacinth (Gossett and Norris, 1971, in: Hill and Coetzee 2008). Two sources were identified, namely, (1) the upper reaches of the Nseleni River, and (2) the Mposa River. Causes of high nutrient levels in the river system were identified as emanating from (1) the Nseleni Township sewerage treatment plant on the western bank of the Mposa River that was discharging waste directly into the Mposa River, and (2) agricultural and forestry practices using fertilizers in the vicinity of the Nseleni and Mposa rivers, where the possibility of runoff during the periods of high rainfall was substantial.

Mapping

A mapping exercise was undertaken by Ian Gordon and Roy Jones (KZN Wildlife), who produced a detailed map and distribution of water hyacinth within the river system. Management units were divided into manageable area's of infestation, using both natural features (confluence of two rivers) and man-made structures (roads or bridges) to determine the boundary of a specific MU. Water hyacinth infestations were recorded as being between 40% and 100% for the different management units (MU's). The total control area was identified as: from the weir on the Mposa River near Nseleni Township (top of MU 3), and from the upper reaches of the Nseleni River (top of MU 1), down to Lake Nsezi (bottom of MU 7) as indicated in Figure 3.1 and Table 3.1.

3.2.3.2 Planning

The importance of working with a management plan was recognized, due to the fact that it aids in the effective use of resources, namely:

Reducing unnecessary expenditure

Allowing for self-reliance

Continuity

Training of labour

Identification of new problems

Increase in competence

Maintenance of cleared management units, and

Continual monitoring and reporting.

Identify and Consult Interested & Affected parties

During the planning phase a list of important role players that were required to have input (refer 3.3.2 above) were identified. These persons were requested to attend meetings and provide both input and feedback. It was further noted that these key role players were to further consult with interested and affected parties within their sphere of work. Meetings were to be held every three months at the Enseleni Nature Reserve. Of importance, was the fact that these meetings were not only for the key role players, but individuals could be invited to attend ie. industry, municipalities, the press and other organs of State.

Appoint Lead Agency

It was agreed that KZN Wildlife, due to them being involved since the infestation was first recorded would lead in control efforts on the ground, with assistance from the other parties to be identified. They were also in a position to be on the river more frequently than others.

Confirm level of acceptability of infestation

It was confirmed that a realistic acceptable level of total infestation, to start with, would be 20%. The aim was to drop this level to a total infestation level of 5%, as control progressed, in the years to come. Although certain MUs were presently 100% infested at the time, it was believed that this was an achievable goal and would result in the recovery of the aquatic ecosystem.

Consider control options available

The committee confirmed that there were different control options available, namely:

Biological

It has often been suggested that biological control is the only option that offers economical and sustainable control of the weed (Harley *et al*. 1996 in: Hill and Coetzee, 2008).

Weevils - (*Neochetina eichhorniae*) (Warner)

This adult weevil is approximately 5mm in length and are cryptic, dull-brown colour, becoming mottled when wet. They are nocturnal and feed on the leaves of *E.crassipes*. They remove the epidermal layers of the laminae and petioles, making characteristic rectangular scars. Females chew through the epidermis and excavate cavities into which single eggs are laid. Females lay up to five eggs per day and live for more than 50 days. There are three larval instars which tunnel internally through the petioles and into the crown of the plant, causing them to rot, die and submerge. There are usually three generations per year (Cilliers, 1991).

(*Neochetina bruchi*) (Hustache)

This weevil has a similar biology to its close relative *N.eichhorniae*. The damage caused by this weevil is indistinguishable from that of *N.eichhorniae* and the only notable difference between the two species is the shorter generation time (approximately 96 days for *N.bruchi* and approximately 120 days for *N.eichhorniae*) (Cilliers, 1991).

Mite - (*Orthogalumna terebrantis*) (Wallwork)

Adult mites are less than 1mm and tear dropped shaped. Adults aggregate in the feeding scares of the two weevil species. The females oviposit on the lower surface of young water hyacinth leaves. More than one egg is deposited per cavity. The eggs hatch in 7 to 8 days and the nymphs tunnel extensively in the laminae, completing their development in approximately 15 days. There are several generations per year (Cilliers, 1991).

Moth - (*Niphograpta albiguttalis*) (Warren)

Adults are a yellowish, tan colour with brown markings, whereas the females are much darker. A female can lay up to 300 eggs which are deposited singly in exposed aerenchyma cells of injured water hyacinth leaves. The larvae feed below the epidermis and tunnel into the petiole, creating ‘windows’ of transparent epidermal cells. The larvae pass through five instars and complete their development in approximately 3 weeks. They pupate in a white silken cocoon within the petiole and adults emerge approximately 7 days later. The larval feeding damage causes the petioles to collapse, which also destroys buds and arrests the growth of the plants (Cilliers, 1991).

Mirid - (*Eccritotarsus catarinensis*) (Carvalho)

This sap sucking mirid was introduced into quarantine in South Africa in 1992. Both the adults and nymphs feed on leaf tissue of water hyacinth, causing yellowing and browning, chlorosis of the lamina due to the extraction of chlorophyll. The adults are slender and black and highly mobile and live for approximately 50 days. The females insert their eggs into leaves of water hyacinth. There are four Nymphal instars, which are white with red eyes and feed gregariously. The duration of development of the immature stages is approximately 23 days (Hill, 1999).

Pathogens - (*Acremonium zonatum*) (Sawada & Gams)

This fungus was found naturally occurring on the Nseleni River in 1996 for the first time in South Africa (Den Breeÿen, 1999). This fungus causes distinct zonate necrotic lesions with dark and light bands. Reportedly to be more prevalent where the mite *O. terebrantis* occurs but the association between these two agents has not been studied.

(*Alternaria eichhornia*) (Nag-Raj & Ponnappa)

This fungus causes red-brown leaf spots and blotches on older leaves. Lesions are variable in size. It mainly affects the older leaves. This fungus is indigenous to South Africa, but the local hosts are not known.

(*Cercospora piaropi*) (Tharp) (=*C.rodmanii* – Conway)

This fungus causes small dark-brown spots on leaves which may coalesce and lead to entire leaf necrosis. This agent is indigenous to South America, and was first recorded in South Africa in 1987 on an infestation of *E.crassipes* in the Eastern Transvaal (Cilliers, 1991).

Chemical

In South Africa, only herbicides that contain the active ingredient glyphosate are registered for use in aquatic ecosystems (Vermeulen *et al*. 1998). The use of Roundup 360 was identified as being the most suitable herbicide to be used on water hyacinth. However, the Mhlathuze Water Board advised that they were opposed to and concerned about any possible large-scale chemical spraying of water hyacinth and the effect that the decaying organic material would have on the odour and taste of the water. In addition, they also felt that water hyacinth partly purifies the water, because of the nutrients it takes up and therefore assists them in "cleaning" the water. Large-scale aerial spraying could also have detrimental environmental effects on lake and riparian vegetation such as *Papyrus* spp. and *Barringtonia racemosa,* as well as other indigenous flora. This would be undesirable and ecologically unacceptable. In addition, any uncoordinated large-scale chemical spraying at the wrong time would nullify the effect of the biological control agents, as all sessile stages are killed when plants are sprayed when there is not a peak of adult insects.

Mechanical / Manual

No manual removal was considered due to the threat from crocodiles, however this method is used elsewhere in South Africa, but is considered to be labour intensive and only suitable for small infestations (Hill and Coetzee*,* 2008). However, recently some 75km of the Guadiana River in Spain was controlled mechanically, but at a cost of around € 18 million (Têllez *et al.* 2008).

The only mechanical manipulation of this system was in the form of demarcating management units with the use of a steel cable, with a weak link, that was attached to a point on either bank. Plastic buoys were attached to the cable to allow it to float just beneath the water surface. The physical removal of the weed by the local community was not encouraged due to the threat of attack by crocodiles.

Community involvement

Community involvement has no doubt been the secret of the success of the integrated control programme. Although the control of water hyacinth was initiated by staff from the Enseleni Nature Reserve (EKZNW), it soon became apparent that additional assistance was required from the surrounding community, as well as the ‘end users’ of water, i.e. industry and urban communities. The surrounding communities became involved in the project because they depend on the water resource directly for their livelihood (fishing and agriculture), or as an extractable resource (for mining, industrial and urban uses). Awareness campaigns were conducted at the same time, through lectures, radio talks and articles in the local press.

Each MU was assigned to an individual, organization or company. For example, MU 1 was assigned to a sugarcane farmer and KZNW, MU 2 to KZNW, MUs 3 to 5 to MONDI Forestry and Kwambo Conservancy, MUs 6 and 7 to KZNW and MU 8 to the local water authority—the Mhlathuze Water Board (to merely inspect and report on the status of biological control agents).

Evaluate and Adjust

It was recognized that the integrated control plan was a working document and that it would change over time. At each committee meeting, the work that had been carried out over the previous three months was evaluated and the control plan was adjusted accordingly.

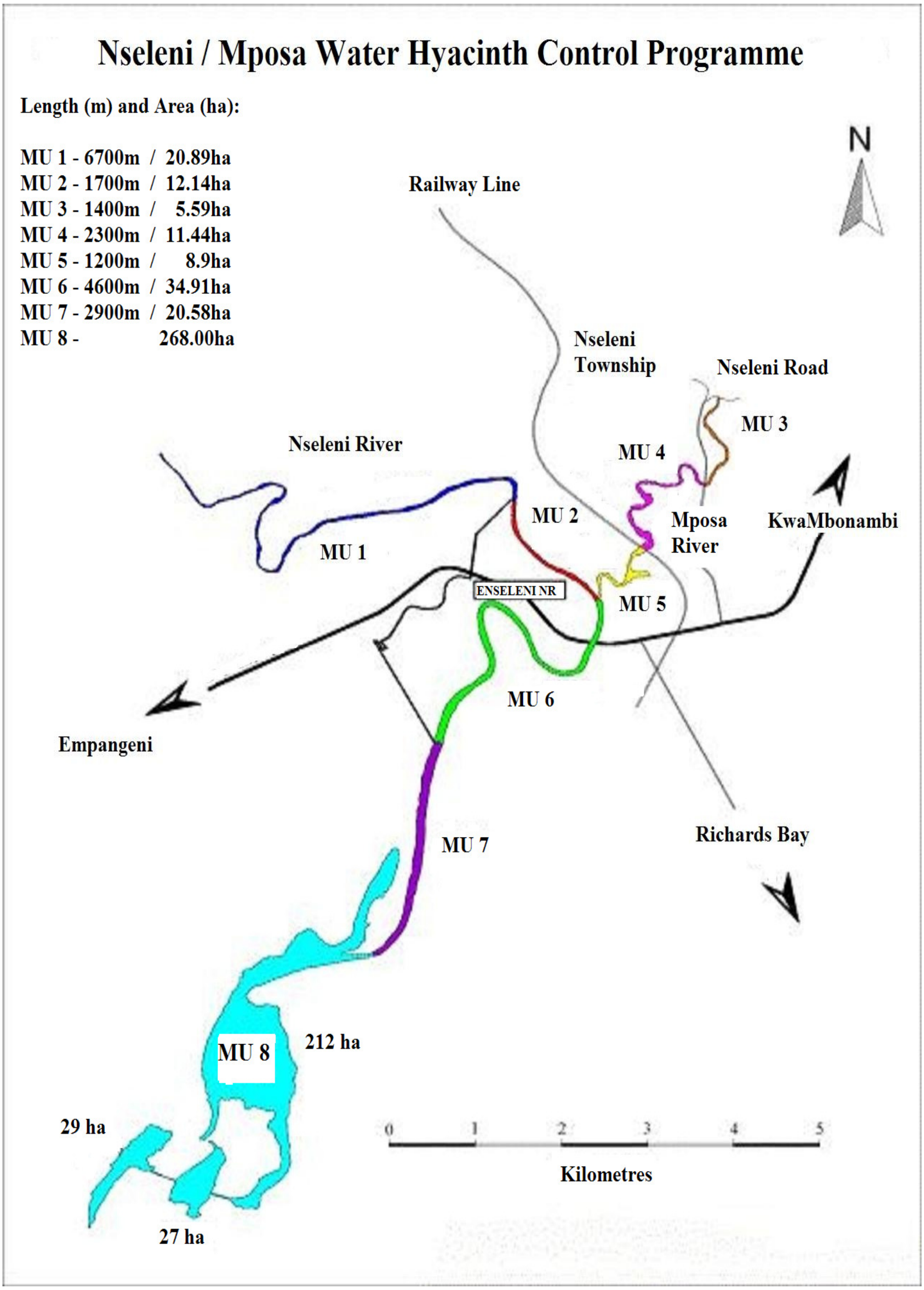

Fig. 3.1 Updated map of control area indicating: areas and distances of the different management units (MU's).

Identify course of action.
A map of the system (affected areas: Nseleni River – 17.1 km, Mposa River – 4.9 km and the Nsezi lake – 268 ha) was drawn up and used to designate eight management units (MUs) of controllable size (Fig. 3.1). Further to this, each MU was assigned a level of control, i.e. total control or containment, as well as the appropriate method of control, i.e. chemical, biological, and mechanical or a combination of control methods (Table 3.1).

Table 3.1 Results of survey using a 1994 aerial photo (1:5000) and ground truthing by boat and both initial and post control options.

Management Unit	Hectares	Length (km)	Infestation %	Initial Control Option	Post Control Option
1	20.89	6.7	40	Total	Biological/Chemical
2	12.14	1.7	40	Total	Biological/Chemical
3	5.59	1.4	100	Total	*Chemical/Biological
4	11.44	2.3	100	Biological	*Chemical/Biological
5	8.9	1.2	100	Biological	*Chemical/Biological
6	34.91	4.6	60	Biological	Biological/Chemical
7	20.58	2.9	60	Biological	Biological/Chemical
8 (Lake Nsezi)	268	-	80	Biological	Biological

* MU 3 to 5 are directly influenced by the high nutrient discharge from the Nseleni sewerage works and it is therefore believed that chemical control will remain the main control method.

3.2.3.3 Control

Early control efforts
The first reaction to the infestation of water hyacinth on the Nseleni River was to use chemicals to control the growing infestation. At the time, a "quick-fix" solution was desired due to the threat of damage to the N2 Highway road and important extraction points. This "belief" was held for some time, as the problem was perceived to have been resolved. It must however be said that the majority of persons involved in resolving the

water hyacinth infestation, believed that the best solution had been used (the use of a helicopter to mass spray the water hyacinth infestation). An amount in excess of R30 000- was spent on the purchase of chemicals, flying time for a helicopter and boats to spray the water hyacinth. The infestation of water hyacinth returned soon thereafter.

At the same time as chemicals were being sprayed on the water hyacinth infestation, employees from the then KZN Wildlife, stationed at the Enseleni Nature Reserve, erected a cable across the river at the confluence of the Nseleni and Mposa rivers, to prevent any mats of water hyacinth being blown upstream on the Nseleni River. The steel cable was anchored on each river bank to a tree and was held afloat by 2 litre cool drink bottles or empty chemical containers placed along its length. Unfortunately, during the times of heavy rainfall or floods, the anchor tree was pulled out of the river bank or the cable snapped, resulting in the river being polluted with plastic containers. The intention was to allow mats of water hyacinth to accumulate at the cable, which in turn made chemical treatment easier and more cost effective.

During 1984 and 1987, northern KwaZulu- Natal experienced two severe floods which alleviated the impact of water hyacinth infestation levels to such an extent that it was believed that the problem had been solved, as most of the water hyacinth was washed out of the Mposa and Nseleni rivers into Lake Nsezi and then into the Mhlathuze estuary and out to sea. The infestation of water hyacinth soon returned, following these floods.

3.2.3.4 Record and report

All work that was carried out on the control of the water hyacinth infestation was recorded by the Conservation Manager at the Enseleni Nature Reserve and logged. These data were used to compile a report for the committee. These data are extremely important over time, as a complete analysis can be completed upon request.

3.3 Implementation of integrated control

In March 1995 it was stated that the objective for MUs 1 to 4 would be total control using all methods available, and that containment of the infestation using biological control agents in MUs 5 to 8 would take place (table 3.1). Further to this, various sectors from the community were assigned MUs to control. Instead of using labour from the local rural community to remove water hyacinth manually, school children and their elders were successfully prompted to replant and stabilize the banks of the river with suitable indigenous vegetation where they had previously chopped down trees to practice subsistence farming. This was done because of the threat from crocodiles in the river, which killed several children every year while swimming or washing clothes. These deaths were therefore not related to water hyacinth control efforts.

In an attempt to reduce the spread of water hyacinth daughter plants and to make the chemical control cost effective, permanent cable booms (28mm diameter steel) were placed across the river at the confluence of the Mposa and Nseleni rivers (MU5), at the southern end of MU2 and at the northern end of MU6. Cables were also installed across the river where MUs 6 and 7 met and where MUs 7 and 8 met. The cables were placed in such a manner that they hung beneath the surface of the water, at approximately 15 to 20cm depth, thereby catching the root system of the water hyacinth. Plastic buoys (donated by the Richards Bay Coal Terminal) were used as flotation on the cables. Note that each permanent cable had a 'weak link' in it. Previous experience showed that during floods, not only was there a vast volume of water, but that the cable anchors (trees) were unable to hold the weight of the water hyacinth that built up on the cables. In addition to the permanent cables across the river, temporary cables were placed across MUs 1, 2 and 6 to allow the water hyacinth to back-up against them, which assisted chemical control.

Further assistance to the control programme occurred when the Nseleni sewerage works on the Mposa River was upgraded, and the effluent quality improved dramatically. Before upgrading, the ammonia (NH3) level was 14.2 ppm and the chemical oxygen demand (COD) 130 ppm. After commissioning, the ammonia level dropped to 1.2 ppm and the COD to 53 ppm, a vast improvement. These data were received from Mhlathuze Water Board, who take out regular readings, at three different sites. However, it was further recorded that nutrients were entering the system from adjacent sugarcane farms and forestry areas.

During the course of 1995, a total of approximately 2400 litres of glyphosate had been sprayed in MUs 1, 2, 3, 5 and 6 and seven river patrols were carried out to monitor water hyacinth infestations, inspect the effect that spraying and biological control had on water hyacinth and to carry out routine maintenance of the cables (total cost US$1617). As a result of the success achieved by the end of 1995, the control committee agreed to adjust the management plan objectives and to elevate MU6 to total control and to retain MUs 7 and 8 as containment MUs (biological control only). Because the local water authority needed to remove water hyacinth from its inlet screens, it agreed to remove biological control agents from the water hyacinth and to return them to Lake Nsezi, thereby ensuring that they were maintained in the system.

In December 1985, Cilliers (1991) released the first batch of 1400 *N.eichhorniae* into MU 5 on the Mposa River. (Table 3.2). Cilliers (1991) recorded beetle activity, estimated by adult feeding scars on *E.crassipes* leaves, to be common by December 1986, one year after release. It was further recorded that by November 1988 there was an average of 25 (range 0-101) scars per mature leaf.

In March 1996, the first release (50 adults and 100 nymphs) was made of a new biological control agent, the mirid *Eccritotarsus catarinensis*, at the entrance to Lake Nsezi (MU8) marking the first release of this agent in South Africa and indeed anywhere in the world outside of its native range. During June 1996, a further 500 adult *E.catarinensis* were released. It was reported at the June 1996 meeting that no chemical spraying had been done in MUs 1, 2 and 6, due to the decreased infestation level of water hyacinth, and that these units had merely been monitored. The status of biological control agents throughout the system was positive, with one or more agents being recorded in the MUs where water hyacinth infestations occurred. In addition, the pathogen *Cercospora piaropi* was found on some plants, and the fungus *Acremonium zonatum* was recorded for the first time (Table 3.2).

During October 1996, another weevil species, *Neochetina bruchi*, was obtained from Plant Protection Research Institute (Pretoria), as well as additional *E. catarinensis* (10 infested plants), and these were released into the system. In addition, the management plan objectives were again adjusted
to reflect the progress being made. The management plan now allowed for total control in MUs 1–7, with only MU8 designated for containment (biological control only). It was also agreed to drop the total allowable coverage from 20% to 10%.

During 1997, glyphosate herbicide continued to be applied to water hyacinth in MU 5 (100% infestation) and MU 7 (infestation increased to 60%), with varying amounts of success. It is important to realize that islands of water hyacinth are left after the application of chemicals. This is to allow the biological control agents to continue to move within the system.

Entry into the Mposa River (MU 5) from the south became extremely problematic, because not only was there a 100% infestation of water hyacinth, but also indigenous aquatic vegetation had severely encroached on the area. Of note was the invasion of *Echinochloa pyramidalis,* an indigenous perennial plant, which enjoys moist terrestrial or aquatic conditions and uses water hyacinth as a substrate on which to form dense stands. Other possible contributing factors towards the establishment of *E. pyramidalis*, are nutrient enrichment of water and silt-laden watercourses.

During 1997, a distance of approximately 200 m was gained into MU 5 (Mposa River), from the southern side. In addition, MU 6 had to receive attention, because the total allowable percentage coverage exceeded 10%. Some 296 litres of glyphosate was used in MUs 5 and 6, with the required result being achieved. The status of biological control agents in MUs 3, 4, 5, 7 and 8 remained positive. A further 300 adult *E. catarinensis* were released on Lake Nsezi during the latter part of 1997.

By September of 1998, a further 238 litres of glyphosate had been applied to MUs 5, 6 and 7. Some 28 hours and 78 labour units, over a period of 25 days, were expended to inspect, carry out cable maintenance and chemically spray the water hyacinth infestations. The results of the water hyacinth infestation inspections indicated a high percentage of biological control agent activity throughout the system. During August 1998 a setback occurred when an area of approximately two hectares of water hyacinth was blown from MU7 into MU6, during a period of exceptionally strong southeasterly winds. Fortunately, the cable did not break and a high percentage of water hyacinth was retained in MU7. With the aid of temporary cables the approximately two hectares of water hyacinth that had blown into MU6 and which had subsequently broken up into smaller pockets, was cordoned off and chemically sprayed.

A major injection into the control programme in 1998 was the assistance received from the MONDI Forests company, which achieved excellent chemical control results in MU4 (Mposa River). Between May and October 1998, MONDI forestry spent US$467 per month on chemicals and labour, to open up stretches of the Mposa River from both water hyacinth and invasive indigenous aquatic plants. In addition, Kwambo Conservancy approached various industries in Richards Bay in an effort to get them to become involved in the project. The result of this drive was that US$6334 was received (to purchase new spraying equipment and an outboard engine) and MONDI Kraft offered to construct a barge-like boat and a trailer (approximately US$8334) which would be used in spraying. Further to this, Kwambo Conservancy pledged 200 litres of Roundup (glyphosate) and Richards Bay Minerals pledged US$ 1000 towards the project.

A flood during February 1999 opened up about 1 km of MU5, and MUs 1, 2, 6 and 7 became 98% free of water hyacinth. The infestation in Lake Nsezi had dropped dramatically to approximately 35%. During May 1999, for the first time in many years, members of the control committee were able to proceed from a launch site in MU 2 and travel all the way to the Mhlathuze Water Board extraction point on the southeast bank of Lake Nsezi (MU 8). Biological control agents persisted on the remaining water hyacinth. As a result of the high success rate achieved with the integrated control on the Nseleni River and a small section of the Mposa River (MU5), it was been decided to expand this project to include the catchment of the Mposa River, namely the Mbabe and Nyokaneni rivers. A management plan was drawn up to focus on 14 management units on these rivers. These additional management units are to be controlled by forestry and private landowners adjacent to a specified management unit (Fig. 3.2).

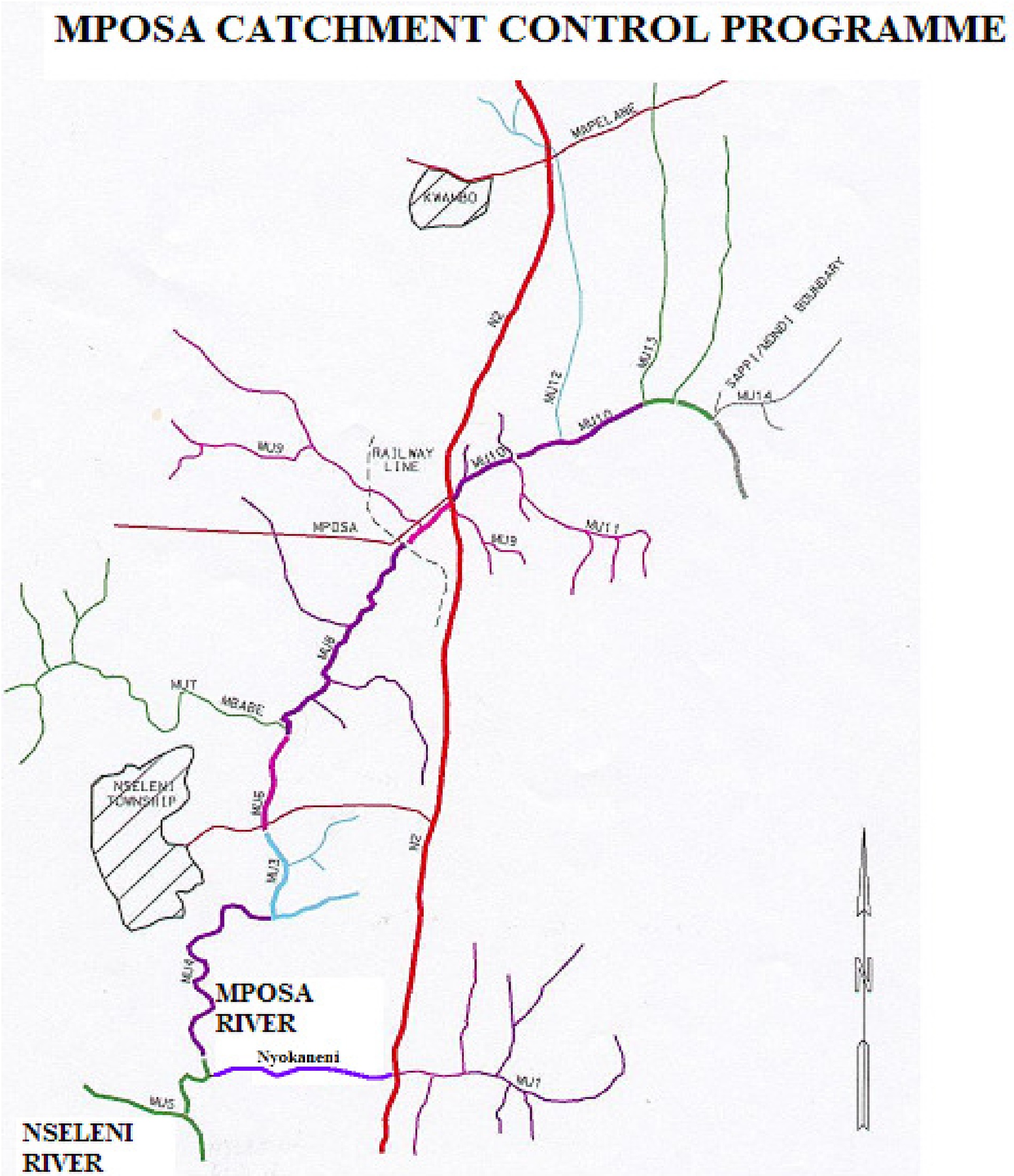

Fig. 3.2 Expansion of 1995 Integrated Control programme on the Nseleni River to include the Mposa River catchment, which includes the Mbabe and Nyokaneni rivers as far north as the town of Kwambonambi.

In a period of five years, the water hyacinth infestation had been brought adequately under control to the extent that only infrequent chemical application now has to be applied and the biological control agents are now in a position to assist fully in controlling water hyacinth (Figures 3.3 and 3.4).

Fig. 3.3 Nseleni River – 1994.

Fig. 3.4 Present situation on Nseleni River - 2008.

3.4 Financial Implications

One of the key issues that separates aquatic weed from terrestrial weed programmes is that the impact of water weeds on riverine communities is easy to quantify (Hill and Julien, 2004). It was recognized that none of the committee portfolio's had a dedicated budget for the control of water hyacinth on the Nseleni River system and that Government Departments were unlikely to come to the assistance of the committee with any dedicated funding. KZN Wildlife, via the Conservation Manager at the Enseleni Nature Reserve, started a dedicated Special Project budget within his station's budget that would be carried forward from year to year and be administered by the Conservation Manager. All financial assistance received would be paid into the Special Project budget. Any expenditure followed a required format, namely:

Management Plan to identify expenditure needs;

Approval for expenditure from the Control Committee;

Detailed reporting of expenditure to donor / sponsor was required, and;

Expenditure details had to be included in Committee minutes.

Of importance, is the fact that staff turnover due to organizational arrangements, showed an immediate negative effect on control effort and therefore financial input increased immediately thereafter. An integral part of controlling exotic weeds and achieving the required results is the fact that stable management is required. In addition, another important factor is the need to have a continual interest in controlling the weed which will be assisted by achieving visible positive results. During the integrated control programme, there were two years, 1996 and 2001, when the conservation manager at the Enseleni Nature Reserve was transferred from the reserve before being transferred back after a year. The impact on control effort can be clearly seen in Figures 3.5 and 3.6 whereby chemical use and man hours decreased due to little control being carried out by the new incumbent, but later increased when control effort was resumed.

The chemical useage on the Nseleni and Mposa rivers averages approximately 26 litres / month over the period 2000 to 2007 (Fig. 3.5). The use of herbicide has gradually declined over time. Chemical control rose in the 2002 to 2003 period, due to lack of control effort in the 2001 to 2002 period, due to staff changes at the Enseleni Nature Reserve.

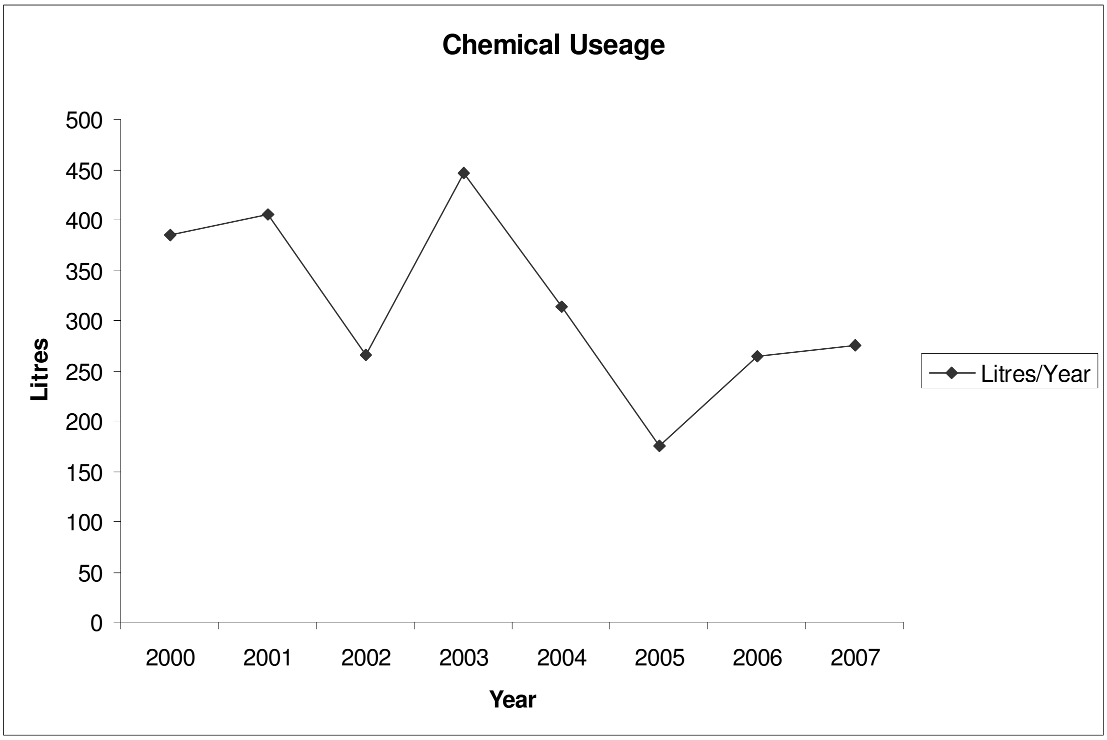

Fig. 3.5 The number of litres of chemical (glyphosate) used on the Nseleni and Mposa rivers in the period 2000 to 2007.

Due to the success of integrated control, the amount of man hours spent on controlling the infestation, by staff of the Enseleni Nature Reserve, has dropped dramatically (Fig. 3.6) and therefore the staff are now able to use their time more productively, elsewhere on biodiversity issues, as is the case with Kwambo Conservancy members who gave up their free time to assist. The same trend was observed with year on year costs (Fig. 3.7) which also declined over time.

Fig. 3.6 Decrease in man hours spent on controlling water hyacinth for the period 2000 to 2007.

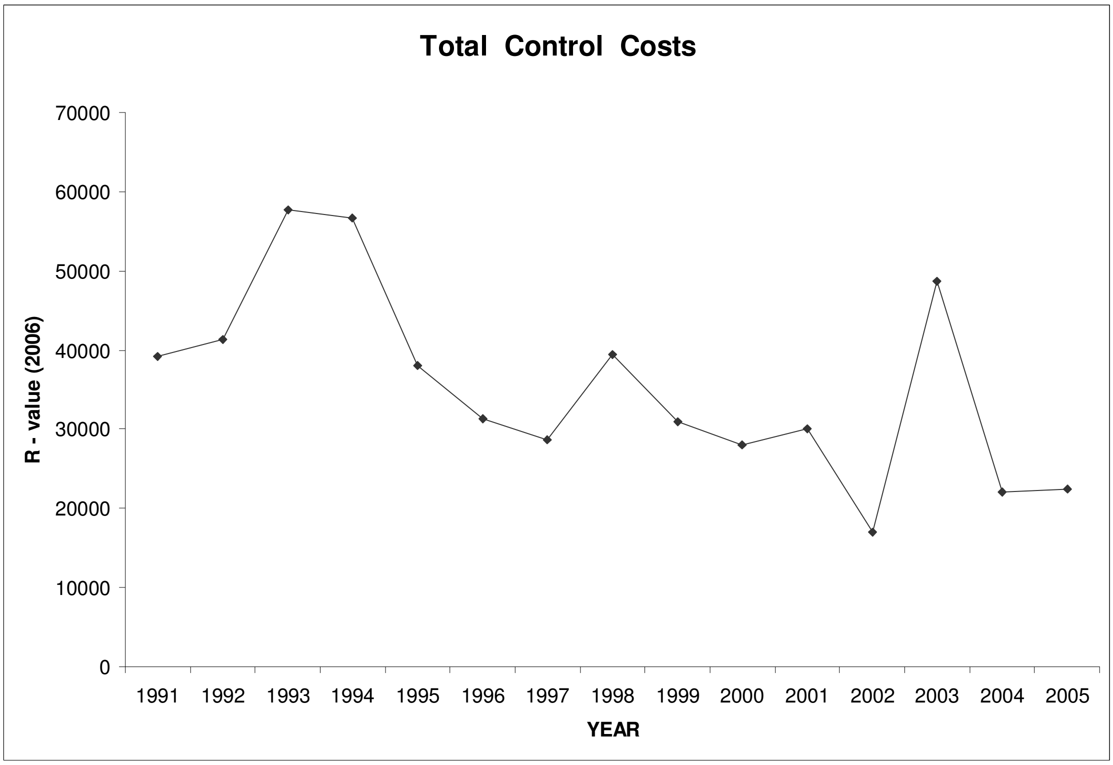

Fig. 3.7 Year to year actual costs (chemical, fuel, salaries and maintenance) of controlling water hyacinth over a 15 year period.

Honorary Officers from the Enseleni Nature Reserve hold an annual fishing competition on the Nseleni River to generate funds (Fig. 3.8), which are then spent on biodiversity issues within the nature reserve. The sharp increase in total income and profit for the year 2008, is due to the competition being held over two days, compared to only one day over the previous years day, as per request from the anglers. Due to river accessibility in 2008, a total of 177 anglers (boat and shore) and 52 boats were entered. A record fish of 20.3 kilograms was recorded.

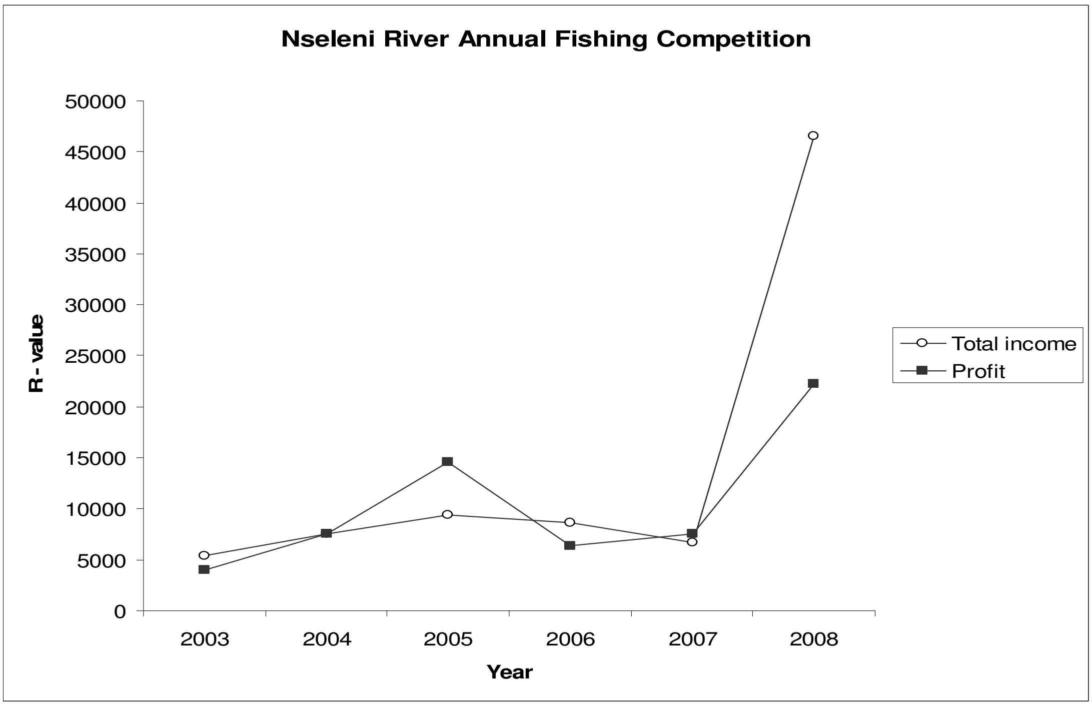

Fig. 3.8 Financial income earned from holding fishing competitions on the Nseleni River.

3.5 Biological control.

The importance of using biological control throughout the entire process cannot be stressed enough. Biological control played a major role in controlling water hyacinth infestations in MUs that were set aside for later chemical control, in as much as the agents were in a position to dissipate throughout the infested areas.

At the same time that chemical applications were being applied, biological control agents were being released, in different MUs, to assist in the integrated control approach. This was considered a major boost to the integrated control efforts, by ARC-PPRI (Table 3.2).

Table 3.2 Record of biological control agents released by ARC-PPRI (Pretoria).

Date:	Agent:	Number Released:	Management Unit:
12/1985	*Neochetina eichhorniae*	1400	MU 5
01/1994	*Niphograpta albiguttalis*	150	MU 7 & 8
	Orthogalumna terrabrantis	800	MU 7 & 8
03/1996	*Eccritotarsus catarinensis*	550	MU 7 & 8
06/1996	*E.catarinensis*	500	MU 7 & 8
	Neochetina bruchii	800	MU 5
10/1996	*E.catarinensis*	10 infested plants	MU 7 & 8
1997	*E.catarinensis*	300	MU 8
09/1995	*Cercospora rodmanii (piaropi)* **Acremonium zonatum* **Alternaria eichhornia*	5x20Ltr. Plastic bags with infested plants.	MU 4

* Identified on *E.crassipes* without being introduced intentionally.

All of the above biological control agents have established with varying degrees of success on the Nseleni and Mposa rivers and have played a major role bringing the water hyacinth infestation under control. In both of the biological control designated areas (Lake Nsezi and this research study site, see below) the level of infestation has reduced dramatically over the years. Whereas both of these sites had high levels (80% to 100%) of infestation in the late 1980's and early 1990's, the infestation coverage today is estimated at less than 10%.

3.6 Chemical control

During spraying operations, entire mats of water hyacinth were not chemically treated, for two reasons, namely (1) to allow biological control agents to migrate, and (2) to prevent a build up of detritus that would affect water quality. Spraying took place as early in the morning as possible to prevent "drift" of herbicide by wind.

Spraying equipment consisted of a high pressure pump that was loaded onto a boat, together with a 100 litre container of glyphosate at 3% and water. A high pressure pump was originally required as long distances had to be sprayed to reach far enough into large mats of water hyacinth. Today, this is no longer the requirement and the Conservation Manager at the Enseleni Nature Reserve has developed a new system that reduces the amount of wastage and can be done by two people from a boat thereby reducing staff costs (Fig. 3.6). From a safety point of view it is also much safer, as the spray equipment is run from a battery and therefore no additional fuel for a high pressure pump has to be taken.

Finally, chemical application has reduced from weekly treatment (mid-1990's) to approximately one day every three / four months presently on the Nseleni River.

3.6.1 Cost analysis of controlling water hyacinth

The invasion of natural ecosystems by alien plants is a serious environmental problem that threatens the sustainable use of benefits derived from such ecosystems (Van Wilgen *et al*. 2001). Furthermore, Van Wilgen *et al*. (2001) suggest that very little work has been done on the economic aspects and consequences of invasive alien species.

Van Wyk and Van Wilgen (2002) carried out a cost analysis on three different water hyacinth control options, namely biological control, herbicide control and integrated control to determine the effectiveness of each of the options. The case studies covered the Hartebeespoort Dam (herbicide control) in Gauteng Province, New Year's Dam (biological control) in the Easter Cape Province and the Nseleni river system (integrated control) in KwaZulu-Natal Province.

Van Wyk and Van Wilgen (2002) compared the different management approaches and found that the integrated approach to controlling water hyacinth in South Africa was the most effective approach in monetary investment terms per hectare cleared. They also calculated that biological control was only slightly less cost-effective and that herbicide control was approximately five times less cost-effective than either integrated or biological control.

In using ZAR rands (1995), they concluded that herbicide control equated to R1 481/hectare, that biological control equated to R309/hectare and integrated control equated to R277/hectare, using data obtained for the different study areas. Van Wyk and Van Wilgen (2002) used the production price index (PPI) to determine the ZAR 1995 costs. With an exchange rate of ZAR6 / US$1, this would equate to; chemical control at US$ 247/hectare, biological control at US$52/hectare and integrated control at US$46/hectare.

Further analysis of the data from the Nseleni and Mposa rivers and Lake Nsezi showed that at the height of the water hyacinth infestation, in the 1990's, when sections of the Nseleni and Mposa rivers were 100% infested, it cost approximately R14,735 to control an area of 20,89 hectares or R737/ hectare of that management unit (MU1 – Fig. 3.1). In 2008 it cost R13, 903.00 to control 115 hectares (excluding Lake Nsezi which is a biological control area) to the maintenance level of approximately 10% total coverage allowable. This equates to approximately R120/hectare or US$12/hectare (ZAR10 to US$1) to maintain infestations at present, all inclusive of fuel, chemical and staff costs.

This is extremely favourable when comparing costs elsewhere in the world to control water hyacinth. Centre *et al*. (2002) in: Van Driesch *et al*. states that controlling water hyacinth on an annual basis in California was costing US$500 000 compared to US$3 million in Florida and US$2 million in Louisiana.

3.7 Discussion

One of the aims of this study was to develop and implement an integrated programme for water hyacinth control on the Nseleni River and Lake Nsezi (Chapter 1), which has been achieved.

One of the largest challenges that the committee faced was the sewerage works situated on the western bank of the Mposa River. The water hyacinth in the Mposa River thrived on the amount of nutrients that were made available from this source, as well as downstream. Success was achieved, when a DWAF official became involved, whereby pressure was put onto the local municipality to upgrade the sewerage works (1994) and thereby reduce the amount of nutrients entering the Mposa River. Nutrient control from adjacent timber plantations, sugar cane farms and the Nseleni rural population, however remains a point of concern.

Ad hoc control of water hyacinth has proven to be a waste of human resources and financially unsound. There are two general approaches when it comes to controlling invasive alien weeds, namely (1) the "quick fix" solution, and (2) the long-term cost effective solution. The "quick fix" solution generally comes about due to the lack of original foresight when the plant is first observed i.e. no action is taken. This could be caused by lack of knowledge as to the plants capabilities, lack of will to get involved, lack of responsibility or lack of capacity. These actions, or the lack of any action, lead to the plant becoming problematic.

A "quick fix" solution is then sought to prevent loss or damage to some form of infrastructure. Generally this involves the use of chemicals, which are extremely expensive. Once the "problem" has been resolved, the problem is perceived to have gone away and no or little thought is given to follow up actions and ultimately the problem returns. The integrated approach presented here, has proven extremely successful, even though it has taken many years to achieve. This has come about due to sound planning, involvement of all stake holders and a will to arrive at realistic goals / objectives that have been set. Of importance is the fact that those involved are fully aware that the water hyacinth will not be eradicated from these systems and that it will require to be controlled at all times. It has been noticed that one of the largest hurdles to overcome, is the continuity of persons involved in the project.

Biodiversity in the area has benefited from the integrated control approach with the return of rare and endangered species of animals, that have been absent for many years. This has benefited the tourism trade as well as many previously disadvantaged community individuals who have been trained as bird guides.

Hill and Julien (2004) maintain that the key to success of such control programmes, but particularly in poorer rural countries, are appropriate transfer of technology and flexibility of the programmes. Furthermore, political support is vital to the success of the water hyacinth control programmes, engendered through the publicizing of the success, where impacts can be observed at the landscape level and real impacts accrue to affected communities.

The question is frequently asked: "How long does it take to control water hyacinth?" Cilliers and den Breeÿen (1999) state that it is not easy to give a time limit as to how long it will take to control the weed. It will, for example, depend on the extent of the problem, climate, budget, commitment of not only the researchers but also by the policy makers and decision makers and the community and public as a whole.

In certain situations where water hyacinth is problematic in cooler areas and where nutrient enrichment of the aquatic ecosystem has occurred, an integrated management approach that includes the utilization of all available control methods, but especially nutrient control is required to achieve the acceptable level of control (Julien, 2001). Furthermore, the key elements to integrated control are: the appointment of one individual or organization to drive the control programme, the involvement of all interested and affected parties on the river system, the division of the river system into management units and the implementation of appropriate control methods for each of the management units (Jones and Cilliers, 1999; Jones, 2001).

Roy Bateman, who chaired the integrated management session 6 and Martin Hill who prepared the summary (Hill, 2001), at the second Global Working Group for Biological and Integrated Control of Water Hyacinth in Beijing, summarized the session as follows: "This Nseleni River programme was well planned from the start. It relies on biological control but uses herbicidal control and mechanical intervention (the use of cables across the river to prevent the movement of water hyacinth into previously cleared areas) in a coordinated manner. In addition, nutrient control through the upgrading of a wastewater treatment plant in the upper catchment has facilitated the control efforts. Furthermore, the public awareness campaign through the production of a video, the involvement of the local community around the system and the fact that the programme has been well documented has ensured that this is possibly the best example of integrated management of water hyacinth that we have".

The economic costs of controlling water hyacinth on the Nseleni river system were easy to quantify, as strict records have been maintained since 1991, a period of 18 years. Regrettably, the same cannot be stated for the ecological impact of water hyacinth, as very little scientific work has been carried out on this subject. The only records of the decline in biodiversity are internal records, held at the Enseleni Nature Reserve's office. However, the impact of water hyacinth on the ecology of the Nseleni river system will be addressed in Chapter 4.

CHAPTER 4

IMPACT OF WATER HYACINTH ON ASPECTS OF THE BIODIVERSITY OF THE NSELENI AND MPOSA RIVERS AND LAKE NSEZI

4.1 Introduction

The negative impacts of water hyacinth on freshwater systems are numerous and varied, largely due to its rapid growth that forms expansive colonies of tall interwoven floating plants (Penfound and Earle, 1948). As its doubling time can be as little as one week, it blankets large water bodies soon after it invades, creating impenetrable barriers and obstructing navigation (Zeiger, 1962; Gowanloch and Bajkov, 1948). Floating mats block drainage, causing flooding or preventing subsidence of floodwaters. Large rafts accumulate where water channels narrow, sometimes causing bridges to collapse. Water hyacinth hinders irrigation by impeding water flow, by clogging irrigation pumps, and by interfering with weirs (Penfound and Earle, 1948, Chapter 3). Multimillion-dollar flood control and water supply projects, which require decades to construct, can be rendered useless by water hyacinth infestations (Gowanloch and Bajkov, 1948).

Infestations can also block access to recreational areas and decrease waterfront property values, often impacting the economies of communities that depend upon fishing and water sports for revenue (see Chapter 3). Shifting water hyacinth mats sometimes prevent boats from reaching shore, trapping the occupants and exposing them to environmental hazards (Gowanloch and Bajkov, 1948; Harley, 1990).

Water hyacinth has a negative effect on the quality and quantity of potable water. For example, the water treatment plant for Lusaka in Zambia was forced to retain the water in the plant for further treatment due to a reduction in the water quality drawn from the Kafue River that was infested with water hyacinth (Hill pers.comm.). Water hyacinth increases water loss due to evapo-transpiration. Estimates of increased water loss vary from 2.67 times (Lallana *et al.,* 1987) to 3.2 times (Penfound and Earl, 1948) more from a mat of water hyacinth in comparison to open water. Lallana *et al.* (1987) calculated that water hyacinth caused an increase in water loss of about 70 000 L/ha/d from a dam in Argentina.

Water hyacinth impacts all aspects of water resource utilization including fisheries, transport, hydropower generation and the quantity and quality of potable water. Annual fish and wildlife losses associated with water hyacinth infestations in the six south-eastern states of the USA exceeded US$ 4 million per year in 1947 (Tabita and Woods, 1962), while it caused annual losses of US$ 65-75 million in Louisiana alone (Gowanloch and Bajkov, 1948). Holm *et al*. (1969) estimated that in 1956 water hyacinth caused losses of US$ 43 million in Florida, Mississippi, Alabama, and Louisiana. These studies attribute the losses to reduction in recreational fishing, river transport and flood water mitigation, but also include the cost of control options. The U.S. Army Corps of Engineers estimated that the cost of controlling water hyacinth accrued benefits of nearly US$ 14 million in 1965 (Gordon and Coulson, 1974). Between 1980 and 1991, Florida spent over US$ 43 million to suppress water hyacinth and water lettuce (Schmitz *et al.,* 1993). Currently, annual costs for water hyacinth management range from US$ 500,000 in California to US$ 3 million in Florida (Mullin *et al*. 2000). The largest infestations of water hyacinth in the USA occur in Louisiana where the Department of Fisheries treat about 25,000 acres of water hyacinth with herbicides per year, mostly at boat ramps, at an annual cost of US$ 2 million (Center *et al.* 2002). While the cost to control water hyacinth on the Nseleni and Mposa rivers was considerably less, it was still a significant amount for communities in the region (Chapter 3).

Water hyacinth threatens the production of electricity through hydropower generation throughout Africa. A few examples have been noted in the literature. The hydropower station at the Kafue Gorge Dam in Zambia is responsible for supplying 900Mw of power to the country (Hill pers.comm.). At the height of the water hyacinth problem on the dam, at least one of the 5 turbines was forced to be shut down for one day per week. This was due to the increased concentration of nitrous oxides in the water that caused a certain amount of corrosion on the turbines. The hydropower dams on the Shire River in Malawi and the Owen Falls Dam at Jinga in Uganda on the Nile River are also frequently forced to stop production due to water hyacinth clogging the intakes for the water cooling system. No estimates of costs of this are available, but it must amount to several million US$ per year.

Lake Victoria is the world's largest fresh water tropical lake and has been heavily impacted by water hyacinth. The weed was first recorded on the lake in around 1990 but by 1998 covered some 20,000ha of the lake (Albright *et al*. 2004). The lake basin supports approximately 25 million people and has an estimated worth of some US$ 4 billion annually, with fishing benefiting the livelihood of at least 500,000 people and having a potential sustainable fishery export value of US$ 288 million (Albright *et al*. 2004). Water hyacinth severely threatened the economic activities on the lake and the development of the region. Economic impacts in Uganda in 1995 were estimated by Mailu (2001) as:

- Maintaining a clear passage for ships to dock at Port Bell in Uganda cost US$ 3-5 million
- Clearing the intake screens at Owen Falls hydroelectric plant cost US$ 1 million
- Losses in fisheries were about US$ 0.2 million
- Losses in beaches, water supply for domestic, stock and agricultural purposes were US$ 0.35 million
- Sociological impacts such as lack of clean water, increase in vector-borne diseases, migration of communities, social conflict and biodiversity losses were not calculated.

The impacts of water hyacinth infestations are not only limited to economic impacts, but also social impacts through, for example, intensifying mosquito problems by hindering insecticide application, interfering with predators such as fish, increasing habitat for species that attach to plants, and impeding runoff and water circulation (Seabrook, 1962). Despite there being numerous references attributing an increase in malaria to water hyacinth infestations, in one of the quantified surveys, Mailu (2001) was unable to show a correlation between the explosion of water hyacinth on Lake Victoria and an increase in the disease. Water hyacinth provides the ideal habitat for the snail vectors (*Biomphalaria* spp. and *Bulinus* spp.) (Gopal, 1987) of the bilharzia schistosome and there is some evidence from Ghana that increases in infestations of water hyacinth is linked to an increase in the prevalence of this disease. Water hyacinth blocks light penetration to the water column and leads to a reduction in oxygenation of the water and a build-up of sulphur dioxides, causing the water to smell and taste bad. It also blocks access to water points and, as such, has been linked to an increase in cholera and typhoid (Navarro and Phiri, 2000). Furthermore, water hyacinth provides cover for poisonous snakes, crocodiles and hippos making the collection of water dangerous, sometimes fatal.

While the economic impacts of water hyacinth (above) and the costs associated with control (see chapter 3) are fairly easy to quantify, the impact of the weed on ecosystem functioning has received less attention. Dense mats reduce light to submerged plants, thus depleting oxygen in aquatic communities (Ultsch, 1973). The resultant lack of phytoplankton (McVea and Boyd, 1975) alters the composition of invertebrate communities (Hansen *et al.* 1971; O'Hara, 1967), ultimately affecting fisheries. Drifting mats scour vegetation, destroying native plants and wildlife habitat. Water hyacinth also competes with other plants, often displacing wildlife forage and habitat (Gowanloch, 1944). Higher sediment loading occurs under water hyacinth mats due to increased detritus production and siltation. In addition, herbicidal treatment or mechanical harvesting of water hyacinth often damages nearby desirable vegetation.

Drifting mats of water hyacinth smother submerged beds of aquatic vegetation which are important to waterfowl (Tabita and Woods, 1962) and declines in populations of the endangered Florida Everglades Kite, *Rostrhamus sociabilis*, have also been ascribed to water hyacinth mats removing emergent plant species that serve as hosts for their food source, apple snails (Tabita and Woods, 1962). Masifwa *et al.* (2001) showed that water hyacinth enhanced the abundance and diversity of macroinvertebrates at the water hyacinth interface with open water in comparison to indigenous aquatic macrophyte species on Lake Victoria and Toft *et al.* (2003) showed that water hyacinth roots offered excellent habitat for epibenthic and benthic invertebrates in California, USA. In contrast, Midgley *et al*. (2006) showed that species richness, diversity and abundance and the concentration of chlorophyll *a* were significantly negatively affected by a cover of water hyacinth at two impoundments in the Eastern Cape Province of South Africa.

Because the impacts of water hyacinth are varied and wide, this study aimed to quantify the impact of water hyacinth on several aspects of biodiversity on the Nseleni and Mposa Rivers and Lake Nsezi, focusing specifically on benthic invertebrates and riparian vertebrates.

4.2 Materials and Methods

4.2.1 Impact of water hyacinth on benthic biodiversity

This study was carried out on the Nseleni River, in the proximity of Lake Nsezi (28º43´54.67´´S and 31º58´47.77´´E), to the west of Richards Bay on the north coast of KwaZulu-Natal (see Chapter 2 for full site description) between September 2007 and November 2008. Five sites were chosen, approximately three metres from the edge, which had permanent mats of water hyacinth (extending approximately eight metres from the edge and were constant in size) and five control sites were chosen that had no water hyacinth coverage and had not had any water hyacinth coverage for at least three years. Water hyacinth was first recorded in the study site in the early 1990's.

Artificial substrates similar to those used by Midgley *et al.* (2006) were constructed using mesh onion bags (20cm x 50cm) and fastened using cable ties. Each bag was filled with 2.0kg of small pebbles. The bags were closed using a cable tie and attached to a 2m length of nylon string. The string was attached to two plastic toilet cistern floats and a 30cm wooden dropper. The reason for attaching two floats was an attempt to not lose the sample bag to curious crocodiles. A total of five sites (each site comprising of an open water site and an under water hyacinth mat site), were chosen randomly within the study area. The bags were dropped in a site, after having measured the depth from water surface to substrate at a maximum of 1.5m depth. Five sample bags were placed under water hyacinth mats and five bags were placed in proximity, but in open water, each marked with a wooden stake to prevent loss during periods of high rainfall. The sites were between 50 and 80m apart. The sample bags were left for a period of six weeks, to allow for complete colonization by invertebrates (Thirion, 2000), and then collected with use of a boat. This was repeated on ten occasions with the first set of bags being placed in the river on the 19th of September 2007 and the last on the 12th of November 2008.

On each sampling event, the artificial substrate bags were carefully removed and placed into large plastic bags. The plastic bags were placed below the water surface with the openings slightly above the water level until the artificial substrate bag reached the surface, at which point the plastic bag was dropped below the water level to ensure no loss of specimens. Each artificial substrate bag was placed into a separate plastic bag and labeled with site number and either open water or under water hyacinth mat. Each artificial substrate bag was then replaced.

All bags were then returned to a working area and individually opened. The contents (pebbles) were emptied into a sorting tray, including the sample bag, and were washed with clean water to separate any invertebrates from the bag and pebbles. Each pebble was individually cleaned with fresh water and a small paint brush. Both the sample bag and individual pebbles were examined before being removed from the sorting tray. The contents of the plastic bag were mixed with fresh water and were also emptied into the sorting tray.

The contents of the sorting tray (water and substrate) were then poured through a sheet of mosquito gauze (1mm mesh size) and invertebrates and invertebrate body parts were removed with forceps and placed into a glass vial, containing 75% alcohol. Each vial was emptied into a dish and examined for invertebrates with a light sourced magnifying lamp. All macroscopic invertebrates were removed and placed into vials containing 75% alcohol. Specimens were identified to family level using a series of identification keys (Day and De Moor, 2002a, b; Day *et al.* 2003; Gerber and Gabriel 2002; De Moor *et al.* 2003a, b). It was decided to identify the specimens to family level as keys to this level are readily available.

4.2.2 Impact of water hyacinth on other aspects of biodiversity

As the Nseleni and Mposa Rivers flow through a protected area, excellent records have been kept of the fauna associated with the river. To quantify the impact of water hyacinth on riparian fauna, other than the benthic invertebrates (see above), records of the fish species caught and amphibian, reptile and avian fauna associated with the rivers were made from records housed on the reserve between 1980 and 2008. This allowed a comparison between periods when the river was 100% covered to the present where the river is less than 20% covered by water hyacinth.

4.2.3 Statistical analyses

In order to determine if the study sampled sufficient invertebrate families, individual-based accumulation curves were compiled using the analytically calculated S_{obs} (Mao Tao) (number of species expected) for each collecting method to establish sampling representivity using EstimateS V 8.0.0 (Colwell, 2005). The Michaelis-Menten Mean (MMMean) estimator (Toti *et al.* 2000) was used to evaluate sample size adequacy and incidence-based coverage estimator (ICE) was also used (Chazdon *et al.* 1998). The richness estimates may be considered representative when the observed individual-based accumulation curves (Gotelli and Colwell 2001) and the estimators converge closely at the highest observed richness (Longino *et al.* 2002).

Community analyses

Multivariate community analyses of the family abundance data were made using the PRIMER 5.2.0 software package (Clarke and Warwick, 1994). A cluster analysis plot and non-metric multi-dimensional scaling (MDS) ordination plot were constructed from a similarity matrix to examine relationships between communities beneath water hyacinth mats and those in open water environments The Bray-Curtis coefficient and a double root transformation were used to determine similarity.

Biodiversity indices

Data were used to compare site specific differences between open water and sites under water hyacinth mats, both with and without the dominant Thiaridae data. This was done by calculating various nonparametric biodiversity indices.

Species richness (d)

Magurran (2004) suggests that there are two main methods of expressing estimates for species richness, numerical species richness and species diversity. Furthermore, the real challenges in biodiversity assessment concern poorly documented (usually invertebrate) taxa in tropical or deep-sea assemblages, which means that an estimate of species richness is usually the best that can be achieved. Two species richness indices that attempt to compensate for sampling effects are frequently used, namely: Margalef's diversity index (D_{Mg}) and Menhinick's index (D_{Mn}). .

Species abundance evenness (J')

As a heterogeneity measure, the Shannon-Wiener index takes into account the degree of evenness in species abundance. The ratio of observed diversity to maximum diversity can be used to measure evenness, where $J' = H' / H_{max} = H'/1nS$ (Pielou) (Magurran, 2004).

Shannon-Wiener index (H')

One of the most enduring of all diversity measures is the Shannon-Wiener index. The Shannon-Wiener index assumes that individuals are randomly sampled from an infinitely large community and that all species are represented in the sample (Magurran, 2004). The Shannon-Wiener index is calculated by $H' = - \sum p_i 1n p_i$. There is no unbiased estimator of the Shannon-Wiener index, which causes a substantial source of error when the data do not include all the species in the community (Magurran, 2004).

Simpson's measure of diversity (D)

Simpson's measure of diversity emphasizes the dominance component of diversity and is therefore not a pure evenness measure (Magurran, 2004) and was therefore not further examined.

Two separate analyses were carried out, one with the snail family Thiaridae present in the data and the other without Thiaridae included in the data, to determine if there would be any significant difference in community structure as this family was by far the most dominant in terms of individuals and the number of samples in which it was recorded.

4.2.4 South African Scoring System.

The SASS version 5 is a rapid bioassessment method used to determine the condition of an aquatic system. Benthic macroinvertebrates are recognized as valuable organisms for bioassessments, due to their visibility, ease of identification, rapid life cycle and sedentary habits (Dickens and Graham, 2002).

4.3 Results

A total of 31 different families comprising 18,797 individuals were recorded, all of which were identified to family level (Table 4.1). Of the individuals collected, 817 were collected from under water hyacinth mat sites compared to 17,980 that were collected from open water sites. Far more taxa were collected from the open water (28 families) in comparison to that of samples gathered from under water hyacinth mats (17 families). Interestingly, Dytiscidae, Hydraenidae and Ancylidae were not collected from open water sample sites.

Table 4.1 The percentage of samples containing a given family of benthic invertebrates found to inhabit artificial substrates placed under water hyacinth mats (WH) and in open water OW). % of TOTAL sample (WH + OW) is the total of all invertebrates collected from both under water hyacinth mats plus open water, whereas the % of SITE sample is for total sample for under water hyacinth compared to total sample from open water.

	% of TOTAL sample (WH + OW)		**% of SITE sample (WH / OW)**	
Taxon	**WH**	**OW**	**WH**	**OW**
Ephemeroptera				
Baetidae	0	0.005	0	0.005

Leptophlebiidae	0.021	0.627	0.489	0.656
Polymitarcyidae	0.138	0.372	3.182	0.389
Trichoptera				
Polycentropdidae	0.164	2.558	3.794	2.675
Hydropsychidae	0	0.015	0	0.016
Coleoptera				
Dytiscidae	0.047	0	1.101	0
Elmidae	0	0.005	0	0.005
Gyrinidae	0	0.015	0	0.016
Hydraenidae	0.005	0	0.122	0
Hemiptera				
Pleidae	0	0.005	0	0.005
Odonata				
Aeshnidae	0	0.005	0	0.005
Gomphidae	0.015	0.063	0.367	0.066
Corduliidae	0	0.010	0	0.011
Libellulidae	0.005	0.037	0.122	0.038
Chlorolerstidae	0	0.015	0	0.016
Coenagrionidae	0	0.031	0	0.033
Lestidae	0.005	0.053	0.122	0.055
Protoneuridae	0.005	0.005	0.122	0.005
Diptera				
Chironomidae	0.063	0.218	1.468	0.228
Amphipoda				
Amphipoda	0	0.010	0	0.005
Decapoda				
Potamonautidae	0	0.005	0	0.005
Atyidae	0.005	0.095	0.122	0.100
Annelida				
Oligochaeta	0.223	1.026	5.140	1.073
Hirudinae	0.404	0.033	9.302	3.476
Gastropoda				
Ancylidae	0.021	0	0.489	0
Planorlisdae	0.074	0.303	1.713	0.317
Thiaridae	2.835	86.093	65.238	90.005
Corbiculidae	0	0.047	0	0.050
Sphacriidae	0	0.010	0	0.011
Unionidae	0.138	0.430	3.182	0.450
Isopoda				
Isopods	0	0.015	0	0.016

Snails in the family Thiaridae were by far the most abundant benthic invertebrate family sampled both under water hyacinth mats (WH) and in open water (OW) (Table 4.2). The dominance by one group could mask the results and therefore all analyses were conducted with and without this family.

Table 4.2 Comparison of dominance of benthic invertebrates of total sample (18,797 individuals), from underneath a water hyacinth mat [WH] and from open water [OW].

		% Dominance	
Taxon	**% Of Total Sample**	**WH**	**OW**
Ephemeroptera			
Baetidae	0.005	0	0.005
Leptophlebiidae	0.648	0.489	0.656
Polymitarcyidae	0.51	3.182	0.389
Trichoptera			
Polycentropdidae	2.722	3.794	2.675
Hydropsychidae	0.015	0	0.016
Coleoptera			
Dytiscidae	0.047	1.101	0
Elmidae	0.005	0	0.005
Gyrinidae	0.015	0	0.016
Hydraenidae	0.005	0.122	0
Hemiptera			
Pleidae	0.005	0	0.005
Odonata			
Aeshnidae	0.005	0	0.005
Gomphidae	0.078	0.367	0.066
Corduliidae	0.01	0	0.011
Libellulidae	0.042	0.122	0.038
Chlorolerstidae	0.015	0	0.016
Coenagrionida	0.031	0	0.033

Lestidae	0.058	0.122	0.055
Protoneuridae	0.01	0.122	0.005
Diptera			
Chironomidae	0.281	1.468	0.228
Amphipoda			
Amphipoda	0.01	0	0.005
Decapoda			
Potamonautidae	0.005	0	0.005
Atyidae	0.1	0.122	0.100
Annelida			
Oligochaeta	1.249	5.140	1.073
Hirudinae	0.437	9.302	3.476
Gastropoda			
Ancylidae	0.021	0.489	0
Planorlisdae	0.377	1.713	0.317
Thiaridae	88.928	65.238	90.005
Corbiculidae	0.047	0	0.050
Sphacriidae	0.01	0	0.011
Unionidae	0.138	3.182	0.450
Isopoda			
Isopods	0.015	0	0.016

4.3.1 Duration of study – Accumulation curves

Accumulation curves are used to illustrate the rate at which new species (but in this case families) are found (richness), but unless sampling has been exhaustive these curves do not indicate total richness (Magurran, 2004; Clark and Warwick, 1994). Because fewer families were sampled beneath the water hyacinth canopy sites, the family accumulation curve levels off, suggesting that sample effort for these sites was adequate (Fig. 4.1). However, the accumulation curve for open water sites does not level off, indicating that greater sampling effort was required to adequately sample this community (Fig. 4.2). This is further expanded in the discussion.

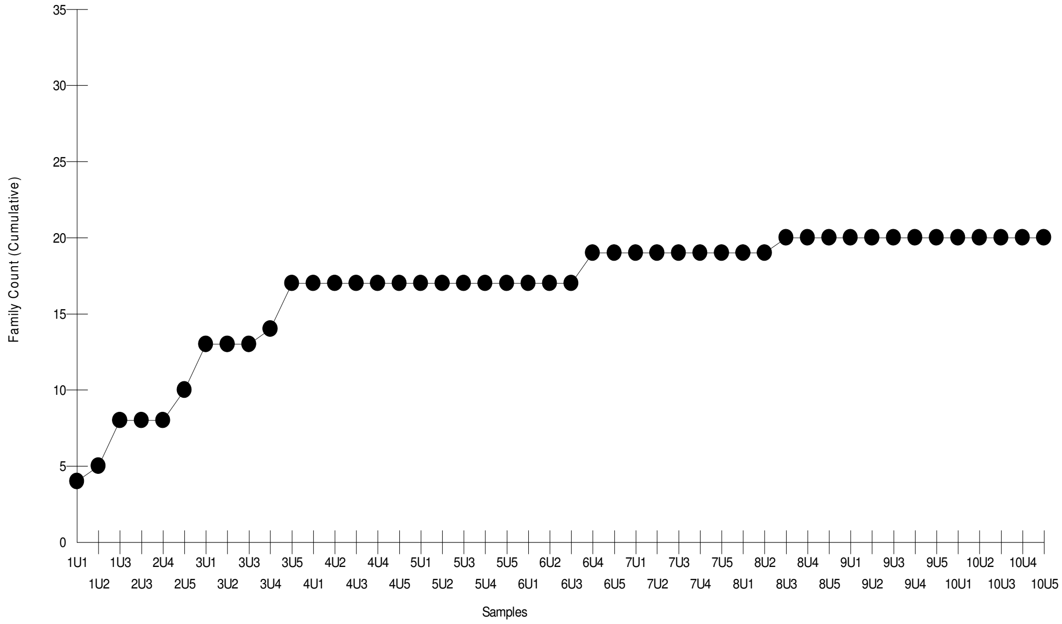

Fig. 4.1 Accumulation curve of families found under water hyacinth mats. The curve flattens out due to the presence of few families, and therefore lower diversity.

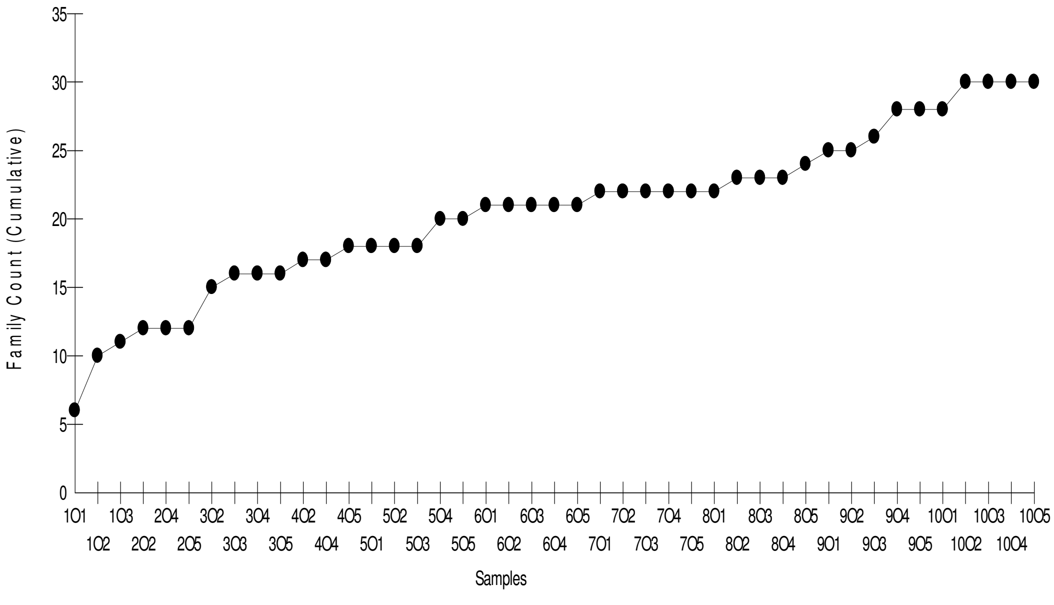

Fig. 4.2 Accumulation curve of families sampled in the open water sites, indicating that the saturation level of sampled families has not been reached for sample effort.

Observed family richness (S_{obs}) did not converge closely with the two richness estimators, MMMean and ICE, for either open water (Fig. 4.3) or under water hyacinth (Fig. 4.4) samples, indicating that these communities were not sampled completely.

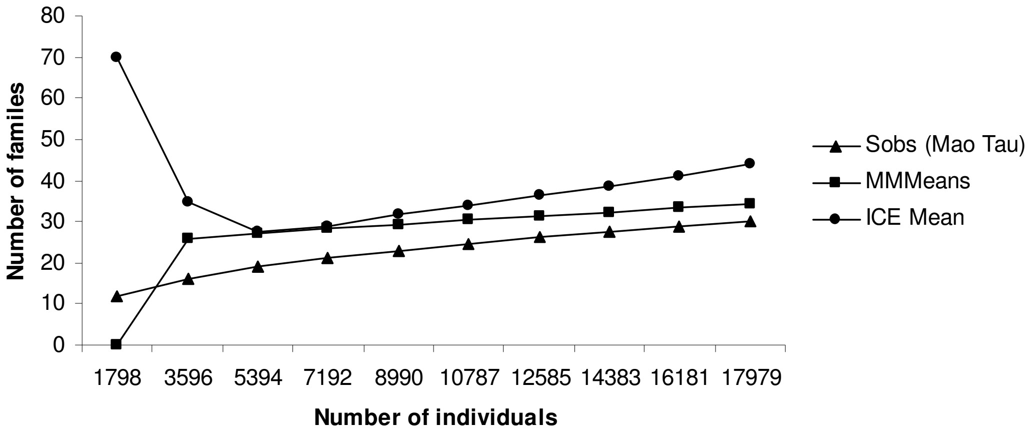

Fig. 4.3 Individual-based rarefaction curves indicating observed number of species (S_{obs} Mao Tao), Michaelis-Menten Mean (MMMean) richness estimators and incidence-based coverage estimator (ICE) of benthic invertebrates collected from open water sites.

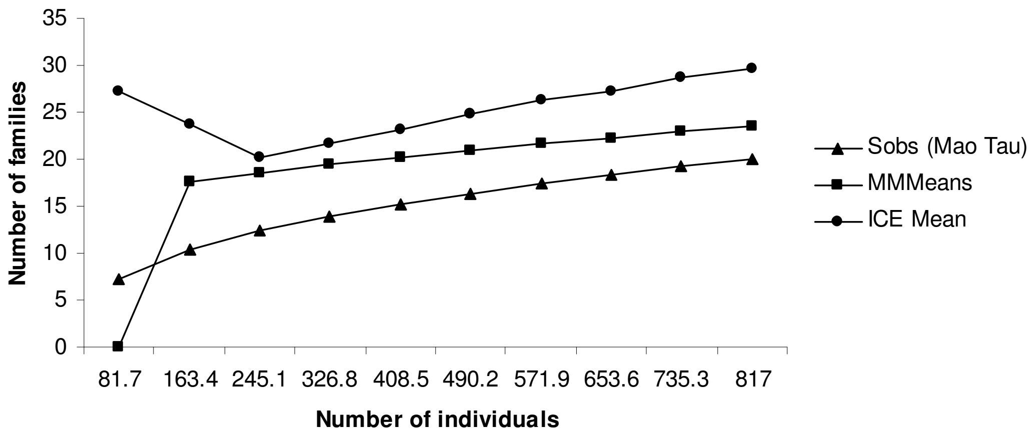

Fig. 4.4 Individual-based rarefaction curves indicating observed number of species (S_{obs} Mao Tao), Michaelis-Menten Mean (MMMean) richness estimators and incidence-based coverage estimator (ICE) of benthic invertebrates collected from under water hyacinth canopy sites.

The presence of the dominant family, Thiaridae, did have a significant effect on the observed family richness, for both open water (Fig. 4.5) or under water hyacinth (Fig. 4.6) samples. Furthermore, there was a significant difference in observed richness (with and without Thiaridae) between the open water and under water hyacinth samples (Figs. 4.7 and 4.8).

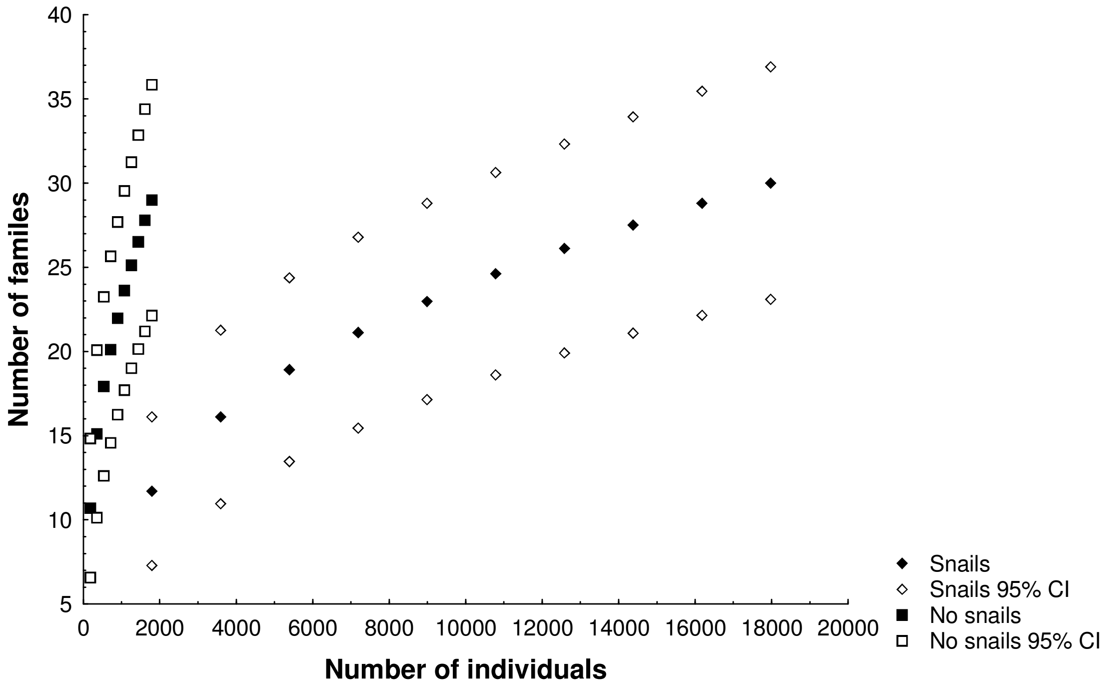

Fig. 4.5 Rarefaction curves, scaled by number of individuals, for open water samples comparing observed family richness, with and without the dominant snail family, Thiaridae. Non-overlapping 95% confidence interval bands indicate no significant difference ($P < 0.05$) between the two curves.

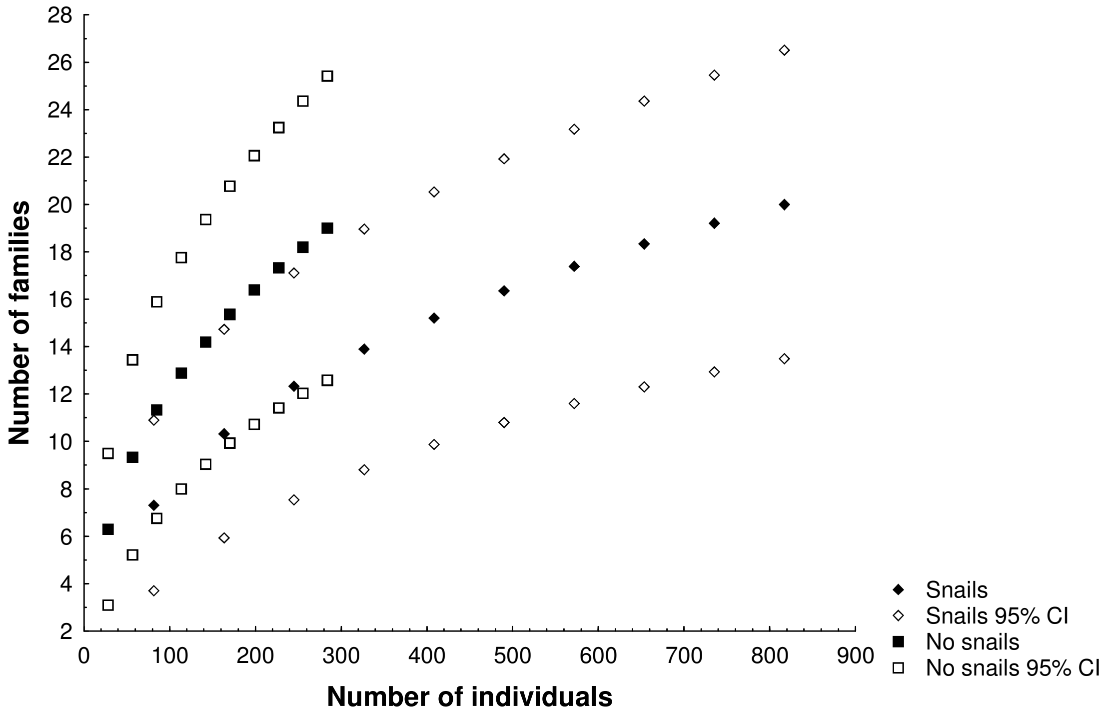

Fig. 4.6 Rarefaction curves, scaled by number of individuals, for under water hyacinth canopy samples comparing observed family richness, with and without the dominant snail family, Thiaridae. Non-overlapping 95% confidence interval bands indicate no significant difference ($P < 0.05$) between the two curves.

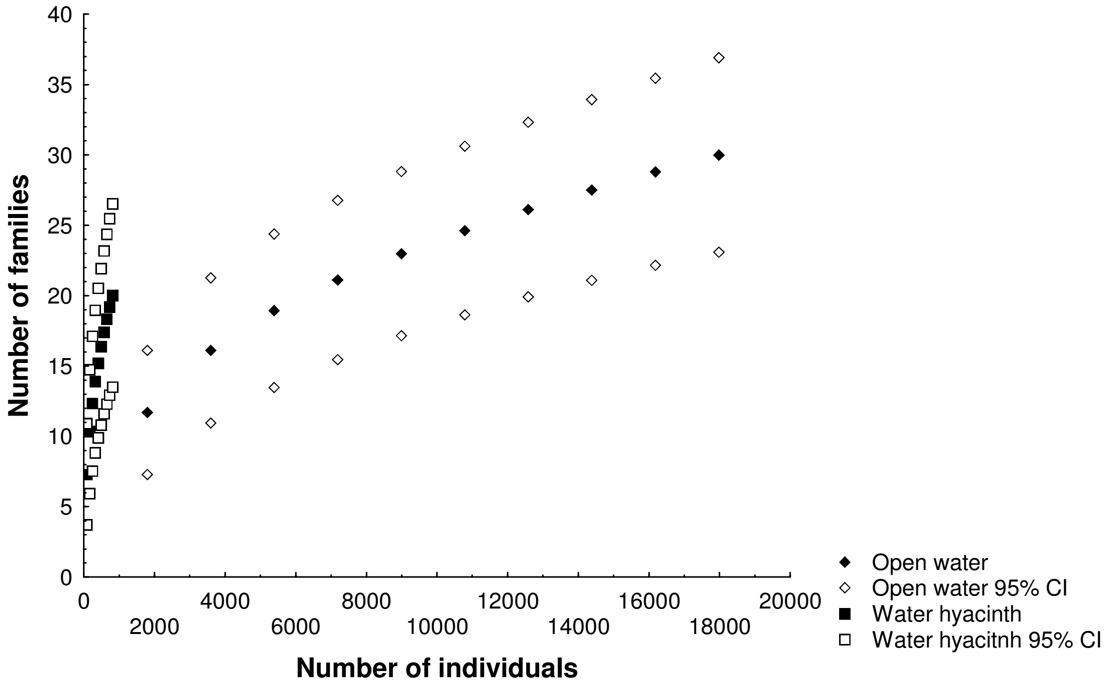

Fig. 4.7 Rarefaction curves, scaled by number of individuals, comparing observed family richness between open water samples and under water hyacinth canopy samples, inclusive of the dominant snail family, Thiaridae ($P < 0.05$).

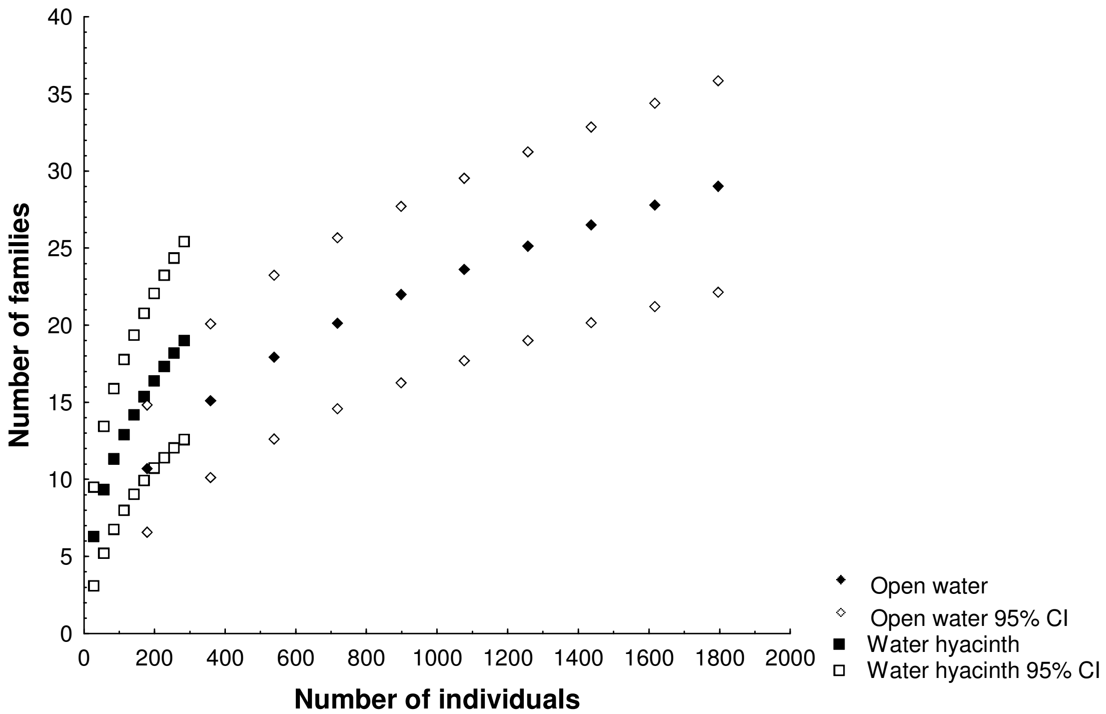

Fig. 4.8 Rarefaction curves, scaled by number of individuals, comparing observed family richness between open water samples and under water hyacinth canopy samples, excluding the dominant snail family, Thiaridae ($P < 0.05$).

4.3.2 Community analyses

Community analysis was carried out using accumulative data cluster plots and multi-dimensional scaling plots. All of the data tested presented very distinct similarities, both with the dominant family present in the data, as well as when it was omitted. The stress levels indicated in the multi-dimensional scaling plots were similar indicating a potentially useful 2-dimensional picture. Due to the MDS stress level, in both cases being at the upper end of the range, a cross-check was carried out using the PRIMER MDS programme whereby the random number of restarts used was 25, which is in excess of the minimum of 5 or 6 suggested by Clark and Warwick (1994). This was done to ensure a correct representation of the data.

Results of the Cluster Analysis and MDS indicate the presence of three distinct communities **(**Fig. 4.9 and 4.10**)**. The Cluster Analysis first divides the communities into two groups where both communities comprise samples from both under the water hyacinth canopy and open water samples. The first group comprises the first three sample events, while the second group comprises the remaining sample events. The second group is further divided into two distinct branches, comprising one group containing open water sample events and the other group from under canopy sample events. The first three sample events are grouped together due to interference from crocodiles and illegal gill netters and all sample bags (5) were not collected and can thus be ascribed to a small sample size.

As previously mentioned, sample events 4 to 10 have two distinct branches comprising open water samples and samples from under the water hyacinth canopy. Within each of these sub-branches, there are similarities ie both sub-branches are again divided into three further sub-branches, also only containing only open water sample events or under canopy sample events. Of interest are the similarities that are observed, within the sub-branches, namely: 5 and 8 (open) to that of 9 and 10 (open) and 10 (under) to 6 and 8 (under). Further similarities are between 4, 5, 7 and 9 (all under).

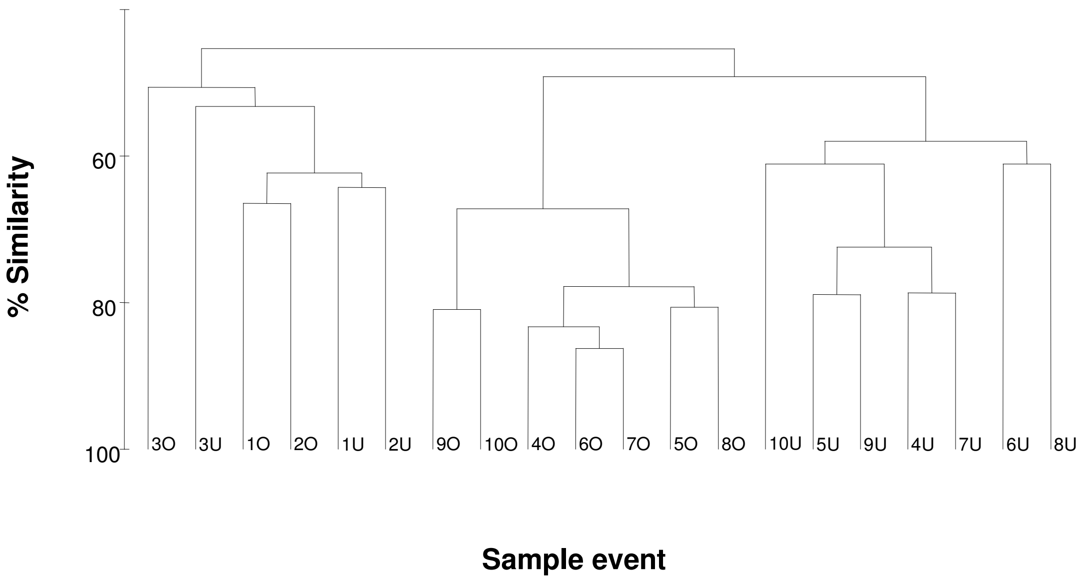

Fig. 4.9 Cluster Plot indicating percent similarity of total samples <u>with</u> the dominant Family Thiaridae included in the analysis. Each branch represents sample event (number) and site (O = open water, U = under water hyacinth canopy).

The MDS plot grouped the samples into similar communities, and using the results of the cluster analysis, distinct delimitations were placed around the communities (Fig. 4.10).

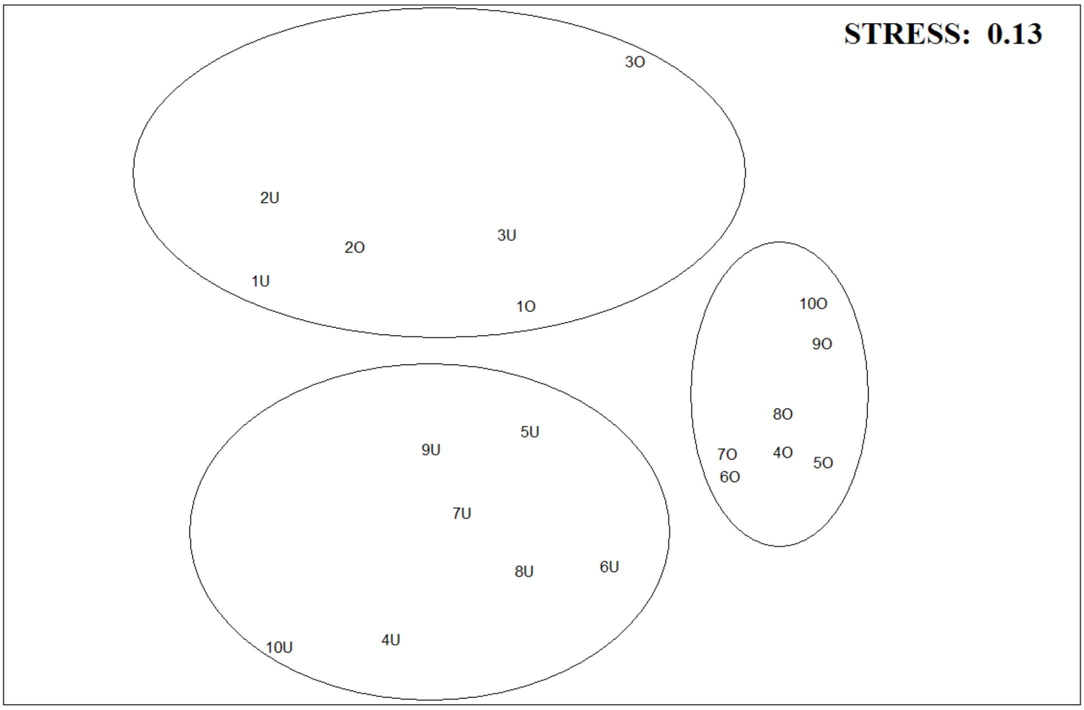

Fig. 4.10 Multi-Dimensional Scaling Plot (with the dominant Family Thiaridae included in the analysis indicating a stress of 0.13, with Cluster Plot overlay, indicating three distinct communities). Sample event is indicated by number, followed by site (O = open water, U = under water hyacinth canopy).

While the presence of the Thiaridae did not significantly influence the results of the family richness analysis, it did affect the results of the community analyses. Again, both the Cluster Analysis and MDS Plot have very distinct similarities (Figs. 4.11 and 4.12), and clearly define three communities, however, sample 10U is isolated because with the exclusion of the Thiaridae, it had fewer families and individuals sampled compared to the other samples.

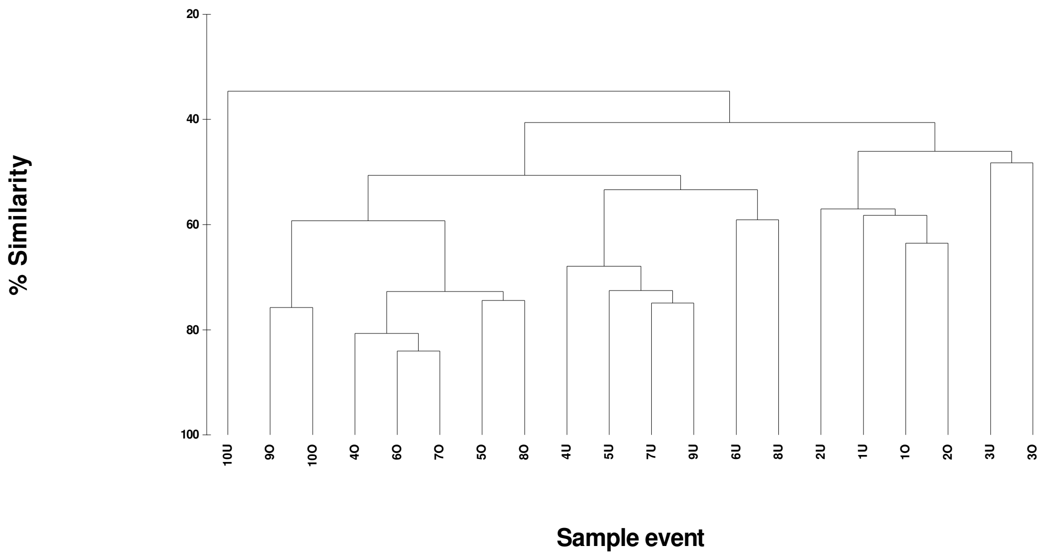

Fig. 4.11 Cluster Plot without the dominant Family Thiaridae included in the analysis indicating percent similarity in communities under the water hyacinth canopy, and in open water. Sample 10U is isolated. Each branch represents sample event (number) and site (O = open water, U = under water hyacinth canopy).

The MDS plot excluding the Thiaridae grouped the samples into similar communities as the MDS plot with Thiaridae, and again, using the results of the cluster analysis, distinct delimitations were placed around the communities, while 10U remained an isolated sample (Fig. 4.12).

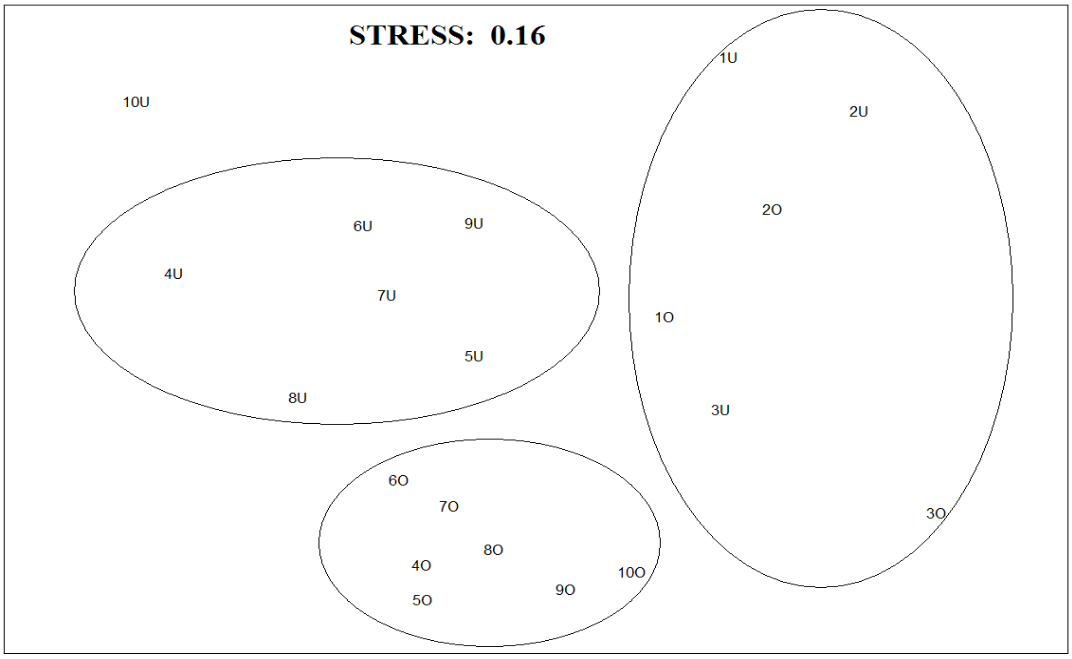

Fig. 4.12 Multi-Dimensional Scaling Plot indicating a stress value of 0.16 with Cluster Plot overlay. Ordinates indicate three distinct groups with sample 10U isolated. Sample event is indicated by number, followed by site (O = open water, U = under water hyacinth canopy).

4.3.3 Comparison of diversity results for open water versus under water hyacinth mats using total data sampled

A number of diversity measures were considered in this study to determine the impact of water hyacinth on benthic invertebrate communities, and an important part of this study was also comparing both the inclusion and exclusion of the dominant Thiaridae family in order to observe its effect on diversity between the two sites. The first index considered was family richness. Figure 4.13 represents family total data, with and without the dominant family present, and clearly indicates that more families were collected from open water sites than from under water hyacinth mats, except for sample event 3. The reason for this is because the first false substrates placed at sample points (open water) were meddled with by crocodiles and illegal gill netters. The presence or absence of the Thiaridae did not affect the results because the data represent total number of families, and the exclusion of one family is not significant. It is important to note that the richness indices ie Margalef's diversity index or the Menhinick's index (*n* and *s*) are not meaningful, from a point of view that they do not take into consideration any measure of numbers of individuals.

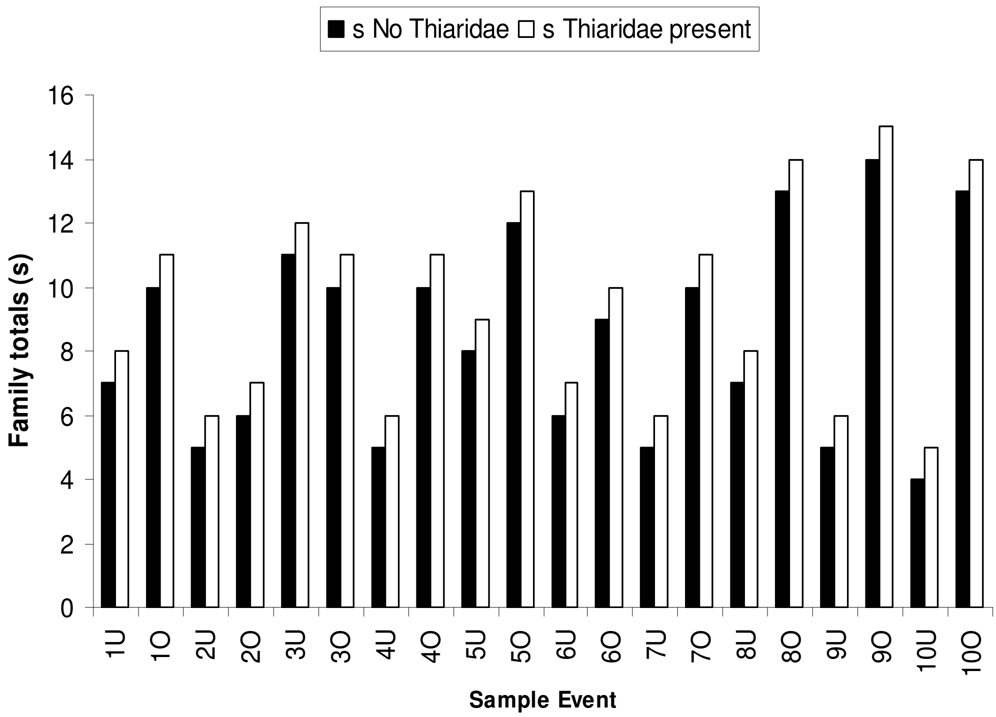

Fig 4.13 Comparison of the total number of families collected from open water sites and from under water hyacinth mats, with the exclusion and inclusion of the dominant family, Thiaridae. Numbers represent sample event, followed by site (U = under water hyacinth canopy sites, O = open water sites).

A measure of abundance is indicative of the total number of individuals collected. Figure 4.14 is an indication of abundance of individuals collected from the two sites, with and without the dominant family Thiaridae. It is clear that open water sites were far more productive than under water hyacinth mats. As with Figure 4.15, the same reason applies for low numbers in sample events 1-3 ie crocodile and human interference.

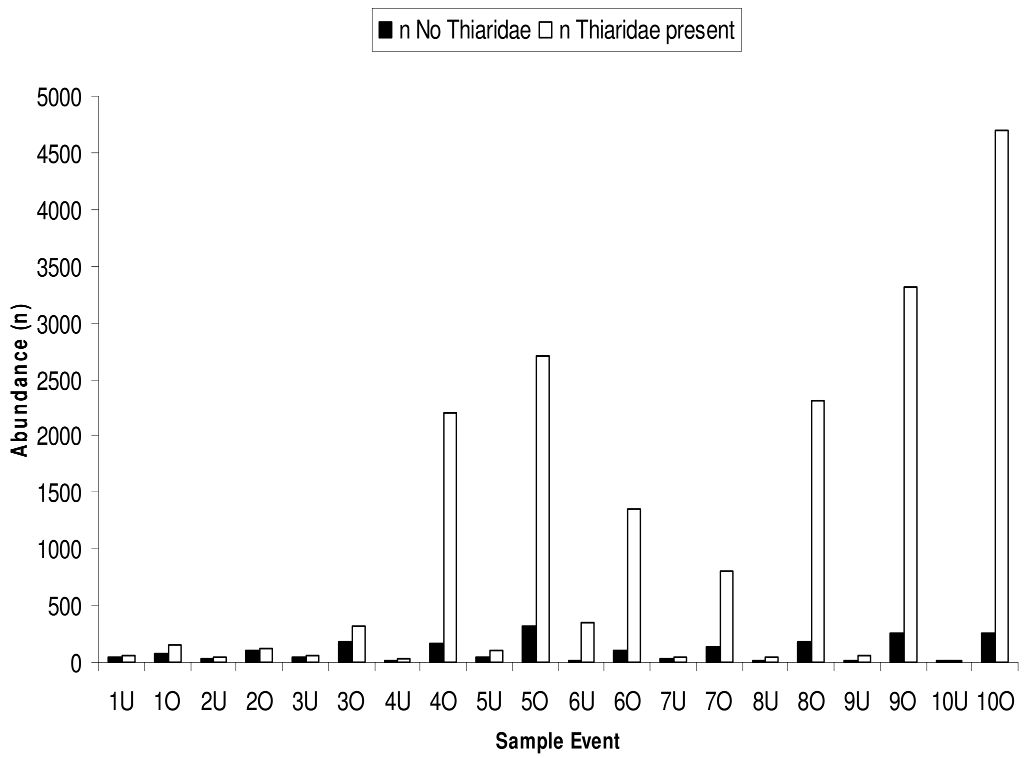

Fig 4.14 Comparison of abundance of individuals sampled from open water sites compared to samples from under water hyacinth mats, with the inclusion and exclusion of the dominant family. Numbers represent sample event, followed by site (U = under water hyacinth canopy sites, O = open water sites).

The Shannon evenness index takes into account the degree of evenness in species (but in this case family) abundance (Magurran, 2004). Magurran (2004) further suggests that it is however possible to calculate a separate evenness measure. The maximum diversity (H_{max}) that could possibly occur would be found in a situation where all species (Family) had equal abundances $H'=H_{max}=1\text{n}S$. The ratio of observed diversity to maximum diversity can therefore be used to measure evenness (J' – Pielou's evenness). Figure 4.15, unlike the previous two figures, indicates that there is far more evenness underneath water hyacinth mats. This is due to fewer families found underneath water hyacinth mats compared to open water, and more individuals occurring in open water sites than under the water hyacinth canopy (Figure 4.15). Further, the exclusion of the Thiaridae in all samples results in greater evenness because the sheer numbers of Thiaridae collected in the samples decrease the evenness.

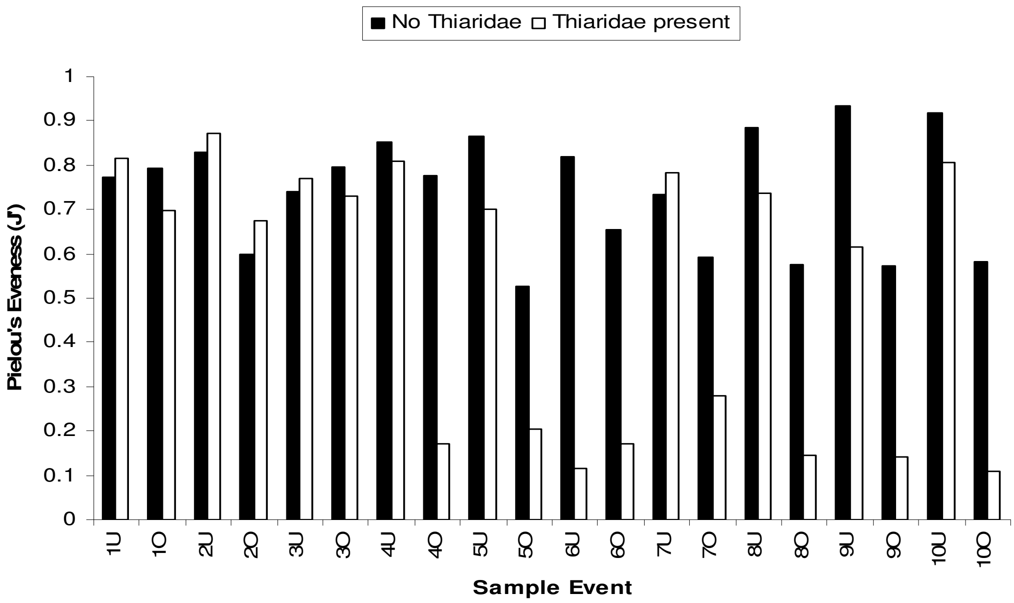

Fig 4.15 Comparison of evenness of samples from open water sites compared to samples from under water hyacinth mats, with the dominant family present and not present. Numbers represent sample event, followed by site (U = under water hyacinth canopy sites, O = open water sites).

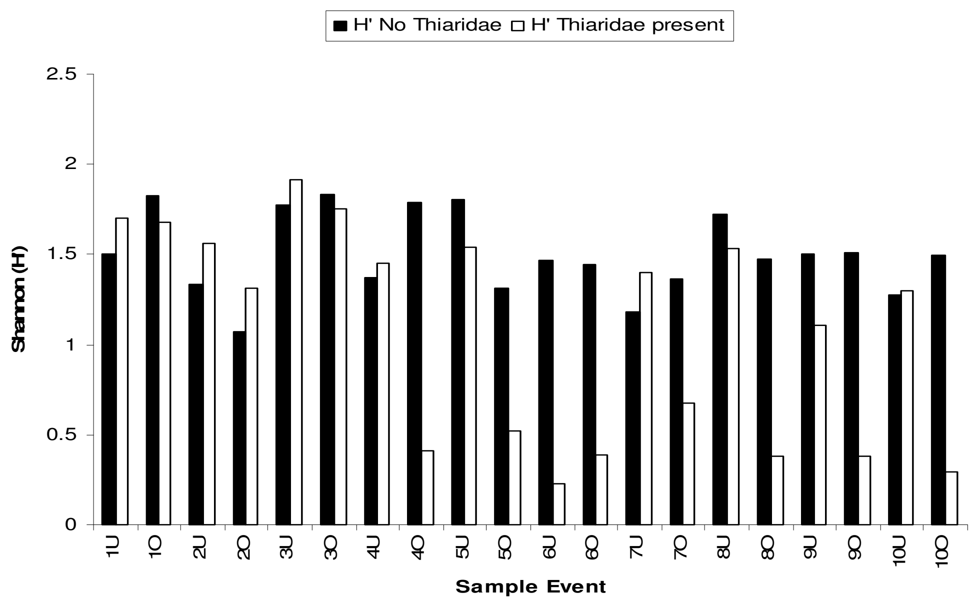

Fig 4.16 Comparison of the degree of evenness and abundance, using the Shannon-Weiner (H) index, of samples from open water compared to samples from under water hyacinth mats, with the dominant family present and not present. Numbers represent

sample event, followed by site (U = under water hyacinth canopy sites, O = open water sites).

Using the Shannon-Wiener index, it appears that there is greater family evenness in abundance from under water hyacinth mats sampled (Fig. 4.16). This is due to the fact that fewer families were sampled without the main family (Thiaridae) being included in the data. The Shannon-Wiener takes into account the number of species and the evenness of the species. The index is increased either by having additional unique species, or by having a greater evenness. From sample event four onwards the presence of Thiaridae decreases H diversity in both open water and under the water hyacinth mats due to overabundance. Overall, open water sites have a higher H diversity than the water hyacinth sites, indicating that water hyacinth decreases benthic invertebrate biodiversity.

4.3.4 Sensitivity of the taxa sampled to pollution

All organisms are sensitive to one form of pollution or another and in this study the benthic invertebrates (Gerber and Gabriel, 2002) are a good indication of the level of pollution in the aquatic environment. The SASS5 scoring system (Dickens and Graham, 2001) was used to determine the sensitivity of invertebrates sampled from the Nseleni River system. From the results it would appear that the Nseleni River system, at the study site, appears to be polluted as only 8% of the invertebrates sampled had a very low tolerance to pollution. In this instance, it is believed that the Mposa sewerage works and adjacent agriculture and timber plantations play a role in nutrient loading of the river.

Sensitivity scales are recorded on a level from 1 to 15 and is derived from the tolerances to pollution as used in the SASS5 scoring system (Dickens and Graham, 2001), namely:

- 1 – 5 Highly tolerant to pollution
- 6 – 10 Moderately tolerant to pollution
- 11- 15 Very low tolerance to pollution

Of all the families collected, 49 % are considered highly tolerant of pollution, 43% are moderately tolerant of pollution and 8% have a very low tolerance to pollution

(Table 4.3), thereby indicating, using the above indices, that the sample area is moderately to highly polluted in one form or another. High nutrient levels are known to occur, due to forestry and agricultural practices adjacent to the sample area and the presence of a sewerage works on the Mposa River which flows directly into the Nseleni River and then downstream into Lake Nsezi.

Table 4.3 Sensitivity indication of benthic invertebrates sampled using the SASS5 scoring system.

Taxon	Sensitivity Level		Taxon	Sensitivity Level
Ephemeroptera			Coenagrionidae	1 – 5
Baetidae	1 – 5		Lestidae	6 - 10
Leptophlebiidae	6 – 10		Protoneuridae	6 - 10
Polymitarcyidae	10		**Diptera**	
Trichoptera			Chironomidae	1 - 5
Polycentropdidae	11 - 15		**Amphipoda**	
Hydropsychidae	1 – 5		Amphipoda	11 - 15
Coleoptera			**Decapoda**	
Dytiscidae	5		Potamonautidae	1 – 5
Elmidae	6 - 10		Atyidae	6 - 10
Gyrinidae	5		**Annelida**	
Hydraenidae	6 - 10		Oligochaeta	1
Hemiptera			Hirudinae	1 - 5
Pleidae	1 – 5		**Gastropoda**	
Odonata			Ancylidae	6 – 10
Aeshnidae	6 – 10		Planorlisdae	1 – 5
Gomphidae	6 – 10		Thiaridae	1 - 5
Corduliidae	6 – 10		Corbiculidae	5
Libellulidae	5		Sphacriidae	1 – 5
Chlorolerstidae	10		Unionidae	6 - 10

4.3.5 Impact of water hyacinth on other aspects of biodiversity

Tables 4.4 to 4.6 are an indication of the importance of conserving the biodiversity in the area. Both the local community from the rural area of Nseleni and the surrounding urban community rely on the Nseleni River and the Enseleni Nature Reserve, for two different reasons. Firstly the Nseleni River is a sole source of staple food for many unemployed rural community members from the Nseleni township area and secondly, a means of recreation for those urban community members, who enjoy the Nseleni River for boating and fishing. The Enseleni Nature Reserve is used as a mode of relaxation for many local, national and international visitors, who especially enjoy the two game trails that pass along the western bank of the Nseleni River.

Table 4.4 South African Red Data species found in the Nseleni River system.

	CATEGORY			
	Endangered	**Vulnerable**	**Rare**	***Intermediate**
Species				
BIRDS				
Bitten (*Botaurus stellaris*)		√		
Pinkbacked pelican (*Pelecanus rufescens*)			√	
Little bittern (*Ixobrychus minutus*)			√	
White stork (*Ciconia ciconia*)			√	
Woolynecked stork (*Ciconia episcopus*)			√	
Openbilled stork (*Anastomus lamelligerus*)			√	
Marabou stork (*Leptoptilos crumeniferus*)			√	
Pygmy goose (*Nettapus auritus*)			√	
Lesser jacana (*Micropara capensis*)			√	
Pel's fishing owl (*Scotopelia peli*)			√	
Dwarf bittern (*Ixobrychus sturmii*)				√
Baillon's crake (*porzana pusilla*)				√
African finfoot (*Podica senegalensis*)				√

REPTILES & AMPHIBIANS				
Nile crocodile (*Crocodylus niloticus*)		√		
MAMMALS				
Hippopotamus (H*ippopotamus amphibious*)			√	

* Intermediate species are those suspected of belonging to the other categories but for which insufficient information is available.

Table 4.5 Protection of species in terms of Provincial legislation – Nature Conservation Ordinance 15 of 1974**,** related to the Nseleni River system.

	CATEGORY	
	PROTECTED	***SPECIALLY PROTECTED**
Species		
Blue duiker (*Cephalophus monticola*)	√	
Bushbuck, female (*Tragelaphus scriptus*)	√	
Hippopotamus (*Hippopotamus amphibious*)	√	
Red duiker (*Cephalophus natalensis*)	√	
Reedbuck (*Redunca arundinum*)	√	
Waterbuck *(Kobus ellipsiprymnus)*	√	
Zebra *(Equus burchelli)*	√	
Hottentot teal (*Anas hottentota*)	√	
African black duck (*Anas sparsa*)	√	
Fulvous whistling duck (*Dendrocygna bicolor*)	√	
Southern pochard (*Netta erythrophthalma*)	√	
Pygmy goose (*Nettapus auritus*)	√	
Knob-billed duck (*Sarkidiornis melanotos*)	√	
Cape shoveler (*Anas smithii*)	√	
Whitebacked duck (*Thalassornis leuconotus*)	√	
Nile crocodile (*Crocodylus niloticus*)	√	

Nile monitor lizard (*Varanus niloticus*)	√	
Pinkbacked pelican (*Pelecanus rufescens*)		√
Osprey (*Pandion hallaetus*)		√
All *Nymphaeacea*		√

* A higher category of legal protection compared to protected.

Table 4.6 Protection of species in terms of National legislation – National Environmental Management: Biodiversity Act, Act 10 of 2004, related to the Nseleni River system.

	CATEGORY		
Species	**ENDANGERED**	**VULNERABLE**	**PROTECTED**
Pel's fishing owl (*Scotopelia peli*)	√		
Blue duiker (*Cephalophus monticola*)		√	
Freshwater mullet (*Myxus capensis*)		√	
Nile crocodile (*Crocodylus niloticus*)			√
Cape clawless otter (*Aonyx capensis*)			√
Reedbuck (*Redunca arundinum*)			√

However, from the late 1970's until the mid 1990's, the use of the Nseleni and Mposa rivers as both a food source and for recreational purposes was no longer available due to the infestation of water hyacinth. In addition, the then Natal Parks Board, had no option but to stop offering birding trips on the Nseleni River, as the river was no longer navigable. Not only was the river no longer navigable, but a high percentage of the avi-fauna that people wanted to view were no longer able to survive in the area and had moved away. The three main bird species that people wanted to "tick-off" on their bird check lists, were the Pel's fishing owl (*Scotopelia peli)*, African Fish eagle (*Haliaeetus vocifer*) and the African Finfoot (*Podica senegalensis)*. These species were not recorded in the area again, until the late 1990's (African Finfoot) and 2008 was the first time that a pair of Pel's fishing owl, again became resident in the Enseleni Nature Reserve. A total of twelve breeding pairs of African Finfoot (2005) have since been recorded on the Nseleni River. African Fish eagles are heard daily with their distinctive call while both in flight and while perched at a hunting spot. At least three pairs are known to be breeding in the area. Pel's fishing owls are frequently observed at different locations in the reserve by staff, an indication that they are utilizing the entire stretch of river, for hunting purposes.

Records at the Enseleni Nature Reserve indicate that annual nesting sites in the reserve and along the Nseleni River, were no longer being used by Nile crocodiles (*Crocodylus niloticus*), as they were no longer able to access them due to the water hyacinth infestation in the period early 1980's to mid 1990's. Fortunately, the hippopotamus (*Hippopotamus amphibious*) was not so severely affected, as a few were able to remain in open pools of water and make use of Lake Nsezi. Since the late 1990's both the Nile crocodile and hippopotamus have returned and are permanently resident in the area and are once again breeding successfully.

The Nseleni River is once again well utilized by the rural community of Nseleni township, as a source of obtaining their staple diet of fish and the river is used for fishing competitions and for recreational purposes. A negative aspect of having numerous crocodiles back in the river system, is that on an annual basis mainly during summer months when it is hot, human life is lost to crocodile attacks.

4.4 Discussion

The aim of this chapter was to quantify the impact of water hyacinth on the aquatic biodiversity in the Nseleni River and Lake Nsezi. This chapter has shown that water hyacinth does have a negative impact on aquatic biodiversity using various scientifically sound indices and statistical analyses.

Data obtained to determine the accumulative curve were carried out in a systematic way and not in an *ad hoc* way. In addition, sampling was carried out in an area of reasonably homogenous habitat, as has been suggested by Colwell and Coddington (1994) in: Magurran (2004). Further, Magurran (2004) suggests, that from a cost effectiveness point of view, it is rarely effective to identify every species in an assemblage unless the survey site is extended which justifies our decision to identify specimens to the family level. Further to this, it is suggested by Southwood and Henderson (2000) in: Magurran (2004) that some species are difficult to sample (detectability) and that methodological edge effects arise when the probability of species capture is not directly related to species abundance (Longino *et al*. 2002).

This study has determined that water hyacinth has severe implications for biodiversity, as well as to the management thereof. Masifwa *et al*. (2001) carried out a study to determine the impact of water hyacinth on the abundance and diversity of aquatic macroinvertebrates along the shores of northern Lake Victoria. It was determined that both numerical abundance and diversity increased from the fringe of the water hyacinth mats which had been colonized by *Cyperus papyrus* towards open water. Furthermore, dissolved oxygen decreased from open water into vegetation where it approached anoxia and that impoverished abundance and diversity of the macroinvertebrates deeper into vegetation mats suggested negative environmental impacts of the water hyacinth when the fringe is too wide. Masifwa *et al*. (2001) concluded that at the fringe / open water where it is well oxygenated, it supports diverse and abundant invertebrate communities, but that the opposite is true the deeper one samples into the bed of water hyacinth, where the oxygen concentration in and below the mat declines. This is mirrored by the decline in abundance and diversity of invertebrates. Although we undertook no measurements of water chemistry, it is likely that the water hyacinth has had a similar impact on the water quality in the Nseleni system and the benthic invertebrates have responded in the same way shown by Masifwa *et al*. (2001).

Midgley *et al*. (2006) concurred that little is known about water hyacinth's impacts on biodiversity in aquatic ecosystems. In the similar study to the one carried out here, the benthic invertebrate community and algal biomass were sampled under water hyacinth and in water hyacinth-free water, using false substrates in two impoundments on the New Year's River, Eastern Cape, South Africa. The study conducted by Midgley *et al*. (2006), also using families, concluded that the presence of water hyacinth had a detrimental effect on both the abundance and diversity of benthic invertebrates and algal biomass and finally that there are significant biodiversity benefits, and therefore ecosystems goods and services benefits, to be gained by controlling this weed.

Although this study has similar conclusions to that of Midgley *et al*. (2006), there are some noticeable differences. This study recorded a total of 31 families, compared to that of 21 recorded by Midgley *et al*. (2006). This could be ascribed to differences in where the studies were carried out as the Nseleni system is far more tropical than the area of the Eastern Cape where Midgely *et al*. (2006) carried out their study. This could further explain why the Thiaridae (dominant taxa sampled) were as dominant as they are described as tropical freshwater snails that use a silty substrate as a habitat. The Nseleni River fits both of these requirements. Of interest is the fact that Midgley *et al*. (2006) did not record any Thiaridae in their study (Eastern Cape) which supports the previous statement. Midgley *et al*. (2006) did not record any vast differences in invertebrates collected from open water compared to under water hyacinth mats. The largest mean abundance differences occurred with the Annelida (Glossiphonidae) of 14.48% (OW) and 1.44% (WH), as well as with Diptera (Chironomidae) of 9.73% (OW) and 0.04% (WH). However in our study the only significant difference, was with Thiaridae sampled from open water (OW) and from under water hyacinth mats (WH), with 90% dominance in open water compared to 65% dominance from under water hyacinth mats. Thiaridae are also highly tolerant of polluted waters. This is further borne out by the fact very few Chironomidae were collected in this study; a total of 53 individuals or 0.281% of the total samples collected. Midgley *et al*. (2006) state that Chironomidae are known to survive anoxic conditions, which are typical of water hyacinth infested systems.

This study has further shown that far more taxa were collected from the open water (28 families/17,980 individuals) in comparison to that of samples gathered from under water hyacinth mats (17 families/817 individuals), indicating that a decrease in biodiversity (under water hyacinth mats) affects the ability of the ecosystem to function normally. Of the 17 families collected from under water hyacinth mats, 11 families were of very low abundance in nature, further indicating the negative impact of water hyacinth on biodiversity. Reduced diversity in an ecosystem also makes it vulnerable to disturbance as the average number of interspecific interactions is decreased (Hurlburt 1971, Fullick 2002 in: Midgely *et al.* 2006).

Of importance in this study, is the fact that it has been shown that there is lower diversity under water hyacinth and that the presence of the dominant family, Thiaridae, did not significantly effect observed family richness from either open water or from under water hyacinth mats. Furthermore, Hulbert (1971) in: Midgley *et al*. (2006), states that species diversity is a function of species richness and species evenness, both of which we have shown in this chapter.

CHAPTER 5

GENERAL DISCUSSION & CONCLUSION

Negative impacts of water hyacinth on freshwater systems were recognized as far back as 1913 (Stent, 1913) and 1948 (Penfound and Earle 1948). In addition, Gowanloch and Bajkov (1948) have also recorded the detrimental effects of water hyacinth on freshwater systems. This study has shown, as has Masifwa *et al*. (2001) and Midgely *et al*. (2006), that water hyacinth has a severe impact on aquatic biodiversity, as well as other forms of biodiversity (Chapter 4). These impacts are fairly easy to measure in aquatic ecosystems and are so unequivocal that they can be used as leverage to ensure that there is a commitment to control this invasive species, especially in protected areas. Another possible reason for the continued infestation of freshwater systems is that, although it is ubiquitously acknowledged that ecosystems are essential to human existence, ecosystem services are typically unpriced or not priced correctly at their marginal value because of a lack of private, organized markets for such services (Alexander *et al*. 1998). Furthermore, Jewitt (2001) suggests that the rising demand for water and the degradation of its quality, represents the most serious threat to the provision of various goods and services required by society.

This study has clearly indicated that by implementing an integrated approach (Chapter 3) aquatic biodiversity, and associated biodiversity (Chapter 4) will benefit. It is suggested that the most important part of an integrated approach to controlling water hyacinth, is the planning phase. This study showed that the key aspects to the successful long-term control of water hyacinth include: identification of the weed, mapping the extent of the weed, identifying the cause of the infestation, consulting interested and affected parties, appointment of a lead agency or champion, ascertaining an acceptable level of control, considering control options, implementing control options, monitoring control options and evaluating the plan and adjusting it accordingly.

Instituting the above will enhance the opportunity to reach a long-term and cost effective way of controlling water hyacinth. This will undoubtedly lead to aquatic ecosystem restoration, which is the objective of any control programme.

However, there are broader issues that this study has highlighted. South Africa has a scarcity of water, as discussed in Chapter 1 (Jacot Guillarmod, 1979) and chapter 2. The Richards Bay (uMhlathuze Municipality) area is one of the highest development / economic growth points in South Africa, with the result that freshwater in the area is under severe pressure, and in fact is unable to meet the demand in as much as water has to be transferred from one freshwater system to another. The population has grown from 196,183 (1996) to 318,299 (2008) and is expected to reach 347,658 by 2023. It is therefore of utmost importance that our water resources in this and other areas must be protected, even against aquatic alien plants, which have numerous detrimental effects (Chapter 1).

Although this study has shown that the symptom of aquatic ecosystem degradation, water hyacinth, can be treated, the cause, increase in eutrophication, has not been addressed. Although this study presents an effective integrated management plan for the control of water hyacinth on the Nseleni and Mposa rivers and Lake Nsezi that could be implemented throughout South Africa and other areas of the world where water hyacinth and other aquatic weeds are problematic, it needs to form a component of a much wider integrated catchment management approach.

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