

**Biological control as an integrated control method in the management
of aquatic weeds in an urban environmental and socio-political
landscape
Case study: Cape Town Metropolitan Area**

Thesis

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By

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Abstract

Aquatic weeds transform and degrade the ecosystems which they invade, impacting various aspects of their surroundings ranging from the community level to disrupting important processes affecting ecosystem services. All of the major aquatic weeds of South Africa are found in the Cape Town Metropolitan Area. Landowners, whether private or public, are legally obliged to manage the listed invasive species through applying environmentally acceptable methodologies. This thesis provides an overview of the strategic management options, prevention, early detection, rapid response and eradication of new invasions, and containment and control species of established species. It discusses the different control methods available for managing aquatic weeds, namely mechanical, manual, chemical and biological, and the integration of different methods to improve their effectiveness. Although various studies have shown that biological control is the most cost-effective, environmentally-friendly and sustainable method, it is not yet fully integrated into weed management programmes in South Africa. In addition, the successes achieved in other parts of the world with the control of water hyacinth through biological control have not been repeated in the urban environment, despite the fact that South Africa has the highest number of biological control agents available for the weed. Urbanisation puts pressure on the natural environment and ecosystem functioning. Nutrient-enriched waters support aquatic weed growth and pose a challenge to the management thereof, in particular with regard to integrating biological control into management programmes. The aims of this study were to determine the reasons for the lack of integration of biological control into weed management programmes in South Africa, to determine the feasibility of integrating biological control in aquatic weed management programmes in a complex urban environmental and socio-political landscape by means of three case studies in the Cape Town Metropolitan Area, which showed that biological control is feasible in urban environments and should be considered. Two surveys were conducted to determine the reasons for the lack of integration of biological control into weed management programmes. The surveys showed that there is a gap between research and implementation as a result of

poor communication, non-supporting institutional arrangements and a lack of appropriate capacity and skills at the implementation level. Recommendations were offered to address these issues.

Frontispiece



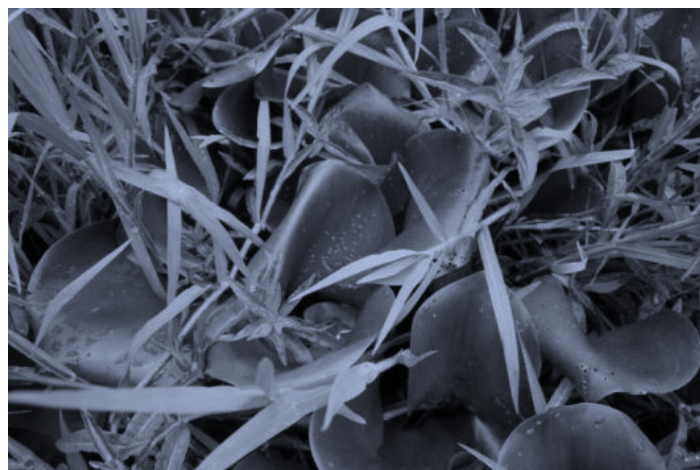
The Diep River on 8 May 2012 prior to manual clearing



The Diep River on 1 August 2012 after manual clearing



The Diep River section where biological control is integrated with manual control of water hyacinth



Diep River: *Neochetina* sp. damage is evident on the water hyacinth leaves



Black River on 26 March 2012 prior to manual and mechanical clearing



Black River on 10 June 2012 after manual and mechanical clearing



Westlake River after biological control

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Chapter 1

An Overview of Aquatic Weeds and their Impacts

1.1 Introduction

The introduction of plants and animals to regions outside of their native range is largely the result of global trade and the movement of people (McNeely, 2001a). Not all introduced species are problematic, as they may not establish in their new habitats or have negligible impacts due to very small populations. However, some introduced species may become invasive after a period of dormancy, known as the lag phase, of up to several decades (Larkin, 2011). Factors such as changing broad-scale climatic conditions, habitat modification, or a single event such as the introduction of a plant pollinator, may trigger invasiveness (Maynard and Nowell, 2009). In the absence of their natural enemies, namely predators, parasites, and diseases (Maynard and Nowell, 2009), some introduced species become problematic and might grow to densities where they cover entire landscapes or water bodies. Invasive species are an epidemic around the world, resulting in major economic losses in the countries they invade (Pimentel et al., 2005). They have adverse effects on ecosystem functioning, resource utilisation, biodiversity, human health, and economic development, and are considered to be only secondary to habitat loss and degradation, the biggest threat facing biodiversity (Wilcove et al., 1998).

Invasive species can occupy terrestrial, freshwater and marine aquatic environments, and represent different taxa. Invasive alien aquatic plant species, the topic of this thesis, are a global problem and have invaded freshwater lakes, dams and rivers worldwide, including many parts of South Africa and specifically the Cape Town Metropolitan Area (CTMA). For example, *Eichhornia crassipes* (Marius) Solms-Laubach (Pontederiaceae) (water hyacinth) was first discovered in Langvlei near Retreat in the Cape Flats in the early 1900s (Brown and Magoba, 2009), and is now a major weed, invading several water bodies in the CTMA. The Working for Water Programme, a nationwide initiative, was established in 1995 to address the growing invasive plant infestations and their related economic and environmental impacts (van Wilgen et al., 2012). Although Working for Water promotes invasive plant control by means of integrated control methods, including mechanical, manual and biological methods, integration of biological control is not yet achieved (van Wilgen et al., 2012).

Controlling invasive species is complex, and the complexity is compounded in metropolitan areas. Managing invasive weeds often involves negotiating environmental, economic and socio-political considerations. Priority setting and planning are further complicated by the absence of

supporting legislation, bureaucratic systems, unrealistic expectations, uncertain funding and tumultuous political environments. The aims of this thesis were to explore the reasons for the lack of integration of biological control at a national level, and to determine whether there is a place for biological control as an integrated control method into aquatic weed management programmes in a complex socio-economic, environmental and political urban landscape (City of Cape Town) and to offer recommendations for integrating biological control into aquatic weed management programmes.

1.2 Invasive species introduction pathways

Human-induced movement of plants and animals from one area to another, dating back millennia, have shown three clear step changes: the first at the end of the Middle Ages, the second at the beginning of the Industrial Revolution, and the third, the most recent, during the Era of Globalisation (Hulme, 2009). The number of people travelling around the world and the volume of human-facilitated movement of organisms and goods is vast and increasing (Maynard and Nowell, 2009). In the 1980s, the growth in global economic output exceeded the growth over the several thousand years from the beginning of civilisation until 1950, and the rate of growth increased even further in the 1990s. The total import value of goods increased 25-fold in 30 years from about US\$ 192 billion in 1965 to US\$ 4.8 trillion in 1995. Agricultural products and industrial raw materials, potentially the greatest contributors to the movement of invasive species, increased from US\$ 55 billion in 1965 to US\$ 850 billion in 1998 (McNeely, 2001a).

Although globalisation has many benefits for human societies, it also introduces the critical element of organisms moving between different parts of the world (McNeely, 2001a). Through these movements, pathways are created for the introduction of potential invasive organisms. The introduction of invasive species grows exponentially with the increase of trade and travel across international boundaries (Mack and Lonsdale, 2001). Many of these introduced organisms are beneficial, while others have little or no benefit and some species might even have detrimental impacts on their new environments (McNeely, 2001b). Maynard and Nowell (2009) classify the various pathways of introduction into three broad categories, namely natural pathways, accidental pathways and deliberate introductions.

1.2.1 Natural pathways

Natural introduction of potentially invasive species can be divided into passive introduction, such as water or wind movements, and active introduction such as flying, crawling or swimming of organisms. In addition, natural disasters can cause the movement of organisms over abnormally long distances while large-scale modifications of the landscape can create ideal

conditions for invasive species to establish (Maynard and Nowell, 2009). As an example of natural pathways in the CTMA, indigenous range-expanding bird species, such as the hadeda ibis (*Bostrychia hagedash*) (Latham), the pied crow (*Corvus albus*) (Müller) and guinea fowl (*Numida meliagris*) (Linnaeus) are frequently highlighted for their increase in numbers and related nuisance factors. These species naturally expand their distribution range as a result of the suitable habitat in the metropolitan landscape and easily accessible food sources (D. Wright, personal communication). Some of these species, such as the pied crow, have detrimental impacts on indigenous fauna. Although conservation authorities are concerned about these impacts, the management of indigenous range expanding species is complicated and therefore, not yet a consideration.

1.2.2 Accidental pathways

Accidental introductions can occur as a result of ignorance, or invasive organisms being introduced as contaminants of legal trade. For example, the seeds or rhizomes of the invasive yellow floating heart (*Nymphoides peltata* Kuntze (Nymphaeaceae)), were accidentally introduced into New Zealand as a contaminant on imported water lily rhizomes, and has since moved around to many nurseries that stock water lilies (Champion and Clayton, 2000). Aquatic diseases are introduced through ornamental fish hyper-parasites and marine organisms such as the Mediterranean mussel are introduced through ballast water (Maynard and Nowell, 2009). The lack of knowledge of the impacts caused by invasive species can result in aquatic invasive organisms escaping from the overflowing of ponds, or the disposing of unwanted plants into ponds, ditches, streams and rivers. During a survey of sixty-four pet stores in South Africa, Martin and Coetzee (2011) found that 34% of the pet store owners could not identify a single plant species presented in the survey. There is little doubt that the lack of knowledge about invasive species and the related legal requirements amongst pet store owners could cause the repeated importation and trade of harmful species. The fact that 600ha of hydrilla infestation in the Pongolapoort Dam was traced to Malaysian origin, the centre of the aquatic plant and animal trade, supports this point (Madeira et al., 2007).

1.2.3 Deliberate introductions

Deliberate species introductions can be divided into legal and illegal. Introductions without considering the impacts through prior risk assessment may have far-reaching and often unexpected consequences. Species introduction is a practice that has occurred for many thousands of years, especially during the colonial endeavours of the past few centuries. Species were introduced for different purposes, including food, hunting, and ornamental reasons in order to create a sense of home for new inhabitants (Maynard and Nowell, 2009). Early records show that Mediterranean pine species were introduced in the Western Cape

shortly after the arrival of Jan van Riebeeck, during the years 1685 to 1693 for afforestation, construction and aesthetic reasons (Zwolinski, 2007). The main deliberate introduction pathways for aquatic weeds are the aquarium trade through pet stores, online trade and the horticulture industry (Martin and Coetzee, 2011).

1.2.3.1 Aquarium trade and pet stores

The aquarium industry is rated as one of the top five introduction pathways of invasive alien species. Of the species listed on the International Union for the Conservation of Nature (IUCN) Invasive Species Specialist Group's list of the top 100 worst invasive species, one third were introduced via the aquarium trade or through ornamental releases (Padilla and Williams, 2004). The control of just three aquarium-related escapees, purple loosestrife (*Lythrum salicaria* L. (Lythraceae)), spiked water milfoil (*Myriophyllum spicatum* L. (Haloragaceae)), and water-chestnut, (*Trapa natans* L. (Trapaceae)) in the USA cost in excess of US\$ 800 million per year (Cohen et al., 2007). Aquatic weed species introduced into South Africa through the aquarium trade, include dense water weed (*Egeria densa* Planch (Hydrocharitaceae)), fanwort (*Cabomba caroliniana* Grey (Cabombaceae)), tape grass (*Vallisneria spiralis*. (Hydrocharitaceae)) and hydrilla (*Hydrilla verticillata* (L. f.) Royle (Hydrocharitaceae)) (Cook, 1985). To control frequently sold invasive and prohibited species such as *E. densa*, Canadian waterweed (*Elodia canadensis* Michx. (Hydrocharitaceae)) and *C. caroliniana* could ultimately cost the country millions of rands (Martin and Coetzee, 2011).

1.2.3.2 Internet and e-commerce

A relatively new pathway of introduction is via the internet and e-commerce. The invasive seaweed *Caulerpa taxifolia* (Vahl) C. Agardh (Caulerpales), responsible for significant ecological and economic damage around the world, is readily available for purchase over the internet (Derraik and Phillips, 2010). Species movement and introduction of invasive species through the internet is difficult to monitor and regulate. Although online trade is easily accessible and increasingly recognised as an important vector to biological invasions, it has mostly been disregarded by policy makers and researchers (Derraik and Phillips, 2010). Martin and Coetzee (2011) found only eight vendors to be trading online in plants in South Africa, however, more than 40 prohibited invasive species were made available online. It was also found that it is common practice amongst aquarists to trade species online for other plants, and this is impossible to quantify.

1.2.3.3 Horticulture industry

The horticultural industry is an important pathway for species introduction (Reichard and White, 2001). For example, *Salvinia molesta* D. S. Mitch. (Salviniaceae), native to South America and one of the world's most damaging weeds, was introduced in South Africa as an ornamental plant (Henderson et al., 2002), while water hyacinth, a major aquatic weed, was introduced intentionally for its aesthetic and horticultural value (Cook, 1985). Pickerelweed (*Pontederia cordata* L. (Pontederiaceae)), another ornamental plant invading watercourses in the CTMA, was found in a nursery in the CTMA. The movement and trade of submerged aquatic weeds pose significant risk of introductions into the natural environment (Martin and Coetzee, 2011). Martin and Coetzee (2011) identified four risk areas for aquatic weed introductions in South Africa: (a) invasive plants sold by pet stores; (b) a lack of knowledge concerning identification and regulation of submerged species may lead to unintentional trade of potentially invasive species; (c) difficulty to monitor what species and quantities of plants are moved around South Africa by the aquarium industry; and (d) although the internet trade in South Africa has not yet reached its full potential, it may grow into an important pathway in the spread of invasive species and needs to be monitored.

1.3 Metropolitan areas as hotspots for species invasion

Cities are focal points for the global economy and therefore become hotspots for alien and invasive species introductions. The high volume of commodities arriving or passing through metropolitan areas such as CTMA for trade and commercial activities cause them to be vulnerable to invasive species introductions. With the majority of the world's human population living in cities, cities provide entry points for many invasive species (McNeely, 2001a). Not only are Metropolitan areas vulnerable as recipients of invasive species, but they also play a role in the movement of species into other areas.

1.4 Aquatic weed problems around the world

Aquatic weeds infestations in rivers, wetlands and lakes around the world, cause economic, ecosystem and biodiversity problems. Water hyacinth native to the Amazon basin in Brazil, South America, regarded as the world's worst aquatic weed, has spread rapidly in the countries where it was introduced as an ornamental pond plant. It was first introduced in the USA in the 1880s, in Egypt, Australia, and Southern Asia in the early 1890s, in China and the Pacific in the 1900s, and in East Africa in the 1930s, and is now found throughout the tropical regions of the world (Julian et al., 1999a). Water hyacinth occurs in countries such as Mali, Burkina Faso and Niger and is especially damaging in Côte d'Ivoire, Ghana, Togo, Benin and Nigeria where local people depend on the productive areas and lagoon systems for their livelihoods (De Groote et al., 2003).

Since water hyacinth was introduced as an ornamental plant into China in the early 1900s it was spread to 17 provinces as animal feed. Jianqing et al., (2001), describe the water hyacinth infestation in Guangdong, Yunnan, Fujian, Zhejiang and Taiwan as a bio-disaster. Despite an estimated 100 million RMB yuan (US\$ 12 million) spent annually in China on the control of water hyacinth, the weed remains vigorous and continues to spread. Plant diversity in Caohai, a section of Dianchi Lake in the Yunnan province in south-western China, was impacted severely over the past few decades as a result of water hyacinth infestation. For example, the number of water plant species in Caohai decreased over a 30 year period (1960 – 1990) from sixteen to three (Wu, 1993).

Salvinia molesta, is considered one of the world's worst weeds. It was first observed outside of its native range in 1939 in Sri Lanka, and has since become established in more than 20 countries (Nelson, 2009). In 1982 *S. molesta* invaded half of the 500km² lakes in the lower flood plain of Sepik River in Papua New Guinea (Thomas and Room 1986). The first discovery of salvinia in the USA, in South Carolina, was on a small private pond. Although this infestation was eradicated, the weed still spread throughout the USA and was recorded in 12 states, in more than 90 localities and in 41 freshwater drainage areas. It appears on the US Department of Agriculture's Federal Noxious Weed list, but sales still occur through the nursery industry and the species is readily available on the internet (Nelson, 2009). The weed has major ecological and economic impacts. It impedes recreational activities, affects property values and causes agricultural problems, such as clogging water intakes, affecting rice and fish production systems and limiting irrigation (Nelson, 2009).

Two biotypes (monoecious and dioecious) of the submerged weed *Hydrilla verticillata* (L. f.) Royle (hydrilla) were introduced into the USA from Asia. The dioecious hydrilla biotype, denoting that reproductive organs are borne on separate plants, was introduced through the aquarium industry in the 1950s. Although hydrilla appears on the Federal Noxious Weeds List since the late 1970s, and is prohibited in a number of states, inadvertent movement between watersheds occurs through boat trailers. Hydrilla has negative impacts on native submersed plants through competition and affecting the water temperature, pH and oxygen production, causing the habitat to be unsuitable for indigenous species (Haller, 2009a).

Purple loosestrife (*Lythrum salicaria*), an emergent perennial herb originating from Europe and Asia, was introduced into the USA in the early 1800s by settlers on the east coast. The weed was intentionally introduced for its ornamental and medicinal attributes, and is a popular plant for honey production. It is inadvertently spread through, for example, ballast water and seed-

containing wool shipments. *Lythrum salicaria* is a major weed in the USA and occurs in every state and province of the USA and Canada, except Florida (Johnson, 2009). Due to its aggressive nature, *L. salicaria* quickly invades a wide range of aquatic habitats resulting in vast economic and agricultural losses. In the USA alone, the weed causes annual losses of approximately 200,000 acres of wetlands, costing between 45- and US\$ 50 million per annum to control. Substantial economic losses, exceeding millions of US dollars annually as a result of damages to irrigation systems and entire crops of wild rice, are at risk as a result of purple loosestrife invasions (Johnson, 2009).

Aquatic weed infestations impact on biodiversity, the environment, and ecosystem functioning, as well as causing substantial economic losses. When aquatic weeds are left unattended, they are able to cover the surface areas of water bodies. Water hyacinth is the most problematic aquatic weed in South Africa: it is widespread, has severe economic and environmental impacts, and is difficult to control (Coetzee et al., 2011). Water hyacinth is highly competitive and displaces indigenous plants and other invasive species (Wright and Purcell, 1995; Bownes et al., 2010a) and is usually the dominant invader species in aquatic communities (Wright and Purcell, 1995). Under favourable conditions, aquatic weeds proliferate and can cover entire water bodies over a very short period. For example, a single giant salvinia plant can double in size within 5 to 7 days and quickly form dense mats up to 0.5m thick (Nelson, 2009). Water lettuce is acknowledged as being one of the world's worst aquatic weeds. If left unattended, water lettuce spreads quickly; for example, in Cape Recife Nature Reserve, Port Elizabeth, Eastern Cape Province, it invaded a 1.5ha pond within two months (Moore and Hill, 2012). Aquatic weeds limit light penetration into the water column (Henderson and Cilliers, 2002; Van Wyk and van Wilgen, 2002), and as a result reduce zooplankton, deplete fish stocks and cause the disappearance of rare birds such as the case of the African finfoot (*Podica senegalensis* (Vieillot,)) on the Nseleni system in Kwa-Zulu Natal which disappeared with the increase of water hyacinth (Jones, 2001).

Restricted light penetration also reduces photosynthesis of submerged aquatic plants and alters water temperature. Dense infestations deprive water bodies of oxygen by building up organic debris with negative consequences for fish and other aquatic organisms. Poor water quality as a result of accumulated organic matter and low dissolved oxygen levels reduce plant, invertebrate and animal diversity (Nelson, 2009). Public health is threatened in areas where dense aquatic weed infestations occur, as it provides a breeding habitat for vectors of the mosquito-borne diseases malaria and bilharzia (Henderson and Cilliers, 2002).

South Africa is highly dependent on water resources to support the livelihoods of rural communities, as well as for mining, industrial and metropolitan uses (Jones, 2001). Aquatic plants such as water hyacinth impact negatively on water resources by reducing water flow (Henderson and Cilliers, 2002; Van Wyk and van Wilgen, 2002) and increase siltation (Van Wyk and van Wilgen, 2002). Water hyacinth causes water loss through evapotranspiration (Henderson et al., 2002) with each plant being able to transpire on average 5 mm/day (Singh and Gill, 1996). On a 2000ha water body such as Hartebeespoort Dam, losses can add up to 37 million cubic meters costing US\$ 331 244 (Van Wyk and van Wilgen, 2002). Water hyacinth also causes serious economic impacts through damage to bridges, dam walls and canals, stormwater outlets, roads and properties during flooding. It clogs waterways and impedes navigation and recreational activities such as fishing and boating (Jones, 2001; Henderson and Cilliers, 2002; Van Wyk and van Wilgen, 2002).

1.5 Aquatic weed problems in South Africa

In a water-scarce country such as South Africa, water resources are of extreme importance to sustain the environmental, agricultural, industrial and domestic requirements. Services derived from freshwater ecosystems support humans, plants, animals and economic development and growth. Water provision is ensured through water supply schemes in the form of dams, pipelines, inter-basin transfers and canals. Aquatic resources are under pressure from various sources such as over-extraction, river modification, aquatic habitat destruction, development, and industrial, stormwater and domestic runoff (Hill and Olckers, 2001). In addition to these pressures, major impacts are caused by woody and aquatic alien plant invasions on freshwater ecosystems. The four main aquatic weeds at present in South Africa are *Pistia stratiotes*, *Eichhornia crassipes*, *Salvinia molesta* and *Myriophyllum aquaticum* (Coetzee et al., 2011). Red water-fern, *Azolla filiculoides*, is no longer considered a major weed in South Africa as a result of the success achieved with the frond-feeding weevil, *Stenopelmus rufinasus* (McConnachie et al., 2003; Coetzee et al., 2011). The main aquatic weeds, including *A. filiculoides*, originate from South America, and the main pathway for introduction is the ornamental plant trade. All the other aquatic weeds, except water hyacinth, *E. crassipes*, have been brought under complete control as a result of biological control programmes. Biological control programmes against *E. crassipes* have not yet reached their full potential, and it is therefore still the main problematic weed in South Africa. Water hyacinth was introduced in South Africa in the early 1900s (Jacot Guillarmod, 1979) and has since spread rapidly and is found in water bodies throughout South Africa (Figure 1.1) with significant environmental, economic and biodiversity effects.

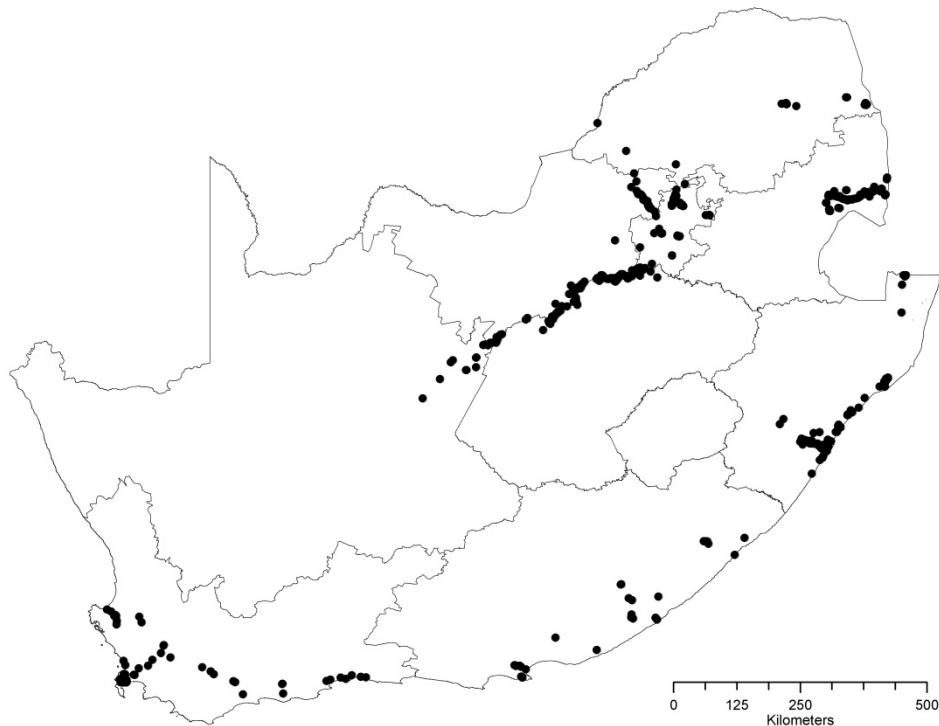


Figure 1.1: Water hyacinth distribution in South Africa (Coetzee, 2012, Rhodes University database)

Water hyacinth forms dense mats and proliferates under high nutrient conditions. The impenetrable mats make it a difficult plant to control. Methods such as herbicidal, mechanical and manual control all provide short-term relief and require regular re-applications (Cilliers, 1991a). Biological control is the most desirable and sustainable control method (Cilliers, 1991a; Julien et al., 1996). Poor integration of other control methods, such as herbicidal control, often impacts negatively on biological control (Hill and Olckers, 2001).

1.6 Aquatic weed problems in the Cape Town Metropolitan Area (CTMA)

The Cape Town Metropolitan Area (CTMA) (33°55'31"S 18°25'26"E) is located in the Western Cape Province and is one of the major metropolitan areas in South Africa (Figure 1.2). The total surface area of the CTMA is 2 455 km². In this thesis I refer to the Cape Town Metropolitan Area (CTMA) which is the physical area of the city while City of Cape Town (COCT) refers to the administrative boundary.

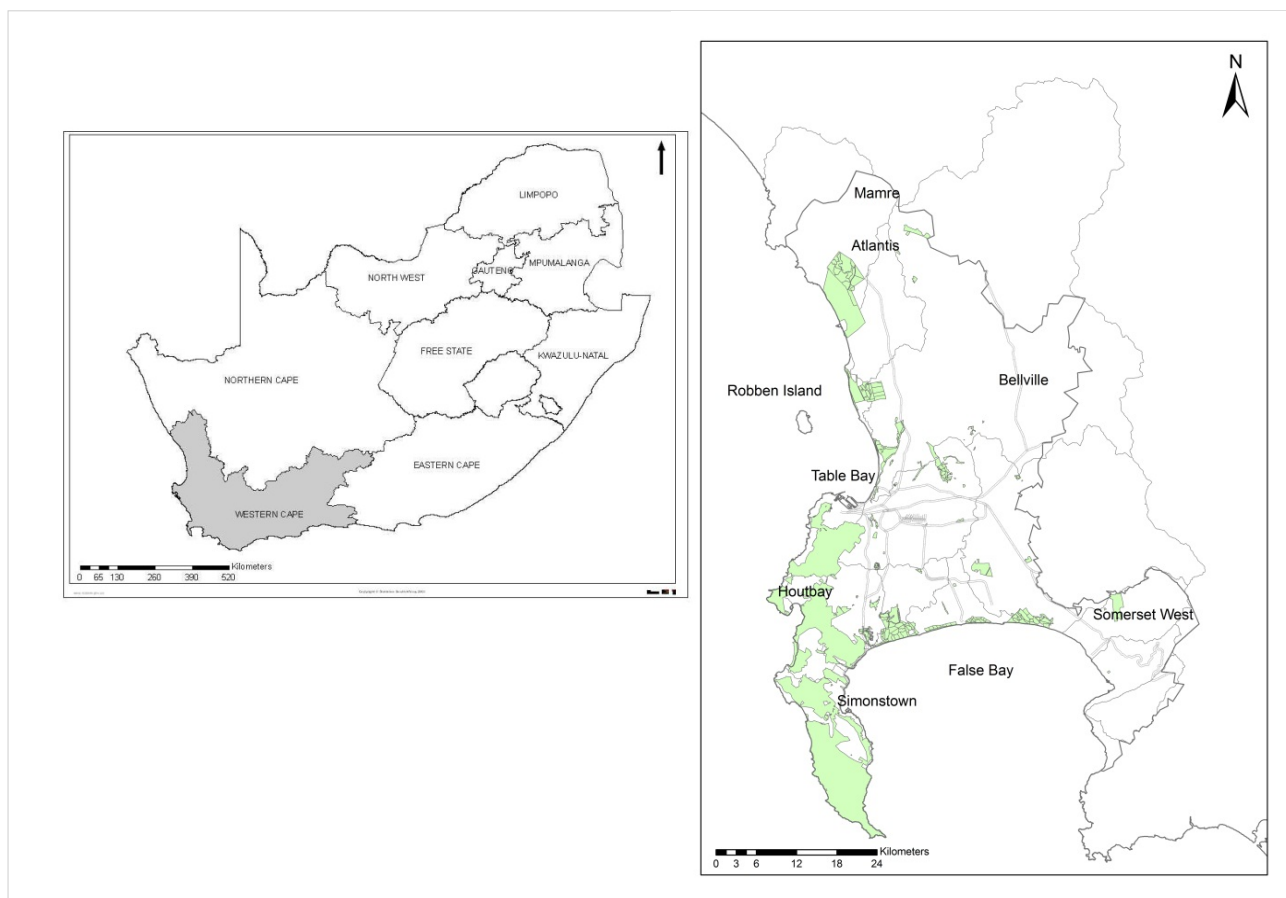


Figure 1.2: Locality of the Cape Town Metropolitan Area (CTMA), Western Cape, South Africa

The highly disturbed CTMA landscape triggers the creation of vacant niches where invasive species thrive, many of them close to natural landscapes such as Table Mountain National Park and the CTMA protected area network. The CTMA is situated in the heart of the Cape Floristic Region (CFR), the smallest of the world's six recognised floral kingdoms, an area known for its extraordinarily high diversity and endemism and home to more than 9 000 vascular plant species, of which 69% are endemic. The CFR is also one of the world's richest and most endangered global terrestrial ecosystems, otherwise known as a global biodiversity hotspot. Table Mountain, with its UNESCO world heritage status and recently-awarded status as one of the world's seven natural wonders, shares its boundaries with an urban environment, the CTMA. The CTMA contains 19 vegetation types of which six are endemic. Of the more than 3 250 plant species (a third of the CFR's plant species) found in the CTMA which includes the Table Mountain National Park, 13 have become extinct and 319 are threatened with extinction. This is exceptional, as, for example, the entire United Kingdom has only just over 1 200 native plant species. The most important threats to this unique biodiversity of CTMA are urban

development and invasive species. Invasive plants not only displace indigenous plants, but they also alter the habitat for wildlife and impact negatively on ecosystems on which people, plants and animals depend for their sustenance and well-being (COCT, 2012).

There are currently 16 aquatic weed species present in the CTMA, representing 15 families, four floating, two floating-attached, eight emerging, and two submerged, (Table 1.1). The four main aquatic weeds in South Africa, all originating from South America, are also found in the CTMA (*E. crassipes*, *P. stratiotes*, *M. aquaticum*, and *S. molesta*). Aquatic weed infestations are exacerbated by the nutrient-enriched water bodies in the CTMA, with negative economic, biodiversity, environmental, and human and animal health impacts

Table 1.1: List of the main aquatic weeds found in the CTMA (adopted from COCT, 2011)

	Species	Common names	Family	Mode of reproduction	Region of origin	Status
Free floating						
1	<i>Azolla filiculoides</i>	Red water fern	Azollaceae	Spores, plant fragments	South America	Established
2	<i>Eichhornia crassipes</i>	Water hyacinth	Pontederiaceae	Seeds, vegetatively, budding	South America	Established
3	<i>Pistia stratiotes</i>	Water lettuce	Araceae	Seeds, vegetatively, budding	South America	Established
4	<i>Salvinia molesta</i>	Giant salvinia, floating fern, Kariba weed	Salviniaceae	Fragmentation (sterile hybrid)	South America	Established
Floating attached						
5	<i>Myriophyllum aquaticum</i>	Parrot's feather	Haloragaceae	Stem fragmentations	South America	Established
6	<i>Nymphaea mexicana</i>	Yellow water lily	Nymphaeaceae	Stolons	North America	Established
Emergent						
7	<i>Commelina bengalensis</i>	Wandering jew, Benghal dayflower	Commelinaceae	Seed, vegetatively	Africa, Asia, Pacific	Established
8	<i>Ludwigia stolonifera</i>	Willow Herb	Onagraceae	Vegetatively	Cosmopolitan	Established
9	<i>Lythrum salicaria</i>	Purple Loosestrife	Lythraceae	Seed, vegetatively	Europe, Asia	Emerging
10	<i>Pontederia cordata</i>	Pickerel weed	Pontederiaceae	Vegetatively	North, Central, South America	Established
11	<i>Nasturtium officinale</i>	Watercress	Brassicaceae	Vegetatively, seed	Europe, Asia	Established
12	<i>Persicaria lapathifolia</i>	Persicaria, curlytop knotweed, pale smartweed	Polygonaceae	Seed	Europe	Established
13	<i>Canna indica</i>	Indian shot	Cannaceae	Seed, vegetatively	Central - South America,	Established

14	<i>Arundo donax</i>	Giant reed	Poaceae	Vegetatively	West Indies North Africa, Western Europe, South East Asia	Established
Submerged						
15	<i>Egeria densa</i>	Dense waterweed	Hydrocharitaceae	Seed, stem fragments	North America	Emerging
16	<i>Ceratophyllum demersum</i>	Rigid hornwort	Ceratophyllaceae	Stem fragments	North America	Established

1.7 Aims of this study and structure of the thesis

The main aims of this study were to determine the status of waterweed infestation and control in the CTMA environs. The legal and regulatory frameworks with respect to aquatic weeds that have to be upheld in the CTMA are reviewed in chapter 2. Chapter 3 determines if biological control can be used as part of an integrated control approach for aquatic weeds in a highly disturbed urban environment , while chapter 4 more specifically investigates why it is not used more as a control intervention . Chapter 5 presents three case studies of the integrated control of aquatic weeds in the CTMA, and finally chapter 6 presents an interpretation of the findings and recommendations for the integration of biological control into existing control strategies for aquatic weeds in urban environments.

Chapter 2

Regulatory Frameworks for Invasive Species Management in South Africa

2.1 Introduction

There is currently no invasive species by-law in the City of Cape Town to regulate the introduction and enforce the control of invasive species within the boundaries of the CTMA. The City of Cape Town relies on the Conservation of Agricultural Resources Act, 43 of 1983 (Anonymous, 1983a) and the Health and Environmental by-law (COCT, 2003) to deal with invasive alien plants. This chapter gives context to international and national legal frameworks for the management of Invasive Alien Species (IAS) and within this framework the City of Cape Town as a local authority is compelled to control aquatic weeds and other invasive species within its area of jurisdiction. Biological control involves the introduction of natural enemies originating from the country of origin of the aquatic weed, and this practice is also regulated by law.

2.2 Convention on Biological Diversity (CBD)

The Convention on Biological Diversity (CBD), an international legally binding treaty, opened for signature at the Earth Summit in Rio de Janeiro on 5 June 1992 and entered into force on 29 December 1993. South Africa ratified the CBD in 1995. The CBD has three main goals: biodiversity conservation, sustainable utilisation of biodiversity and the fair and equitable sharing of benefits arising from the use of genetic resources. Article 8 (h) of the CBD commits participating countries “to prevent the introduction of, to control, or to eradicate those alien species which threaten ecosystems, habitats or species” (Anonymous, 1992).

2.3 International Plant Protection Convention (IPPC)

The purpose of the IPPC is to ensure that signatory countries implement actions to prevent the spread and introduction of plant pests and plant products, and to promote control measures by adopting legislative, technical and administrative procedures. The IPPC further requires signatories to make provision for an official body for plant protection to, among others duties, to control and prevent the outbreak and spread of plant pests, to prevent cross national boundary distribution of plants and plant products, to issue phytosanitary certificates, and to conduct research and investigation in the field of plant protection. Article VI specifies requirements in relation to the regulation of imports with the purpose of preventing the introduction of plant pests and products (FAO, 1999). The National Department of Agriculture, Forestry, and Fisheries

(DAFF's) regulatory process for importing and releasing biological control agents is in accordance with the IPPC (Klein et al., 2011).

2.4 International Standards for Phytosanitary Measures

The International Standards for Phytosanitary Measures (ISPM) was developed by the Food and Agriculture Organisation (FAO) of the United Nations' Secretariat of the International Plant Protection Convention (FAO, 1999). The ISPM provide protocols for biological control release applications regulating the import and release of biological control agents (Klein et al., 2011).

2.5 The Constitution of the Republic of South Africa, 1996

Section 24, Environmental Right, states that everyone has the right to have the environment protected through reasonable laws or other means that: (a) prevent ecological degradation; (b) promote biodiversity conservation; and (c) secure ecologically sustainable development while promoting justifiable economic and social development (Anonymous, 1996). Invasive plants impact negatively on the environment, biodiversity, ecologically sustainable development and the use of natural resources. Section 24(A) places an obligation on the state to protect the environment "for the benefit of present and future generations" by means of reasonable legislative and other measures. These measures are aimed at reaching specific environmental goals, namely preventing pollution and ecological degradation; promoting conservation; and safeguarding ecologically sustainable development and the use of natural resources "while promoting justifiable economic and social development". This places an obligation on the state to implement reasonable legislative or other measures to ensure the eradication or control of invasive alien species. Section 27 of the Bill of Rights in the Constitution of the Republic of South Africa stipulates that everyone in South Africa has "the right to have access to sufficient water" and that "The State must implement reasonable legislative and other measures to achieve the progressive realisation of each of these rights". This section thus relates to the control of invasive plants because of their detrimental impacts on water resources.

2.6 The Agricultural Pests Act, No.36 of 1983 (APA) as amended

The importation and release of agents for biological control in South Africa is currently regulated by the Division of Plant Health in the Department of Agriculture, Forestry and Fisheries (DAFF) by means of the Agricultural Pests Act (APA), No.36 of 1983 (Anonymous, 1983b) and its amendments. Before DAFF issues a permit, certain information is required concerning the target weed, namely the candidate biological control agent, the intended research, and the potential impact of the biological control agent on the environment (Holzhausen and Bolton, 1994). A permit is issued for the import of a biological control agent on condition that the agent is restricted to an approved quarantine facility. On receipt of a comprehensive report and

recommendations for release, reviewed by biological control specialist scientists, DAFF lifts the quarantine restrictions (Klein et al., 2011).

2.7 The Conservation of Agricultural Resources Act, 43 of 1983 (CARA) as amended

The Conservation of Agricultural Resources Act 43, of 1984 (CARA) is aimed at combating the spread of “weeds” and “invader plants”(Anonymous, 1983a). Although the CARA regulates agricultural resources, section 2(2)(a) of the act relates to alien vegetation on municipal land, stating that “[t]he provisions of this Act relating to weeds and invader plants shall also apply to land which is situated within a metropolitan area”. Landowners are obliged to control weeds occurring on their property by means of prescribed control measures. CARA is administered by DAFF, through its Directorate: Land Use and Soil Management (D:LUSM). The act empowers the Minister of Agriculture to prescribe “control measures” in order to (*inter alia*) control weeds and invader plants. The 2001 Regulations classified plants as either “weeds” or “invader” plants and grouped them into three categories, namely category 1, 2 and 3 plants.

Category 1 Declared weeds: Prohibited plants that may not occur on any land or inland water surface other than in biological control reserves. Land users of the land or inland water surfaces are therefore obliged to control category 1 weeds by means of prescribed methods. Land users are prohibited from carrying out certain activities in relation to category 1 plants such as planting, propagating, importing and selling. Category 2 Declared invader plants: with commercial or utility value, for example, animal fodder, soil stabilisation or woodlots, are only allowed to grow in specified demarcated areas under controlled conditions and in biological control reserves. A permit is required and steps are to be taken to prevent their spread. Regulations apply to the sale, acquisition and importation of propagating material of category 2 plants. Category 3 Mostly ornamental plants: May no longer be planted. Those plants that were “already in existence at the time of the commencement of the regulations” can remain, but reasonable steps are to be taken to prevent their spread. The exemption of category 2 and 3 plants does not extend to plants occurring within 30 meters of the 1:50 year flood line of certain water sources, or in wetlands.

Resource Auditors are authorised to visit any property at a reasonable time to inspect it for the presence of declared weeds or invader plants (Anonymous, 1983b). Currently thirteen aquatic plant species are declared weeds or invader plants in South Africa (Henderson and Cilliers, 2002) and their control is subject to the CARA (as amended in 2001).

2.8 National Water Act 36, of 1998

Although the National Water Act does not explicitly mention invasive aquatic weeds, the provisions of the Act are relevant because water is a scarce and unevenly distributed national resource. The Act aims to promote the efficient, sustainable and beneficial use of water in the public interest. Invasive plants impact on water resources, and should therefore be controlled and managed to ensure the sustainability of the resource. The National Water Act imposes a general duty of care on landowners, land managers, and land users to prevent pollution of water resources and to address the effects of such pollution if it has already occurred. The negative impacts of invasive alien plants on water resources can be defined as “pollution” and require control. According to the Water Act, the national government is the public trustee of all water resources. Because invasive plants use more water than indigenous plants (Le Maitre et al., 2002; van Wilgen et al., 2008), landowners with invasive plants on their land are therefore responsible for the additional water use. Section 151(1)(j), states that no person may “unlawfully and intentionally or negligently commit any act or omission which detrimentally affects or is likely to affect a water resource” (Anonymous, 1998a).

2.9 National Environmental Management Act 107, 1998 (NEMA)

The Department of Environment Affairs (DEA) is the authority responsible for implementing the NEMA. The NEMA section 28 places a general duty of care on all persons to take reasonable measures to prevent pollution or degradation of the environment. In light of the negative effects alien plant infestations have on the environment, the impact of invasive alien vegetation could be seen as “degradation” of the environment. Actions to prevent the degradation may include the management and control of invasive plants. In terms of section 30 of the NEMA the relevant authority may request a person causing pollution or damage to the environment to control or eliminate these adverse effects which may include removing the cause of the pollution or degradation (Anonymous, 1998b).

2.10 The National Environmental Management: Biodiversity Act 10, of 2004 (NEM:BA)

The NEM:BA Chapter 5 deals with invasive species in the context of the threat they pose to biodiversity. The objectives of Chapter 5 are to: (a) prevent the unauthorised introduction and spread of alien and invasive species; (b) manage and control alien and invasive species with a view to preventing or minimising harm to the environment and biodiversity; and (c) eradicate alien and invasive species from ecosystems and habitats where they are causing harm.

In addition, according to Section 73:

- Landowners must notify the competent authority of the presence of a listed invasive species on their land and take steps to control or eradicate the species, prevent it from spreading and prevent or minimise harm to biodiversity;

- Competent authorities may direct persons who have engaged in restricted activities involving listed invasives without a permit, or who, as landowners, have failed to meet their obligations, to take such steps as may be necessary to remedy any harm caused to biodiversity;
- Should the person fail to implement the directive, the competent authority may do so and then recover the costs.

Section 75 makes provision for the (1) control and eradication of listed invasive species by means of appropriate methods in such a way that it (2) minimises harm to biodiversity and the environment. Section 76 deals with invasive species control plans for organs of state, requiring (2) (a) all organs of state in all spheres of government to prepare an invasive species monitoring, control and eradication plan for land under their control; (b) The invasive species monitoring, control and eradication plans of municipalities to be part of their integrated development plans (IDPs). Subsection (4) states the content of the control plans to include (a) a detailed list and description of listed invasive species on the land; (b) a description of the invaded areas; (c) the extent of the infestation; (d) a status report regarding the efficacy of control and eradication measures; (e) the current monitoring, control and eradication measures; and (f) measurable indicators of progress and success, and indications of when the control plan is to be completed (Anonymous, 2004).

2.11 Discussion

Even the best legislation is meaningless without enforcement. Capacity is required in terms of skills, funding, appropriately trained staff, support systems and protocols for communication and decision-making. Currently, a gap exists in South Africa in terms of implementation capacity. The main pieces of legislation in South Africa dealing with invasive species are NEMBA and CARA, which are implemented by different national departments, DEA and DAFF respectively. The NEMBA regulations were still in the process of being completed at the time of writing this thesis. Although the current situation does not provide an optimal legal environment for managing invasive species, it does waive public and private landowners' responsibility to manage invasive species. To give effect to the legal obligations placed on managers, invasive species control programmes are implemented at all the different tiers of government. The DEA Natural Resource Management Programme's (NRMP) Working for Water (WfW) implements a large-scale national invasive plant management programme since 1995. Working for Water uses implementing agents to manage invasive plant control projects across South Africa. The City of Cape Town was appointed as an implementing agent for Working for Water in 2010. The WfW programme also makes provision for a landowner incentive and disincentive scheme to compel landowners to manage invasive plants on their properties (Working for Water, 2008).

Although CARA applies to agricultural and urban land, DAFF understandably focuses more on agriculture than on the urban environment, as a result of the capacity constraints. DAFF is responsible for serving notices on private landowners to control aquatic plants, but due to the resource and capacity limitations, serving notices on private landowners in the CTMA seldom happens, with the result that aquatic weed management on private dams cannot be enforced. The City of Cape Town relies on the goodwill and understanding of landowners about the impacts posed by aquatic weeds to get them to control aquatic and other invasive plants.

The City of Cape Town does not currently have an invasive species by-law. The Environmental Health by-law, part 1, entitled “Prevention and suppression of health nuisances”, Section 1, determines that “no person shall allow any erf to be overgrown with bush, weeds or grass or other vegetation, except cultivated trees, shrubs and grass, to such an extent that, in the opinion of the Council, it may be used as a shelter by vagrants, wild animals or vermin or may threaten the public health or the safety of any member of the community” (COCT, 2003). Aquatic weeds may provide breeding habitats for mosquitos and vectors of mosquito-borne diseases (Henderson and Cilliers, 2002; Nelson, 2009) and can therefore be considered as a health hazard under this section of the Environmental Health by-law. Furthermore, dense water hyacinth infestations may result in flooding and therefore threaten public safety, compelling landowners to control infestations to prevent flooding. This by-law is not adequate for the prevention and control of aquatic weeds, and in order to overcome this inadequacy the city can either develop an invasive species by-law or apply to be appointed as competent authority in terms of NEM:BA. A competent authority can serve notices on private landowners. It is recommended that the city develops and adopts an invasive species by-law to issue notices for prevention and control of invasive species.

Section 76 of the NEM:BA determines that appropriate control and eradication methods should be applied in such a way that they cause minimum harm to biodiversity and the environment. This raises the questions of, firstly, what can be considered appropriate methods, and secondly how these measures can be applied to cause minimum harm and to achieve maximum efficiency and effectiveness in dealing with invasive species. The next chapter provides an overview of the available control methods for aquatic weeds, their advantages and disadvantages, and how to integrate different control methods to ensure sustainability and the best return on investment.

Chapter 3

Aquatic Weed Management Options

3.1 Introduction

Different strategic options are deployed against invasive species, namely prevention, early detection and rapid response, containment and control. Pre-border interventions involve the prevention of species from entering the country's borders through deploying biosecurity measures as the first line of defence (Maynard and Nowell, 2009). If a potentially invasive species enters a country's borders and it is detected during the early stages of invasion, while the population is still small and localised, eradication is still possible (Halcombe and Stohlgren, 2009). Once a species becomes established in its new environment and it starts spreading, eradication is no longer possible. The available options to manage such a species are containment or control (Grice, 2009). For management programmes to be effective, they should have clear, achievable targets and include a monitoring programme to assess progress against the targets (van Wilgen et al., 2012).

3.2 Preventing the introduction of invasive and potentially invasive species

Prevention is the first line of defence against biological invasions, and involves measures to prevent invasive and potentially invasive species from entering the country's borders. According to Maynard and Nowell, (2009) actions to prevent species introductions can be divided into three broad categories, namely pre-border-, at the border -, and emergency actions. Pre- border actions involve risk assessments and implementing risk mitigation actions. Actions at borders include inspection of goods, keeping species in containment for observation, and destroying them or returning them to their place of origin if they are found to be harmful. Emergency actions are implemented if an undesirable species is detected after entering the country's border. It is necessary to ensure that contingency response plans are included in risk assessments to trigger the appropriate emergency responses.

Although prevention is a national departmental (DAFF) responsibility, provincial and local authorities have an important role to play in preventing invasive species introductions and movement between biomes and regions. Industries such as the nursery, pet and aquarium trades are major aquatic weed introduction pathways, and therefore they are important role-players in preventing introduction of invasive weeds into the country (Martin and Coetzee, 2011). The South African Nursery Association (SANA) is the regulatory authority of nurseries in

South Africa, and nurseries affiliating with SANA are collaborating with authorities to prevent invasive species introductions. The challenge lies with the nurseries not registered with SANA and with the informal sector, such as street vendors trading in invasive aquatic weeds and the internet trade (Martin and Coetzee, 2011). In the absence of enforcement capacity, trading in invasive aquatic plants will continue. Educating the public and finding ways to obtain buy in from the informal sector are important, but in reality very difficult to obtain.

3.3 Early Detection and Rapid Response

The second line of defence is detecting an invader species before it forms established populations and invades large areas. During the early stages of invasion, small populations are found in the landscape or water bodies, and responding rapidly by removing these small infestations could save cost and prevent detrimental environmental impacts. Halcombe and Stoltgren (2009) use a wildfire as a metaphor for invasion. Wildfires send out sparks causing spot fires in areas where the conditions are favourable for a fire to start. Wildfire managers prioritise these small spot fires and respond quickly to put them down before they are allowed to grow larger. Plant and animal invasions work in the same way by starting small populations away from the parent. Responding rapidly and removing them before they become established and start spreading results in saving costs over the long term. Invasive species management always competes for resources with other services such as health and education, and it is therefore essential to prioritise rapid response actions. Focussing on smaller infestations slows down the spread of invasive species and requires fewer resources than tackling large, well-established invasions (Rejmánek and Pitcairn, 2002).

The South African National Biodiversity Institute's (SANBI's) Early Detection and Rapid Response Programme (EDRR) has been funding the City of Cape Town since 2011 to implement an EDRR programme in the CTMA. The programme depends on civil society to participate and report target species. An online spotter network (<http://www.capetowninvasives.org.za/edrr>) has been established whereby the public can report the target species, which in turn triggers rapid response. *Lythrum salicaria* is currently the only aquatic weed listed as target species for eradication.

The challenge lies with how to detect small infestations, especially in complex environments such as urban areas. Many potential and existing invasive species are found on private properties, estates or in areas where safety is an issue and access is difficult. Species are often not detected before they spread beyond these properties or wash down rivers and streams. The second challenge is that it is not possible to know the extent of the distribution unless all the species are located. Spotter networks are one of the ways to encourage the general public to

report species localities. Web-enabled spotter sites such as iSpot and the City of Cape Town's spotter network, which are available and accessible to the public, are powerful tools whereby small invasive species populations can be detected.

Another public involvement programme, the river warden system, was initiated in January 2012 in the CTMA. River wardens patrol and survey priority water bodies to detect aquatic weed infestations during the early stages of invasion, and to remove them before they establish and spread. Not only is the river warden system an effective way of detecting early infestations, but it also provides much needed jobs to alleviate the high unemployment in the City of Cape Town. Friends Groups in various parts of the CTMA work closely with the river wardens in alerting them about invasive plant infestations and other problems associated with urbanisation such as illegal dumping.

3.4 Integrated Weed Management

The term Integrated Weed Management (IWM) has been used by scientists since the 1970s and refers to the integration of different control methods. IWM involves a broad-based approach to ecosystem management and combines the use of different of control methods to achieve the desired results (Walker and Buchanan 1982). Integrated Weed Management can be defined as "the application of many kinds of technologies in a mutually supportive manner. It involves the deliberate selection, integration and implementation of effective weed control measures with due consideration of economic, ecological and sociological consequences" (Buchanan, 1976).

Control methods are not mutually exclusive, and the best results are achieved when using a combination of suitable methods for the control of aquatic weeds such as physical removal either by hand or machine, chemical control and biological control. Mechanical and chemical control can never achieve eradication of invasive plants (van Wilgen and De Lange, 2011). Invasive plant management require on-going, long-term human and financial resources to keep cleared areas under control, to prevent species from reaching their full capacity and to control emerging invader plants. There is no guarantee that the current levels of resources allocated by the Working for Water programme can be sustained in perpetuity. A more sustainable and cost effective control method is required to be integrated into invasive plant management operations. Biological control is an economically feasible method as it is relatively cheap and sustainable for as long as the biological control agents are active on the host plants.

Van Wyk and van Wilgen (2002) studied the cost of water hyacinth control in South Africa by means of three case studies. The three sites represented different control methods: herbicides at Hartebeespoort Dam, which is 2000ha and situated in the North-West Province; biological

control at New Year's Dam which is 80ha in the Eastern Cape Province; and integrated control at the Mposha River which drain into Lake Nsezi, which is 260ha and located in Kwa-Zulu Natal. This study found integrated control to be the most cost effective control option at a cost of US\$ 24.80/ha, while herbicide control is at least five times less cost effective than either biological or integrated control, at US\$ 132.58/ha. Herbicide control requires on-going resource-intensive follow-up applications. Biological control is a long-term, more cost-effective option at US\$ 27.66/ha and potentially US\$ 0.32/ha if the site is not intensively monitored. Although biological control on its own is less effective than integrated control, where it is effective on its own, it is potentially more than 400 times more cost effective than herbicide control at a ratio of US\$ 132.59/ha:US\$ 0.32/ha (Van Wyk and van Wilgen, 2002).

A strategy should therefore be to maximise biological control on those aquatic weeds where agents are available, and re-direct resources to focus on those where biological control options have not yet been researched (van Wilgen and De Lange, 2011). For example, for *Nymphaea mexicana* (yellow water lily), a rapidly expanding species in the CTMA, no biological control agents are available and it is an extremely difficult plant to control. Instead of clearing weeds where biological control is already effective, resources should be directed to control *N. mexicana*.

3.4.1 Mechanical control of aquatic weeds

Mechanical control of aquatic weeds includes the utilisation of heavy machinery, such as long reach excavators or weed harvesters, to remove aquatic weeds from water bodies. The nature of the water body and the weed to be removed are important when considering the selection of the type of machinery to be used (Haller, 2009b). Mechanical means of control are expensive and damaging to morphological structure of water bodies. Mechanical harvesters or swan neck cranes are often abandoned because they are ineffective and costly without any long-term results (Julien et al., 1999). Another means of mechanical control includes dragging a heavy chain along a stream between two tractors to dislodge rooted weeds. This method is also highly detrimental to river and wetland ecology and therefore not desirable. Weed harvesters cut and pick submerged weeds from a water body and convey them to the side. In high discharge canals and very large water bodies, weed cutters or harvesters are used to control rooted aquatic weeds. Dredging, by means of a machine equipped with a forked bucket that can be opened or closed, is used on large water bodies to remove weeds and excess silt. It is a slow, costly and time consuming method (Lancar et al., 2002).

The need to improve river hydrology prior to winter rains in the CTMA causes mechanical control to be the preferred method for the removal of aquatic weeds. Mechanical control works

antagonistically to biological control because biological control agents cannot establish viable populations in order to do damage to the weeds when machines are regularly deployed to remove reeds, silt and aquatic weeds. A more cost effective long-term solution is to improve water quality since excessive reed infestations and aquatic weeds are a result of poor water quality.

The disadvantages of mechanical control outweigh the advantages (Table 3.1), and should therefore only be used when there is an immediate risk of flooding. The water bodies in the CTMA are high in nutrients and as a result, aquatic weeds grow rapidly after mechanical removal, causing mechanical control to be impractical (McConnachie et al., 2003).

Table 3.1: Advantages and disadvantages of mechanical control

ADVANTAGES	DISADVANTAGES
Immediate results by opening a water body for boat traffic, fishing and recreation (Villamagna and Murphy, 2010).	Large machines and equipment are expensive and mechanical control may not be cost effective for large water bodies (Villamagna and Murphy, 2010).
Increase dissolved oxygen as a result of water flowing into the water body (Perna and Burrows, 2005).	Large machinery damage river banks and riparian zones and increase siltation (personal observation).
Under emergency situations where aquatic weed mats pose an immediate danger to infrastructure and cause flooding, mechanical removal of the mats can reduce the risk in a short period of time.	Long reach excavators do not remove all the plants and leave fragments behind, resulting in re-invasion (Haller, 2009b). Large machines are not selective (Haller, 2009b) and remove biological control agents with the weeds, causing agent population to crash (Personal observation). Weed regrowth occur soon after mechanical control (Haller, 2009b).

3.4.2 Manual control of aquatic weeds

Manual control refers to the use of labour intensive methods to remove aquatic weeds, using equipment such as fork-spades and rakes. Manual control of weeds is time consuming and not

ideal for large infestations (Hill et al, 1999a). Small boats or floats are often used to load the weeds and are then pulled to the banks to offload the biomass.

If correctly applied and under the appropriate conditions, manual control offers some advantages (Table 3.2), the most important of which is the creation of employment opportunities. Manual control can be successfully integrated with biological control. Not all aquatic weeds are targets for biological control, but grow in the same water body as the weeds with biological control. Manual and biological control are successfully integrated where the weeds without biological control, such as *Pontederia cordata* and *Nymphaea mexicana*, are manually removed, while weeds such as *P. stratiotes* and *M. aquaticum* are left for biological control. Manual control is a means of addressing socio-economic problems by creating much needed jobs. Through integrating biological and manual control, jobs are created, while aquatic weed problems are addressed.

Table 3.2: Advantages and disadvantages of manual control

ADVANTAGES	DISADVANTAGES
Effective in small water bodies and small infestations (Nelson, 2009).	Labour intensive, costly (Nelson, 2009).
Can be effectively integrated with biological control.	Water bodies are quickly reinvaded, requiring on-going follow-up interventions.
A means of addressing socio-economic issues through job creation.	Impractical for larger infestations (McConnachie, et al., 2003)

3.4.3 Chemical control of aquatic weeds

The use of registered herbicides to control aquatic weeds is a method that is widely used in South Africa and in other parts of the world. The advantages and disadvantages (Table 3.3) of controlling aquatic weeds with herbicides, and whether herbicides can be integrated with biological control, will be discussed in this section.

Herbicides can be applied as either foliar or submersed treatments, or as a combination of the two, and their mode of action can be either systemic or contact. Foliar application involves the mixing of herbicides with water according to the label instructions, and spraying the mixture directly on emergent, floating-leaved, and free-floating aquatic weeds. Submersed herbicides are applied to the entire water column and used to control submersed aquatic weeds or planktonic algae. These herbicides occur in different forms: concentrated liquids, granules or

pellets (Netherland, 2009). Systemic herbicides are slow acting, and distributed throughout the plant, resulting in mortality of the entire plant. Contact herbicides are fast acting, causing cellular damage on the plant tissues they touch, but may not kill roots, rhizomes or root crowns (Petty, 2005). The recommended herbicides for controlling aquatic weeds in South Africa are diquat (dibromide) and glyphosate (ammonium; isopropylamine; potassium and sodium), applied as foliar or aerial spray regimes in specific formulations (Working for Water, 2013). Effective chemical control requires long-term vigilance, strict spray regimes, frequent re-applications and skilled operators (Julien et al., 1999) (Table 3.3).

Table 3.3: Advantages and disadvantages of chemical control

ADVANTAGES	DISADVANTAGES
Immediate impact, results visible over a short period (Van Wyk and van Wilgen, 2002).	Far-reaching ecological impacts (Rocha-Ramirez et al., 2007) and dangerous de-oxygenation of water (Lugo et al., 1998).
Can be integrated with biological control under certain strict protocols (Byrne, et al., 2010; Jones, 2001).	No long-term solution without substantial financial investment (Van Wyk and van Wilgen, 2002).
	On-going applications required to suppress weeds (Van Wyk and van Wilgen, 2002) up to a period of 20 years (Wise et al., 2007).
	Decaying large masses of dead plants have negative impacts on water body (Van Wyk and van Wilgen, 2002).
	Risk of herbicide spray drift (Van Wyk and van Wilgen, 2002).
	Appearance of herbicide resistant weeds (Van Lenteren, 2012; Ghosheh, 2005) following the large scale pesticide application in the 1950s (Van Lenteren, 2012).
	Non-target effects on aquatic plants e.g. algae, a critical foundation of aquatic food webs (Wetzel, 1983) and macrophytes (Seagrave, 1988).
	Contamination of water bodies (Ghosheh, 2005).

The disadvantages of herbicide control outweigh the advantages (Table 3.3). However, there is a place for herbicide control if used within strict protocols, with careful planning and implemented by experienced and appropriately equipped operators. *Ad hoc* applications of lethal dosages of herbicides destroy entire populations of biological control agents (Hill and Cilliers, 1999; Hill and Olckers, 2001). Herbicides can be effectively integrated with biological control when applying glyphosate based herbicides at a sub-lethal dosage (Hill et al., 2012; Jadav et al., 2008; Byrne et al., 2010). At low dosages, herbicides containing glyphosate have insignificant impacts on biological control agents such as the *Neochetina* weevils, the water hyacinth mirid, *E. catarinensis* and on other aquatic fauna such as amphibians. Sub-lethal dosages also do not kill plants, but stop the production of new leaves for more than eight weeks (Jadav, et al., 2008). However, plants proliferate under high nutrient conditions and recover quickly after spraying with a lethal dosage; a sub-lethal dosage will therefore have very little effect. Label instructions for glyphosate based herbicides recommend a 3% lethal dosage to compensate for the varying sizes of plants occurring in water bodies. When spraying entire water bodies with a lethal dosage of glyphosate herbicides, biological control populations are wiped out (Byrne et al., 2010). Adjustments to the application methods by spraying a lethal dosage in the middle of the infestation, but not dosing the perimeter will overcome this problem. Although the perimeter will be subjected to herbicide drift, it will occur at a sub-lethal level, which will not kill the plants or the biological control agents, and allow weevils to migrate from the lethally sprayed area (Hill et al., 2012; Byrne et al., 2010). This method ensures that biological control agents are able to survive herbicide applications and build up their numbers to contain resurgence after spraying and to suppress the plants weakened by the herbicide application (Byrne et al., 2010).

3.4.4 Biological control

In its natural environment, plants and animals form part of a complex ecosystem, kept in balance by different processes. Natural enemies such as insects, mites and pathogens (disease-causing organisms such as fungi) play a role in maintaining the balance within and between species, and prevent one species from dominating another. Anthropogenic movement of species around the world cause species to arrive at their new destinations without their natural suite of enemies that suppress them in their native ranges (Henderson, 2001; Zimmermann et al., 2004). There are various barriers a species must overcome before it can naturalise and become invasive, and one of these is escaping its natural enemies (Maynard and

Nowell, 2009). The natural enemies or biological control agents target specific parts of a plant, such as the leaves, roots or stems (vegetative parts) or the flowers, seeds or fruits (reproductive parts) (Klein, 2002). Different types of biological control agents have different feeding habits and the maximum effect is achieved by a combination of agents feeding on different parts of the weed. Biological control is the practice of sourcing, host specificity testing, and transferring suitable natural enemies, such as host specific plant feeding insects, mites and pathogens, from their country of origin and releasing them in the country where the weed has become a problem (Zimmermann et al., 2004). The natural enemies remove the competitive advantage a species may have in its new habitat to a level comparable to the indigenous species (Klein, 2002). It provides opportunities to halt or even reverse the rapid increase of invasive alien plants, and the resulting degradation of the ecosystems they invade (van Wilgen et al., 2013).

3.4.4.1 Advantages of biological control

Biological control offers many advantages to managers as a non-labour or equipment-intensive method, and potentially offers a self-sustainable alternative to physical removal (Seagrave, 1988). Biological control is relatively cheap in comparison with other control methods, and very safe when compared with risks posed by chemical control (van Wilgen and De Lange, 2011).

Biological control is a cost-effective, permanent, environmentally friendly and self-sustaining control method (Seagrave, 1988; De Groote et al., 2003; Zimmermann et al., 2004) and should be started as soon as an infestation is noticed (De Groote et al., 2003). However, this method is seldom employed early enough, and is usually implemented as a last resort.

Biological control can be integrated with other control methods, and should already be considered as an option during the planning stages of weed management programmes. Benefits are to be viewed on a case by case basis in order to gain the most advantage out of biological control. This is due to the fact that what works in one system may not necessarily apply to the next.

The integration of biological control into aquatic weed management in urban areas has many advantages. Aquatic weed management competes with other resources such as housing, health, safety and security, and infrastructure maintenance, along with various other important services in society. The highly eutrophic aquatic ecosystems found in a city like Cape Town provide ideal conditions for aquatic weeds to proliferate, with negative consequences to the environment and the economy. Aquatic weeds with effective biological control can be left for the agents to establish populations and reduce the infestations while resources can be focussed on those species without biological control. In so doing, the highest return on financial investments is achieved. With the many existing pressures on water bodies in the CTMA, biological control

provides the opportunity to avoid yet another pressure such as the introduction of harmful chemicals into the environment (Seagrave, 1988). Further, many water bodies in the city are not accessible due to safety concerns, dense reeds and at certain times of the year, the threatened endemic western leopard toad (*Amietophrynus pantherinus* (Smith) (Bufonidae)), which breeds in water bodies on the South Peninsula. Under these circumstances, biological control agents provide an economically viable alternative for controlling aquatic weeds.

3.4.4.2 Disadvantages of biological control

Although biological control is widely regarded as the most appropriate long-term control option with many advantages, there are some disadvantages. However, if projects are carefully selected and rigorous procedures are followed to minimise risk, the advantages of weed suppression through biological control outweigh the disadvantages (Fowler et al., 2000). The disadvantages include high initial expenses (Fowler et al., 2000; Cuda, 2009) and the time period to develop successful biological control programmes (Cuda, 2009). The methods are time-consuming and the ultimate extent of the impact is often uncertain (Fowler et al., 2000). In addition, the establishment and control of the target weed is not guaranteed (Cuda, 2009).

3.5 Biological control against the five main aquatic weeds

Four of five main aquatic weeds in South Africa, which also occur in the CTMA, are free-floating weeds. The rooted plant, *Myriophyllum aquaticum*, or parrot's feather, has terminal emerging leafy shoots which appear above the water surface (Henderson, 2001). These weeds are native to South America and were introduced to areas outside their native range through the ornamental plant trade. In the absence of their natural enemies, they proliferate, invade large areas and have reached pest status in their introduced range. Aquatic weed biological control in South Africa started in 1974 on water hyacinth, and since then, biological control also started on *Salvinia molesta*, *Pistia stratiotes*, *M. aquaticum* and *Azolla filiculoides*. The most successful aquatic weed biological control programme in South Africa was achieved on *A. filiculoides* with the frond feeding weevil *Stenopelmus rufinasus* Gyllenhal (Coleoptera: Curculionidae). This weed has been brought under complete control and no further action is required (McConnachie et al., 2003; Coetzee et al., 2011). *Salvinia molesta*, *P. stratiotes* and *M. aquaticum* were also brought under complete control in South Africa through biological control alone (Coetzee et al., 2011). Biological control on *E. crassipes* in South Africa was successful on some sites, but lack the success of the other species (Hill and Olckers, 2001; Coetzee et al., 2011). The spectacular successes achieved with biological control against, for example *A. filiculoides*, created the perception that biological control on its own is the solution to all cases of invading species (Hoffmann and Moran, 2008). This is not entirely true for water hyacinth, where biological control is the most effective when integrated with other methods (Byrne et al., 2010).

3.5.1 Biological control of water hyacinth

The importance of the water hyacinth problem in South Africa is realised when considering that 10 researches were involved in investigating biological control of water hyacinth at any one time over the last 15 years (Coetzee et al., 2011). Since 1974 eight species of biological control agents have been introduced, either deliberately or accidentally, against water hyacinth in South Africa, namely two weevils, a moth, a leaf sucking mirid, a pathogenic fungus and a mite (Table 3.4) (Cilliers, 1991a; Coetzee et al., 2011). Two more biological control agents were introduced against water hyacinth recently, the grasshopper *Cornops aquaticum* Br  ner (Orthoptera: Acrididae: Tetrataeniini) in 2011, and a bug *Megamelus scutellaris* Berg (Hemitera: Delphacidae) in 2013. This makes South Africa the country with the highest number of biological control agents against water hyacinth in the world (Coetzee et al., 2011).

Table 3.4: Biological control agents released against water hyacinth in South Africa

Year	Agent	Type
1974 - 1985	<i>Neochetina eichhorniae</i> Warner (Coleoptera : Curculionidae)	Weevil – stem borer
1992	<i>Cercospora rodmanii</i> Conway (Mycosphaerellales: Mycosphaerellaceae)	Anamorphic fungus – leaf pathogen
1990 and 1996	<i>Neochetina bruchi</i> Hustache (Coleoptera : Curculionidae)	Weevil- stem borer
1989	<i>Orthogalumna terebrantis</i> Wallwork (Acari: Sarcoptiformes: Galumnidae)	Mite – leaf miner
1990	<i>Niphograptia albiguttalis</i> Warren (= <i>Samoides albiguttalis</i> (Warren)) (Lepidoptera: Crambidae)	Moth – petiole borer
1996	<i>Eccritotarsus catarinensis</i> Carvalho (Hemiptera: Miridae)	Mirid – leaf sucker
2011	<i>Cornops aquaticum</i> Br��ner (Orthoptera: Acrididae: Leptysminae)	Grasshopper, leaf feeder
2013	<i>Megamelus scutellaris</i> Berg (Hemitera: Delphacidae)	Bug – leaf sucker

Despite this achievement of having the highest number of biological control agents against water hyacinth in the world, successes in South Africa do not compare well to other countries (Hill and Olckers, 2001; Bownes et al., 2010a). Various factors contribute to the lack of success, such as nitrate and phosphate-enriched surface waters, cold winter temperatures, stochastic events such as flooding, insufficient effort or number of releases (Hill and Cilliers, 1999a), the use of herbicides, and the hydrology of small water bodies (Hill and Olckers, 2001).

3.5.1.1 The *Neochetina* weevils

The *Neochetina* weevils, *N. eichhorniae* and *N. bruchi* complete their entire life cycles on *E. crassipes* (Coetzee et al., 2011). The two *Neochetina* species interact in a complimentary and synergistic way, and better control occurs when both species are present (Table 3.6). The adult weevils are nocturnal and feed on the epidermis of water hyacinth leaves and petioles, causing characteristic rectangular scars (Cilliers, 1991a). *Neochetina* feeding causes shorter petioles and the production of fewer ramets (Coetzee et al., 2007b). It also causes water hyacinth leaves to desiccate and curl, the petioles to become thin and spindly to the point where the plant becomes stressed and waterlogged, and eventually sinks. Weevil herbivory may cause entire water hyacinth mats to sink (Center et al., 2002). Adults lay their eggs beneath the leaf and the petiole epidermis, the larvae tunnel through the petiole and often through the meristematic tissue in the crown of the plant (Julien et al., 1999). It is the larvae that do the real damage and eventually kill the plant (Julien et al., 1999). Water hyacinth plants compensate for herbivore damage by increasing leaf turn-over and ramet production under low insect density levels (Briese et al., 2002), it is therefore important to use a combination of biological control insects and ensure that insect populations are established sufficiently to bring water hyacinth under control. The differences between the *N. eichhorniae* and *N. bruchi* are summarised in Table 3.5.

Table 3.5: Differences between the two *Neochetina* weevils

<i>N. eichhorniae</i>	<i>N. bruchi</i>
Less sensitive to plant quality – less effective under high nutrient conditions.	More sensitive to plant quality – more effective under high nutrient conditions.
Prefer mature plants.	Prefer developing plants, lush, growing in nutrient-rich water and previously unstressed by herbivory.
Lower fecundity.	Higher fecundity.
Longer generation time (approximately 120 days).	Shorter generation time (approximately 96 days).

Herbivory by the *Neochetina* weevils suppress water hyacinth growth and slow down infestation rates (Center et al., 1999b). Success of the two *Neochetina* species depend on various factors such as nutrient levels and temperature, flood occurrence and degree, the number of insects

released and the amount of disruptions due to chemical and physical control measures (Julien et al., 1999). Host plant quality is important for establishing biological control agent populations on water hyacinth (Hill and Olckers, 2001). The best results are obtained through integrating different biological control agents (Moran, 2005) or integrating biological control with other methods such as herbicides. The synergistic effects of the combination of control methods increase the negative impact on aquatic weeds (Van and Center, 1994, Center et al., 1999a).

3.5.1.2 The pathogen: *Cercospora piaropi*

The two water hyacinth pathogens, *Cercospora rodmanii* Conway and *C. piaropi* Tharp have been merged into one species, namely *C. piaropi* (Tessman et al., 2001). This agent has established at a number of sites throughout South Africa, and at Westlake River in the CTMA. It causes necrosis (fungal scarring) on mostly the old leaves of the water hyacinth plant, accelerating leaf senescence. Where both the fungus and *Neochetina* weevils are present, a positive association occurs between scarring on the young leaves as a result of weevil herbivory and necrosis of the old leaves. These results show that integration between the pathogen and *Neochetina* weevils may accelerate control of water hyacinth infestations (Moran, 2003).

3.5.1.3 The mite: *Orthogalumna terebrantis*

Orthogalumna terebrantis (Acarina: Galumnidae) is a shiny black leaf-mining mite, approximately 0,5 mm long with piercing mouthparts with which it sucks plant juices (Cordo and DeLoach, 1976) causing discolouration and desiccation (Julien, 2001). However, it still has to be determined how this visible damage translates into overall fitness, growth and photosynthetic physiology of the host plant (Marlin et al., 2013). Females chew small round holes in the youngest water hyacinth leaves with their mandibles and lay their eggs in the middle layer of the parenchyma (Silveiro-Guido, 1965). The larvae and nymphs feed on inner leaf tissue while they develop. The feeding makes the leaf porous as a result of openings being created in the tissue (Marlin et al., 2013). Their feeding removes plant tissue and produce galleries (distinctive yellowish linear markings) from where the adults emerge (Cordo and DeLoach, 1976). The mite is restricted to warmer parts of Africa (Wise et al., 2007). Feeding by *O. terebrantis* lowers photosynthetic rates and efficiency (Marlin et al., 2013). The combination of *O. terebrantis* and other insects inflict the most damage on the host plant, and their synergistic interactions should be considered when testing the efficacy of biological control (Van et al., 1998; Coetzee et al., 2005).

3.5.1.4 The moth: *Niphograptia albiguttalis*

The water hyacinth moth, *Niphograptia albiguttalis*, was previously known as *Epipagis albiguttalis* Warren (Bennett, 1974) and *Sameodes albiguttalis* Warren (Bennett, 1984). The species has been released in 13 countries, including South Africa, where it was first released in 1990, and established in six countries, including in South Africa. Most of the moths that were released originate from Argentina, except for the release in Zambia in 1977, which was from Trinidad (Julien et al., 2001).

The species has a high fecundity and a short generation time (Harley, 1990). They are highly mobile and good dispersers (Center and Durden, 1981) at a rate of between 1 – 4km/day (Center, 1984). The females lay their eggs in the aerenchyma of the leaves of the water hyacinth plant (Coetzee et al., 2009), and the larvae feed within the petioles causing damage to the growth meristems resulting in necrosis and water-logging. It encourages secondary invasion by fungi that rot tissues, hindering the ability of the plant to stay afloat (Center and Van, 1989) and leads to sinking (Coetzee et al., 2009). The moth prefers smaller plants with bulbous leaf petioles (Center, 1984), and they are rarely found in older plants (Julien et al., 2001) possibly as a result of the larvae finding it difficult to penetrate the hardened epidermis (Wright and Bourne, 1986). The preference of this species for young and tender plants makes *N. albiguttalis* a good candidate for rapidly growing new plants at a low density along open water margins (Julien et al., 2001). As a result, *N. albiguttalis* can play an important role in limiting further expansion of water hyacinth (Wright, 1981; Center, 1984). Plants in established, dense infestations tend to be taller and more slender and therefore less suitable for *N. albiguttalis* (Center, 1987). The moth is able to tolerate temperatures as low as 4°C for a number of hours (Center, 1984), but does not survive constant temperatures of 35°C (Center and Spencer 1981).

3.5.1.5 Sap-feeding mirid: *Eccritotarsus catarinensis*

The leaf sucking mirid *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae) was first released in South Africa in 1996 (Hill et al., 1999). The adults are mobile and can live up to approximately 50 days. The female lays her eggs in the leaf tissue on the under surface of the leaf parenchyma (Hill et al., 1999). Studies have shown a direct relation between plant growth and biological control agent development and survival and nutrient levels (Room, 1990; Ripley et al., 2006). For example the number of *E. catarinensis* adults and nymphs increase when the nutrient levels increase and the first generation adults emerge earlier and develop faster under higher nutrient conditions (Ripley et al., 2006). The adults and nymphs feed communally under the surface of the leaf, causing chlorosis and ultimately death of the leaves as a result of chlorophyll loss from palisade parenchyma (Hill et al., 1999). The mirid reduces the length of

second petioles and the production of daughter plants. Any reduction in the production of daughter plants will have a negative impact on the rate of spread of water hyacinth (Coetzee et al., 2007b). The loss of the plant's photosynthetic capacity leads to a reduction in carbon fixation and reduced biomass production, and ultimately limits the overall growth rate of the plant (Coetzee, et al., 2007a). Studies have shown that *E. catarinensis* establishment is limited by cold temperatures and it may therefore not be an ideal agent in areas receiving winter frost, such as the South African Highveld. It will also have the greatest impact under mesotrophic conditions (Coetzee et al., 2007b). The best results will most likely be achieved when *E. catarinensis* is used in conjunction with other agents as it is unlikely to bring water hyacinth under complete control especially in more temperate areas (Hill and Oberholzer, 2003).

3.5.1.6 The water hyacinth grasshopper: *Cornops aquaticum*

Cornops aquaticum, an oligophagous grasshopper, was introduced in South Africa into quarantine for host specificity testing in 1995 (Oberholzer and Hill, 2001) and the release permit was granted in 2007 (Bownes et al., 2010a). The grasshopper has a ferocious appetite and is able to consume large amounts of plant tissue (Oberholzer and Hill, 2001). Both the nymphs and adults inflict serious damage by defoliating the plant (Bownes et al., 2010b), and destroy the flowers and strip the epidermis from the petioles (Coetzee et al., 2011). The defoliation causes the plant to lose photosynthetic area which in turn severely limits plant growth and reduces vegetative reproduction. Early instar nymphs create scars by scraping tissue from the surface, while adults and late instar nymphs chew large holes in the leaves. Both the nymphs and adults are agile and good swimmers, and the adults are also strong fliers (Bownes et al., 2010b). Establishment of the water hyacinth grasshopper is still unconfirmed.

3.5.1.7 The water hyacinth hopper: *Megamelus scutellaris*

Megamelus scutellaris (water hyacinth hopper), is found throughout the water hyacinth native range in South America and is the most recent agent to have been introduced on water hyacinth in South Africa. The species produces multiple, overlapping generations per year. The adults form wings in response to factors such as the quality of the host plant and crowding. Studies conducted in its native range, have shown that *M. scutellaris* is capable of inflicting considerable damage on the host plant (Sosa et al., 2007) and is therefore a potentially significant addition to the existing suite of biological control agents against water hyacinth in South Africa (Coetzee, 2012). The adults and the nymphs feed extensively on the petioles and the leaves causing chlorosis. Under high populations the hoppers kill actively growing plants (Sosa et al., 2007). While the findings are not yet conclusive, it is hoped that the agent will be effective in the cooler areas of South Africa. The first release of the agent was in October 2013 on Zeekoevlei, CTMA. Establishment of *M. scutellaris* is yet to be confirmed.

3.5.2 Biological control of *Pistia stratiotes* (water lettuce)

A biological control programme was initiated against *Pistia stratiotes* in the 1980s, mainly to prevent it from spreading further outside of a fairly restricted distribution (Coetzee et al., 2011). Dramatic results were achieved in Australia with the weevil *Neohydronomus affinis* Hustache (Coleoptera: Curculionidae), reducing *P. stratiotes* biomass by 80% within a year following its release. Host specificity was conducted in Australia and it was introduced in South Africa without host specificity testing (Cilliers, 1991b).

Neohydronomus affinis was first released in South Africa in the Pafuri area of the Kruger National Park in December 1985. Despite initial fluctuation of weevil populations and plant damage *P. stratiotes* completely disappeared from this water body by October 1986 (Cilliers, 1987). Several successful releases followed and *N. affinis* is considered to be a successful biological control agent in South Africa against *P. stratiotes*, resulting in the weed being under complete control. During a survey conducted in 2008, less than 7% of the surveyed water bodies were infested with water lettuce and the weevils were present on approximately 60% of the sites (Coetzee et al., 2011).

The weevils can control the weed under eutrophic conditions of high levels of nitrates and phosphates (Moore and Hill, 2012) generally influencing the success of aquatic weed biological control programmes (Hill and Olckers, 2001). However, the control programme may take up to five years to achieve the desired outcomes (Neuenschwander et al., 2009). Complete control may take several seasons until the seed bank is depleted (Coetzee et al., 2011). Control programmes should therefore not be discontinued until there is no further evidence of water lettuce in a water body. Even then, monitoring programmes should be implemented to detect reoccurrence of the weed and biological control agents are to be released as soon as possible to prevent further infestation. Successful control of *P. stratiotes* by means of the weevil *N. affinis* can be ensured through continued inundated releases (Coetzee et al., 2011).

3.5.3 Biological control *Salvinia molesta* (salvinia)

In the 1980s *Salvinia molesta* was regarded as second only to water hyacinth as the most problematic aquatic weed in South Africa. Biological control by the weevil *Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae) in South Africa is considered to be complete, meaning that no other interventions are necessary, except for redistributing the weevil to newly invaded areas (Coetzee et al., 2011). *Salvinia* compensates for initial herbivory by activating new and previously damaged buds (Room, 1990). Augmented releases to ensure weevil populations establish are important for the success of biological control programmes on

salvinia. The status of the weed in South Africa is quantified through on-going surveys to detect populations and the sustained implementation of biological control (Coetzee et al., 2011).

3.5.4 Biological control of *Myriophyllum aquaticum* (parrot's feather)

The concerns about *M. aquaticum* becoming a secondary invader on sites where *Pistia stratiotes* and *Salvinia molesta* have declined have led to the initiation of a biological control programme against the weed in 1991. The undescribed leaf-feeding beetle species, *Lysathia n. sp.* (Coleoptera: Chrysomelidae) was collected from *M. aquaticum*'s native range in the Rio de Janeiro Province, Brazil in 1991. It was released in 1994 after a series of host specificity tests on 32 plant species in 22 families found it to be host specific. The beetle was released in different climatic zones throughout South Africa (Cilliers, 1999a).

Lysathia n. sp. is able to survive South African winters and periods of flooding when the host plant is temporarily submerged. Although their numbers decline during winter, populations build up rapidly in summer and it takes between 23 and 26 days to complete one generation (egg to egg). Their numbers also quickly recover following a flooding period and they start feeding on emerging shoots of the host plant when the water levels drop. *Lysathia n. sp.* beetles are good dispersers, able to move up to 50 km from original release site within a period of less than a year (Cilliers, 1999a).

The beetle defoliates parrot's feather leaves causing the emergent shoots to become thinner and shorter with die-back of the growth tips. The beetles migrate to healthier plants after defoliating clumps of plants, giving the host plants an opportunity to recover. Severely damaged plants start re-sprouting after three weeks and recover completely after six weeks. The host plant shoots become thinner and shorter and are stripped of leaves with die-back of the growth tips. It takes longer for the host plants to recover with continued feeding (Cilliers, 1999a).

It can take up to three years for *Lysathia n. sp.* to reduce *M. aquaticum* populations by 30%. The *M. aquaticum* populations in South Africa are female; no male plants are present. The weed grows vegetatively, meaning that it does not produce seeds and is therefore unable to recover from prolonged periods of damage caused by biological control agents (Cilliers, 1999a). Parrot's feather is considered to be under complete control in South Africa (Coetzee et al., 2011) and no other control measures are required to reduce its populations. It is very well established within the CTMA (Coetzee et al., 2011), but periodic inundated releases of *Lysathia sp.* ensure control is achieved within a shorter timeframe than if left to classical biological control.

3.5.5 Biological control of *Azolla filiculoides* (red waterfern)

In the mid-1980s, red water fern infested every river system and impoundment in the Free State Province of South Africa (Hill, 1998). A frond feeding weevil *Stenopelmus rufinasus* was released in South Africa in December 1997 with dramatic results. The weevil is self-dispersed or dispersed through waterfowl movement, and spreads rapidly to other weed infested water bodies. Within less than a year the weevil caused significant reduction in the distribution and impacts of *A. filiculoides*. Three years after the start of the biological control programme, *Azolla* sp. was no longer regarded as a significant weed in South Africa (McConnachie et al., 2003). This weed provides a unique example where no further implementation of its biological control agent is required and only monitoring of previously infested sites is recommended.

3.6 Discussion

Various studies (Hill and Olckers, 2001; van Wilgen et al., 2004; Van Wyk and van Wilgen, 2002; van Wilgen and De Lange, 2011) have shown that biological control is a cost effective, environmentally friendly, sustainable control option. Biological control is available for the five main aquatic weeds in South Africa and these species are under complete control in many sites (Coetzee et al., 2011). However, biological control of the worst aquatic weed in South Africa, *E. crassipes*, has not yet reached its full potential, despite the fact that South Africa has the highest number of biological control agents available against water hyacinth in the world (Hill and Olckers, 2001).

This situation poses several questions:

- 1) Is biological control of aquatic weeds achievable in urban environments that are subjected to stochastic events such as flooding?
- 2) Can biological control of aquatic weeds be effectively integrated with other control methods that result in more rapid control?
- 3) Is biological control of aquatic weeds too technically challenging to be routinely implemented by invasive alien clearing programmes?
- 4) Is there a need to demystify the process of biological control?

These questions will be addressed in the next chapter.

Chapter 4

Public and government perceptions of biological control

4.1 Introduction

This chapter starts by demystifying the concept of biological control, clarifying what it is, what it is not and the value of biological control. The absence of documented, successful aquatic weed biological control programmes in complex metropolitan environments raises the question of whether biological control is indeed an option to be considered in these areas. Urban environments pose additional layers of complexity through environmental degradation, transformed environments, modified aquatic weed systems, species introductions, poor water quality, conflicts of interest, socio-economic pressures on limited resources, political pressures on how the resources should be distributed and a general lack of understanding of aquatic weeds, their impacts and the most appropriate management options under different conditions. With all these factors in mind, the question of whether biological control can be successfully integrated remains to be answered. To answer these questions, a general survey was conducted to determine the level of understanding of aquatic weeds, their impact and their management, and this survey was followed by a discussion about the various layers of complexity in urban areas and recommendations for dealing with those layers of complexity.

The lack of knowledge about the biological control process often leads to abandonment of potentially effective control options. When immediate results are not visible, the perception that biological control is ineffective causes managers to select control options that deliver more immediate, albeit short term results. Biological control is not a quick fix, but a slow-working process. The unrealistic expectations which managers hold about biological control, such as the time it should take for biological control agents to increase in numbers to a level at which they can significantly decrease invasive plant infestations, are amongst the factors which cause a “frustrating lack of uptake of biological control” that van Lenteren (2012) refers to.

It is unrealistic to regard biological control as a mechanism for complete restoration of severely degraded ecosystems. However, biological control is a safe, cost effective and sustainable management option for the protection of un-invaded ecosystems or the partial restoration of invaded ecosystems. Biological control therefore warrants consideration during the planning stages of invasive plant management programmes (van Wilgen et al., 2013), but this consideration is seldom given.

Economic assessments of biological control programmes are useful for describing its benefits and successes in economic terms. An improved understanding of the economic value of biological control programmes further adds to the motivation for investment in research and implementation. The ultimate test of a control strategy is the return on investment (ROI). Biological control programmes are assessed by calculating the benefit-cost ratios (Huffaker et al., 1976; McConnachie et al., 2003). A biological control programme is considered to be economically viable if the ratio of the present value (PV) of benefits exceeds the present value (PV) of costs. Another important factor is the economic viability of other potential control methods using the same approach (PV benefits: PV costs). This enables a comparison between the different control options and the ranking of biological control amongst other control methods in terms of their cost, efficacy of control, and the avoidance of potential economic losses (McConnachie et al., 2003). Cost benefit evaluations are derived from available data in terms of the situation prior the implementation of control programmes, the documented successes or failures of the control programme and the related costs. Historical successes of similar programmes give an indication of the probability of a positive return on investment of new programmes (McFadyen, 2008).

For example, the front feeding weevil, *Stenopelmus rufinasus*, reduced *Azolla filiculoides* (red water-fern) from having significant economic impacts, to a point where it was no longer considered a problem, within a period of three years (1997 – 2000). The benefit:cost ratio, took three factors into account, the cost of the biological control programme over the period 1995 – 2000; the cost of the other control methods, namely mechanical and chemical methods, over the same period; and the present value of the future cost and benefits from the biological control programme. It cost a total of US\$ 46 962 (US\$ 276/ha) to develop biological control and control 170ha over the period 1995 – 2000 (McConnachie et al., 2003). The average cost of the mechanical control and chemical control was US\$ 1141/ha. The present value of the future costs and benefits of biological control, projected over a period of 15 years, 1995 – 2010, showed an increased benefit:cost ratio over time, 2.5:1 in 2000, 13:1 in 2005, and 15:1 in 2010.

Ten years after water hyacinth was first observed in Southern Benin in 1977, it had become a prevalent weed (van Thielen et al., 1994). Water hyacinth invaded the lower reaches of the Ouémé and the Sô rivers, Lack Nokoué a 1000 km² floodplain, and the lagoon of Porto Novo. The biological control programme in Southern Benin started with the release of the weevil *Neochetina eichhorniae* in December 1991, followed by *N. bruchi* in March 1993, and the moth *Niphograpta albiguttalis* in December 1993 (van Thielen et al., 1994). An economic impact study by De Groote et al., (2003) has shown the benefit:cost ratio of the biological control programme of water hyacinth in Southern Benin to yield ratio of 124:1. Total biological

programme cost US\$ 430 000 over a 7 year period 1991 – 1998. The impact of the water hyacinth invasion on about 200,000 people was estimated to be approximately US\$ 84 million per annum an average of US\$ 2151 per household. Since the water hyacinth infestations were reduced through biological control, the households' annual income increased by US\$ 30.5 million from fishing and trading food crops. Present value of future income streams of US\$ 30 million per year over 20 years at a rate of 10% depreciation per annum amounts to US\$ 260 million as a conservative estimate (De Groote et al., 2003).

A study by van Wilgen and de Lange (2011) has shown that biological control in South Africa yields an economic benefit:cost ratio ranging between 8:1 to 3726:1. Perceptions can greatly affect the implementation and success of biological control. It is therefore important to understand that biological control is a long-term process, involving mainly two distinctive, inter-dependent actions, namely research and implementation. The results of these two actions are underpinned by careful record-keeping, monitoring and evaluation. The benefits of biological control become evident only after taking both research and implementation costs into account. Although the research cost is high, it is balanced by the much lower cost of implementation. To build a credible argument for biological control, more economic studies are required. Resources should therefore be allocated to study the economic value of biological control programmes (van Wilgen et al., 2004). Biological control is a public-interest science and depends on funding and supporting policies. Funding for research is essential to ensure non-target effects are minimised and to build trust and credibility to convince the public to move from merely supporting biological control to active advocacy (Warner et al., 2008).

Biological control programmes are often viewed as unsuccessful before the usual benchmarks for success or failure are even considered. The factors discussed by Hill and Olckers (2001), apply to biological control programmes in general as well as in urban environments. For programmes to be successful within the context of the different layers of complexity present in urban environments, these factors need to be understood and addressed. Conflicting interests occur at different levels, and play an important role in deciding whether to consider biological control as a viable method. The reasons for controlling aquatic weeds vary between the relevant agencies and departments. Public expectations also play an important role in the selection of control methods, especially in urban areas. Conflicts of interest are often the result of poor communication within institutions, between different institutions, and between the biological control community, the public, policymakers and political leaders. Biological control research depends on the availability of public funding, and is therefore a public-interest science (Warner et al., 2008). The fear that biological control is risky originates from the discovery of non-target effects, and additional levels of precaution are therefore required (Howarth, 1991).

The pesticide industry is interested in developing and marketing new chemicals, and considers biological control as cumbersome and of limited use. Integration of biological control with herbicides is perceived to be difficult, and requires additional training of sales personnel and landowners (van Lenteren, 2012). The slow rate of action found in biological control causes conflicts when a quick reduction of infestation levels is required (Ghosheh, 2005).

A range of poorly known environmental factors have a negative impact on the effectiveness of biological control agents, and limit their distribution. Although biological control agents are selected to withstand different environmental conditions, weaknesses in agents will lead to failure (Scheepers et al., 2001). In addition, biological control agents are sensitive to climatic conditions such as temperature and relative humidity. Variable environmental conditions and increased climatic variability affect the availability of control options and their efficacy (Strand, 2000). Biological control agents respond differently under variable climatic conditions. In tropical areas for example, successful biological control of water hyacinth usually takes 3 – 5 years (Harley, 1990) while it takes between 8 – 10 years under more temperate conditions (Hill and Olckers, 2001). The presence of aquatic invasive plants is usually a symptom of the enrichment of waters as a result of urbanisation, industry and agriculture (Coetzee et al., 2009). Eutrophication could simultaneously have positive and negative consequences for the biological control agents, as the populations may proliferate because of the higher quality host plants, but on the other hand their impact may be negated by the vigorous plant growth caused by rapid leaf production (Hill and Olckers, 2001).

Variations in climatic conditions affect both the plants and insects. When temperatures drop during the cold winter months of May to August in South Africa, aquatic plants such as water hyacinth go dormant because they suffer from cold stress. Agent mortality increases and they become dormant and stop reproducing, resulting in agent population numbers dropping (Hill and Olckers, 2001). Climatic conditions play an important role in the metabolic rates, nutrition, growth rate, fecundity and longevity of aquatic plants and biological control agents (Clarke, 1996). When the conditions change with the onset of spring (mid-September to early October), the plants start growing actively, while the insect numbers are unable to recover at a similar rate. Temperature extremes are critical determinants of plant and insect distribution limits and useful in predicting activity and phenology of plants and animals (Chown and Terblanche, 2007). Insect populations have to “catch-up” with the growth of the host plants before they are able to inflict considerable damage. This often leads to impatience, causing authorities to revert to other methods such as chemical and mechanical control, which further impact the ability of insect populations to bounce back (Center et al., 1999a). Although the winter climate is attributed as one of the main reasons for fluctuations in insect numbers, studies on the impacts

of the cool, wet, frost free winters and hot dry summers of the south-western Cape have not been conducted (Hill and Olckers, 2001).

Hydrological features of water bodies are important as they affect both water hyacinth infestations and biological control operations (Hill and Olckers, 2001). In larger, slow flowing, deep water bodies, water hyacinth mats are able to break up and plants are able to sink as a result of damage caused by biological control agents. Small water bodies are less exposed to wind and wave action necessary for enhancing the damage caused by natural enemies. Wind movement and wave action contribute to plant stress through fragmentation and sinking of weed mats. Plants are unable to sink in shallow water (Julien and Orapa, 1999), because the roots rest on the substrate, as was confirmed through observations in the New Year's Dam near Alicedale in the Eastern Cape (Hill and Olckers, 2001). Successful biological control programmes were achieved in larger water bodies with a wind-fetch of more than 2km (Hill and Olckers, 2001), such as Lake Kyoga in Uganda (Ogwang and Molo, 1999), the Sepik River in Papua New Guinea (Julien and Orapa, 1999) and Lake Victoria (Cock et al., 2000). In South Africa most water bodies are relatively shallow and small, and may contribute to the lesser degrees of success in comparison with those achieved in the Sepik River, Lake Victoria and Lake Kyoga (Hill and Olckers, 2001). In the absence of wind and wave damage, the ability of plants to sink or to be flushed is limited, causing biological control to be less successful (Hill and Olckers, 2001).

The general lack of knowledge of the different herbivorous insects and the way they interact with their host plant both on individual and population levels, is a serious limitation (Weston, 1999, Ceasar, 2003). For biological control programmes to be effective, the distribution of insect attacks on individual plants or plant parts is as important as the attacks on the level of infestation (Rieder et al., 2001). Knowledge of the biology and interaction of the weevils, the weed and their environment is required to ensure the establishment of biological control agent populations in the shortest possible time (Julien and Orapa, 1999). Without understanding the different host plant requirements, biological control programmes are doomed. For example the moth *Niphograpta albiguttalis* is unlikely to establish on water hyacinth plants growing under oligotrophic conditions as they require plants with actively growing, young tissue (Hill and Olckers, 2001). *Neochetina eichhorniae* is less damaging than *N. bruchi* under eutrophic conditions (Heard and Winterton., 2000). Host plant resistance limits the spreading of biological control agents and therefore their effectiveness (Newman et al., 1999).

Without sufficient numbers of biological control agents, biological control cannot be effectively integrated into weed management programmes. Large, multiple releases of biological control agents on target weeds increase the chance of establishment of large enough insect

populations to inflict sufficient damage on the host plant. Another reason from the lack of success of biological control on water hyacinth in certain parts of South Africa may be that very low numbers (less than 100) of *N. bruchi* were released at several sites (Hill and Olckers, 2001). In contrast, large agent releases were carried out in the successful biological control programmes of Lake Victoria (> 100,000) (Hill and Olckers, 2001) and Papua New Guinea, with 339 separate releases on 150 sites with an average release size of 778 (Julien and Orapa, 2001).

Appropriate release techniques are essential for ensuring the establishment of biological control agents (Hill and Olckers, 2001). Establishment of biological control agents depends on the correct timing and release of large, healthy populations of agents on healthy plant populations. More effective release methods ensure quicker distribution of agents and achievement of measurable impact on the target weed (Briese and McLaren, 1997). Appropriately trained and skilled practitioners in release techniques will ensure the success of biological control programmes, and as a result their full integration into weed management programmes.

The City of Cape Town's invasive species management programme is relatively new. Aquatic weed control was, until 2011, fragmented and uncoordinated. Biological control is not yet fully integrated into aquatic weed management in the CTMA and the emphasis is still on mechanical control as a preferred method. Although great strides have been made over the past two years to integrate biological control into aquatic weed management programmes, buy-in from key role-players, such as the Biodiversity Branch responsible for the management of water bodies in protected areas, and the Transport Roads and Stormwater Department (TRSD) responsible for managing the freshwater ecosystems in the City, is still lacking. A study was conducted to get a better understanding of the perceptions about biological control and the implementation thereof. The aims of this study were to determine the respondents:

- level of understanding of aquatic weeds;
- perceived threats posed by aquatic weeds
- awareness about the different available control methods;
- perceived responsibility for biological control and
- considerations for integrating biological control in the CTMA

4.2 Materials and Methods

4.2.1 Stakeholder survey

Ten questions were asked by means of a questionnaire (Appendix A). The survey was conducted during stakeholder meetings and through one-on-one discussions. Questions (1) and (2) were aimed at determining the basic level of understanding about what aquatic weeds are and whether the respondents were able to identify the five main aquatic weeds in the CTMA by means of pictures. The next two questions (3) and (4) were to find out whether the respondents think aquatic weeds need to be controlled and what they think the reasons for control are. Questions (4) and (5) were asked to find out whether respondents are aware of what methods are available for controlling aquatic weeds and what method(s) they regard as the most effective. The respondents' perceptions of biological control were assessed by asking three questions (6 – 8): what they think biological control is, who should be responsible for implementation and who should fund biological control. For the question of who should be responsible for biological control implementation, the respondents were given a choice between national government, provincial government, two city departments – TRSD and the Invasive Species Unit (responsible for freshwater ecosystems, with the invasive species unit responsible for controlling aquatic weeds in the city), and landowners. They could select one or multiple options. Respondents could select any of, or a combination of three options: national government, provincial government or the City of Cape Town.

The last two questions were aimed at getting an understanding of whether respondents think it is possible to control aquatic weeds by means of biological control and to give reasons for their answers. Lastly they were asked to list the three most important considerations should biological control be considered as a control method for managing aquatic weeds in the CTMA.

Respondents were randomly selected and include a combination of members of friendship groups, conservation agencies, NGOs and the TRSD.

4.2.2 Researcher and implementation officer survey

The research/ implementation survey was conducted by means of a questionnaire consisting of six questions. Question 1 asked for a description of the current level of integration; Question 2 asked how biological control should be integrated into weed management programmes; Questions 3 and 4) requested respondents to list the roles of research and implementation; Questions 5 asked whether there is a gap between research and implementation; and the final question (6) asked for recommendations to fill the gap between research and implementation. The questionnaire was sent by email to 40 individuals consisting of 24 researchers, 4 national managers (based at the WfW national head office), 2 Western-Cape provincial managers, 6 biological control implementation officers and 5 project managers from the City of Cape Town. The provincial manager interviews were restricted to the Western Cape.

4.3 Results

4.3.1 Stakeholder survey

A total of 50 respondents completed the questionnaire, 35 from conservation agencies, six from TRSD, seven from NGOs, and two were environmental education (EE) officers. Three of the six respondents from the TRSD were directly involved in river management, two in planning and one in administration.

The responses to Question 1, dealing with what aquatic weeds are, were categorised under good, reasonable and poor, based on the respondents' level of understanding of aquatic weeds. The majority of the respondents (66%) had a good understanding, 27% had a reasonable understanding and 7% understood very little about aquatic weeds.

In Question 2, respondents were asked to identify the five main aquatic weeds found in the CTMA, *Pistia stratiotes*, *Eichhornia crassipes*, *Azolla filiculoides*, *Myriophyllum aquaticum* and *Salvinia molesta*. Most respondents (94%) were able to identify *E. crassipes*, followed by *P. stratiotes* (76%), *M. aquaticum* (66%), *S. molesta* (58%) and *A. filiculoides* was the least identifiable species at 40%.

To the question of whether aquatic weeds should be controlled (Question 3), all the respondents said that aquatic weeds need to be controlled. The reasons given for the response were grouped into five categories, namely ecosystem (integrity and functioning), resource protection (water), hydrology (floods), socio-economic (impeding on recreational and commercial use, aesthetically unpleasing, odour, health) and biodiversity. The impacts of aquatic weeds on biodiversity were regarded as the main reason for control, followed by socio-economic and resource protection which were considered equally important, and hydrology was considered the least important.

The responses to Question 4 were divided between mechanical, manual, chemical and biological. A point was allocated for each of the methods and added up to get a total per method. Integrated control represents a selection of one or more control options. Mechanical control is often referred to as a combination of machinery and hand tools. For the purposes of the questionnaire, mechanical and manual control were listed separately because the use of mechanical control involves heavy duty machinery such as weed harvesters and long-boom excavators operated by one person, while manual control involves labour intensive methods using hand tools such as forks, rakes or hand pulling. Biological control received 88%, chemical

33%, manual 27%, mechanical 21%, prevention 3% and early detection and rapid response 3%.

All of the respondents indicated that they knew what biological control was. The selection of responsibility and funding options are listed in Table 4.1. The cells that were not applicable to the selection were greyed out. The percentage allocated to the different institutions in terms of implementation and funding responsibilities were captured in the relevant cells.

Table 4.1: Suggested institutions to assume responsibility for funding and implementing biological control in CTMA

Responsibility	National	Provincial	City of Cape Town	TRSD	Invasive species unit	Landowners
Implementation	88%	70%		33%	88%	61%
Funding	100%	64%	64%			

To the question of whether it is possible to control aquatic weeds in the CTMA by means of biological control, five respondents said “no”, nine said “unsure” and 36 said “yes”. Conditions for implementing biological control included that some weeds are more likely to be controlled than others, biological control should be integrated, and the correct selection of biological control agents is important. Reasons provided by the respondents who said biological control will not be effective in the CTMA include eutrophication, hydrology and climate. The final question (10) required respondents to list the three most important considerations for implementing biological control in the CTMA. The responses were grouped into 10 themes and the respondents were categorised into two groups: general (friends groups, public, NGO, EE officers) and management (TRSD, conservation agencies). The number of respondents citing a specific theme was captured under the relevant group (Table 4.2).

Table 4.2: Categories of considerations for implementing biological control (Survey results)

Theme	General	Management
Integration of different control methods	2	11
Possible non-target effects	7	6
Agent selection	1	7
Stakeholder buy-in through awareness and communication	3	14
Time-frames for biological control to be effective	1	3
Understand the invaded system (release requirements, site selection)	1	10

Climate and water quality	3	6
Monitoring & Research	1	10
Socio-economic impacts	3	3
Sustainability (resources, cost considerations, rearing capacity)	4	11

4.3.2 Researcher and implementation officer survey

Of the 40 individuals, a total of 23 (58%) responded. Of the 24 researchers approached, 16 (67%) responded, eight of the 14 (57%) implementers approached responded, two from the national office, none from the provincial senior management, two biological control implementation officers responded, from the Eastern Cape and Western-Cape respectively, and four project managers from the City of Cape Town responded (Table 4.3).

The collective number of years' experience of the 16 researchers is 380 years, an average of 24 years per individual. The respondents include heads of departments, a senior ecologist, a retired senior biological control researcher, senior researchers, researchers and research assistants.

Table 4.3: Demographics of the research respondents

Organisation	Respondents	Experience (years)
Rhodes University	4	46
Independent	1	43
ARC-PPRI	8	176
CSIR	1	39
UCT	2	76
Total	16	380

The collective numbers of years' experience of the implementers is 91 years; the national managers have 48 years, the City of Cape Town project managers 21 years and the biological control implementation officers have 22 years' experience between the two of them.

Table 4.4: Demographics of the implementation respondents

Organisation	Respondents	Years
NRMP (National office)	2	48
City of Cape Town	4	21
Bio control implementation	2	22
Total	8	91

The collective years of experience of the implementation respondents is 91 years of which the two respondents from the DEA Natural Resource Management Programmes contribute 48 years – 53% of the total implementation experience. Without these two senior managers, the average experience per individual of the implementers is seven years.

The responses to describe the current integration of biological control into weed management programmes were classified under six categories: excellent, good, acceptable, sub-optimal, poor and non-existing. Responses such as “integration has not reached its full potential, restricted, inadequate, insufficient and under-utilised” were all placed under the category “sub-optimal”. “Generally poor, poor and little evidence” were interpreted as “poor”. Of the 16 research respondents, 10 said that integration did not reach its full potential and five said integration is poor. No respondents said it is excellent, good, acceptable or non-existing. The reasons listed by the respondents for the lack of integration were collated under four categories, namely planning and management, implementation, communication and institutional reasons (Table 4.5). Five management respondents said integration is sub-optimal. Reasons included conflict of interest, unrealistic expectations, premature clearing of infestations before biological control agents had the chance to make an impact, and biological control sites destroyed because their localities were unknown.

Although recognition was given to recent progress in terms of both awareness and integration of biological control into management strategies, the overall response is that integration is sub-optimal. Successes cited were in biological control of terrestrial weeds, *Hakea*, *Sesbania*, *Opuntia*, and *Acacia*, and only one reference was made to integration of biological control into aquatic weed management, namely the Nseleni system in Kwa-Zulu Natal. Specific mention was made of progress by CapeNature and SANParks with integrating biological control into

ecological planning programmes. Of the seven implementers, two respondents said integration is good, as it is successfully and actively integrated in all nine provinces.

Table 4.5: Summary of current status of integration and the reasons

Planning and management	Communication	Capacity and competence	Institutional
Lack strategic planning and prioritisation at different levels-national, provincial, local.	General lack of communication between research and implementation.	Inexperienced biological control implementation officers.	Perceived political interference regarding priorities.
Lack of proper management plans for invasive plant control, with clear, time-based goals and guidelines for implementation.	Researchers not invited to regional biological control implementation meetings to give their input.	Inadequately trained biological control implementation officers.	Bureaucracy and restrictive policies delay the approval of biological control release application.
Successes are not maintained and managed causing them to collapse.	Researchers are not receiving information about releases.	Biological control officers do not take advice of researchers.	WfW structures do not enable close collaboration and lack guidance.
No basis of evaluating the successes of programmes.	Researchers not being informed of newly appointed persons involved with biological control.	Biological control officers have very little authority to influence the levels at which biological control is integrated into weed management programmes.	General lack of understanding of what biological control is.
No formalised agreements with landowners, to ensure landowners protect areas under biological control.	Very few land owners are aware of the existence of biological control, or whom to contact about it.	Shortage of biological control officers in certain provinces worst affected by cactus.	Lack of commitment from WfW to implement recommendations from researchers.
Sub-optimal mass-rearing programmes.	It is not clear how biological control fits into the overall management of a particular target weed species	Inefficiency of biological control implementation officers.	Conflict of interest e.g. emphasis on delivering person-days.
Lack of economic studies into the most efficient use of control options per species.		Poor data management.	Expectations – instant results.
The cost ratio of biological control person-days versus the cost of person-days for other control methods.			Lack of co-ordination.
Biological control is			Lack of leadership and

tried as last resort after every other option has failed.

direction to ensure proper implementation

The lack of strategic planning and prioritisation, goal setting, time frames and guidelines for implementation prevent biological control from reaching its full potential as method of control. The lack of communication between research and implementation has been highlighted throughout the survey as having a major limiting impact on implementation of biological control programmes. Biological control implementation officers do not approach researchers for information, assistance or training and researchers do not know who needs this information.

The responses to Question 2, about how biological control should be integrated into weed management programmes, were grouped into four themes: planning and management; collaboration and communication; implementation; and research, monitoring, evaluation, and adaptive management (Table 4.6).

Table 4.6: Recommendations for integrating biological control into weed management programmes

Planning and management	Collaboration and communication	Implementation	Research, monitoring, evaluation, and adaptive management
Develop national weed management strategy per weed species/ functional group of species, and for each biological control agent.	Foster closer communication between biological control practitioners and clearing contractors.	Accessible and comprehensive databases incorporating all relevant information, release sites, establishment of agents, impact on the weeds.	Implement monitoring and evaluation programmes and review of biological control implementation programmes required (for mass-rearing and implementation) against the targets set out in the management plans.
Incorporate research findings into management plans to maximise the effectiveness of the control options and to minimise the indirect effects of one type of control over others.	Annual / bi-annual update of optimal biological control implementation per species / functional group incorporating latest research findings. Foster co-operative relationships and obtain buy-in from all interested and affected parties.	Training and mentorship programme for biological control implementation officers under the auspices of the biological control experts to ensure well-trained and experienced biological control officers.	Research: agents and what they do; Effect of other control operations on weeds, agents and weed dynamics. Strengths and limitations of different control options Develop monitoring protocols
Identify responsible agencies and action plans with timelines.	Secure biological control reserves through public awareness campaigns and signage	Enter into agreements with landowners and managers to get guarantees that the biological control sites will not be destroyed	Prioritise species as well as areas for biological control, monitor and evaluate impacts.
Management plans to include expert input and	Clear understanding of the role of biological	The biological control implementers should be	

compiled in
collaboration with
interested and affected
parties

control from the outset;
end clear expectations
of what biological
control can contribute to
an integrated
management
programme.

mandated and have the
authority to ensure
biological control is
integrated into weed
management according
to the management
plans

More mass-rearing
facilities, to supply
agents. Clear
prioritisation of mass-
rearing programmes

Management plans are
to follow a systems
approach
Clear and sufficient
allocation of resources.

Biological control to be
regarded as integral
part of weed
management
programmes during all
phases.
Species where no other
control methods are
required need to be
identified and
incorporated into
management plans.
Establish multi-
disciplinary
management teams

Question 3 dealt with the role of research and Question 4 with the role of implementation. The responses to these questions were consolidated and presented in accordance with the biological control process described by Moran et al., (2013). It was clear from the responses that one of the main reasons for biological control not reaching its full potential in South Africa is the lack of understanding of roles and responsibilities between the different role-players. It was suggested that National WfW should play an oversight role and create an enabling environment for researchers, implementers and landowners to fully integrate biological control into weed management programmes. Researchers should guide implementers through the process and thereby build capacity and transfer knowledge about all facets of the implementation of biological control implementation.

One researcher compared the different roles of research and implementation with those of a client and supplier, by saying that “implementation” is the user or client of biological control, thus they receive the product (biological control agent), and apply it to their situation using

available information (research). As with any product, the user will evaluate whether the product (biological control agents) is effective if applied as per suggestions from the supplier. This usually leads to feedback on the perceived success to the supplier (research).

The roles and responsibilities of National (N), Research (R), Implementation (I), and Landowner or manager (L) are summarised in Table 4.7. The summary is based on the description of the weed biological control process by Moran et al. (2013).

Table 4.7: Summary of roles and responsibilities of the role-players involved in the weed biological control process (Based on Moran et al., 2013)

WBC process	N	R	I	L
Funding for research, resources and capacity				
Advocacy to get high level political support and buy-in and to mitigate conflicts of interest				
Build regional and implementation biological control capacity				
Support awareness and training programmes				
Coordination of regional biological control programmes and technical liaison committee activities				
Determine identity of target weed species. Undertake taxonomic, phylogenetic and molecular genetic studies				
Determine origin of target weed species. Perform herbarium and literature searches; explore area; search historical records.				
Explore for suitable plant-feeding agents in area of origin of target weed. Identify candidate agents; explore indications of host ranges; study biology of agents and of close taxa elsewhere.				
Identify candidate agents; explore indications of host ranges; study biology of agents and of close taxa elsewhere.				
Export candidate agents from country of origin to country where releases are intended. Determine optimal conditions for maintenance and transportation.				
Perform studies to confirm that agents are suitable and safe for release. Determine host ranges (safety) of candidate agents under quarantine conditions; assess potential efficacy by type and extent of damage caused.				
Inform implementation about the outcome of the host specificity testing. Potential means of communication – technical liaison committee meetings, quarterly research/management meetings, annual biological control seminars.				
Apply for permits to release agents. Analyse research findings on host range and potential efficacy of agents; prepare motivations for release.				
Mass rear approved agents. Develop techniques to maintain large colonies as a source of agents for field releases onto the target weed.				
Release approved agents onto the target weed in the field. Determine optimal release				

techniques to improve chances of agent establishment.				
Document release techniques and communicate with implementation. Familiarise with release techniques and apply.				
Give feedback to research with regard to release techniques.				
Determine whether populations of agent have established on target weed. Monitor persistence and fluctuations in numbers, as well as spread of agents on target host				
Enhance distribution of agents in the field. Determine where agent populations are thriving and use for wider distribution.				
Assess direct impact of agents on target weed. Quantify in detail the damage caused to different parts of the plant.				
Evaluate effects of agents on weed population dynamics. Determine changes in density and dispersal patterns of target weed before and after agents have established.				
Knowledge flow: make research papers available to implementation; read papers.				
Integrate WBC with other control practices. Determine optimal use of WBC as a supplement or replacement for other control strategies.				
Perform cost: benefit analyses. Determine long-term costs of research and implementation of WBC; estimate benefits and economic viability of WBC				
Educate landowners about biological control.				
Liaise with landowners ensure they know who to contact, how to protect biological control sites.				

Responses to Question 5, which asks whether there is a gap between research and management, were categorised as “yes”, “no” and “partially”. The response from 15 out of the 16 research respondents was “yes”, one respondent answered “yes” and “no” which was taken as “partially”. The respondent qualified the response by saying that the irony lays in the fact that WfW funds all the biological control research, but they implement it the least.

All but one of the managers responded that there is a gap. One respondent said the gap depends on personalities and the relationship between researchers and managers. One implementation respondent said that implementation officers are often intimidated by the research that is published, either because it is written in a way that is not comprehensible to the manager, or because the research is not easily attainable. Furthermore, the research is often not necessarily what the managers need to know about, but more what the researcher personally wants to find out or is based on where the funding for research comes from (i.e. the funder will determine what the research is conducted on). Research and management seem to have different priorities. For example, the quality of detailed data is more important for researchers compared to implementers. Implementers need to ration their time when they do fieldwork due to the logistics of their operations. Implementers may not be able to collect

information in the same amount of detail as researchers. This often leads to frustration on both sides.

The responses were grouped into four categories namely (a) research–management, (b) management–research, (c) mismatch and (d) communication. Research–management indicates the researcher’s understanding of why the gap between research and management exists. Management–research, reflects the manager’s understanding of the reasons for the existing gap. Mismatch indicates those areas where research and management have different focus areas and those focus areas are not well understood and possibly not well communicated. Communication refers to the factors contributing to the gap, attributed to the lack of communication (Table 4.8).

Table 4.8: Summary of the reasons for the current gap between research and implementation

Research – management	Management – research	Mismatch	Communication
Research papers not read by managers at different levels.	Research papers not easily understood by managers.	Different focuses.	Research messages do not come through to managers, resulting in old/ incorrect methods used.
Researchers not included in WfW meetings in certain regions.	Research not focussed on management needs.	Different goals between researchers and implementers when release and monitoring data is collected	On the ground info does not always reach/ feed into research, resulting in methods suggested not always being practical on the ground. Obstructed knowledge flow.
The WfW biological control implementation officers do not take the advice of researchers. Managers do not attempt to understand the complexities of biological control.	Researchers do not listen to the needs of managers. Researchers do not communicate clearly.	Too few implementation officers. Implementation officers lack adequate and appropriate training.	Researchers do not receive information about releases, establishment or problems and can therefore not respond to address these. Insufficient information, along with too little communication. Very few landowners are aware of the existence of biological control, or whom to contact about it.
Researchers are excluded from WfW planning and prioritisation.			

Although collaboration between research and implementation has long been recognised as an essential component of natural resource management, knowledge flow between science and management is often unobstructed. The Working for Water biological control implementation

programme does not appear to be working well. Researchers can contribute a great deal to these programmes, but are often excluded from decision making and are therefore completely unaware of the programmes. In addition, there are far too few biological control implementation officers, and some of the existing ones or persons acting on their behalf are not sufficiently trained in the field of biological control. The persistent notion of division between these parties hampers communication and collaboration, and limits eventual integration. On a positive note, however, the WfW/ Rhodes University Short Course on Biological Control was singled out as an excellent example of knowledge transfer and capacity building which aims to minimise the gap between research and management. There is also a good level of interaction between biological control researchers and other organs of state, interest groups and individual landowners. Both parties are to take responsibility for the existing lack of communication between research and implementation managers. In some cases, there seems to have been an unwillingness to collaborate due to negative impressions of both role-players on the part of the other. On the whole, both parties tend to operate autonomously. The gap is larger in some regions or between certain individuals within the field. One of the researchers responded by saying "I must say that it seems that very little of my work is read by managers at all levels" (personal communication). Implementation officers do not approach researchers for information, assistance or training, and researchers do not know who needs this information. There seems to be a misconception that the research scientists work for the WfW implementation officers.

In Question 6, recommendations, on how to close the gap between research and implementation were requested, and these responses are summarised in Table 4.9. The responses were grouped into five themes: Working for Water (WfW); researchers; implementation; institutional; and communication. Working for Water was separated from the institutional category, because the national WfW office place a strategic oversight role, while "institutional" refers to the regional WfW officers. A commitment is required at all levels, and between all role-players to collaborate, communicate and integrate planning and decision-making. Biological control programmes should be institutionalised with appropriate capacity and skills to ensure knowledge transfer, and to make sure that biological control implementation is fully incorporated into weed management programmes. Chemical control must take into account the role and advantages of biological control. In many instances, infestations have been chemically controlled while biological control could have saved millions. The autonomy of regional WfW managers to make decisions concerning whether to apply herbicides or use biological control should be addressed. One party should not make decisions with such far-reaching implications without consultation.

Biological control implementation officers are to become specialists in their field, and therefore need to be under the authority and mentorship of specialists. They need to learn from other programmes such as the LandCare programmes in Australia and New Zealand. Researchers need to work towards demystifying weed biological control. Investment in training and mentorship programme through existing structures, such as Rhodes University, is crucial. The full integration of biological control into management programmes is hampered by logistic and administrative problems, such as different authorities being involved, often competing for the same financial resources and the role of personal interests. Negative perceptions and impressions should be addressed through constructive, unambiguous, regular and structured communication.

Table 4.9: Recommendations on how to close the gap between research and implementation

WfW	Researchers	Implementation	Institutional	Communication
Invest in accredited biological control training programmes for biological control implementation officers.	Active involvement in implementation process.	Implementation officers should communicate with researchers and make them aware of actions and decisions that have been taken.	Strategic alignment with clearly defined and complementary goals.	Annual biological control implementation and research collaboration meeting.
Invest in a mentorship programme for biological control implementation officers.	Supply the implementation officers with all relevant information about currently available and future agents.	Management plans to be drawn up in collaboration with researchers.	Facilitate collaboration, integration and communication.	Bi-annual provincial/biome biological control implementation meeting.
Establish a dedicated biological control coordination unit.	Involve implementation officers in preparations for mass-rearing and first releases.	Accept the authority of researchers.	Define and understand roles and responsibilities.	Establish a quarterly biological control e-newsletter.
The National Waterweed and Biological control Coordinator needs to facilitate knowledge interfacing and sharing between researchers and the biological control implementation managers.	Guide implementation officers in what is required of them in the line of redistributing the agents and providing feedback to the responsible researcher.		Implementation officers should be based at research centres such as ARC-PPRI offices or participating universities.	Lines of communication between the researchers and the WfW biological control implementation managers to be established and remain open.
Revive the Technical Liaison			Collaborate earlier on, to	

Committee meetings.

allow research and implementation to carry on concurrently to save time.

WfW regional managers need to be trained in biological control issues to ensure optimum biological controlling the regions.

Biological control implementers to work under the authority of researchers.

Researchers to evaluate the performance of the implementers

Appoint appropriately qualified and trained people to different groupings of weeds.

Invest in effective public awareness and biological control advocacy.

Set up several dedicated weed biological control mass-rearing facilities with qualified, skilled (entomology, plant pathology) staff, preferably at experienced insectaries.

Appointment of biological control implementation coordinator at research institutions to interact with biological control implementation (national and regional level).

Biological control integration to become part of regional WfW manager's Key

4.4. Discussion

The aims of this chapter were to determine if biological control was an achievable goal for waterweeds in a highly disturbed urban environment that is characterised by stochastic events such as flooding. Further, and probably more importantly, this study set out to determine why biological control of aquatic weeds, which is generally accepted as being highly successful, has not been better implemented, not only in the City of Cape Town, but country-wide.

Fifty respondents completed the general questionnaire. Of the 50 respondents, 100% said they know what aquatic weeds are. *Eichhornia crassipes* could be identified by 94% of the respondents, 76% could identify *P. stratiotes*, 66% could identify *M. aquaticum*, 58% identified *S. molesta* and the least identifiable species was *A. filiculoides* at 40%. Water hyacinth is South Africa's worst aquatic weed and it is therefore no surprise that most respondents could identify the plant. What was interesting from the group responses was that of the five TRSD respondents, only one could identify all the species, except *A. filiculoides*. The other four respondents from TRSD could only identify water hyacinth. The fact that the highest number of respondents in the general survey could identify *E. crassipes* shows the importance and the prominence of the weed. The least recognisable aquatic weed is *A. filiculoides*, presumably because it is under complete biological control (McConnachie et al., 2003). *Azolla filiculoides* occurs from time-to-time in the Silvermine wetlands (Peninsula Catchment), some of the rivers in the Sand River catchment and the canals at Century City (Salt River Catchment). This outcome aligns with the role of the TRSD to ensure hydrology, and water hyacinth is a major weed in the CTMA impacting on hydraulics. Relative to water hyacinth, the other weeds pose a lesser problem for the TRSD. From an ecosystemic and biodiversity point of view, other species are of significance due to their various impacts discussed in Chapter 3. All of the respondents agreed that aquatic weeds are to be controlled, and regarded the impacts of aquatic weeds on biodiversity as the main reason for control, followed by socio-economic and resource protection which were considered equally important, and finally hydrology which was considered the least important. All (100%) of the respondents from the TRSD selected hydrology as the main reason for control, while 20% of the Biodiversity Branch respondents mentioned flooding as a reason. A further breakdown of the Biodiversity Branch responses has shown that those respondents who indicated hydraulics as a reason for control are all concentrated in the areas where the water bodies forming part of the protected areas they are responsible for pose flooding problems during winter. Of significance is that four out of five of the TRSD's respondents selected

mechanical control as the most effective control option, and one respondent selected integrated control. The response is significant in the sense that on-going collaboration between the TRSD and the Invasive Species Unit pays off and that buy-in is possible even from the Department who historically relied on mechanical means of control as the only option. The involvement of different role-players at different levels, including national, provincial, and local government as well as civil society, was highlighted in these findings.

Working for Water is a national level initiative (van Wilgen et al., 2012) and the main recipient of government funding for the control of invasive plants in South Africa (Zimmermann et al., 2004). The programme operates in all nine provinces with a current annual budget of US\$134 288 million (C. Marais, personal communication). Other control methods such as mechanical and chemical control are preferred over biological control by the Working for Water programme (van Wilgen et al., 2012; van Wilgen and De Lange, 2011). van Wilgen and De Lange (2011) calculated that Working for Water spends seven rand on chemical control for every rand spent on biological control and for every fourteen on mechanical control, a ratio of 7:14:1.. Several water hyacinth populations in South Africa have been significantly reduced through biological control, but programmes in the Western Cape Province and CTMA in particular have not reached the levels of success of programmes in the Eastern Cape Province, for example the New Year's Dam (Hill and Olckers, 2001).

It is against this background that a study was conducted by means of a questionnaire survey amongst researchers and implementers (Appendix B). The aims of the study were to:

- determine the current status of biological control integration
- determine the reasons for the current status of integration
- determine how researchers and implementers view their roles and responsibilities
- identify gaps between research and implementation
- request recommendations from both researchers and implementers to improve the current situation.

The research/ implementation study shows that integration of biological control into weed management programmes in South Africa is lacking despite all the successes achieved so far. The average years of experience held by the researchers is 24 years per individual while the average years of experience of implementation? practitioners is 11 years per individual. This figure is skewed by the two senior managers of national office as they collectively contribute to 53% of the years of experience for implementation. When the two senior managers' years of experience are taken out of the equation, the average years of experience is seven years per

individual. This result confirms the lack of experience held on the part of implementation managers and emphasises the need for capacity building and skills transfer. The gap between research and implementation is a result of insufficient communication. There is a lack of direction, experience and appropriate skills at implementation level. The return on investment into biological control research can only be optimised if put into practice through implementation; if this does not happen, biological control in South Africa will not reach its full potential, and the impacts of weeds will continue to escalate. Integration requires understanding, buy-in and support at all levels. Unsuitable data and failure to provide compelling arguments in favour of biological control prevent full uptake and recognition of biological control as an important component of integrated management of invasive alien plants.

The factors limiting the full integration of biological control into weed management programmes were discussed by Hill and Olckers (2001). Here recommendations are offered to overcome these limiting factors and allow weed biological control to reach its full potential. The recommendations have potential for application at all levels - national, provincial and local – and are relevant for both aquatic and terrestrial weed management practices.

Cumbersome legislative and regulatory environments unnecessarily delay the approval of importation and release permits of biological control agents. These delays eventually impact on weed management programmes in the sense that agents that could potentially be released at a relatively early stage of invasion, are released when the infestation levels are much higher. Delayed action to respond to aquatic weed infestations results in ecological and economic impacts, as aquatic weeds inflict ecological damage and costs increase exponentially with the increase in density and area covered. Although local authorities such as the City of Cape Town, do not play a direct role at regulatory level, delays in agent releases have impacts in the weed control programmes when agents are not available for release. A simplified and harmonised approach is necessary (van Lenteren, 2012) to speed up the issuing of importation and release permits. Klein et al. (2011) suggests the establishment of an appropriately mandated and constituted biological control peer review committee to evaluate release applications. The review committee's assessments and decisions should then be accepted by both DAFF and DEA. Early and open communications between the weed biological control research community and regulating authorities are necessary. Communication about progress and feedback should be supported by on-going development and implementation of new and enabling systems. Permit application documentation should be standardised to ensure legal compliance (Klein et al., 2011).

In the absence of integrated weed management plans, conflicts between biological control and other control methods are most likely to occur. It is therefore useful to develop strategies to integrate biological control into existing control programmes. Areas can be left untreated to provide pockets of plants serving as refugia for biological control agents. These refugia allow biological control agents to build their population numbers and disperse to plants recovering after herbicide treatment (Center et al., 1999a). Integrated weed management plans need to have clear objectives and timeframes (van Wilgen et al., 2012) and need to spell out the control methods to be used under different scenarios. It is important to accept that there is no universally applicable strategy, and site specific plans are required. If a particular combination of control methods works on a particular site, it will not necessarily work on another site. A fundamental principle to ensure effective weed management is to accept that the management of aquatic weeds is not a once-off operation, but a long-term, on-going programme with scheduled interventions, requiring on-going resources. Management plans have to be flexible and make provision for the change in priorities required to respond to changes in environmental conditions and stochastic event such as floods (Julien and Orapa, 1999). Without flexibility in terms of timing of control and the selection of the best control method for the specific situation, weed biological control programmes may not achieve the desired results and will most likely cost more over the long term. Clear understanding of the requirement of biological control projects, appropriate expertise, training, staff and resources are important to increase the likelihood for a successful outcome (Julien and Orapa, 1999).

Biological control requires longer time-frames and it is therefore better to consider a combination of manual, mechanical and chemical control, especially under the eutrophic conditions. Biological control is most suited on sites where flooding risk is of lesser concern, because of the timeframes involved. Communication with relevant stakeholders such as the TRSD is essential to ensure refugia for biological control agents are not destroyed through the deployment of heavy machinery such as long reach excavators. It is therefore important to coordinate releases and allow agents time to establish and inflict sufficient damage. If the release timing is well planned, the TRSD may not need to remove weeds to prevent flooding, because the agents would have enough time to reduce the weed populations to levels where they do not pose a risk of flooding. It is vital to get the TRSD to buy into the concept of integrated weed management by educating staff about biological control. It is then possible to further improve integration of mechanical and biological control by allowing biological control agents to reduce seed output and suppress plant growth or populations before proceeding with mechanical clearing. Following this strategy can make a substantial contribution to the success of the entire operation (van Wilgen et al., 2012).

Nutrient-enriched water bodies in densely populated areas such as the CTMA exacerbate aquatic weed growth (Hill and Olckers, 2001; Byrne et al., 2010). It is therefore essential to consider local enhancements of water quality as part of the integrated approach to aquatic weed management. Measures are to be implemented to ensure discharge water complies with South Africa's water quality standards (Byrne et al., 2010). It is essential to select the most appropriate agents for the site, the nutrient levels and the climatic conditions. For example *N. bruchi* performs better at high nutrient conditions than *N. eichhorniae* (Heard and Winterton, 2000). It will also be necessary to conduct augmented releases of a combination of biological control agents where appropriate to give agents a chance to establish large enough populations to inflict sufficient damage to reduce weed infestations (Hill and Olckers, 2001). Augmented releases refer to intense release effort biological control agents aiming to release as many agents as possible, as quickly as possible, instead of depending on a slow, natural accumulation of agents by reproduction from a small core of individuals (Byrne et al., 2010). Finding a balance between insect population and plant growth will maximise the impact of biological control on the host plant. Cold winter climates and extreme conditions such as frost impact on plants and agent populations. Augmented releases with the onset of spring will therefore assist with agent population establishment, allowing the agents to inflict damage and impact on weed populations (Hill and Olckers, 2001).

It is important to understand the hydrological features of sites where aquatic weeds are to be controlled in order to select the optimum combination and timing of control methods. Impounded systems lacking wind and wave action and the inability to flush these systems, coupled with stochastic events such as regular floods, impact negatively on biological control operations (Hill and Olckers, 2001; Byrne et al., 2010). Invasive weeds regrow rapidly after flood events from seeds or remaining plant material. Both biological control agent refugia and repeated releases following stochastic events can assist with biological control agents building up their population numbers and, as a result, increasing their impact on the target weeds (Hill and Olckers, 2001). The Diep River in CTMA is an impounded system sheltered from wind and wave action and densely invaded with reeds and water hyacinth. In this and similar systems, biological control should be integrated with manual control to loosen the mats and remove parts of the infestation. Leaving sections as refugia for the biological control agents to establish viable populations and inflict damage to the water hyacinth will require time, and on-going integration of manual and biological control provides a cost-effective long term control option. It is important to select the correct method at the correct time to have the least impact on weevil populations, such as interventions in spring or autumn (Byrne et al., 2010).

Where more than one biological control insect species is available for a weed, the combination of a suite of insect species is more effective than one single species (Julien and Orapa, 1999; Pitcairn et al., 1999). Releases are to coincide with plant growth in early spring to allow them to establish early enough and have viable populations during the active growth season in order to inflict maximum damage. An understanding of weed biology, dispersal methods and phenology improves selecting appropriate control methods and seasonal control programmes (Byrne et al., 2010).

Hoffmann (1995) provided three categories of success, namely complete, where no other control method is necessary, substantial, where other control methods are required, but at a reduced effort, and negligible, where other methods of control are required. Complete control is not the same as eradication; it means that the weed is not important any longer and biological control is the only required method (McEvoy et al. (1991). Post-release monitoring is an essential element of biological control programmes, but often neglected to the detriment of the programme. Through post-release monitoring, the level of success or failure can be determined, adaptive management actions can be facilitated, the integration with other control methods can be coordinated and overall management can be improved (Coetzee et al., 2011).

Long-term monitoring is necessary to substantiate the impacts of control programmes. Successes cannot be claimed without quantitative assessments. Monitoring programmes are to be conducted over time to provide sufficient information for decision-making. Good quality data forms the basis of any invasive plant control monitoring programme. It improves the understanding of the extent and distribution of aquatic weeds and ensures informed strategic responses and allows assessment of the impacts of biological control programmes. Monitoring results improve efficiency and effectiveness of future programmes, and justify investment in research and implementation of biological control programmes. For example, during the Rhodes University's annual, country-wide aquatic weed surveys, an increase in *Salvinia molesta* sites were detected for the period 2008 to 2010. As a consequence of this survey, mass-rearing and distribution of *C. salviniae* has improved and weevils were distributed to all of the new sites to enhance rapid control (Coetzee et al., 2011). *Salvinia* is no longer considered a major aquatic weed in South Africa. Monitoring results over several seasons and annual census results should be fed back to scientists for assessing the economic impact of biological control programmes and assisting with adaptive management. Monitoring results assist scientists in evaluating non-target effects as well as partial successes. In turn, feedback from scientists is important to inform management decisions. Sufficient resources and funding should be made available to undertake monitoring programmes. A prerequisite for monitoring is management plans containing clear, explicit and realistic targets to evaluate effectiveness. The economic and

environmental impacts of integrated weed management programmes should be evaluated, and the benefit:cost ratio should be quantified. The return on investment should be quantified in terms of the absence of weed management programmes.

Scientists can be involved in building adequate capacity to rear and release agents, and they can ensure contingency by passing knowledge on through mentorship and on-going training. Involving managers in release procedures will also give them some ownership of the projects. Managers should be trained in rearing and release techniques, and informed about the agent's ecology to create a better understanding of the requirements for successful integration. Implementers could also become involved in mass-rearing where possible. Julien et al. (1999a) recommend the following release techniques: select release sites away from possible interference with other control methods such as herbicidal, mechanical or manual controls; plants should be in good condition; water hyacinth mats should be stable and unlikely to be flushed downstream; floating booms can be used to stabilise mats and demarcate biological control reserves; select water bodies with slow moving water or protected sections of rivers rather than fast flowing waters; release agents as high up in the system as possible; release sufficient numbers of insects, as the greater the number of releases the more rapid the impact on the target weeds; multiple releases are recommended to ensure dispersal of agent populations; and finally, records should be kept of releases, dates of releases, and conditions surrounding releases, as well as photographic records of all aspects.

4.5 Conclusion

Environmental challenges in urban areas are an important consideration which often conflicts with socio-political needs such as the housing, health and safety of communities. The nutrient-enriched aquatic ecosystems, conflicts of interest and socio economic pressures put additional pressure on resources. By understanding the different factors influencing the implementation of biological control into weed management programmes, plans can be put into place to mitigate these factors. Biological control on its own is not enough; water quality improvements and integration with other methods will ensure the highest return on investment. Closing the gap between research and implementation, and understanding and implementing actions to overcome factors limiting integration are important to ensure biological control is fully integrated into weed management programmes in South Africa.

Three case studies in the CTMA provide guidelines for the implementation of the integrated aquatic weed management plans suggested by Hill and Coetzee (2008). The case study results will be discussed in the next chapter.

Chapter 5

Integrating biological control into aquatic weed management: case studies in the City of Cape Town

5.1 Introduction

The aim of this chapter was to assess whether biological control is a suitable control option for integrated aquatic weed management programmes in urban environments by means of three case studies.

5.2 Materials and methods

Not all sites are suitable for biological control, and many biological control programmes fail because an indiscriminate approach, which does not cater methods to particular sites, is followed. Three sites representing different scenarios were selected for this study. Figure 5.1 shows the locality of the three study sites, Diep River (Diep River Catchment), Black River (Salt River Catchment) and Westlake River (Sand River Catchment).

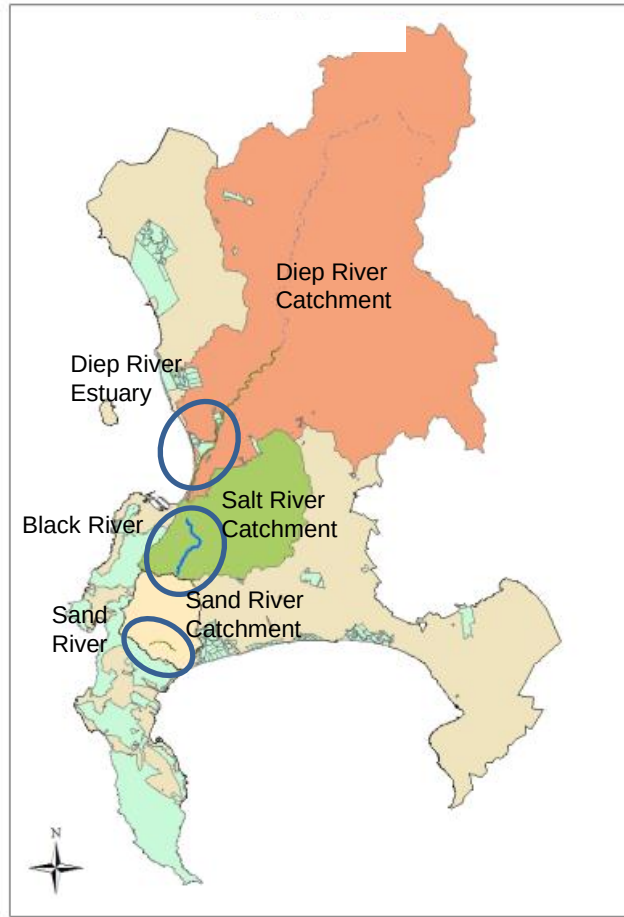


Figure 5.1: The locality of the three case studies in the CTMA

Management plans were developed for each of the sites based on recommendations by Hill and Coetzee (2008).

5.2.1 Identify the weeds

Surveys were conducted to identify the species present on each of the three study sites. The correct identification of the aquatic weed species is important for mainly two reasons. Firstly, if species are correctly identified during the early stages of invasion, rapid response can be triggered and eradication may even be possible (Hill and Coetzee, 2008; Holcombe and Thomas, 2009). Secondly, the species present determine the selection of control methods, because not all aquatic weeds have biological control agents available. In the absence of biological control agents, other options such as mechanical, manual and chemical control are to be considered.

5.2.2 Map extent of infestation

The categories described by Byrne et al. (2010) were modified to serve as a norm for recording the extent of aquatic weed infestations in the CTMA (Table 5.1). Three additional categories, 5 – 20%, 20 – 50% and 50-80 % were added.

Table 5.1: Density categories for aquatic weeds adopted from Byrne et al. (2010)

0%	1-5%	5 – 20%	20 – 50%	50 – 80%	100%
No signs of aquatic weeds	Narrow strip fringing the bank or in sheltered pools	Weed grow several meters back, or several areas are clear	Up to half of the surface area is invaded	Small patches are clear	The whole water body is covered with aquatic weeds;

Aquatic weed distribution maps were compiled using data from three sources: the Rhodes University's annual survey data, the Aquatic Weed Management plan for the City of Cape Town (COCT, 2011a), and the City of Cape Town's aquatic weed database. The information was ground-truthed and recorded. Biological control release records were obtained from the City of Cape Town Invasive Species Unit's biological control database. Aquatic weed distribution and biological control release maps were produced for each of the study sites. After mapping the extent of the invasion and the species present, the rivers were divided into management units using landmarks such as bridges. Floating booms were used to separate the management units (Jones and Cilliers, 1999).

5.2.3 Cause of infestation

Water bodies in the city are either inter-connected or isolated. The causes of infestation can be the result of the downstream movement of aquatic weeds, long-lived seed banks or unintentional distribution between water bodies by means of waterfowl or equipment used during clearing. Species such as *Azolla filiculoides*, for example, can be transferred between water bodies by birds. Another cause of infestation may be intentional or unintentional introductions through dumping garden waste in rivers or in the flood-line. Causes of infestation for the study sites could not be determined due to the absence of historical data. Data collected through future monitoring programmes will determine causes of infestation and inform future plans. Freshwater ecosystems in highly populated urban environments such as the CTMA contain characteristically high levels of nutrients as a result of water-borne sewage systems (Gossett and Norris, 1971; Hill and Olckers, 2001; Coetzee and Hill, 2009; Byrne et al., 2010). Eutrophication increases the occurrence of floating and rooted aquatic macrophytes (Byrne et al., 2010; Hill and Coetzee, 2008). Water hyacinth is more tolerant than many other aquatic plants to survive eutrophic conditions, and can double its biomass within six days under ideal

conditions and 14 days under less optimal conditions (Gopal 1987; Wise et al., 2007). Managing aquatic weeds without addressing water quality issues will not have the desired effects (Hill and Olckers, 2001; Hill, 2003). Nutrient levels affect the selection of control options, the time required to achieve the desired result and the level of control likely to be achieved (Hill and Coetzee, 2008).

5.2.4 Consult interested and affected parties

Local authorities, such as the City of Cape Town, consist of many different departments with diverse mandates and objectives. In the case of the CTMA, the water and sanitation department manages the waste water treatment works and reticulation systems, the scientific services section of the Transport Roads and Stormwater Department (TRSD) monitors water quality, and the TRSD is responsible for managing the stormwater system, rivers, retention ponds, wetlands and vleis. Some of the wetlands and vleis are protected areas, and managed by the Environmental Resource Management Department's (ERMD's) Biodiversity branch. Departments such as City Parks and Sport and Recreation are responsible for managing and maintaining areas surrounding dams and ponds on public open spaces and amenities. So-called "grey areas" occur from time to time when agreement cannot be reached about what constitutes "in the water" and "outside the water" as in the case of riparian zones. The ERMD's invasive species unit is responsible for coordinating invasive species management projects across the city. The invasive species unit has no executive authority or access to ring-fenced funding for invasive species management, and relies on cooperation from the various stakeholders. Other interested and affected parties include national and provincial government departments, Non-Governmental Organisations (NGOs), small farming communities, people with vegetable gardens, recreational users (canoeists, wind surfers, fishermen), friends groups and residents abutting rivers and wetlands. The stakeholder interests vary and influence the selection of control methods and timing of interventions. Conflict occurs when the various role-players cannot agree on the same control method and the timing of control operations.

The stakeholders were identified for each site and the most appropriate medium and frequency for communication and information sharing was selected on a case-by-case basis with the input from the key stakeholders.

5.2.5 Identify the lead agency

Integrated weed management requires a long-term commitment and necessitates a lead agency or champion (Hill and Coetzee, 2008). In the case of the CTMA, the invasive species unit is ideally placed to fulfil the role of champion and has played this role since 2008. Roles and responsibilities were determined and communicated for each of the sites.

5.2.6 Acceptable level of control

Aquatic weed management plans require clear objectives in terms of the acceptable levels of control. If eradication is no longer possible, infestations require on-going control. Acceptable levels of control for the CTMA were set, according to the rule of thumb of 20% cover suggested by Hill and Coetzee (2008), for South Africa. These thresholds are reviewed regularly and adjusted according to specific water bodies. Without setting clear targets and timeframes and assigning responsibilities (van Wilgen et al., 2012), control programmes are a waste of resources and staff time.

5.2.7 Selection of control options

Control options are considered on a site-by-site basis and depend on different factors such as level of infestation, acceptable level of control for the site and resources available (Hill and Coetzee, 2008).

The suitability of the sites for biological control was evaluated according to the six factors impacting biological control operations: species and level of infestation, conflict of interest, water quality, climate and hydrological features. The type (river, wetland), characteristics (natural, channelised, combination), aquatic weed species present, impacts, reason for control (hydrology, public pressure, access, recreational use, protected area), and historical control efforts were used to evaluate the representivity of the different sites.

5.2.8 Implementation

The plans for each site were implemented.

5.2.9 Monitoring

Monitoring the successes of biological control operations and to what level biological control is integrated into weed management programmes is an integral part of weed management programmes. Post release monitoring confirms establishment of agent populations, as well as the prevalence and abundance of agents. Monitoring indicates whether the control of invasive species is successful or not, and whether the selected methods have the desired impact. A monitoring database was set up by the invasive species unit to ensure the monitoring data is on record and to allow for analysis to determine the efficacy of the selected control methods.

5.2.10 Evaluate and adjust

It is vital to evaluate the progress against the targets and the efficacy of control methods. Reporting by means of monthly reports serves as means of communication with stakeholders and ensures accountability. Contingency plans make provision for unforeseen events such as

floods or new invasions. Flexibility was built into the plans, and included reprioritisation and adapting control methods following unforeseen events. Collaboration with Rhodes University and researchers ensures that the latest research findings are taken into account to inform management decisions (Hill and Coetzee, 2008).

5.3 Case Study : The Diep River Estuary

The Diep River Catchment is located north of Cape Town and comprises a total area of approximately 1495km². Most of the catchment area is situated outside the boundaries of the CTMA. The Diep River rises from the Riebeeck-Kasteel Mountains in the north-east, from where it flows in a south-westerly direction past the town of Malmesbury for approximately 65 km before it discharges into Table Bay (C.A.P.E., 2011).

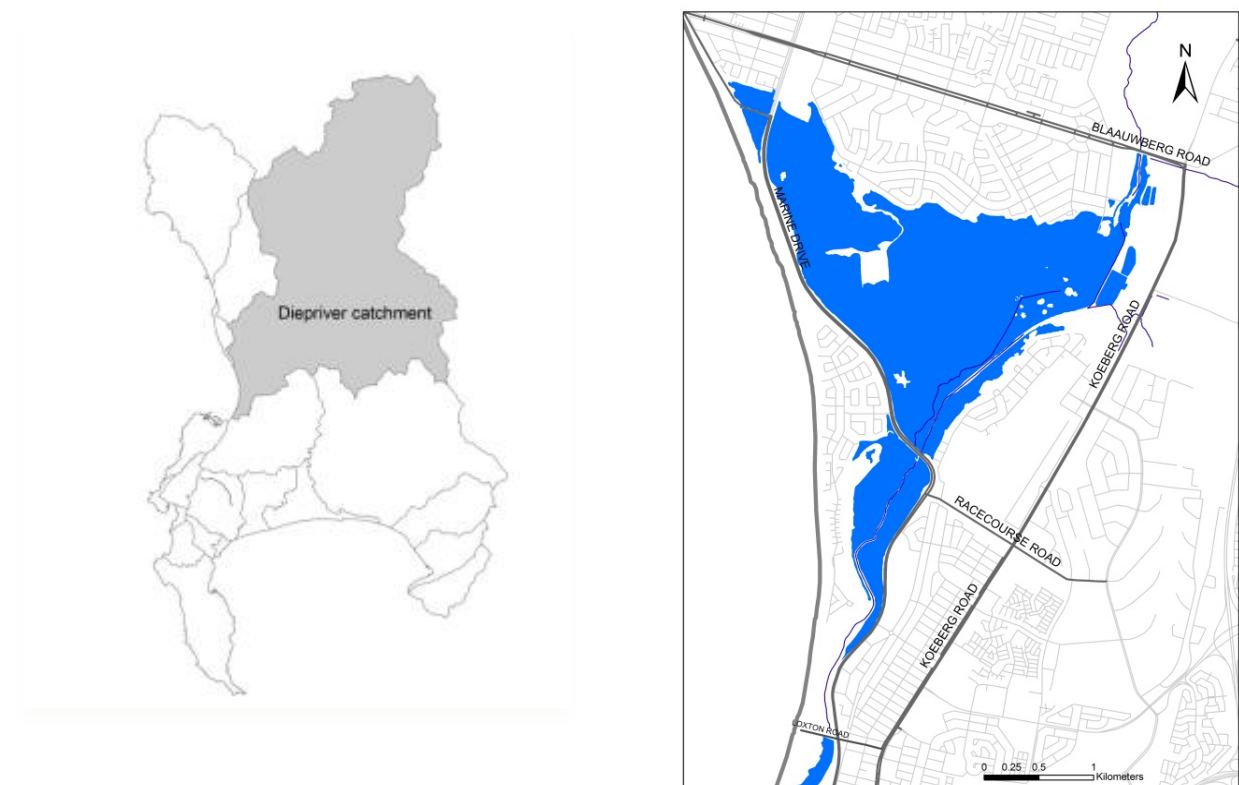


Figure 5.2: The locality of the Diep River estuary, Diep River Catchment

The Diep River estuary is approximately 900 hectares in extent and includes the Rietvlei and Milnerton Lagoon. The Blaauwberg road bridge forms the north-eastern boundary of the estuary and the Otto du Plessis Drive Bridge the south-westerly boundary (C.A.P.E., 2011).

5.3.1 Site description

The Diep River broadens near the coast to form the Rietvlei and enters the vlei at the north-eastern corner. Except for Flamingo Vlei, an artificial water body which has been dredged to a depth of 9m, the Diep River estuary is flat with an elevation of 1.0 to 2.0m above Mean Sea Level (MSL) (Lochner et al., 1994). Rietvlei forms a triangular shape with its maximum width of 2km in an east-west direction and 1.5km in a north-south direction. The Milnerton Lagoon runs from the southern end of the Rietvlei to the estuary mouth (C.A.P.E., 2011).

The Diep River has been rated as a Category 1, or “core” river in the City’s Conservation Priority dataset based on its high habitat integrity score and the fact that it feeds directly into Rietvlei, a protected area. The estuary, including sections of Rietvlei, is an important fish and birdlife habitat and ranked in the top seven of the 42 largest estuaries in South Africa in terms of water bird conservation importance (C.A.P.E., 2011).

5.3.2 Impacts

The Diep River is heavily impacted by agriculture and urbanisation, with cultivation of the river banks dating back as far as 1690. The removal of riparian vegetation and poor land management practices resulted in extensive erosion and the silting up of the river, Rietvlei and the Milnerton Lagoon. The Potsdam Wastewater Treatment Works started discharging into the Diep River Estuary in 1960 and caused changes in the hydrology of the river, vlei and estuary. Earlier records (1608) show that the Rietvlei comprised a series of seasonally flooded pans, and early winter rains caused the Diep River to break its banks. The pans were filled with water and silt in winter and gradually dried up during the summer months. Strong winds during summer removed the silt that was deposited during winter. The winds lifted dust and sand from the dry pans. River bank erosion increased the silt deposits, and the Diep River gradually became shallower over the years. Residential developments on Flamingo vlei led to pressure on the city to control the dust during the dry summer. Residents complained about the fine silt deposits during windy days, resulting in the city pumping water from the vlei into the Central Pan during dry periods to control the dust. This practice exacerbated the sedimentation problem in the seasonal wetland area as it prevents the removal of sand and silt from the system. Road embankments confine the river to a channel (C.A.P.E., 2011; Brown and Magoba, 2009).

5.3.3 Aquatic weed species and levels of infestation in the Diep River Estuary

No records of the aquatic weed infestations in the Diep River Estuary prior to 1988 could be located. A CSIR report by Grindley and Dudley (1988) recorded an increase in reeds, but no reference was made to water hyacinth or other aquatic or emergent weeds. It is therefore assumed that the Diep River Estuary was free of aquatic weeds in 1988. The first detailed and recorded assessment of the aquatic weed infestation of the Diep River Estuary was in May

2008. During the 2008 survey the dense water hyacinth and emergent weed (*Commelina bengalensis* and *Persicaria lapathifolia*) infestations were recorded. Emergent species such as *Commelina sp.* and *Persicaria lapathifolia* are found along the river banks and the opportunistic nature of these species causes them to grow on top of the water hyacinth. This mixture of weeds made access and control difficult. The Rietvlei wetland borders onto residential areas and is prone to *Pennisetum clandestinum* (Hochst. ex Chiov.) (Kikuyu grass) invasion. The emergent weeds growing on top of the water hyacinth stabilise the mats and prevent them from being washed out of the system during the winter rainfall periods. The rainfall figure of 429mm for the 2012 winter rainfall season (May – September), with its peak in August (205.5mm) was the highest monthly rainfall experienced in 10 years. The abnormally high rainfall and subsequent floods during the winter of 2013 resulted in the water hyacinth being flushed out to sea. The floods resulted in only a few remaining water hyacinth plants in the reed beds; the overall water hyacinth presence after the floods was <5% and the emergent weeds <10%. Prior to the 2013 floods, the Diep River Estuary was densely invaded by water hyacinth from the M14 (Blaauwberg Rd) bridge through to the servitude road, approximately 300 meters from the R27 (Otto du Plessis Drive) bridge.

5.3.4 Stakeholders

Several stakeholders are involved in the Diep River Estuary. The Diep River Estuary forms part of the Table Bay Nature Reserve and is under management of the ERMDs Biodiversity Branch. The TRSD is responsible for flood prevention, for the annually scheduled pre- and post-winter river cleaning programme, and for maintaining the storm water system. The biological services section in catchment management's scientific services is responsible for monitoring water quality and responding to related issues. The Water and Sanitation department is responsible for managing and maintaining the sewage system and the Potsdam Waste Water Treatment Works. The Rietvlei Management Working Group oversees the implantation of the Diep River Estuary Management Plan. The Department of Water Affairs is responsible for implementation of and compliance with the National Water Act. Other role-players include CapeNature (Estuary management programme), WWF, Chevron, Friends of Rietvlei, Milnerton Aquatic Club, Department of Environmental Affairs (DEA – Oceans & Coasts (Estuaries & Pollution Divisions), Department of Agriculture (LandCare), Department of Environmental Affairs and Development Planning (W.Cape), and ratepayers.

The Transport Roads and Stormwater Department (TRSD), the Milnerton Aquatic Club and the Table Bay Nature Reserve expressed their concern about biological control as an option. The TRSD is concerned about floods and potential infrastructure damage due to water hyacinth mats moving downstream. The wooden bridge in the Lagoon is a historical monument and may

be damaged or even collapse if large mats of water hyacinth pile up against it. The Milnerton Aquatic Club used to canoe as far as the Blaauwberg Bridge prior to the water hyacinth and reed infestation, and want the city to use mechanical methods to remove the infestations (R. Ikin, personal communication). The Table Bay Nature Reserve management prefers manual control above biological control. The Friends of Rietvlei and ratepayers may potentially also expect a more drastic approach by means of mechanical, manual or even chemical control.

5.3.5 Water quality

The Diep River's water quality is poor as a result of fertiliser run-off, pig and poultry farming, water abstraction, river modification, discharges from the Potsdam Waste Water Treatment Works, and industrial and household pollution. The City monitors water quality monthly by sampling 12 points along the river.

5.3.6 Historical management of aquatic weeds

Invasive weed control at Rietvlei section of the Diep River dates back to 2002 when control was inconsistent and performed ad hoc due to a lack of funding and appropriately skilled teams (K. Retief, pers. comm.). The water hyacinth and silt in the section of the Diep River from Theo Marais Park to Otto du Plessis Drive were removed annually in April with long-boom excavators as part of the Stormwater Department's annual post-winter river cleaning programme. The practice of removing silt and water hyacinth by means of heavy machinery was stopped by the reserve management to prevent the pans from drying up during the summer. The long-term vision is to allow the channel to close completely (K. Retief, personal communication). The Diep River also underwent intermittent manual removal of water hyacinth. None of these methods resulted in a reduction of water hyacinth in the system, and the weed continued to expand as a result. Terrestrial weeds were controlled as and when funding was available. A long-term integrated weed control programme was initiated in May 2012.

5.3.7 Implementing the management plan

Two methods, manual control and biological control, were applied to control aquatic weeds in the Diep River. The river was divided into two management units namely the Diep River Estuary (DRE01) from the M14 (Blaauwberg Bridge) to the Otto du Plessis Drive (R 27) bridge, and Lower Diep River (DRE02) river from the R27 bridge to the river mouth. Different control methods were selected for controlling floating and submerged aquatic weeds in DR01 and DR02. Floating booms were placed across the river to contain the weeds and preventing them from floating downstream to cleared areas. The floating booms consisted of 2 litre plastic cold drink bottles tacked into canvas and tied to a rope, the booms were secured by pegs, one on each side of the river bank.

Management unit DRE01: The initial manual control in DRE01 was conducted by a specialised aquatic weed control team consisting of 20 workers from July to September 2012. Aquatic weeds were manually removed by means of rakes, forks and hand pulling, and stacked on the river bank about 10 meters away from the water. Access was difficult due to dense reed growth at sections of the river. A small boat was used in areas not accessible by foot. The operators wore life jackets and used rakes to move the water hyacinth to the closest access point from where it was placed on a canvas and dragged away from the water to be stacked. The emergent weeds, *P. lapathifolia*, *C. bengalensis* and *N. officinale* were disposed of at Vissershok landfill site to prevent reinvasion. After the initial phase the team returned in February 2013 for five days for a follow up operation. Six river wardens were deployed from October onwards to manually remove the emergent weeds and to conduct by-weekly surveys of the cleared area to detect and remove any water hyacinth regrowth.

The manual clearing produced dramatic results and follow up control ensured DRE01 remained clear from water hyacinth.

The management unit DRE02, the pilot site for biological control, was selected to pilot the use of biological control as a method under the prevailing site and water quality conditions. DRE02 was invaded by water hyacinth and emergent weeds (*Commelina bengalensis*, *Persicaria lapathifolia* and *Nasturtium officinale*). The emergent weeds were controlled manually and biological control was used for the water hyacinth. Augmented releases of four biological control agents on *Eichhornia crassipes* (water hyacinth) commenced in November 2012, with 5400 *Neochetina* weevils, 5100 *Eccritotarsus catarinensis* and 450 *Cornops aquaticum*, being released by August 2013.

The high winter rainfalls from August to October 2013 caused severe flooding, and the water hyacinth infestation and biological control agents were washed out of the system. The infestation quickly recovered and was again accessible by the end of November. The water hyacinth infestation recovered dramatically and reached levels of 60% cover by mid December 2013. Due to SASRI's closure and the reduced levels of available agents as a result of the winter population crash, no biological control agents were available for release, and manual control was implemented in DRE02 without the benefit of biological control agents. Surveys revealed that there was some weevil survival, but not enough to result in the weevil population to bounce back or to inflict any damage to the water hyacinth plants. No signs of *E. catarinensis* or *C. aquaticum* presence were found during the post winter surveys.

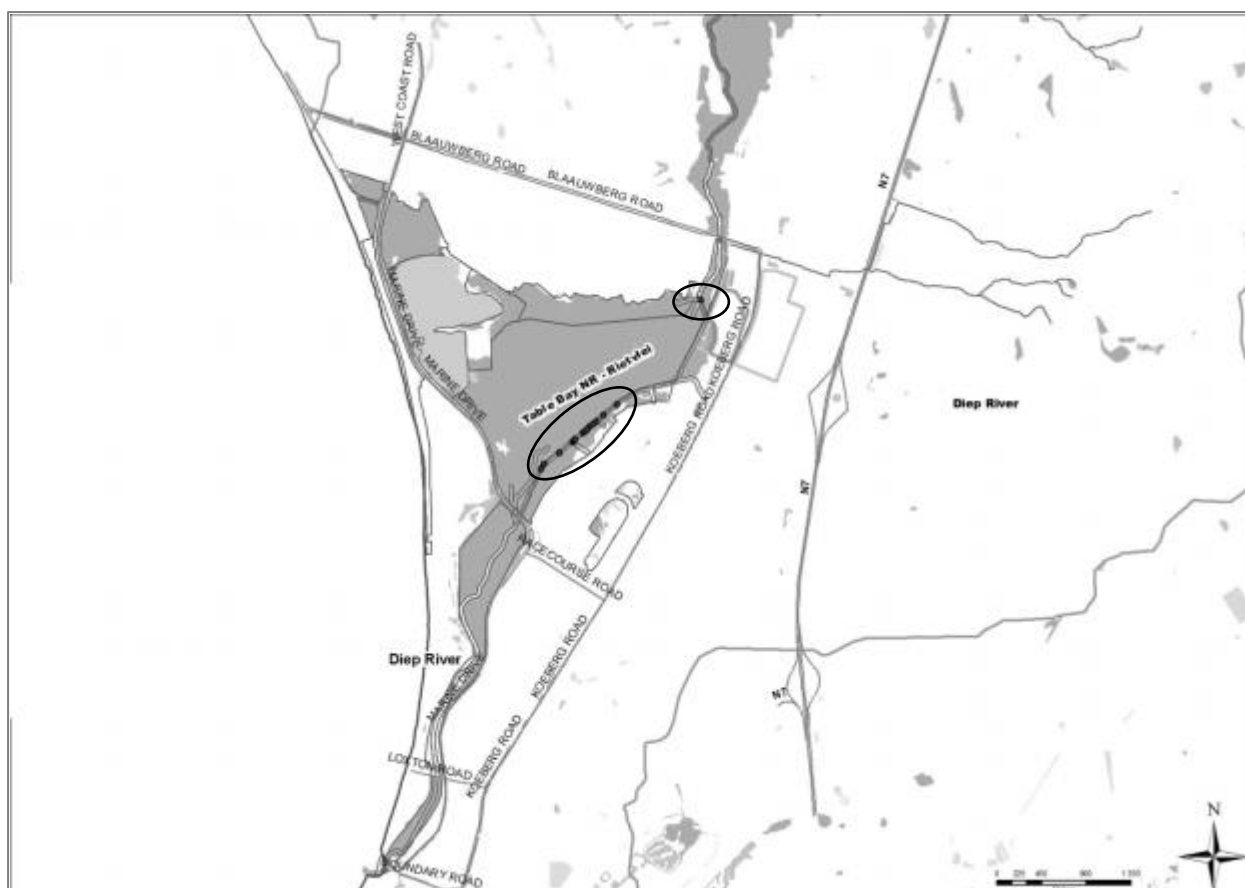


Figure 5.3: Biological control release sites, Diep River Estuary (DRE02)

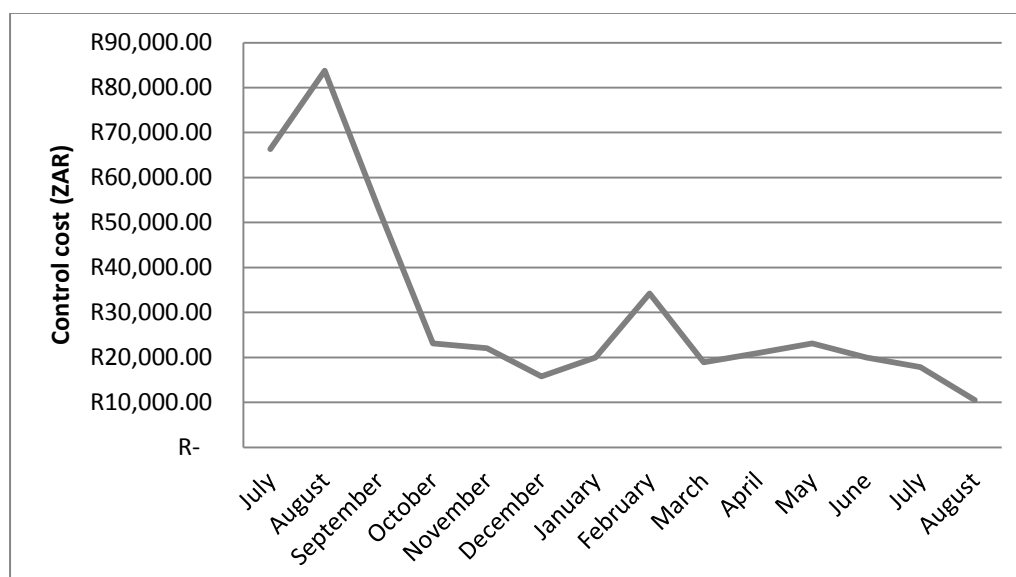


Figure 5.4: The expenditure for the first 14 months of the integrated control programme in the, Diep River Estuary

5.4 Discussion

The suitability of the Diep River estuary for integrating biological control has to be considered against the factors limiting the impact of biological control, such as conflicts of interests, water quality, climate and hydrological features

When considering the aspect of conflicts of interest, the Diep River Estuary may not be an appropriate site for integrating biological control to manage water hyacinth infestations. However, when considering the most cost effective control method, the benefit of integrated control outweighs conflicts of interest.

The poor water quality supports water hyacinth growth while inhibiting the establishment and spread of the biological control population and the effect of the agents on the target weed (Hill et al., 2001). The water quality conditions in the Diep River Estuary favour water hyacinth growth. Biological control programmes are not always successful in eutrophic systems such as the Diep River, because the plants outgrow the agents (Hill and Olckers, 2001). However, integration of biological control will supplement other control methods because the only accessible area for manual control is the channel. Biological control will reduce the vigour of water hyacinth while manual control will keep the infestation levels in the channel under control.

Although frost during winter is absent in the CTMA, browning of water hyacinth leaves were observed during field observations since 2010. The lower temperatures during the winter months have an effect on water hyacinth, causing plant dormancy and reducing plant growth rate and plant quality. However, ramet production continues throughout winter free of natural enemies, giving them an advantage during the onset of spring while the insect numbers are recovering. The impact of temperature on the host plants during winter also negatively influences the biological control agents in terms of their feeding rates, mortality and reproduction, causing limited efficacy (Byrne et al., 2010). In the study by Byrne et al. (2010) it was found that water temperature plays a more significant role in water hyacinth growth than air temperature. The study found a correlation between the rates of leaf production with the increase of water temperature. The threshold temperature for plant growth is 6.9°C. *Neochetina* weevils are able to survive the winter conditions although at a low rate (Byrne et al., 2010). The average annual temperature of 17°C in the CTMA will not have a severe influence on the weevils, and the water temperature in the Diep River is 18°C. The winter will not severely effect water hyacinth growth, but the weevils will be affected.

The Diep River estuary is densely invaded by *Phragmites australis* (Cav.) Steud. and *Typha capensis* (Rohrb.). It is protected from wind and wave action. The impact of biological control agents are more effective on smaller water bodies that are exposed to wind and wave action

(Hill and Olckers, 2001). The insect-damaged plants in more sheltered water bodies such as the Diep River estuary are not affected by wind fetch and wave action. However, what make the site ideal for biological control are the dense reed infestations, because water hyacinth growing amongst the reeds cannot be reached for any other control method, such as mechanical, chemical or manual. The sheltered areas between the reeds therefore serve as refugia for the natural enemies and also assist in building up sufficient numbers.

The Diep River estuary is subjected to stochastic events such as floods during winter, causing the water hyacinth to be flushed out of the system. As a result of the dense water hyacinth mats and the emergent species growing over the water hyacinth, the infestation was not affected during the observation period of 2011 to 2012. The above-average rainfall in the month of September 2013 caused the system to be flooded and the water hyacinth and biological control agents to be driven out of the system. The previous flooding event was in 2009 where the water hyacinth was also flushed out of the system (K. Retie, personal communication). The 2013 floods caused a major disruption of the biological control efforts, because most of the plants and biological control agents were driven out of the system. A South African Water Research Commission (WRC) post-release evaluation study found that stochastic events such as flooding affected eight of the fourteen sample sites at least once during the sampling project of two years. Some sites were more severely affected than others, for example one site was flooded twice and another three times during the two years (Byrne et al., 2010). Frequent floods result in almost total elimination of agent populations, allowing plants to escape insect herbivory following recruitment from seed. Stochastic events allow the opportunity to respond timeously by inundated releases of agents as soon as the plants start to reappear, and herbicides can be used to contain the infestation. Surveys after the floods showed that water hyacinth returned with vigour and re-invaded the Diep River. Due to the closing of SASRI, no agents were available for release and manual control was used. In January 2014, 500 *Neochetina* weevils were released. Booms were put in place to contain the biological control reserve and allow the weevils to establish and disperse. The biological control reserve will receive augmented releases to boost the biological control population. Manual and chemical control was integrated in the rest of LDR and DRE. Glyphosate herbicide was applied at a non-lethal rate of 0.5%. The results have yet to be confirmed.

5.5 Case study 2: Black River

5.5.1 Introduction

The Black River is situated in the Salt River Catchment and is a highly modified and polluted river. Aquatic weed invasions in the Black River date back to the 1930s (Brown and Magoba, 2009). Of the several stakeholders involved in the Black River, the Stormwater Department is the most important. The Stormwater Department is the lead department in managing the Black River with the main focus on improving hydrology and management of stormwater infrastructure. Annual pre-and post-winter maintenance of the river involved the mechanical removal of aquatic weeds (mainly water hyacinth) and silt to prevent flooding during the winter rains. The poor water quality of the Black River supports aquatic weed infestations, and mechanical removal of aquatic weeds on its own is insufficient to keep the infestation under control. The Black River aquatic weed management plan, based on the work of Hill and Coetzee (2008), was adopted in 2012, and made provision for collaboration between stakeholders and integrating control methods.

5.5.2 Site description

Several canals (Elsieskraal, Vygekraal, Blomvlei, Bokmakierie, Kalksteenfontein, Jakkalsvlei) drain the Cape Flats confluence to form the Black River downstream from the Athlone Waste Water Treatment Works (WWTW). The Black River flows past the Rondebosch Golf course and alongside the Settlers Way (N2) and Black River Park Way (M5) until its confluence with the Liesbeek Canal, before it flows into the Salt River Canal near Table Bay Boulevard (N1), which empties into Table Bay (Southern Waters, 2001). The Black River changed from seasonal to perennial mainly as a result of the waste water discharge from two waste water treatment sites, namely Athlone, discharging 73 million m³ of waste per year, and Borchers Quarry, discharging 12 million m³ per year (DWAF, 2005). Three wetland remnants, Vincent Palotti wetland, the Valkenberg wetlands and the Raapenberg wetlands, are virtually isolated from each other as a result of canalisation of the Black River and the construction of berms. Biotic modifications include alien species invasion and the removal of indigenous vegetation, and riparian vegetation along the river has also been lost as a result of urban development (Brown and Magoba, 2009; TRUP, 2012). No indigenous fish are present in the Black River, and only invasive species such as carp (*Cyprinus carpio* (Linnaeus)) and catfish (*Clarias garipinus* (Burchell)) are remaining. The Habitat Integrity/ Ecological Status of the channelised portion of the lower Black River has been classified as a Class F (Southern Waters, 2001) indicating the system has undergone extreme changes from its natural condition (Freshwater Consulting Group, 2012).

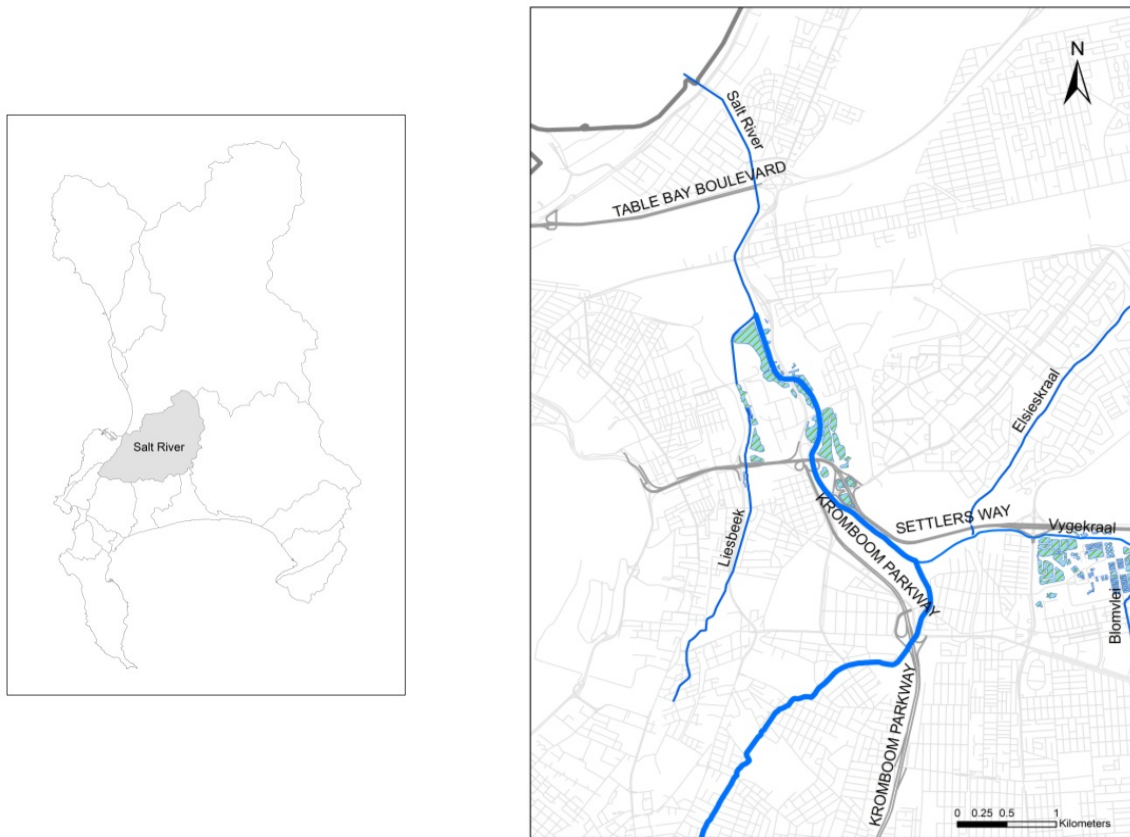


Figure 5.5: The locality of the Black River, Salt River Catchment

The Black River study site is situated between the Athlone WWTW and the Table Bay Boulevard Bridge (N1). The length of this section of the Black River is 6.1 km (48.68ha). The river is shallow as a result of siltation, and the water is slow flowing during summer months while winter rainfall increases the flow and raises the water levels. The Black River is visible from the N2 (Settlers Way) and the M5 freeway.

5.5.3 Black River stakeholders

The involvement of and collaboration between the different stakeholders is important for effective management of the Black River. Several stakeholders are involved, but collaboration has not yet reached its full potential. The main stakeholder, the City of Cape Town's Stormwater Department, is responsible for flood prevention which includes the annual scheduled pre-and post-winter river cleaning programme and maintaining the stormwater infrastructure. The biological services section in catchment management's scientific services is responsible for monitoring water quality and responding to related issues. The Water and Sanitation Department is responsible for managing and maintaining the sewage system and the Athlone and Borchers Quarry Waste Water Treatment Works. Three events were catalysts for the

implementation of the management plan, namely council approval for the launch of the Kader Asmal integrated catchment management programme, the establishment of the Friends of the Black River, and the Peninsula Paddle. The Kader Asmal integrated catchment management programme fosters collaboration and synergy between key departments, and is a major job-creation initiative. The Friends of the Black River was formed to incorporate the community interests into the management of the Black River. The friends group was off to a slow start, but gained momentum under active leadership of, amongst others, Liz Wheeler, and support from the sub-council and the ward councillors in the area. The involvement of the Friends of the Black River is an invaluable mechanism to raise awareness and actively engage communities to take action towards improving the state of the river. The first Peninsula Paddle, initiated by Dr Kevin Winter, a lecturer at University of Cape Town's Department of Environmental and Geographical Science, and three others, took place in 2011 with a small group of canoeists paddling from Zandvlei to the Milnerton Lagoon to raise awareness about the perilous state of Cape Town's Rivers. Since 2011, two more Peninsula Paddle events were held with the slogan "Take back Cape Town's Waters". This growing event is a major drive and aligns with the City of Cape Town's "Save our Waters Campaign". Other role-players include City Parks (Two-Rivers Urban Park) and Department of Water Affairs responsible for implementation of and compliance with the National Water Act.

5.5.4 Water quality

The Black River is a highly impacted system with poor quality as a result of household, stormwater and industrial run-off, river modifications, and waste water discharge. Compacting of the Salt River Catchment caused severe reduction in water quality, particularly after the dry season when oil, litter, fertilisers and decaying material accumulate and are washed into the river as stormwater runoff. The poor water quality of the Black River is further exacerbated by the effluent discharge from the Borchers Quarry and Athlone WWTW as well as the high levels of pollutants from the canals which run into the Black River. Water quality is particularly affected when sewage overflows from the two WWTW occur, resulting in exceptionally high counts of faecal coliforms. The Jakkalsvlei canal for example flows adjacent to informal settlements and receives effluent from the Borchers Quarry WWTW. The City of Cape Town's water quality reports show consistently high levels of *Escherichia coli* (*E. coli*) of between 100 000 and 1 million over an 11 year period from 2000 to 2011. The Langa canal also shows an increasing trend of between 100 000 and 30 million *E. coli*. Although the chlorination treatment of effluent from the Athlone WWTW in 2010 resulting in declining *E. coli* levels downstream of the WWTW, the water quality is still poor with high levels of the two nutrients important for water hyacinth proliferation, namely nitrogen and phosphorous.

5.5.5 Aquatic weed species and levels of infestation of the Black River

The water hyacinth infestation in the Black River dates back to 1930 (Brown and Magoba, 2009). The river has been monitored by the invasive species unit since 2008 and annual water hyacinth infestation levels of up to 100% at times were recorded. The emergent species *Commelina bengalensis* is found along the river banks, and its opportunistic nature causes it to grow on top of the water hyacinth. These dense mats of water hyacinth with the *C. bengalensis* overgrowth prevent light penetration and deprive the water of oxygen. The vegetation on the river banks and river fringe includes several herbaceous and annual weeds, kikuyu grass and emergent species such as *Phragmites australis*, *Persicaria laphatifolia*, and *Nasturtium officinale*. Invasive macrophytes such as parrot's feather (*Myriophyllum aquaticum*) were also recorded (Freshwater Consulting, 2012). The pondweed (*Potamogeton pectinatus* (L)) proliferated over the past 12 months (personal observation) possibly as a result of the opening of the water column due to the on-going water hyacinth control.

5.5.6 Historical management of aquatic weeds in the Black River

The Stormwater Department manages the Black River and the main focus is river hydrology. The main means of aquatic plant removal has been mechanical removal by means of long reach excavators. Although the use of long reach excavators to remove aquatic weeds such as water hyacinth produces immediate results, it is not a recommended method. The long reach excavators are non-discriminating; they remove silt, aquatic submerged or floating macrophytes (invasive and indigenous), aquatic organisms and soil, and they additionally remove useful fringe vegetation, cause soil erosion and perpetuate the steep river banks (Freshwater Consulting, 2012). Historically the use of long reach excavators was the only control method, and it occurred once the water hyacinth infestation levels reached a point where they posed a flood risk. The annual mechanical pre-winter clearing programme in the Black River, scheduled by the Stormwater Department, costs up to R 700, 000/annum (P. Koen, personal communication). Due to the high cost involved and the rotation of the long reach excavators between rivers in the city, the water hyacinth infestations are not maintained, and grow back to a widespread presence before the removal within a few months (T. Present, personal communication).

5.5.7 Implementing the management plan

The Black River aquatic weed management plan was adopted, and implementation commenced in February 2012. The Black River was divided into five management units: BR01 (Athlone WWTW to Raapenberg footbridge) BR02 (Raapenberg footbridge to Settlers Way/ M5 interchange), BR03 (Settlers Way/M5 interchange to Valkenberg footbridge), BR04 (Valkenberg footbridge to M5 bridge) and BR05 (from the M5 footbridge to Table Bay Boulevard (N1)

bridge). Due to the high risk of flooding and the 100% water hyacinth cover, it was decided not to use biological control on the water hyacinth, only on other weeds when present such as *Myriophyllum aquaticum*. Manual control of the dense water hyacinth infestation was not readily accepted as a method by the Stormwater Department, mainly due to the nearing winter rainy season and the potential of floods. The traditional mechanical clearing was the preferred method. It was agreed upon to deploy the long reach excavator in two of the five reaches and clear the rest manually during the high impact, initial clearing phase. Thereafter, only manual and chemical control would be deployed for follow up operations. This agreement was a breakthrough and laid the foundation for the successful integration and collaboration between the lead department (Transport Roads and Stormwater) and the invasive species unit (Environmental Resource Management Department).

Figure 5.6: The Black River management units and control methods

Management unit	Mechanical	Manual	Chemical	Biological
DR01				
DR02				
DR03				
DR04				
DR05				

A specialised aquatic weed team consisting of 22 workers was deployed to manually remove the water hyacinth. The team received water safety training and their safety clothing consisted of a pair of waders and life jacket. Floating booms were placed across the river and secured on the river banks. The purpose of the floating booms was to contain the water hyacinth plants between the different reaches and allow the team to collect and remove the plant material drifting downstream. The team used a floating device constructed out of a wooden platform placed on 4 x 20ℓ drums. Ropes were tied to the floating device. The water hyacinth mats were raked and loaded on the float with fork spades. Workers positioned on the river bank pulled the float once it was loaded and off-loaded the material onto a canvas. The canvas was then pulled to a central collection point. From there the trucks removed the plant material to the Athlone green waste transfer depot. Although manual control is very labour-intensive and usually not recommended for large infestations, it had benefits in the case of the Black River. The main benefit is certainly job creation, since the team removed not only the aquatic weeds, but also litter and objects including tyres, wheelie bins, mattresses, and fridges from the water, resulting in visual improvement of the river and improving hydrology. Six workers were deployed to follow up after the longreach excavator to remove the plants that were left behind. The water hyacinth was sprayed with diquat (dibromide) 200g/ℓ at a rate of 2.5% mixed with water. The biomass

was removed from the river and placed on the banks to dry before it was disposed of at the green waste transfer depot at Athlone.

When considering the financial implications, the personday rate of US\$ 24.56 for the initial clearing phase (February – June 2012) included the removal and disposal of plant biomass and litter, and the average follow up rate was US\$ 16.82 for the period July 2012 – February 2013. The personday rates include wages, personal protective equipment, transport, admin costs and biomass removal. After the initial clearing, the river is maintained by a team of 22 river wardens sourced from the nearby Maitland Village. Maintenance includes removal of aquatic weeds and litter.

Table 5.2: Projected five year budget to control aquatic weeds and remove litter on the Black River

Fin year	Manual/Chemical	Mechanical
2012/13	US\$ 87 253.07	US\$ 61 403.51
2013/14	US\$ 56 408.77	US\$ 61 699.75
2014/15	US\$ 47 947.46	US\$ 65 093.24
2015/16	US\$ 40 755.34	US\$ 68 673.37
2016/17	US\$ 34 642.04	US\$ 72 450.40
Total	US\$ 267 006.67	US\$ 329 320.27

A projected five year project budget of US\$ 267 006.67 will be required for manual and chemical control of the water hyacinth infestation in the Black River including the disposal of biomass and litter. The projected five year budget for mechanical control, assuming a constant CPI of 5.5%, is US\$ 329 320.27, a saving of US\$ 62 316.60.

5.6 Case study 3: Westlake River

5.6.1 Site description

The Westlake River rises on the slopes of the Steenberg Mountains, and flows into the Westlake Wetlands after 4.09km and then into Zandvlei (Figure 5.7). The river runs through a diverse urban landscape which includes a Golf Estate, vineyards, shopping centre, an informal settlement, Pollsmoor correctional facility and a residential area before it mouths into the Zandvlei Estuary.

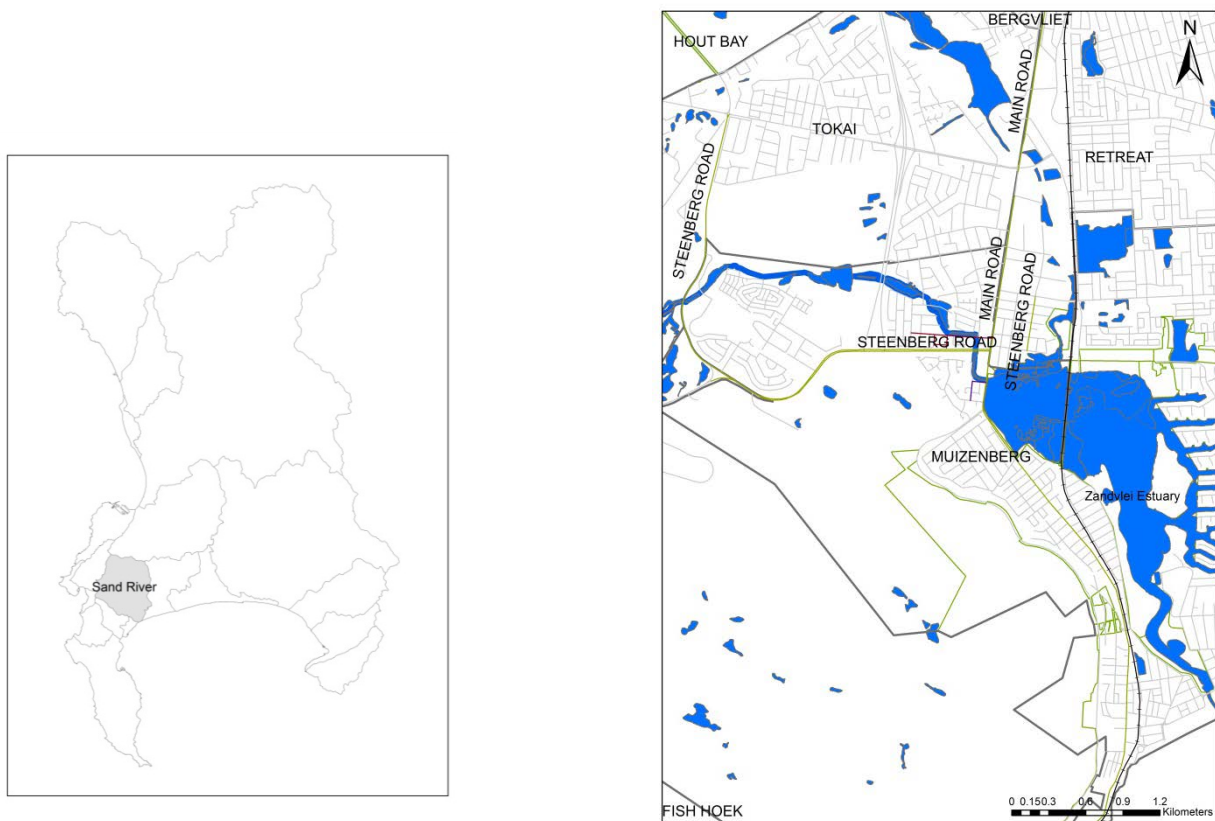


Figure 5.7: The locality of the Westlake River, Sand River Catchment

At Pollsmoor the river flows into the Pollsmoor dam, used for irrigating the correctional facility's gardens. The dam is invaded with alien fish, such as bass and carp, and frequented by several bird species (COCT, 2011).

The Westlake River is heavily impacted by stormwater run-off, and industrial and household pollution. One of the main sources of pollution in the Westlake River is the frequent sewage spills from the reticulation system on the premises of the Pollsmoor correctional services. The Westlake shopping centre and restaurant complex as well as the informal settlement are also

major sources of pollution. Around 1984 the north and south banks of the Westlake River were porous i.e. there were earth banks covered in vegetation with gaps in them which allowed water flow into and out of the adjacent wetlands. Solid banks were created along the north bank as a result of bulldozing to create a solid berm access for large mechanical drag lines and trucks to remove the weed growth in the rivers. The river was canalised as a result, causing an increased water flow, higher siltation levels downstream and increased carriage of litter. The railway bridge at the confluence of the Keyser's and Westlake rivers is narrow, and has a concrete sill at the base and an accumulation of large gravel pieces from the railway bed above. This creates a very effective "choke" on the flow of water into the main Zandvlei water body. During heavy water-flow, the water builds up at the railway bridge and floods back into the Westlake Wetlands. A large brown stain is visible during heavy rainfall periods, spreading out into the Westlake Pond at the end of Rutter Road. This backflow carries the nutrients into the water body (J. Fowkes, personal communication).

5.6.2 The Westlake River Stakeholders

The Transport Roads and Stormwater Department (TRSD) is responsible for managing river hydrology and stormwater systems; the Water and Sanitation Department is responsible for water reticulation and sewage and the invasive species unit for aquatic weed management. Other stakeholders include Friends of Kirstenhof Wetlands, Zandvlei Trust, Table Mountain National Park, Wildlife and Environmental Society of Southern Africa (WESSA), the Western Leopard Toad working group, Sand River Catchment Forum, Sandriver Catchment working group, the ward, Working for Wetlands and the Biodiversity Branch.

The means of communication between the stakeholders is through the quarterly Sand River Catchment Forum meetings. The Sand River Catchment Working Group was formed to coordinate the funding streams and monitor progress. The difference between the two working groups is that one is a forum for sharing information while the other is an action group responsible for putting plans into action and facilitating collaboration at operational level. Feedback is also given at quarterly sub-council meetings.

5.6.3 Water quality

The water quality of the Westlake River is poor as a result of nutrient enrichment from fertiliser, industrial, household and stormwater run-off. Regular overflows as a result of sewer blockings is of major concern. The poor water quality contributes to excessive aquatic weed growth in the Westlake River.

5.6.4 Aquatic weed infestation in the Westlake River

Eleven of the current 14 aquatic weeds found in the CTMA are also present in the Westlake River. The first water hyacinth infestation in the Westlake Wetlands arrived via the Keyser's River in the late 1980s. The Keyser's is one of the main rivers in the Sand River Catchment, and discharges into the Westlake Wetlands. The plant was not identified at the time and therefore not removed (J. Fowkes, personal communication). The macrophytes *M. aquaticum*, *C. demersum*, *Lemna gibba*, *E. crassipes*, *Nympaea* (possibly *N. mexicana*) and *Aponogeton distachyos* were recorded in 1982 (Heydorn and Grindley 1982). By 2000, less than 10 years after it was first observed, water hyacinth covered the whole of the Westlake River, the Keyser's River and the major channels of the wetland.

5.6.5 Historical management of aquatic weeds in the Westlake River.

The most comprehensive set of monitoring records of the aquatic weed infestations and the management thereof are kept by private individuals. Monitoring records for the past 20 years for the lower section of the Westlake River from Main road to Zandvlei are maintained by John and Sandra Fowkes, who kindly made the records available to the author. Their record keeping and intimate involvement in the management of aquatic weeds in this part of the river emphasise the importance of working with communities and residents who have a vested interest and passion for conserving the natural assets of the City.

The dense water hyacinth invasion choking the lower section of the Westlake River resulted in a working group being formed under the auspices of the Zandvlei Trust. The objective of the working group was to stop the water hyacinth infestation from going into the Westlake Pond.

The first step was to contain the infestations by means of a floating boom consisting out of 2litre plastic cold drink bottles enclosed in a net, and a 1.5 meter net hanging below and weighted down by cable tied to the bottom. The booms were put together from mostly recycled material at a minimal cost. "The cost of the booms was purely the sweat equity of the community who built it and put it in place" (J. Fowkes, personal communication).

In 2002 the city TRSD deployed the Kingfisher mechanical weed clearing machines in the Westlake River. The pieces of water hyacinth left behind after the use of the machines were removed by hand. More booms were put in place to contain the breakaway pieces and prevent reinfestation of cleared areas. The biological control agents *N. eichhorniae* and *N. bruchi* were also released in 2002, but they were not successful as they did not survive the cold Cape Town winter. In 2006 the river and wetlands were once again 100% covered by water hyacinth following explosive weed growth. Other species *P. stratiotes*, *S. molesta*, *M. aquaticum*, and *A. filiculoides*, were also recorded.

Four events in 2009 changed the picture on the lower Westlake, namely that the community became involved by following up behind the reed harvester, Rhodes University contributed biological control, the Working for Wetlands provided a team to control the aquatic weeds, and the Peninsula Beverage Company donated R 10 000 to the Zandvlei Trust in 2009 to employ a worker for three days a month. (J. Fowkes, personal communication). The sequence of events illustrates the value of partnerships and collaboration between different stakeholders in pursuit of a common objective.

By November 2009 the Keyser's and Westlake Rivers and all of their water channels were clear of water hyacinth. Water hyacinth remained behind in approximately one hectare of dense inaccessible reed beds. Floating booms were used to prevent pieces of hyacinth floating loose in the strong Cape winds.

In November 2010 the North Channel was infested with water hyacinth and water lettuce. Access was obtained by canoe and the water hyacinth mats were pulled to the banks with a long stick tied to a fork and a pull-net. The Kingfisher was again deployed and the bulk of the water hyacinth cleared. Community members conducted manual follow up in the reed beds and the channels. The community's efforts were supplemented by Working for Wetlands in the Keyser's River and upper Westlake River.

The biological control agents, *N. eichhorniae* and *N. bruchi* and the moth *Niphograpta albiguttalis* were released in November 2009 by Rhodes University and Working for Water into the reed-bed. Water hyacinth was well established in the west end of south channel by November 2010. The *Neochetina* weevils were released in late 2010, and by March 2011 when the weevil populations were at the highest, the water hyacinth started dying. Within two years, by July 2011, the infestation was under control and the mats started sinking in September 2011. The channel was clear and free of water hyacinth by October 2011 (J. Fowkes records).

Since successful integration of mechanical, manual and biological control between 2002 and 2011, the TRSD continued to mechanically remove aquatic weeds, silt and reeds with a long-reach excavator as part of the annual pre-winter preparedness programme. The work in the Sand River Catchment happens annually from mid-January to February on a rotational basis on a 1.6km stretch of river. The machines are deployed from Raapkraal to Seabreeze Rd (190m), Chenel Rd complex to Main Rd (197m), Main Rd to the Railway line (660m, Keyser/ Westlake confluence), and from Keyser River to Lake Rd (554m). It takes on average 13 days for the 22m Ostrich long-reach excavator to clean the 1.6km of river. The long-reach excavator removes silt, reeds and aquatic weeds and stacks the material on the river banks. Depending on accessibility, four trucks (grab trucks and/ or tip trucks with front-end loaders) remove the

material and deliver them to Master Organics and the pig farms in Phillippi. The biomass transfer to Phillippi took on average 10 days.

5.6.6 Implementing the management plan

The Westlake River was divided in five management units: WST 01 from its origin to Steenberg Road; WST 02 from Steenberg Road to the M3 (Blue Route); WST03 from the M3 to the M4 (Main Road); WST 04 at the Westlake Wetland; and finally the canals. The weeds with biological control were left and only the emergent weeds and *N. mexicana* were manually controlled.

Since the implementation of the Westlake River integrated aquatic weed management programme, a drop in aquatic weed biomass was experienced. The TRSD no longer took the biomass to Phillippi, but to Coastal Park landfill, which is closer to Westlake. The time spent with the long-reach excavator dropped from 13 to 8 days and the biomass removal time has dropped to 5 days. (T. Present, personal communication).

The economic impacts of the integrated control plan for the Westlake River is summarised in Table 5.3 and 5.4. Figures were provided by TRSD.

Table 5.3: Summary of mechanical control cost prior to the implementation of integrated weed management plan on the Westlake River

Type	Hourly rate	Hours	Cost/day	Days	Cost
Long-reach 22m ostrich	US\$ 35.09	8	US\$ 280.70	13	US\$ 3 649.12
Trucks x 4	US\$ 30.70	8	US\$ 982.46	10	US\$ 9 824.56
Front end loader	US\$ 30.70	8	US\$ 245.61	10	US\$ 2 456.14
Total			US\$ 1 508.77		US\$ 15 929.82

The average total annual expenditure on the TRSDs annual river maintenance for the 1.6km of the Westlake River is US\$15 929.82, or US\$9 956.14 per km. The expenditure includes the rates for the daily rate for machinery and the disposal of biomass, but excludes staff cost.

Table 5.4: Summary of mechanical control cost post the implementation of the integrated weed management plan on the Westlake River

Type	Hourly rate	Hours	Cost/day	Days	Cost
Longboom 22m ostrich	US\$ 35.09	8	US\$ 280.70	8	US\$ 2 245.61
Trucks x 4	US\$ 30.70	8	US\$ 982.46	5	US\$ 4 912.28
Front end loader	US\$ 30.70	8	US\$ 245.61	5	US\$ 1 228.07
Total			US\$ 1 508.77		US\$ 8 385.96

The integrated control programme resulted in a cost saving of US\$ 7 542.86/annum (US\$ 5 241.23/km) on the annual maintenance programme in the Westlake River. If the total annual expenditure is extrapolated over a 5-year period, assuming the CPI of 5.77 (2013) remains stable, the cost saving is US\$ 42 330.09 or 53%.

5.7 Discussion and conclusion

All three study sites are heavily transformed, and the poor water quality supports aquatic weed growth. The main aquatic weed in the Diep River and Black River is water hyacinth with emergent species invading the river banks. The highest diversity of aquatic weeds occurs in the Westlake River, where water hyacinth, parrot's feather, water lettuce, salvinia and red water-fern are present. Yellow water lily is considered a serious problem in the Westlake River. Conflicts of interest exist in all three sites about the use of biological control.

Diep River Estuary and the Westlake River are ideal for integrating biological control. The most suitable control method for the Black River is manual control. Mechanical control is not sustainable and provides only a short term solution. Aquatic weeds proliferate in the nutrient-enriched water bodies in the CTMA and will return within a short period of time following mechanical clearing. Manual control ensures that reinvasions are detected and removed before becoming a serious problem.

The City of Cape Town's Stormwater Department uses different long reach excavators (12m Swan or 22m Ostrich and Grasshopper) with a water bucket capacity of approximately 1 cubic meter, or shorter reach (7m) tyre or track excavators, depending on the river width and access. A 22m long reach excavator cost up to US\$ 175 438 million. Front loaders (bobcats) are used in lined canals. The excavators are used in conjunction with grab trucks or bulldozers and trucks to remove the material to a waste transfer site. The ratio of long reach excavators, trucks and frontend loaders is normally 1:4:1. The long reach excavators cost between US\$ 28.51 and US\$ 35.09/hour, the front end loader cost US\$ 30.70/hour, and the truck US\$ 30.70/hour (excluding km rate of between US\$ 0.61 and US\$ 0.88/km). The hourly cost of mechanical clearing is US\$ 92.11 or US\$ 469.30/day for 5 hours work per day. Mechanical control can cost up to US\$ 12 280/km in larger systems such as the Black River. The biggest challenge is that the machines have to rotate, and a river gets cleared once before winter and the water hyacinth grows back soon after clearing without the option of a follow up. The Transport Roads and Stormwater Department then relies on the higher water levels and increased winter flow to keep the infestations from covering the entire water body.

Manual and mechanical control has limitations in the sense that they are time-consuming, and relative to integrated control they are expensive (Hill and Coetzee, 2008). Manual control creates employment and from that point of view is beneficial. However, from an invasion biology and economic point of view, manual control is not ideal for larger water bodies. For example, manual removal of water hyacinth on Lake Chivero in Zimbabwe in the early 1980s, consisting of 500 workers working an eight-hour day, was relegated as a result of the weed's rapid regrowth, and no obvious signs of the 500 tonnes of water hyacinth removed manually were evident after six months. Mechanical control also did not produce the desired results, even though a bulldozer, a boat, a conveyor and dump trucks were deployed to remove almost 2 hectares of plants daily (Chikwenhere and Phiri, 1999).

The expenditure for the 10 month period for manual control in the lower Diep River (DRE01) was US\$ 562.20, and US\$ 263.26 for the integrated combination of biological and manual control in the upper Diep River Estuary (DRE02). This study showed a cost saving of US\$298.94/ha between manual and integrated control.

Table 5.5: Cost difference between manual and integrated control in the Diep River Estuary

Method	Total	Cost/Ha
Manual	US\$ 28 284.42	US\$562.20
Integrated	US\$ 6 723.68	US\$263.26

Biological control is a slow acting method and is most effective when integrated with other methods such as herbicide and manual control. The most important aspect of integrated control is the management of nutrients entering aquatic ecosystems (Hill and Olckers, 2001). The Nseleni system provides an example of an integrated programme where a heavily impacted river has been turned into a fully functioning aquatic ecosystem through appropriate management. By using an integrated approach, a section of approximately 19 km with 100% water hyacinth cover was cleared by integrating herbicide and biological control over a period of five years from 1995 -2000 (Jones, 2001).

Chapter 6

General discussion and conclusion

The main aim of this study was to determine the status of waterweed infestation and control in the CTMA environs. The first chapter provided an overview of aquatic plants, their means of introduction and discussed metropolitan areas as hotspots for alien plant introductions. This thesis synthesised prior studies pertaining to the problem of aquatic weeds, and gave insights into the impacts of five of the main aquatic weeds. Chapter 2 provided an overview of the existing legal and regulatory framework, and highlighted certain key issues impacting on aquatic weed management, in order to determine if biological control can be used as part of an integrated control approach for aquatic weeds in a highly disturbed urban environment. Chapter 3 summarised and discussed the different control methods, and focused on biological control of the five main aquatic weeds. This chapter specifically tried to determine why biological control was not used more frequently as a control intervention. Chapter 4 aimed to demystify biological control, determine the reasons for the current lack of integration in South Africa, and consider the factors influencing integration of biological control programmes in complex urban environments. The chapter additionally offered recommendations to improve the gap between research and management. Chapter 5 presented three case studies of the integrated control of aquatic weeds in the City of Cape Town, namely the Diep River Estuary, the Black River and the Westlake River.

The methods and description of the study results are presented in greater detail in the preceding chapters. This chapter synthesises the results of the surveys and case studies, draws from lessons learned, focuses on integrating biological control into aquatic weed management programmes in urban environments, and finally offers recommendation to improve integration in uncertain and complex urban environments.

Invasive species impact significantly on the environments and ecosystems they invade with negative environmental and socio-economic consequences. Landowners, both public and private, are legally obliged to control invasive species in ways that cause the least negative impacts on the environment. Different management options are available, such as prevention, early detection and rapid response, containment, and control. The evidence presented in this thesis suggests that a combination of more than one of the four control methods (manual, mechanical, chemical and biological) would ensure the best results. Various studies have shown that biological control is the most cost-effective, environmentally-friendly and sustainable control method. However, it has not yet reached its full potential in the control of South Africa's

worst aquatic weed, *E. crassipes*. Integration of biological control in urban areas must be seen within the context of national biological control integration. Therefore, a study to determine the level of integration and reasons for the situation was conducted by means of a survey. The survey has shown that biological control in South Africa lacks full integration and is not yet considered a control option during the initial planning phases of weed management programmes. In fact, biological control is often only turned to as a last resort, despite the successes over the past 100 years of biological control South Africa. Biological control is not a quick fix, and except for species such as *A. filiculoides*, this form of control is most effective when integrated with other control methods.

The survey amongst researchers and implementers confirmed the lack of integration and that there is a gap between research and implementation. Closing the gap between research and implementation has the potential to contribute significantly towards full integration of biological control. Recommendations for addressing the gap between research and implementation include four key focal areas, namely institutional support and leadership, communication, capacity building and skills development, and mass rearing capacity. The research support provided by national Working for Water should be sustained through institutional leadership and buy-in at regional WfW level, and ultimately at implementation or project level. When control options are considered during the strategic planning phase, biological control specialists (researchers) are to be included in a multi-disciplinary team. Biological control should be regarded as equally important and incorporated from the start of the intervention, and not merely as a last resort. The lack of communication between stakeholders was prominent in the majority of responses, and presents an important point of concern. Communication is vital in closing the gap between researchers and managers, and is important for the effective integration of biological control. Existing forums could be modified slightly to create a platform for communication between research and implementation. Two-way communication could also be ensured by including researchers into the WfW implementing agent meetings. Clear targets for biological control integration should be discussed at meetings of stakeholders. There should also be a clear element of accountability on the part of both parties in order to effectively manage control of aquatic weeds. The lack of experience and appropriate skills of implementation officers should be addressed to empower the implementers and give them the required authority to promote and implement biological control at regional and project level. A mentorship, training and skills development programme, in collaboration with universities, is a priority to address the current lack of experience and skills.

Finally, this study has shown that biological control is a valuable control option and deserves its rightful place amongst mechanical, chemical and manual control in aquatic weed management

programmes in complex urban landscapes. The general survey in this study identified that the site, biological control selection, sustainability, water quality and clear communication with stakeholders are important when considering biological control as an option. The three case studies have shown that integrating biological control into the management of *Eichhornia crassipes* require careful planning, hydrology, augmented releases and contingency measures in order to ensure success. The Westlake case study has clearly demonstrated the value of integrated control by relying completely on biological control for species such as *Pistia stratiotes*, *Myriophyllum aquaticum*, *Salvinia molesta* and *Azolla filiculoides*, as well as the use of other control methods such as manual control on species where no biological control is available. Managing aquatic weeds is difficult in uncertain and complex urban environmental, socio-economic and political landscapes, and often leads to the lack of sustainability of control programmes.

Following an integrated approach as recommended by Hill and Coetzee (2008) ensures sustainability and successful implementation of aquatic weed management plans. The integrated approach recommended by these authors include identifying and mapping the extent of the weed, the sources of infestation, the interested and affected parties, a champion or lead agency and selecting the most appropriate control options during planning stages, followed by implementation, monitoring, evaluation and adaptive management. The reality is that these complexities are a part of the nature of urban environments, and with growing urbanisation managers will continue to face these issues. Managers should thus learn to understand, accept and consider following an adaptive management approach. The options available to managers when uncertainties occur (Walker, 1998) are the following: to ignore the uncertainties by continuing to follow current strategies, irrespective of the level of success achieved by these strategies; to respond reactively as and when events occur; to follow a passive adaptive management strategy by learning and predicting the consequences of different strategies, without proactive responses; or to actively adapt management to enable the most appropriate responses (Walker, 1998). The main difference between passive and active adaptive management is that passive adaptive management lacks the active plans to learn, experiment and take short term risks for long term gains (Shea et al., 2002). For the city to be effective in integrating biological control in management programmes, active adaptive management should be followed. The best strategy, the research suggests, is to recognise the uncertainties and to actively plan to learn and understand the complexities of the aquatic system and the weeds present in the systems they are managing, and thereafter to implement options to reduce the risk posed by invasive species and maximise the net benefit (Shea et al., 2002). Learning about the systems they manage improves understanding and consequently improves their management decisions. Active adaptive management is an iterative process (Shea et al., 2002)

and equips managers to cope with uncertainties and to achieve their strategic objectives amidst a changing landscape. Managers in urban areas deal with mainly three types of uncertainties: biological processes influencing the underlying behaviour of the system they are managing, uncertainties about environmental processes, and uncertainty about observations (Hillborn and Mangel, 1997; Parma et al., 1998).

Walters (1986) and Parma et al. (1998) recommend the following steps for incorporating active adaptive management from the start.

- Determine the management objective(s).
- Determine and document what is known about the system.
- Acknowledge the uncertainties and formulate credible alternative options.
- Consider different scenarios.
- Decide what variable to measure.
- Design alternative management options, in other words, have a plan B.
- Predict the outcomes of the different management outcomes and what is expected to happen. It may be necessary to develop different outcomes.
- Implement the plans. Replicate both known methodology and experiments.
- Monitor outcomes, compare the results and improve understanding.
- Reassess and improve.

A holistic approach should be followed by aligning control actions with other departments, having regular communication between different stakeholders, and managing water quality, all of which will ensure the success of biological control in urban areas.

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Appendix A: Questionnaire - General survey

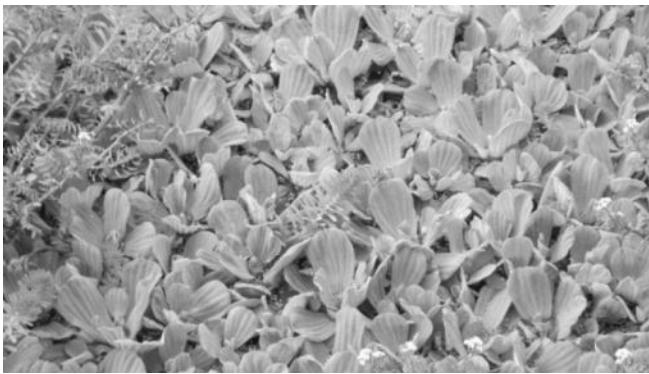
Details of person participating in the City of Cape Town aquatic weed survey

Name:

Affiliation:

1. What are aquatic weeds?
2. Can you identify the following five weeds?

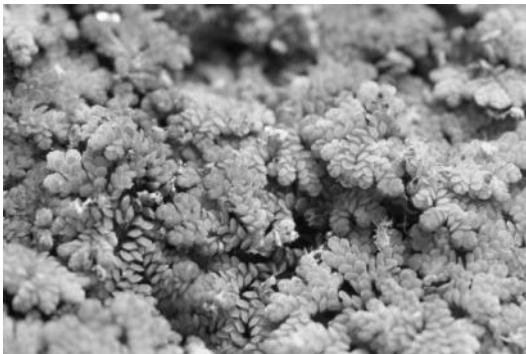
A:



B:



C:



D:



E:



3. Do you think we need to control aquatic weeds? Give reasons for your answer.
4. Do you know what different methods are used for controlling aquatic weeds? List the methods.
5. What do you think are the most effective method(s) for controlling aquatic weeds?
6. What you know think is biological control?
7. Who should be responsible for biological control?

National government

☐

Provincial government

☐

Transport, Roads & Stormwater

☐

Invasive species unit

☐

Landowners

☐

8. Who should fund biological control?

National government

☐

Provincial government

☐

City of Cape Town

☐

9. Do you think it is possible to successfully control aquatic infestations in Cape Town through biological control? Give reason(s) for your answer.
10. What do you regard as the **three** most important considerations should we decide to use biological control to manage aquatic weeds in Cape Town?

Appendix B: Questionnaire - research/implementation survey

Questionnaire to understand the current status of research and implementation of weed biological control and to identify measures to improve the research-management interface

I am currently in the final stages of my MSc through Rhodes University. The title of my thesis is:
The value of biological control in the integrated management of aquatic weeds in a metropolitan environmental and socio-political landscape: Case studies in the City of Cape Town

My supervisor is Professor Martin Hill and co- supervisor Dr. Julie Coetzee.

Although 2013 is the centenary year of biological control in South Africa, we yet have to see biological control reaching its full potential in invasive weed management programmes.

This questionnaire seeks to gain insights into the current situation and what needs happen to ensure biological control is fully integrated into invasive weed management practices.

Your input will be particularly valuable and I will appreciate it if you can spare a few minutes to complete the questions below. If you would like to remain anonymous please fax the questionnaire back to me on 086 578 0410 or email your response back to

Louise.Stafford@capetown.gov.za

Respondent's detail

Name:

Organisation:

Position:

Experience:

1. How would you describe the current integration of biological control into weed management programmes?

2. How should biological control be integrated into weed management programmes?
3. What is the role of research in weed biological control?
4. What is the role of implementation in weed biological control?
5. Is there a gap between research and management?
6. How should the gap be filled?

THANK YOU!