QUANTIFICATION OF THE CROSS-SECTORAL IMPACTS OF WATERWEEDS AND THEIR CONTROL IN GHANA

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Frontispiece

Water hyacinth, *Eichhornia crassipes,* blocking the main landing site at Jewi Wharf, south-western Ghana

Water hyacinth blocking the main Tano Channel in the dry season

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Abstract

The Akosombo Dam on the Volta River in Ghana was built in 1963 to provide cheap energy to fuel industry and to accelerate the economic growth of the country. It provides hydroelectric power, enhanced fishing and water transportation upstream, and improved opportunities for irrigated farming, especially in the lower reaches, and their attendant economic multiplier effects. A few years after the construction of this major dam, a rapid expansion of industrialization took place in Ghana. This brought about an exponential increase in demand for more electrical power. This led to the construction of a smaller dam at Akuse, downstream of the Akosombo Dam in 1981 and the formation of a headpond at Kpong. The impoundment of the river at the two sites (Akosombo and Kpong) caused an alteration in the existing ecological and biophysical processes in the river basin, including a slowing of the flow of the river, upstream and downstream. Changes in the natural processes, such as a reduction in the flow of the river and an increase in nutrient status of the water, resulted in an invasion of aquatic weeds, increasing the density of aquatic snails (intermediate hosts of schistosomiasis), silting and closure of the estuary, as well as other more subtle effects. The invasion of the river's main course and the dams by aquatic plants led to a corresponding reduction of navigable water both upstream and downstream. The aim of this thesis was to quantify the impact and control of waterweeds, especially water hyacinth, *Eichhornia crassipes* (Mart) Solms-Laubach (Pontederiaceae), in Ghana.

A floral survey on the Kpong Headpond recorded 49 emergent, 12 free floating and 1 submerged aquatic plant species, many of which were indigenous, but the exotic or introduced water hyacinth was recorded at most of the sampling sites, and was the most abundant and had the biggest impact on the utilization of the water resource. Mats of water hyacinth served as substrates for other, indigenous species to grow out into the main channel of the headpond, including the intake point of the Kpong head works of the Ghana Water Company Limited (GWCL) and landing sites for boats. These mats resulted in a reduction of the fish (fin and shell) harvest, reducing the annual production to far below demand. Water hyacinth was also shown to have severe health implications. A survey of the Ministry of Health records showed that the prevalence of both urinary and intestinal schistosomiasis had risen significantly over time as the abundance of waterweeds, most notably water hyacinth, increased, and ranged between 70% and 75% but up to 100% in some lakeside communities. Based on the work done by an NGO on board the medical boat ("*Onipa Nua*"), losses in

terms of money due to the effect on health of the aquatic weed infestations on the Volta River in 2006 amounted to US$ 620,000.
Economic losses due to invasive alien aquatic weeds were also calculated on the Oti River Arm of Lake Volta. It was estimated that about US$2.3 million per annum would be lost to the Volta Lake Transport Company and individual boat transport operators if this section of the river were 100% covered by aquatic weeds (water hyacinth and *Salvinia molesta* D.S. Mitchell (Salviniaceae)). It was also estimated that US$327,038 was spent annually in monitoring and managing the weeds in the Oti River.

Control interventions for aquatic weeds have been implemented in river systems in Ghana. The biological control agents *Neochetina bruchi* Hustache (Coleoptera, Curculionidae) and *Neochetina eichhorniae* Warner (Coleoptera, Curculionidae) have been used on water hyacinth infestations in the Oti River Arm of Lake Volta, the Tano River and the Lagoon complex in the south-western part of the country. *Cyrtobagous salviniae* Calder and Sands (Coleoptera: Curculionidae) has been used to control salvinia, and *Neohydronomous affinis* Hustache (Coleoptera: Curculionidae) to control water lettuce, *Pistia stratiotes* Linnaeus (Araceae) in the Tano River and Lagoon complex. Although these projects have been regarded as successful, they have relied on research from elsewhere in the world and no post-release quantification has been conducted. In evaluating the impact of the biological control agents *Neochetina bruchi* and *Neochetina eichhorniae* weevils on water hyacinth infestations in the Tano River, fresh adult feeding scars were recorded as well as the numbers of adult weevils on each water hyacinth plant sampled at six sites. Despite being released in 1994, weevil numbers and resultant damage to plants in the Tano Lagoon was low in comparison to other regions of the world where these agents have been used. The main reason for this is that this lagoon floods seasonally, washing weevil-infested plants out to sea. Water hyacinth then re-infests the lagoon from seed and the weevil populations are low. To resolve this situation, two courses of action are proposed. The first is to mass rear the weevils along the shore of the lagoon and release them when the first seedlings recruit. The second proposal is that additional agents that have shorter lifecycles and are more mobile than the weevils should be released. To this end, the water hyacinth mirid, *Eccritotarsus catarinensis* (Carvalho) (Hemiptera: Miridae) was imported from South Africa and released onto the Tano Lagoon in 2009.

Retrospective laboratory host specificity trials were conducted on *Neochetina eichhorniae* and *Neochetina bruchi* weevils 15 years after their release into Ghana to see if any variation in their host ranges had occurred. Considerable damage was inflicted on the *E. crassipes* leaves by the *Neochetina* weevils, while little feeding damage was recorded on both *Heteranthera callifolia* Kunth. (Pontederiaceae) and *Eichhornia natans* (P.Beauv.) Solms (Pontederiaceae). All the weevils introduced on *H. callifolia* and *E. natans* died after the first week. This study served to confirm the host specificity and thereby the safety of these agents.

Invasive alien aquatic macrophytes have negative impacts on the environment and economy of Ghana. The control of these weeds is essential to socioeconomic development and improved human health standards in riparian communities. Biological control offers a safe and sustainable control option, but requires diligent implementation. However, aquatic weed invasion is more typically a result of the anthropogenically induced eutrophication of water bodies, and this is the main issue that has to be addressed.

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Chapter 1

1. General Introduction

Aquatic macrophytes are a diverse assembly of macroscopic vascular vegetation or plants including some relatively "large plants" living either in, on or at the periphery of freshwaters. These aquatic plants include ferns, mosses, macroalgae, angiosperms (i.e. flowering plants) as well as large trees that require saturated conditions or access to standing fresh water to thrive (Sculthorpe, 1967). They are natural inhabitants of lakes, rivers and wetlands and play several important roles in maintaining ecosystem functioning (Sculthorpe, 1967).

Aquatic plants provide cover for micro- and macrofauna that are part of the food chain, provide shade and shelter for small fish and fingerlings of game fish, improve dissolved oxygen levels, cycle nutrients, reduce turbidity and provide food and shelter for birds and animals (Sculthorpe, 1967). For instance, aquatic plants can increase waterfowl abundance by providing shelter, nesting sites and food. In turn, herbivory by birds and other fauna can contribute to a significant reduction in aquatic macrophytes biomass (Van Donk and Otte, 1996). Fish in particular are vitally interdependent on aquatic plants (Petr, 2000). Macrophytes enlarge the structure of the habitat, provide substrate, refuge and food and increase the diversity of habitats for invertebrates (Diehl and Kornijów, 1998). Although invertebrates directly consume little macrophyte tissue, plants can provide suitable attachment sites and protection from predators and wave action (Lana and Guiss, 1992).

Aquatic vegetation plays an essential role in the ecosystem of lakes. Macrophytes are involved in several feed-back mechanisms that tend to keep water clear, even in relatively high nutrient loadings (Moss, 1990). The composition of aquatic flora influences the phytoplankton, zooplankton and invertebrate communities, and therefore has a bearing on the abundance and composition of fish communities (Duarte *et al.*, 1986).

Native aquatic plants seldom cause problems because they have adapted to one another and their environments over millions of years. Many different insects and diseases have co-evolved with and thus, control native aquatic plants, keeping them from becoming problematic. However, the delicate balance among native aquatic plants is often destroyed when people introduce fast-growing invasive alien aquatic weeds from other areas without the controls that keep them in check in their native range (Williams and Hecky, 2005).

1.1 Invasive Alien Species

Invasive Alien Species are non-native organisms that cause or have the potential to cause harm to the environment, economies or human health. They usually proliferate exponentially, depriving the native species of space, nutrients and moisture thus modifying the entire structure and functioning of the ecosystem (McNeely, 2000). The generic problem of biological invasions involves four phases: the introduction, establishment, naturalization and ultimately spread of a species (Williamson, 1996). The modified ecosystem or flora deprives native animals of food and shelter. Invasive Alien Species are one of the most significant drivers of environmental change worldwide, consequently placing constraints on environmental conservation, economic growth and sustainable development as they can bring about unemployment, impact on infrastructure, food and water shortages, environmental degradation, loss of biodiversity, increased rates and severity of natural disasters, illness and loss of life (GISP, 2002). The exotics may also bring with them new pests and pathogens or allergens and, in some cases, they can hybridise with native species (CSIR, 2004). Invasive species are found in agricultural croplands and in natural and urban areas and can be either terrestrial or aquatic. The effects of invasive species are in most cases irreversible. The spread of species of plants, animals and micro-organisms from one part of the globe to another, through intentional or unintentional human effort, is now recognized as one of the most serious threats to the earth's biodiversity, second only to habitat destruction (Mooney and Hobbs, 2000) as a cause of global biodiversity loss and threatening agricultural production and food security which is a major priority to many African governments (Macdonald *et al.*, 2003).

Globalization has led to more and faster trade, new travel and trading routes, and increased trade in livestock, pets, nursery stock, agricultural produce and forest products; all of which can facilitate the introduction and spread of invasive alien species (FAO, 2001a). Weed seeds, plant pathogens, larval or adult arthropods and other invertebrates, and even some vertebrate species can be transported. Sand, gravel, coal and metal ores, and other inorganic commodities can also be contaminated with seeds, arthropods and pathogens (Cox, 1999). Unprocessed wood, wood products and nursery stock are also a major source of forest pests and diseases. A number of devastating species have been introduced, for instance into the United States of America such as chestnut blight (*Cryphonectria parasitica*, (Murrill) Barr.) Dutch elm disease (*Ophiostoma ulmi sensu lato*), and white pine blister rust (*Cronartium* *ribicola* A. Dietr.) (OTA, 1993). It is believed that *Pineus boerneri* Annand, a pine woolly adelgid, entered Kenya and Zimbabwe on scion material (Diekmann *et al.*, 2002).

In addition to the possibility of the commodities themselves carrying invasive alien species, the containers and vehicles in which they are transported can also facilitate invasions. Wood packaging material made of unprocessed raw wood, including pallets, crates, drums, skids, cases and dunnage, can be a pathway for the introduction and spread of pests, in particular forest pests (McNeely *et al.*, 2001; IPPC, 2002). The Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky), emerald ash borer (*Agrilus planipennis* Fairmaire) and brown spruce longhorn beetle (*Tetropium fuscum* Fabricius) are alleged to have arrived in North America on packing materials from Asia (Keiran and Allen, 2004). The Sirex woodwasp (*Sirex noctilio* Fabricius) probably entered Argentina, Australia, New Zealand and South Africa in wooden packaging from Europe or North Africa. The red turpentine beetle (*Dendroctonus valens* LeConte) may have been introduced into China's pine forests through packaging made from infested North American wood (Keiran and Allen, 2004). The pinewood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle), the causative agent of pine wilt disease, has spread from its native North America to Asia and Europe in wooden packing materials (APHIS, 1999a; APHIS, 1999b).

Containerized cargo can shelter alien species from microorganisms to reptiles and mammals, and since inspecting such freight is very difficult and costly, many invasive alien species may enter a country undetected (OTA, 1993; Cox, 1999). No longer are the effects of alien species invasions being initially confined to areas around the ports of entry, since containers are typically not unloaded until they reach their final inland destinations (OTA, 1993).

Vehicles, including cars, trucks, trains, planes and ships, may also be contaminated with various types of pests. The commercial and recreational movement of vehicles across international boundaries have increased and the threats are considerable (Cox, 1999). Railway sleepers have also been blamed for spreading many insect pests. It is suspected that *Phoracantha semipunctata* Fabricius (Cerambycidae) and *P. recurva* Newman (Cerambycidae), both serious pests of eucalyptus, entered South Africa in freshly-cut railway sleepers imported from Australia (EPPO, 2004).

1.1.1 The role of climate change on invasive alien species

Climate change may produce more favourable conditions for invasive alien species. Once dominant species in native areas are no longer adapted to the environmental conditions of their habitat, it is likely that introduced species will displace them, thus drastically changing successional patterns, ecosystem function and resource distribution (McNeely, 1999; Tilman and Lehman, 2001). For example, Oberhauser and Peterson (2003) investigated the possible effects of global climate change on distributions of migratory populations of monarch butterflies (*Danaus plexippus* L.) and concluded that predicted changes pose potentially significant threats to their survival.

Climate, geography and other variables define the distribution limits of a species; however, with changes in climate these limits are expanding, spreading species into higher latitudes and altitudes due to increased temperatures, humidity, precipitation and other climatic factors (McNeely, 1999; McNeely *et al.,* 2001). Rouget *et al.* (2002) noted that the current distribution of stands of invasive trees in South Africa was largely influenced by climatic factors. Warming trends may also allow for longer breeding seasons for invasive species, as observed for instance, in populations of the collared dove (*Streptopelia decaocto* Frivaldszky) in Europe (Crooks and Soulé, 1999). Since the development of insects is temperature dependent, it has been predicted that increasing temperatures will enhance the winter survival of insects and facilitate population increases and expansions in geographic range (Crooks and Soulé, 1999; Mooney and Hofgaard, 1999). Changes in climate and environmental factors may also allow existing introduced species to become invasive (Mooney and Hofgaard, 1999). Climatically induced stress on plants and other species also reduces their ability to resist invaders and thus make them more vulnerable to insect or pathogen damage (Mooney and Hofgaard, 1999; McNeely *et al.,* 2001). Climate change may change production patterns and trade in agricultural and forestry commodities by species being grown more competitively at higher latitudes and altitudes. Since invasive alien species establish more easily in habitats disturbed by humans, such changes can provide more opportunities for them to invade (McNeely *et al.,* 2001). Climate change also affects the frequency and intensity of extreme climatic events, which may have the greatest influence on invasive alien species by disturbing ecosystems and thus providing them with increased opportunities for dispersal and growth (McNeely *et al.,* 2001).

In addition to the effects of climate change, increasing concentrations of greenhouse gases can have significant effects on the success of invasive alien species. Higher concentrations of carbon dioxide increase photosynthetic rates (Vitousek *et al.*, 1997) and water use efficiency of plants (Mooney and Hofgaard, 1999). The resulting increased soil moisture has potential to provide habitat for late-season annuals, which may be invasive. Distributions of spruce budworm species in Oregon changed in relation to increased atmospheric CO_2 concentrations (Vitousek *et al.*, 1997). However, increased levels of CO_2 affect plant species differently, which is likely to result in substantial changes in the species composition and dynamics of terrestrial and aquatic ecosystems (Vitousek *et al.*, 1997). Changes in the deposition of nitrates from the atmosphere through the burning of fossil fuels, has resulted in large changes in vegetation, as observed in Western Europe, which may favour the growth of some invasive alien species (Mooney and Hofgaard, 1999).

1.1.2 The role of conflict and reconstruction on invasive alien species

Conflict and civil unrest can contribute to the introduction and spread of invasive alien species in a variety of ways (FAO, 2001a). Civil unrest leads to the breakdown of phytosanitary and animal health controls and management systems, the loss of supply lines for materials as well as to the displacement of substantial numbers of people. These displaced people and their belongings can be a dispersal mechanism for, or the source of, invasive alien species. Inflows of food aid may be contaminated with pests, diseases and also contribute to the spread of exotics. In conflict regions, difficulties in obtaining access to border areas because of landmines and other hazards make these areas difficult to survey. Increased smuggling can relocate potential invasive alien species to new regions. Areas where there is civil unrest or war are more vulnerable to the entry of pests and diseases because of the increased unregulated movement of military personnel and refugees. Military transport, equipment and supplies, often covered with dirt or mud from the field, are effective means of dispersal for many species which can be detrimental to new environments. For example, the puncture vine (*Tribulus terrestris* L.), native to the Sahara Desert, may have been introduced into North America on the tires of military aircraft and vehicles returning from Europe after World War II (Cox, 1999). The brown tree snake (*Boiga irregularis* Merrem), native to New Guinea and neighbouring areas, was accidentally introduced to the island of Guam in the late 1940s or early 1950s, most probably in military shipments of fruit (OTA, 1993; Cox, 1999).

1.2 The global perspective

In Africa, classical biological control started in the late 19th century, increased in the 1980s, with about 150 introductions per year, which led to the establishment of 65% of all introductions and 10% of them contributed to control (Greathead, 2003). However, the science of invasion biology was only really developed in the 1950s with the publication of Charles Elton's book in 1958 (Elton, 1958).

Article 8(h) of the Convention on Biological Diversity (CBD, 1992) calls upon the parties to prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats, or species. In July 1996, an international conference on invasive alien species was held at Trondheim, Norway at which experts discussed the threats to biodiversity from alien species. The World Conservation Congress (Montreal, October 1996) also highlighted this problem. In 1997, the Conference of the South Pacific Regional Environment Programme also gave attention to invasive species. In March 1998, IUCN's Global Initiative on Invasives held a planning workshop in California. Realising the importance of the problem globally, international organisations such as Global Environment Facility and Food and Agricultural Organisation have launched several initiatives to reduce invasive species that cost developed countries such as the United States of America billions of dollars to battle and which can be ill-afforded by developing countries. The African Union is also implementing an Invasive Species Programme of Action on the Environmental Initiative of NEPAD adopted at the 2nd Assembly of Heads of State of the African Union held in Maputo, Mozambique in July 2003.

1.3 The African scene

Based on Vavilov's (1935) proposed centres of origin of species, tropical Africa can boast of very few native species that have been domesticated. On this assumption, Africa has benefited tremendously from crops introduced from other parts of the world. But along with these beneficial introductions have come some planned or inadvertent introductions that have threatened African ecosystems, displacing native species, hampering the restoration of degraded lands and reforestation projects, choking water ways, drying out ponds and lakes, obstructing water transport, lowering fish catch, harbouring pests and diseases and threatening hydroelectric power generation (CSIR, 2004). For example, the global movement of domesticated species in the form of emergency food aid introduced the neo-tropical weed *Parthenium hysterophorus* L (Helianthaceae: Asteraceae) through grain shipments for famine relief in Ethiopia, where it has now earned a local indigenous name which translates to "no crop" (McNeely *et al.*, 2001). Some of these species are problematic in specific countries while others have international implications and are recognised in the current globalization trends, albeit in the negative sense. The economic impact of alien plants such as water hyacinth (*Eichhornia crassipes*) (Mart) Solms-Laubach (Pontederiaceae) in Africa's aquatic ecosystems is well known (UNEP, 2007), but these alien aquatic plants may also threaten African wetlands which are of unique global value (including many RAMSAR sites) (CSIR, 2004).

1.4 Waterweeds

The invasion of rivers, dams and lakes throughout Africa by introduced aquatic vegetation poses one of the largest threats to the socio-economic development of the continent (Cilliers *et al.*, 2003). The rapid growth of the weed infestations has been both spectacular and frightening. In the book "The World's Worst Weeds: Distribution and Biology" Charudattan (2001a), in citing Holm *et al.* (1977), listed just 10 aquatic weeds, including the three most notorious weeds; *Eichhornia crassipes*, *Pistia stratiotes* L (Araceae) and *Salvinia auriculata* Aublet (later identified as *Salvinia molesta* D.S. Mitchell) (Salviniaceae). Since the book was published, the number of the world's worst aquatic weeds had grown to about 36. However, five aquatic weeds are especially problematic in Africa: water hyacinth, red water fern, *Azolla filiculoides* Lam. (Azollaceae), parrot's feather, *Myriophyllum aquaticum* (Vell.) Verde. (Haloragaceae), water lettuce and salvinia (Cilliers *et al.*, 2003). The exact date and mode of introduction of these species in some countries is often not known, but water hyacinth has been present in Africa since the late 1800s (Table 1.1), while water lettuce is thought to have been used as a medicinal plant in ancient Egypt (Holm *et al.*, 1977). These plants were sought after ornamentals, which would have aided their dispersal to new areas. However, in the absence of natural enemies, and in eutrophic tropical waters, these aquatic weeds have proliferated and become problematic (Cilliers *et al.*, 2003).

Table 1.1: The distribution of water hyacinth, *Eichhornia crassipes*, in Africa and the first recorded date of presence (adapted from Cilliers *et al.*, 2003).

Country	Date first recorded	Reference
Angola	1972	Navarro and Phiri, 2000
Benin	1977	van Thielen *et al.*, 1994
Burkina Faso	1989	Ouedrago *et al.*, 1999
Burundi	1957	Navarro and Phiri, 2000
Cote d'Ivoire	1980	Koffi Koffi *et al.*, 1999
Central Africa Republic	1982	Desemboli pers. comm.
Democratic Republic of Congo	1952	Mbati & Neuenschwander, 2005
Egypt	1889	Navarro and Phiri, 2000
Ethiopia	1956	Navarro and Phiri, 2000
Ghana	1984	deGraft-Johnson, 1988
Kenya	1982	Ochiel *et al*, 1999
Malawi	1968	Navarro and Phiri, 2000
Mali	1987	Navarro and Phiri, 2000
Mozambique	1946	Navarro and Phiri, 2000
Niger Republic	1987	Ouedrago *et al.*, 1999
Nigeria	1984	deGraft-Johnson, 1999
Rwanda	1957	Navarro and Phiri, 2000
Senegal	2003	Diop pers. comm.
South Africa	1910	Cilliers, 1991a
Sudan	1954	Navarro and Phiri, 2000
Tanzania	1955	Mailu *et al.*, 1999
Togo	1987	Ouedrago *et al.*, 1999
Uganda	1987	Mailu *et al.*, 1999
Zambia	1965	Navarro and Phiri, 2000
Zimbabwe	1937	Navarro and Phiri, 2000

The spread of invasive aquatic weeds between continents and catchments is largely the result of human activities, while dispersal within a watershed is mostly via floating propagules (Howard and Harley, 1998). Often though, the explosive growth of aquatic weeds in tropical countries is caused by human interference with their habitat, such as alteration of hydrological flows or nutrient status (Pieterse, 1990).

Waterweeds have invaded many lake and river systems in Africa with severe consequences (Hill, 2003). The status of this distribution, impact and control of aquatic weeds in Africa has been reviewed in the proceedings of four workshops, one held in Zimbabwe in 1991 (Greathead and de Groot, 1993) a second workshop in Nairobi in 1997 (Navarro and Phiri, 2000), a third one also in 1999 in Zimbabwe (Hill *et al.*, 1999) and the fourth in Beijing, China in 2000 (Julien *et al.*, 2001).

1.4.1 Impacts of water hyacinth

Water hyacinth is the most problematic of these waterweeds and is the focus of this thesis. Water hyacinth grows rapidly, forming expansive colonies of tall, interwoven floating masses of plants (Penfound and Earle, 1948). It blankets large water bodies, creating impenetrable barriers and obstructing navigation (Gowanloch and Bajkov, 1948; Zeiger, 1962). Floating mats block drainage, causing flooding or preventing subsidence of floodwaters. Large rafts accumulate where water channels narrow, sometimes causing bridges to collapse. Water hyacinth hinders irrigation by impeding water flow, by clogging irrigation pumps, and by interfering with weirs (Penfound and Earle, 1948). Infestations block access to recreational areas, harming the economies of communities that depend upon fishing and water sports for revenue. Shifting water hyacinth mats sometimes prevent boats from reaching shore, trapping the occupants and exposing them to environmental hazards (Gowanloch and Bajkov, 1948; Harley, 1990). Water hyacinth infestations intensify mosquito problems by hindering insecticide application, interfere with predators, increase habitat for species that attach to plants and impede runoff and water circulation (Seabrook, 1962). Mats of water hyacinth also form habitats for disease-carrying snail species (*Biomphalaria* sp.; *Bulinus* sp.) that are intermediate hosts for schistosomiasis, which are among the world's worst parasitic diseases. According to Masifwa *et al.* (2001), in their work along the shores of northern Lake Victoria, Uganda, the two gastropod vectors of schistosomiasis, *Bulinus* and *Biomphalaria* were abundant in the floating vegetation root mats of water hyacinth. They cited earlier work by Okedi, (1990) in Murchison Bay of Lake Victoria, Uganda, which also reported a high prevalence of the disease. The water hyacinth mats also harbour poisonous snakes and other reptiles such as crocodiles.

This fast growing and damaging alien plant can be utilised in the manufacture of paper, handicrafts and furniture, in the treatment of wastewater or for mineral nutrient removal from polluted water bodies, as fodder, compost and fertilizer (Edwards & Musil, 1975).

Unfortunately these uses are outweighed by the threats and problems the weed represents to the ecosystem and economy of affected countries (Julien *et al.*, 2001).

According to (Hill, 1999; Coetzee *et al.*, 2009), the impacts of water hyacinth infestations are socio-economic and environmental and include: a reduction in the quality of drinking water caused by bad odours, taste, colour and turbidity, promotion of the development of waterborne, water based and water related diseases (e.g. malaria, encephalitis and filariasis), increase in filtration of rivers and dams, reduction in useful water surface area for fishing and water transport, clogging of irrigation canals and pumps, enhancing flood damage to road, rail and bridges and deterioration in aquatic biodiversity (Midgley *et al.*, 2006).

1.5 Aquatic plant infestations in water bodies in Ghana

Ghana is blessed with rich and abundant natural resources. Energy, agriculture, forestry and tourism are all resource-dependent industries. The economy relies upon the monetary values and benefits provided by these resources. The rate, diversity and magnitude of all development in Ghana have increased substantially in recent decades and are projected to continue to grow at a significant rate. This is particularly true in the forested regions where growth in the energy and forestry sectors challenges the sustainability of these resources. World demand for energy resources, West African energy security and domestic demands for value-added processing are all projected to grow substantially over the next 20 years (Abdullah Iddrisu Saaka and Telly 1999).

Resource development has modified the Ghanaian landscape considerably. Sound management is required to ensure that the cumulative effects of current and future developments do not adversely affect the country's biodiversity and environment in general (Abdullah Iddrisu Saaka and Telly 1999). World market forces often demand the maintenance of ecosystems and biodiversity as a condition of product sales, so this has to be addressed to keep Ghana's economy competitive. Resource management that effectively integrates biodiversity information will ensure the sustainability of the country's natural assets. There has been no in-depth assessment on the exact paths of entry and scientifically measured impacts of waterweeds on the biodiversity (flora and fauna), socio-economy and health of impoverished riverine, lagoonal and lakeshore communities in affected areas. It is important to quantify these impacts in order to estimate the economic impact, current and potential infestations of water hyacinth and other waterweeds will have on Ghana and the costs and benefits of any management options and prevention strategies that will eventually evolve.

1.5.1 Ghana major river systems

Ghana has eight major river systems: Volta, Tano, Ankobra, Pra, Kakum, Ochi, Ayensu and Densu. Some of these river systems have been dammed for potable water production, irrigation and fisheries. In nearly all the impoundments, serious aquatic macrophyte infestations have developed, affecting their proper use and management (deGraft-Johnson, 1991).

Studies on aquatic vegetation and noxious weeds started in earnest with the establishment of the Volta Basin Research Project (VBRP) at the University of Ghana, Legon, in 1963. The studies were initiated during the implementation stage of the Volta River Project at Akosombo. The studies had been prompted by the experience of Lake Kariba on the Zambezi River in Zimbabwe, where an explosive development of the water fern, *Salvinia molesta* covered 22% of the surface of the reservoir in the early 1960s (Boughey, 1963; Ameka and deGraft-Johnson, 1998).

Water hyacinth was first observed in Ghana in 1984 in a residence of Community 10 in the Tema Metropolis where it was being kept as an ornamental plant (deGraft-Johnson, 1996). By 1987, it had infested some drains in the Tema Metropolis as well as the Odaw River and its tributaries in Accra. It was in 1990 found in the Abby-Ehy-Tano-Nveye River and Lagoon complex in the Western Region and then 1998 in the Oti River Arm of Lake Volta and during 2003 in Kpong Headpond.

The introduction of water hyacinth into Ghana in 1984 and salvinia in 1994 has further heightened fears as to the fate of the Ghanaian water bodies should these water weeds be allowed to invade and spread. Since then, the introduction of water hyacinth has been reported from urban centres, such as Accra, Akosombo, Sekondi-Takoradi and Kumasi, where the plant has sometimes been sold to the unsuspecting public under the false name of 'water lily'. Waterweeds are now recorded as problematic in Lake Volta (Hall *et al.*, 1969; Lawson *et al.*, 1979); Lower Volta River (Hall and Pople, 1969; Ennin and deGraft-Johnson, 1977); Barekese Reservoir (Fiakpornu, 1988); Weija Reservoir (deGraft-Johnson, 1977; Allen and Gaudet, 1979; Ameka, 1987; Ameka and deGraft-Johnson, 1998); Kpong

Headpond (Gyimah-Amoako, 1988) and the irrigation reservoirs at Dawhenya, Ashaiman, Okyereko and Mankessim (deGraft-Johnson, 1991).

1.6 Water hyacinth (*Eichhornia crassipes*)

1.6.1 Origin of water hyacinth

The centre of origin of water hyacinth, *Eichhornia crassipes*, is Amazonia, Brazil, from where it then naturally spread to other areas of the South American continent. The species was introduced by humans to North and Central America and the Caribbean (Barrett and Forno, 1982). The genus *Eichhornia* (Liliales: Pontederiaceae) contains other species – *azurea* (Swartz) Kunth, *natans* (Beauvois) Solms, *paradoxa* (Martius) Solms and *paniculata* (Sprengel) Solms. *Eichhornia* is an entirely aquatic genus, but only *crassipes* has become a problem weed (Sculthorpe, 1971).

1.6.2 Description of water hyacinth

Water hyacinth is an erect, free-floating, stoloniferous, perennial herb. The buoyant leaves vary in size and morphology. There are two leaf forms, ranging from the short swollen or bulbous leaf petioles, produced in uncrowded conditions which provide a stable platform for vertical growth, to plants in crowded conditions, which form elongated (up to 1.5 m) petioles. Leaves are arranged in whorls of six to ten and individual plants develop into clones of attached rosettes (Center and Spencer, 1981). Leaf blades or laminae are smooth, entire, glossy and with semi-parallel veins. (Center and Spencer, 1981).

The lavender flowers display a central yellow fleck and are borne in clusters of up to 23 on a single spike (Barrett, 1980). The flowers may have short, medium or long styles. The 14-day flowering cycle concludes when the flower stalk bends, positioning the spike below the water surface where seeds are released (Kohji *et al.*, 1995). Each seed capsule normally contain fewer than 50 seeds while each inflorescence can produce more than 3,000 seeds and a single rosette can produce several inflorescences each year (Barrett, 1980).

1.6.3 Reproduction

Vegetative reproduction is the most common mode of reproduction and is largely responsible for the rapid increase in populations. Propagation occurs by means of stolons which produce daughter plants at the apices. However, the small, long-lived seeds that sink and remain viable in sediments for 15 to 20 years (Matthews, 1967; Gopal, 1987) are also capable of starting infestations. Seeds germinate on moist sediments Haigh (1936) or in warm shallow water Hitchcock, *et al.* (1950) and flowering can occur 10 to 15 weeks thereafter (Barrett, 1980). Lack of germination sites limits seedling recruitment, however, during drought and on decaying mats after herbicide applications or at the margins of water bodies, there is massive seedling recruitment due to adequate light penetration (Matthews, 1967).

1.6.4 Biology of water hyacinth

Weber (1950), Richards (1982), Watson (1984), and Watson and Cook (1982, 1987) describe water hyacinth growth and population expansion as the result of differentiation of apical or axillary meristems. The single apical meristem on each stem tip can be vegetative, producing leaves with axillary buds, or reproductive, producing flowers. If an inflorescence develops, termination of the apical meristem halts leaf production. In this event, the axillary bud immediately below the inflorescence differentiates into a continuation shoot. This produces a new apical meristem that allows leaf production to proceed. If the axillary bud does not form a continuation shoot, it produces a stolon. Elongation of the stolon internode moves the axillary bud apex away from the parent rosette. It then produces short internodes that grow vertically into a new rosette (Center *et al.*, 2002).

Water hyacinth grows best in neutral pH, water high in macronutrients, warm temperatures (28° to 30°C), and high light intensities. It tolerates pH levels from 4.0 to 10.0 (Haller and Sutton, 1973), but not more than 20 to 25% sea water (Muramoto *et al.*, 1991). The plants survive frost if the rhizomes do not freeze, even though emergent portions may succumb (Webber, 1897). Prolonged cold kills the plants (Penfound and Earle, 1948), but reinfestation from seed follows during later warmer periods. Plants stranded on moist sediments can survive several months (Parija, 1934).

Temperature has an important and pervasive influence on the distribution and abundance of organisms through its effects on physiological processes such as photosynthesis and nutrient fixation (Somero, 2002). Therefore water hyacinth reproduction and development is also greatly influenced by temperature. The weed has been observed to actively grow under optimum temperatures of 25 to 27.5°C (Gopal, 1987). At temperatures below 10°C and above 40°C, the plants cease to grow. However, it has been observed that even at temperatures below 10°C, ramets are still produced (Gopal, 1987); and the plant can survive freezing temperatures ranging from 0 to -16°C for at least 24 hours (Owens and Madsen, 1995).

Light quality and quantity have a significant effect on water hyacinth morphological growth (Méthy *et al.*, 1990). The plant's leaves form a canopy which lessens photosynthetic photon flux density and the ratio of red to far-red light throughout the rest of the plant (Méthy *et al.*, 1990). Therefore, like most canopy shaded plants, water hyacinth has the ability to increase its potential to intercept light by elongating its petioles upwardly and subsequently increasing leaf area and through horizontal growth by positioning new ramets laterally (Smith, 1982). Nevertheless, the production of ramets has been noted to decrease under low light conditions (Méthy and Roy, 1993).

High nutrient content in water bodies can contribute to the rapid proliferation of water hyacinth. Many water bodies in Ghana have a high N:P (nitrate: phosphate) ratio. A positive correlation exists between water nutrient concentration, especially nitrate and phosphate, the principal macronutrients responsible for eutrophication in water bodies (Petrucio and Esteves, 2000), and water hyacinth growth (Heard and Winterton, 2000). Ripley *et al.* (2006) found an increase in water hyacinth biomass, ramet production, and plant height resulting from increasing concentrations of nitrate and phosphate.

1.7 Water hyacinth control

The control of invasive alien species includes a number of options: exclusion, eradication, containment (control), mitigation and adaptation (Perrings, 2002). Exclusion implies the use of measures such as quarantine or blacklists to prevent the introduction of potentially invasive species. Eradication is typically, but not always, an option only in the early stages of the spread of an invasive species. Containment implies the restriction of the space occupied by an invasive species. Mitigation and adaptation imply measures to control or accommodate the invasive species.

1.7.1 Methods of control

1.7.1.1 Physical control

Physical control includes the removal of the weeds by manual labour or by mechanical harvesters, the use of physical barriers such as floating booms and, where feasible, by draining the water body. These techniques are useful and sometimes essential in the short-term. However, they are expensive and physical control will have to be a permanent operation if it is the only means of control used. An estimate of the cost of mechanical control for some aquatic weeds in the United States of America is approximately US$ 21,000 ha^{-1}

(Thayer and Ramey, 1986) (figures adjusted to 2005 U.S. dollars). Aquatic weed harvesting also entails transport and disposal of the biomass removed which can add considerably to the cost of control. Physical removal has obvious limitations of scale and re-infestation is certain to occur from plant fragments and seeds. It is environmentally "safe" and is a useful method for reducing small infestations and for maintaining canals or protecting turbines of electric dams (Taylor-Wood, 2003). However, sometimes physical removal can be quite damaging and non-selective. In Ghana, manual removal has been the first control option practiced throughout the country, usually implemented by individuals who need access to water, or by whole communities. In addition physical barriers have been used to prevent water hyacinth blocking boat access to landing sites.

1.7.1.2 Chemical control

This is the most commonly used method of control. It is effective against the smaller infestations of waterweeds but has proved expensive and ineffective against large infestations. In Nigeria, for example, mechanical and chemical control cost of water hyacinth was estimated at US$ 639 and US$ 161 ha^{-1} respectively (Kasulo, 2000). Indeed, where conditions are favourable, water hyacinth can grow faster than the chemicals can kill them. Re-growth from seeds is possible many years after the problem has apparently been solved. The effects of chemicals on human health (real or imagined), on other plants and animals and the damaging effect on the environment are causes for concern. Two additional problems inherent in chemical weed control are the development of herbicide resistance in weeds and, as communities draw water directly from the water source with no treatment, there is a perception that herbicides are poisons (Culliney, 2005). In Ghana, chemical control using systemic glyphosate-based herbicides has been used in the Accra-Tema Metropolis, in the lagoons in the Western Region and in the new infestations in the Oti River Arm of the Lake Volta.

1.7.1.3 Biological control

Biological control is the use of host-specific natural enemies to reduce the population density of a pest (Howard and Harley, 1998). Classical biological control involving the importation, colonization and establishment of exotic natural enemies (predators, parasites and pathogens) to reduce exotic pest populations and maintain them at, economically insignificant densities is the predominant approach to biological weed control (McFadyen, 1998). Biological control can be an economically sustainable, environmentally safe, long-term option to manage certain targeted aquatic weeds in multi-use waters. Biological agents have successfully controlled water hyacinth, salvinia, red water fern and water lettuce in a number of localities around the world, including Africa (Cilliers *et al.*, 2003; Coetzee *et al.*, 2009). Invasive aquatic weeds that colonize vast areas of water bodies in monotypic stands are ideal targets for biological control. However, biological control is not meant to eradicate a target weed, but merely to suppress the weed populations substantially below an economically or ecologically determined threshold, allowing native species to return (Charudattan, 2001a).

Research into biological control of water hyacinth began in 1961, and the first control agents were released in the USA about 10 years later (Perkins, 1972, 1973). Today, one or more species have been introduced in 34 countries (Limon, 1984; Julien, 2001). As a result, water hyacinth is under control in some countries while infestations have been reduced in others. Seven arthropods and three fungi have contributed to biological control of water hyacinth (Harley and Wright, 1984; Julien, 1987, Coetzee *et al.* 2011). These include:

- *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae), a nocturnal, leaf-feeding weevil. The larvae tunnel internally through the petioles and into the crown of the plant, causing it to rot, die and sink. This agent is the most abundant and widespread of the natural enemies, but its impact has been variable. It does not do well in cool climates and in systems that are prone to seasonal flooding. Floods wash away host plants and deplete the insect's population (also see chapter 4). Nutrient enrichment, physical removal and herbicide sprays further reduce its effectiveness (Hill and Cilliers, 1999)

- *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) is very similar to *N. eichhorniae* except that it has a shorter generation time. When both species occur together, their combined effects integrate well and the resulting damage exceeds that of both their individual effects (Ajuonu *et al.*, 2003). The value of *N. bruchi* lies in its ability to damage weed populations growing in nutrient-enriched water (Heard and Winterton, 2000), where *N. eichhorniae* is largely ineffective. This weevil species is also cold-tolerant, and thus is an important agent in nutrient-enriched water bodies in higher elevation areas (Hill and Cilliers, 1999).

- *Niphograpta albiguttalis* Warren (Lepidoptera: Pyralidae) larvae mine the petioles of the plant, causing necrosis and waterlogging. The moth prefers young actively growing plants and so is effective in areas where water hyacinth has been thinned by herbicides or physical clearing. It is also effective at restricting the spread of water hyacinth mats. The moth has a broad climatic tolerance and has established in subtropical and temperate regions. It has a patchy distribution because of its requirement for young infestations.

- *Eccritotarsus catarinensis* Carvalho (Heteroptera: Miridae) is a leaf sucking mirid. Nymphs feed communally with the adults on the leaf under surface. The insect was released early in 1996 in South Africa and established at numerous sites. *Eccritotarsus catarinensis* is now established in South Africa (Hill and Cilliers, 1999) and its effects are being monitored. Although the impact of this insect on water hyacinth performance has not yet been quantified, it does reach very high densities in tropical areas of the country where it is capable of causing severe die back of the plants (Coetzee *et al.*, 2011). It also has been released in Benin, Zambia, Malawi and most recently Ghana in 2009.

- *Orthogalumna terebrantis* Wallwork (Acarina: Galumnidae) is a leaf-mining mite that is extremely damaging to water hyacinth. However, this mite has not been able to establish in colder climates and is presently restricted to the warmer parts of Africa. Due to the success of the *Neochetina* weevils and *N. albiguttalis*, the water hyacinth mite, *Orthogalumna terebrantis* Wallwork, has not been released in as many countries as these agents. However, in high densities, *O. terebrantis* can produce large numbers of feeding galleries on water hyacinth leaves which can be extremely damaging to the plants (Hill and Cilliers, 1999).

- *Xubida infusellus* Walker (Lepidoptera: Pyralidae) has been released in Australia but is not considered damaging enough (Stanley and Julien, 1999). The larvae damage the leaf petioles and are capable of destroying the shoots by feeding on the apical meristems. Damage is similar to that caused by *N. albiguttalis*, but *X. infusellus* would complement the effects of *N. albiguttalis* because of their divergent preferences for different pheno-stages. *Niphograpta albiguttalis* prefers young plants with bulbous or inflated leaf petioles, whereas *X. infusellus* prefers the mature plants with elongate leaf petioles.

- Most recently, *Megamelus scutellaris* (Berg) (Hemiptera: Delphacidae) and the grasshopper *Cornops aquaticum* (Bruner) (Orthoptera: Acrididae) were released through clearance by the United States Department of Agriculture-Agricultural Research Service (2010) and the Agricultural Research Council-Plant Protection Research Institute of South Africa (2011) respectively, to complement the efforts of existing biological control agents for water hyacinth (Coetzee *et al.*, 2011).

- Fungal pathogens: *Acremonium zonatum* (Sawada) Gams, *Cercospora piaropi* Tharp and *Cercospora rodmanii* Conway. The fungi *Acremonium zonatum* and *Cercospora piaropi*, have spread around the world with water hyacinth (Harley, 1990). On their own, these fungi are not damaging enough but effects increase when plants are stressed by insect attack. However, the effect of *C. piaropi* is so severe that it causes population declines. This fungus causes numerous small dark-brown leaf spots on the leaves and petioles, which join together and kill entire leaves (Morris, 1990).

1.7.1.3.1 Impact of release of biological control agents

In the USA, biological control agents were first released between 1972 and 1977 and are now established on water hyacinth infestations almost everywhere. The results have been good. For example, in the State of Louisiana, the height, density and biomass of water hyacinth have been reduced and the area infested has decreased from 445,500 ha in 1974 to 121,945.5 ha in 1980 (Cofrancesco *et al.*, 1985).

In Australia, water hyacinth occurs mostly on the east coast. *Neochetina eichhorniae* was first released in 1975 and *N. albiguttalis* in 1977. The first reported collapse of water hyacinth was in 1978, following severe damage by *N. eichhorniae* at an infestation at Rockhampton (Wright, 1979). Since then, high levels of control have been achieved at many infestations in tropical regions but biological control has been relatively ineffective in temperate areas (Harley, 1990).

In India, releases of *N. eichhorniae* began in March 1983 and continued up to December 1986, with more than 22,000 adults of this species and 3,500 of *N. bruchi* being released in eight water hyacinth infested tanks in and around Bangalore, with a total surface area of about 1,000 ha. At several sites, a reduction of about 90% was recorded within three years. Following the success of these preliminary trials near Bangalore, releases of both *Neochetina* species were made in other parts of the country. Early observations indicated that similar results would be obtained (Jayanth, 1987; 1988).

Biological control is considered the only sustainable control option for water hyacinth in Africa and several natural enemy species have been released (Cilliers *et al*., 2003). The first successful biological control programme on the continent was in the Sudan (Beshir and Bennett, 1985), and the most recent and dramatic release has been on Lake Victoria where expansive mats of the plant have collapsed (Cock *et al*., 2000).

In Sudan, *N. eichhorniae* was introduced in 1978, *N. bruchi* in 1979 and *N. albiguttalis* in 1980. *Neochetina eichhorniae* was first recovered in 1980 and by 1981, *Neochetina* species were widespread. Virtually every water hyacinth plant was scarred by feeding marks of the adult weevils and control of water hyacinth throughout the Nile in Sudan had started. Compared to the situation prior to establishment of *Neochetina* species, plants were less vigorous, had a lower dry weight, floated lower in the water and no longer formed suitable colonization sites for other plants. Whereas in the early 1960s there was an annual accumulation of up to 11,350 ha of water hyacinth behind the Jebel Aulia Dam, there have been no accumulations since 1982 and since then, few plants can be observed even 30 km south of the dam (Bashir, 1984; Beshir and Bennett, 1985). This is indeed an impressive result of releasing biological control agents and was achieved in an unusually short time (Harley, 1990).

Water hyacinth in Tanzania dates back to 1955 when it was first recorded on the Sigi and Pangani rivers, which empty into the Indian Ocean. The weed was also reported from Lake Kyoga in Uganda in 1987. However, water hyacinth gained importance as an aquatic weed in 1989 when it was first noticed on Lake Victoria. Initial infestations in Kenya were limited to a few bays, but they later increased to cover most of the fishing beaches (Mailu *et al*., 1999), stretching into Uganda. By 1990, the weed had covered most of the southern Tanzanian shoreline of Lake Victoria, with dense infestations occurring on the sheltered bays of

Mwanza, Bauman, Emin Pasha, Mara and Rubafu (Mallya, 1999). Upstream in Rwanda, water hyacinth thrived in a number of small lakes that feed into the Kagera River, which flows into the lake.

At the peak of the infestation, water hyacinth covered an estimated 20,000 ha along Lake Victoria's shoreline in Kenya, Tanzania and Uganda, thus creating socio-economic and health problems for lakeside residents (Mailu, 2001). The two *Neochetina* weevils were released there in 1995. Numerous weevil rearing stations were erected around the lake and with the aid of local fishing communities, several million weevils were released. In a combined effort of mechanical, but mainly biological control, the water hyacinth biomass was reduced by an estimated 80% within a period of 4 years on the Ugandan part of the lake (Cock *et al.*, 2000). On the Kenyan shores of the lake, some 4 years after introduction, adult weevil numbers varied from 0 to 32 per plant with an average of six adults per plant, and weed coverage had been reduced by up to 80% (Ochiel *et al.*, 2001). In Tanzania, an integrated control approach which included manual removal of the weed from fishing beaches and the introduction of the two weevils, resulted in a 70% reduction of water hyacinth within 3 years (Mallya *et al.*, 2001). The source of the water hyacinth coming into the lake has also been targeted with the construction of three weevil rearing stations along the Kagera River in Rwanda (Moorehouse *et al.*, 2001), ensuring that biological control agents have been released at the source of the infestation.

Elsewhere in the region, the weevils reduced water hyacinth coverage by 80% on Lake Kyoga in Uganda (Ogwang and Molo, 1999) The release of the weevils on the Sigi and Pangani rivers in Tanzania in 1995 reduced the amount of manual removal required to keep the river channels open (Mallya, 1999). Weevils have also been released in the Democratic Republic of Congo (Mbati and Neuenschwander, 2005), but it is too soon to tell what impact they are having.

In South Africa, the Agricultural Research Council-Plant Protection Research Institute has since 1974 released six arthropods and one pathogen as natural enemies against the weed (Cilliers, 1991a; Hill and Cilliers, 1999; Coetzee *et al.*, 2011). In some areas of South Africa good control has been achieved, while in other areas, low temperatures in high altitude climatic areas, and interference from other control options have retarded biological control. For example, under a rigorous herbicide programme, biological control agents are suppressed, but once continuous spraying stops the agents can build up and control water hyacinth (Cilliers *et al.*, 2003).

Malawi has a successful water hyacinth biological control programme on the Shire River (Phiri *et al.*, 2001) and the weed is under good control on Lake Kariba (Chikwenhere *et al.*, 1999), but there are still sporadic outbreaks on Lake Chivero in Zimbabwe, which are attributed to high pollution levels (Chikwenhere and Phiri, 1999). The weevils, although present in some areas, have recently been further released in Mozambique (Phiri, 1997; Chiconela, 2000 unpublished data). Unfortunately, due to political unrest little is known of the situation in Angola though it is believed that water hyacinth is becoming a problem there. To date, no biological agents have been released (Hill, pers. communication).

In northern Egypt, *N. eichhorniae* and *N. bruchi* were released in August 2000 on two lakes. By July 2001, water hyacinth on Lake Edko was reduced by 90% (Fayad, *et al.*, 2001) but on Lake Mariout, reduction was slower due to water pollution. The pathogen *Altenaria altenata* (Fr) Keisser (Ascomycotina) has also been utilized (Fayad, 1999).

In West Africa, water hyacinth was observed in Benin in 1977 (van Thielen *et al.*, 1994), and in Ghana and Nigeria in 1984 (Akinyemiju, 1987; deGraft-Johnson, 1988). In Benin, of the four species released (*N. bruchi, N. eichhorniae, N. albiguttalis* and *Eccritotarsus catarinensis*), only the two weevil species have established, which is similar to the situation in most of the other countries in the region. *Neochetina eichhorniae* is the dominant species, having dispersed widely, while *N. bruchi* is confined to the release localities. At Tevedji, Lihu and Kafedji on the Oueme river, water hyacinth cover was reduced from 100% to 5% within 8 years, while the same level of control was achieved in just 5 years on Lake Azili, where the weevils had dispersed from the release site to 15 km away (Ajuonu *et al.*, 2003). Overall, water hyacinth in Benin has been reduced from a serious to a moderate pest. The economic return on investment of the project was 149:1 for southern Benin alone (De Groote *et al.*, 2003). However, at some sites, such as Savalou and Kpokissa, the weevils have not been as effective because the host plants were stranded in shallow mud banks when water receded, thus affecting the root dwelling weevil pupae (Ajuonu *et al.*, 2003). Nigeria receives an annual influx of water hyacinth from the Niger River, which threatens hydropower generation. The weevil *N. eichhorniae* was released in that country in 1994, while *N. bruchi* was released in 1995. In addition, a series of booms were used to collect the weed for manual removal and by 2001, water hyacinth infestation was visibly reduced compared with 1995 (Daddy, 2002 unpublised data). In Niger, *N. eichhorniae* spread from the releases on the Niger River about 700 km upstream to the capital Niamey, where the weevils have had visible impact on water hyacinth infestations. A similar decline has been reported from Côte d'Ivoire (Zebeyou, 2001 unpublished data). Biological control projects on water hyacinth have also been initiated in Burkina Faso, Togo and Mali.

In Ghana, biological control using the *Neochetina* weevils was initiated in 1994. Both species were imported from the International Institute of Tropical Agriculture (IITA), Benin in July 1993, reared at the Zoology Department of the University of Ghana, Legon, and released into the Abby-Ehy-Tano River and lagoon complex in southwestern Ghana from March 1994. They have established and spread throughout the infestations and into neighbouring Côte d'Ivoire. They were collected from the Tano Lagoon in April 2000, reared at Akosombo and Dambai and released between Kitare and Homadikope in the Oti River Arm of Lake Volta in December 2000. The moth *N. albiguttalis* was imported from South Africa and released into the Abby-Ehy-Tano River and lagoon complex in southwestern Ghana in 1996, but did not establish (deGraft-Johnson pers. Communication). However, reports from Accra indicate that there has been considerable decline in the water hyacinth infestation since the release of the *Neochetina* weevils (deGraft-Johnson, personal communication).

1.7.1.4 Integrated control

This system employs physical, chemical and biological methods of control as components of an overall management strategy. The emphasis on each of the three control methods will vary according to the circumstances and over time. An integrated control programme is managed to avoid interference between different control methods, while maximizing use of the water or the waterways for humans and animals. Physical and chemical controls are phased out as soon as is practicable, as total reliance on biological control is the long-term objective. The development of effective, properly integrated management strategies for floating aquatic weeds is a very complex task demanding extensive knowledge of weed biology, ecology, and management techniques. The requisite information is not readily available but the application of expert system technology to this problem should give an interactive, user-friendly computer programme which can be used by aquatic weed control managers across Africa (Harley, 1993).

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

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

According to Charudattan (2001b), the Florida Lakewatch programme in the USA and the Working for Water Programme in South Africa are two good models of public stakeholder involvement in monitoring and protecting water resources from various threats including aquatic weeds. Control strategies should include all appropriate and effective methods of control. Biological control should be the centrepiece of management programmes for non-native invasive species and its integration with other applicable techniques should be achieved in a manner that maximizes effectiveness and benefits.

1.8 Aims and Objectives

As noted above, aquatic weeds have contributed to the decimation of biodiversity in areas where they occur as monotypic stands. In the Tano and Volta River systems, water hyacinth and salvinia infestations are thought to adversely affect biodiversity, fishing, transport, health and water supply, as well as livelihoods of riparian communities. The principal aim of the study is to quantify the impact of water hyacinth and other aquatic plants on biodiversity and socio-economy (health, fishing and transport) of the Lake Volta and the Kpong Headpond, and to assess the impact of the *Neochetina* weevils as control agents of water hyacinth in the Abby/Ehy/Tano River and lagoon complex in the south western part of Ghana.

Chapter 2 provides an inventory of all the aquatic macrophytes present in the Kpong Headpond. It investigates how the diversity of aquatic plants on the Kpong Headpond has changed over time and identifies and discusses the anthropogenic factors in the area that favour the growth of the plants in the headpond. It recommends remedial measures that must be taken into consideration to reduce the level of infestation of the aquatic weeds in the headpond and the Lower Volta River catchment area.

The social, economic and health impacts of water hyacinth in the Oti River Arm of Lake Volta were investigated in chapter 3. The impact of the water hyacinth infestation on social life, economic well-being and effects on the environment were assessed. The chapter quantifies some of these factors and discusses control and management options that have been put in place so far to bring down the level of infestation, and thus the impacts.

Chapter 4 evaluated the impact of the biological control agents *Neochetina bruchi* and *Neochetina eichhorniae* on water hyacinth infestations in the Tano River and the Tano/Abby/Ehy/Lagoon complex, southwestern Ghana. Additional agents that may complement the ones already used in Ghana are discussed.

The weevils *Neochetina eichhorniae* and *Neochetina bruchi* were introduced into Ghana in 1994. Both species were imported from IITA, Benin, in July 1993, reared at the Zoology Department of the University of Ghana, Legon, and released into the Abby-Ehy-Tano River and lagoon complex in southwestern Ghana from March 1994. No host specificity testing was carried out prior to release, relying on data from other countries. Chapter 5 discusses laboratory host specificity tests conducted for these weevils 15 years after their release into

Ghana to see if there has been any host range expansion after some 45 generations in a new environment.

Chapter 6 provides a general discussion and conclusion of the study and puts forward recommendations for enhancing the control of invasive alien species in aquatic systems in Ghana.

Chapter 2

Survey and assessment of aquatic plant communities of the Kpong Headpond

2.1 Introduction

Although excessive aquatic weed growth is unacceptable, some level of aquatic macrophyte presence is necessary for the efficient functioning of water bodies (Joyce, 1990; chapter 1). However, it is difficult to reach a consensus on what density of macrophytes is desirable in a given body of water. Agencies charged with aquatic weed management as well as scientists debate this point, often reaching conflicting conclusions (Charudattan, 2001a). A useful review of the issues involved and how this complex topic may be addressed has been provided by Chambers *et al.* (1999). The primary reason for the divergent views is that these plants have beneficial effects. They can add aesthetic value to water resources, are widely used as aquarium and aquascape plants and can promote waterfowl and fish populations (Joyce, 1990). Some weeds such as water hyacinth, *Typha* sp. and grasses that generate enormous volumes of biomass, have been used as a resource for industrial or handcrafted products, including animal-feed supplements, soil conditioners, composts, paper and biogas (Virabalin *et al.,* 1993; Pandey and Srivastava, 1996). However, these uses require a steady supply of aquatic weeds and maintenance of supply sources is generally incompatible with the need to control these weeds. Furthermore, utilization invariably results in the spread of the weed to new localities as the resource is passed from one community to the next (Anonymous, 2000b).

The quantitative role of macrophytes in lake ecology is closely linked to their biomass, which in turn is a synergy of various environmental factors (Duarte *et al.*, 1986). Different macrophyte life forms require nutrients from different sources and vary in exposure tolerance (Toivonen and Huttunen, 1995). Therefore, macrophyte species richness and proportions of various growth forms closely reflect the trophic state of a water body. In addition, macrophyte stands have been reported to affect lake nutrient status, re-suspension of benthic materials and water turbidity (James and Barko, 1990; Sand-Jensen and Borum, 1991; Horppila and Nurminen, 2001). Aquatic plant biomass often increases when nutrient loading from within a catchment increases (Mitchell, 1974). As rooted-emergent and floating-leaved macrophytes typically gain a substantial amount of their nutrient requirements from sediments via their roots, it is the unrooted-submerged and free-floating plants that generally respond most dramatically to eutrophication.

Free-floating plants depend almost entirely on the water beneath them for their nutrients and can respond in a similar way to phytoplankton (Denny, 1980). However, phytoplankton, being smaller and surrounded by water, have shorter diffusion pathways than macrophytes and thus usually respond to increased nutrient loads quickly. As such phytoplankton can often out-compete macrophytes for increased nutrients. In some circumstances though macrophytes prevent phytoplankton blooms from developing, thus enabling these macrophytes to survive and dominate in relatively high nutrient conditions. Ultimately as eutrophication increases, submerged macrophytes disappear because of light limitation through shading and a phytoplankton dominated state prevails (Timms and Moss, 1984). Floating plants, however, are not affected by decreasing light penetration within the water body and can persist and indeed benefit from increasing nutrient supplies. In fact, if phytoplankton growth becomes light limited because of self shading or shading from floating plants, floating plants can take advantage of the increased nutrient availability and expand their coverage. Overall, eutrophication can increase floating plant biomass of both native and invasive macrophytes, but as invasives are superior competitors with fewer natural enemies, they consequently flourish to a greater extent than natives (Williams and Hecky, 2005).

2.2 Impact of water hyacinth on ecological communities

The structure of a macrophyte community plays a large role in determining community composition of phytoplankton, zooplankton and fish in freshwater ecosystems (Meerhoff *et al.*, 2007). Water hyacinth provides complex structure to the upper portion of the water column that may be novel in ecosystems that otherwise lack floating vegetation, as is the case in Africa Lemnaceae, like *Lemna paucicostata* Hegelm, *Wolffia arrhiza* (L.) Horkel. Ex. Wimm., and *Spirodela polyrrhyiza* (L.) Schleid, are floating and indigenous (Arora and Mehra, 2003). The interconnectivity among organisms within an aquatic system makes the plant's overall influence challenging to assess. A shift in the primary-production base of a lake can resonate throughout the ecosystem, affecting multiple trophic levels both directly through changes in habitat availability, and indirectly through shifts in energy pathways. The strong interdependence among biological communities within aquatic ecosystems makes it difficult to predict the impacts of a non-native species without understanding fully the existing system and the effects of the non-native on various components of the ecosystem (Villamagna and Murphy, 2010).

Dense mats reduce light to submerged plants, thus depleting oxygen in aquatic communities (Ultsch, 1973). The resultant lack of phytoplankton (McVea and Boyd, 1975) alters the composition of invertebrate communities (O'Hara, 1967; Hansen *et al.*, 1971), ultimately affecting fisheries. Drifting mats scour vegetation, destroying native plants and wildlife habitat. Water hyacinth also competes with other plants, often displacing wildlife forage and habitat (Gowanloch, 1944). Higher sediment loading occurs under water hyacinth mats due to increased production of detritus and siltation.

Water hyacinth was found to selectively inhibit planktonic green algae in a shallow Portuguese lake (Almeida *et al.*, 2006), yet phytoplankton density in littoral sites with water hyacinth in Lake Chivero (Zimbabwe) was 10–30 times higher than littoral sites without water hyacinth (Brendonck *et al.*, 2003). Water hyacinth can trap phytoplankton and detritus, thereby increasing, at least temporarily, phytoplankton densities beneath mats (Brendonck *et al.*, 2003). Following the removal of water hyacinth in its native range, Bicudo *et al.* (2007) found a substantial increase in total phytoplankton as well as cyanobacteria biomass that contributed to the loss of water clarity in a shallow Brazilian reservoir. Overall, water hyacinth seems to limit the productivity of phytoplankton and submerged vegetation under mats, with the exception of certain colony forming algae that may initially be entangled within water hyacinth roots (Villamagna and Murphy, 2010).

Reduced phytoplankton productivity can decrease zooplankton abundance by decreasing food availability (Richards *et al.*, 1985; Maceina *et al.*, 1992). On the other hand, the complex structure provided by macrophytes may provide more microhabitats for epiphytic zooplankton. This was documented in the Yamuna River (Egypt), where there was a more abundant and diverse epiphytic rotifer community within water hyacinth than within *Salvinia molesta*, a macrophyte with smaller floating and submerged leaves. The difference in rotifer abundance and species richness was attributed to greater food availability and refuge from predators provided by water hyacinth's complex root structures (Arora and Mehra, 2003). Overall, zooplankton response to water hyacinth appears to vary by taxa and geographic location (Villamagna and Murphy, 2010). Meerhoff *et al,* (2003) did not find a significant difference in micro-crustacean richness or diversity among sites with water hyacinth, sites with *Potamogeton pectinatus* L. (pondweed), or vegetation-free littoral sites of Lake Rodo (Uruguay).

Aquatic plants provide ideal habitat for macro-invertebrate colonisation (Sharitz and Batzer, 1999; Masifwa *et al.*, 2001). Structure provided by the roots and leaves create habitat for macro-invertebrates, especially for epiphytic macro-invertebrates such as snails, arachnids (Brendonck *et al.*, 2003) and amphipods (Toft *et al.*, 2003; Rocha-Ramirez *et al.*, 2007). Several studies have documented a positive correlation between epiphytic macro-invertebrate densities and the surface area of floating aquatic vegetation, including water hyacinth (Crowder *et al.*, 1982; Schramm *et al.*, 1987). Within its native range, water hyacinth is an important substratum for invertebrate colonisation (de Marco *et al.*, 2001). Macro-invertebrate densities tend to be higher near the open water edge of water hyacinth mats than in the centre. For example, the largest quantities of macro-invertebrates sampled from water hyacinth in swamps along the Nile River (Sudan) were found within 6 m of open water (Bailey and Litterick, 1993). Rocha-Ramirez *et al,* (2007) also found a highly diverse macro-invertebrate community (96 taxa) within water hyacinth roots in a coastal lagoon of Mexico.

There is little to suggest a direct relationship between fish and water hyacinth in terms of food. Herbivorous fish, including Grass Carp (*Ctenopharyngodon idella* Valenciennes), avoid feeding on water hyacinth (Villamagna and Murphy, 2010). Water hyacinth stores little protein, thus making it a nutritionally poor dietary choice for herbivorous fish (Cowx, 2003). The indirect effects of water hyacinth on fish communities depend on the initial community composition and structure, the existing food web and likely water hyacinth density or area coverage. Fish density and species composition are known to vary across macrophyte habitats with different levels of food availability, plant density, structural complexity and physico-chemical factors (Grenouillet *et al.*, 2002; Lewin *et al.*, 2004). Compared to submerged or emergent vegetation, water hyacinth provides a highly complex structure near the surface of the water, and it acts similar to a forest canopy by restricting vegetative growth below (Villamagna and Murphy, 2010).

Despite the fact that water birds play an important role in aquatic food webs, research on water hyacinth's effect on birds is sparse. However, prey availability influences bird distributions, and aquatic vegetation provides habitat and cover for aquatic invertebrates and fish that provide a prey base for many bird species (Haag *et al.*, 1987; Bartodziej and Weymouth, 1995; Svingen and Anderson, 1998; Brendonck *et al.*, 2003).

2.2.1 History of aquatic flora studies in Ghana

In Ghana, studies on the aquatic flora began during the implementation stages of the Volta River Project at Akosombo by the Volta Basin Research Project (VBRP) of the University of Ghana in 1963. The studies resulted from lessons learnt from the explosive development of *Salvinia molesta* on Lake Kariba soon after its construction (Boughey, 1963). Since these initial studies, the Volta system has been plagued by aquatic weed infestations which have adversely affected not only its use for hydro-energy generation, water transport and irrigated agriculture but also its inherent resources including the living organisms (shell and fin fishes) and its water quality (deGraft-Johnson, 1999). In the course of time, various studies have been conducted on the Volta system, including those of Lawson (1964), Lawson (1967), Hall *et al,* (1969), Hall and Pople (1969), Odei (1973), Okali and Hall (1974a and 1974b), Ennin and deGraft-Johnson (1977), Opoku (1977), Lawson *et al.*(1979) and Gyimah-Amoako (1988). These studies have given an insight into the development of hydro-macrophytes in the Volta basin prior to and after the formation of the Kpong Headpond (deGraft-Johnson, 1999).

Odei (1987) also reported on the presence of a number of aquatic macrophytes in the headpond area between the Adomi Bridge and Kpong. These included *Ceratophyllum demersum* L. (Ceratophyllaceae) and *Pistia stratiotes*. On the completion of the Kpong Dam, the headpond quickly filled with weeds. Currently, the Kpong Dam is under serious threat following an increase in aquatic weeds on the headpond. The proliferation of weeds such as *Eichhornia crassipes*, *Ceratophyllum demersum, Potamogeton octandrus* Poir (Potamogetonaceae) and *Vallisneria aegyptica* Fenzl. (Hydrocharitaceae) pose a threat.

2.3 Hydrology

Before the dams were built, the Volta River was characterized by annual floods. It began to rise in July, reaching its peak in August and falling by October. The annual floods watered low lands and creeks. The floods also deposited fertile alluvium, and agricultural productivity was significantly greater when crops were produced on land which had been flooded by the previous flood, than when crops were on uplands. The stretch of water was described as a typical low land floodplain with a gently meandering river channel and a number of small seasonally flooded water bodies along its banks (VBRP, 2000).

Prior to the construction of the Kpong Dam in 1981, the river flowed past villages at a rate that was too fast to accommodate growth of weeds. However, due to the regulation of river flows by the dam, the seasonal inundation of the margins has ended, which has caused many problems for the people who inhabit the area. The changing regime of the hydrology, the lacustrine conditions and stoppage of the annual scourging by floods led to the development of aquatic weeds in the Kpong Headpond. The incidence of weeds have been more dramatic and effects more severe in the lower Volta River and Kpong Headpond than on the main Lake Volta because the lacustrine conditions of the headpond now supported the growth of aquatic weeds, since the fertilizers used by farmers leaked into the irrigation canals, and then into the headpond. The Kpong shoreline thus experienced an explosion of aquatic weed growth (Odei, 1987).

Aquatic macrophytes are commonly grouped simply as emergents, free floating, floating-leafed and submerged, depending on the habit of the plant. In this study, the following definitions were used: **Emergent:** These are plants with roots attached to the substratum, with leaves and flowers (if present) protruding from the surface of the water, e.g. *Phragmites, Typha* and *Eleocharis.* **Free floating**: These are plants whose roots are not attached but suspended in the water, with the leaves and flowers borne above the water surface, e.g. *Lemna, Salvinia* and *Eichhornia.* **Floating-leafed:** Plants rooted, with their leaves and flowers only spreading on the water surface e.g. *Nymphaea.* **Submerged:** Submerged plants are those that are entirely suspended in the water column with no part appearing above water and not rooted, e.g. *Ceratophyllum,* some *Potamogeton* and *Vallisneria.* **Sudd formers:** The compact mass of floating vegetation is often called a sudd. It is usually made up of a combination of different macrophytes entangled together. The sudd can be fairly large and can support the weight of an average man. For example, *Leersia hexandra* Sw. (Poaceae), *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase (Poaceae), *Oxycaryum cubense* (Poeppig & Kunth.) (Cyperaceae) and *Polygonum senegalense* (Meisn) (Polygonaceae) are macrophytes that can form sudds if present in the same water body at a particular time.

2.4 Aims and Objectives

This study was designed to survey and assess the populations of aquatic plant species in the headpond since its formation in 1981 and compare the current abundance and diversity with those reported in previous studies, and to correlate plant growth with the current physico-chemical and hydrological status of the waterbody.

2.5 Materials and Methods

Sampling of macrophytes and water was undertaken monthly from July to December 2007 at each of four sampling sites on the Kpong Headpond.

2.5.1 Sampling of macrophytes

The headpond (6^{o} 07′ 17.77′′ N, 0^{o} 07′ 34.39′′ E) was surveyed from a boat and on foot monthly between July and December 2007 and the vegetation recorded. Parameters measured included habit and growth/life-form of plants, substrate type, presence of "sudd" or rooted vegetation and cover of individual species. Four sites, Natriku, Kpong Harbour, Senchi and Atimpoku were selected. The choice of the sites was based on ease of accessibility to the sampling site and the extent of coverage of the aquatic macrophytes present in the headpond. The sites were mapped (Figure 2.1). At these sites, a 0.25 m^2 quadrat was located at random over an area of about 10 m x 20 m each using a table of random numbers (Fisher and Yates, 1963) to locate the position of the quadrats. There were ten quadrats per site. The plant samples were obtained by hand cutting the 10-quadrat samples from each site during each sampling session and then transported to the laboratory where they were identified to species level. The plants were initially identified in the field with the help of literature (Cook, 1996; Press *et al.*, 2000). The data from all four sites were pooled.

The results of this survey were compared with results of two previous similar surveys undertaken on the Kpong Headpond by deGraft-Johnson (1999) as the reservoir was filling up in 1981 and by Gyimah-Amoako in 1988.

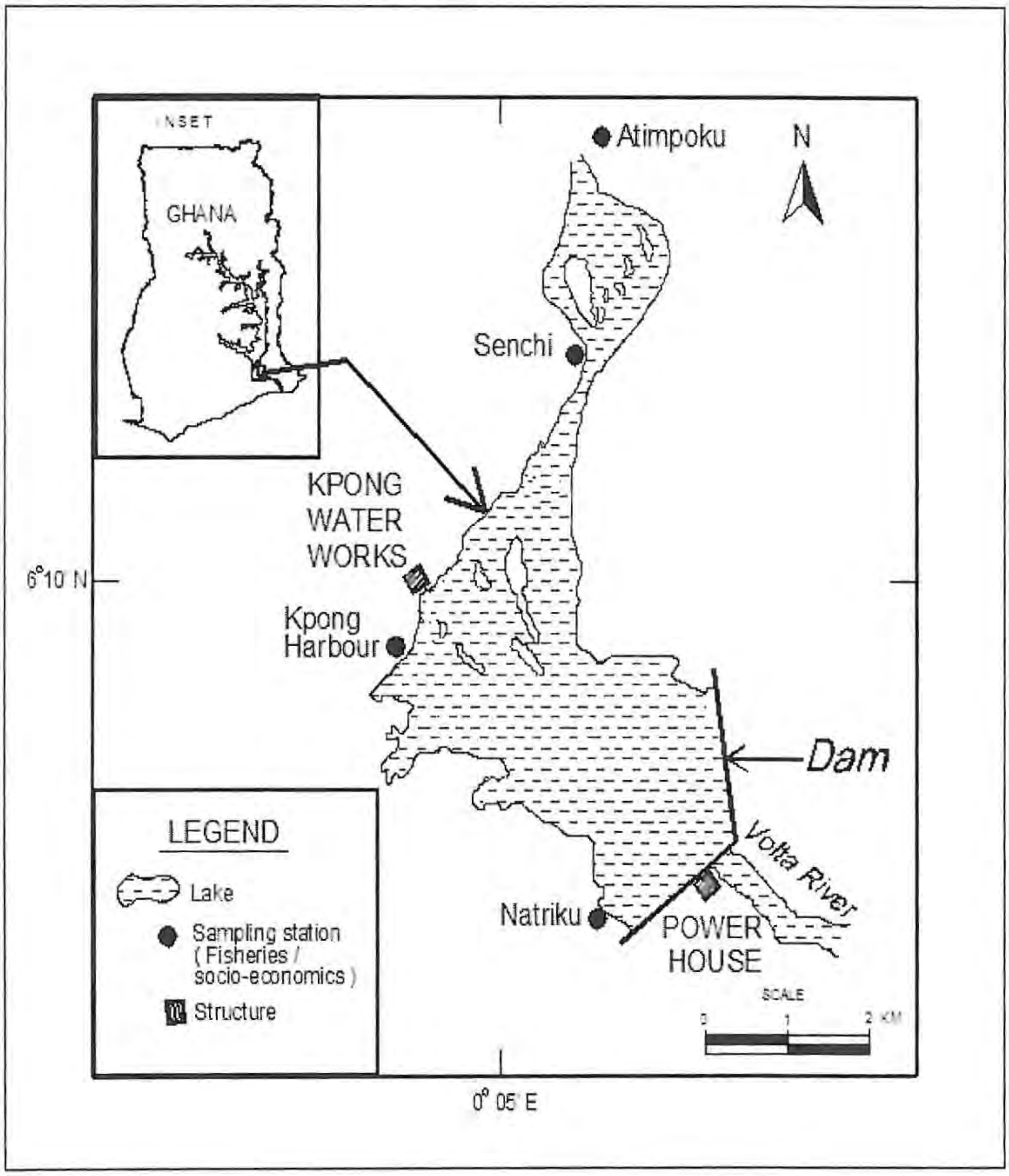

Figure 2.1: The sites on the Kpong Headpond where aquatic vegetation and water chemistry were measured.

2.5.2 Water sampling

Surface water samples from the four sites on the Kpong Headpond were collected monthly from July to December 2007 (Figure 2.1). Sampling covered both the rainy and dry seasons. Measurements of pH, temperature and conductivity were taken *in-situ*. The water samples were stored in cold boxes on ice and taken to the laboratory in Accra for the other physico-chemical analyses. Physico-chemical parameters determined at the sites and data from the analyses of the water samples formed the basis of assessing the quality of the reservoir. The laboratory analyses were undertaken according to procedures outlined in the Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, 1998).

In the field, water and air temperatures were measured using a mercury-in-glass thermometer. Electrical conductivity and pH were determined using portable meters (Hach kit). Water samples for physico-chemical analyses were collected directly into clean 1000 ml plastic bottles. For dissolved oxygen (DO) determinations, separate samples were collected into plain glass bottles and fixed in the field using the Azide modification of Winkler's method for subsequent acidification and titration. Samples for Biochemical Oxygen Demand (BOD_5) determinations were collected into black-painted glass bottles and stored at 20°C for 5 days before the remaining DO was determined. The methods used for chemical analyses in the laboratory were: Suspended Solids – Spectrophotometric determination using Hach Kit; Ammonia-nitrogen (NH_4-N) – Reaction with phenol and hypochlorite in the presence of nitroprusside catalyst followed by measurement of the blue colour at a wavelength of 630 nm; Dissolved Oxygen and Biochemical Oxygen Demand (BOD) – Iodometric titration using Winkler's method; Total Dissolved Solids (TDS) – Spectrophotometric determination using Hach Kit; Orthophosphate (PO_4-P) – Reaction with ammonium molybdate and ascorbic acid to form a blue molybdenum complex, with intensity measured at a wavelength of 880 nm; Nitrate-nitrogen (NO_3-N) – Hydrazine reduction followed by diazotising and measurement of colour intensity at a wavelength of 520 nm; Cations and Anions – Titrimetric (using titration method); Chloride – Titration with silver nitrate and Ion Chromatography; Trace elements – Atomic Absorption Spectrophotometry.

2.5.3 Statistical analyses

Statistical analysis was performed using SPSS (version 12.0, SPSS Inc., Chicago, IL, USA) for Windows, 2003. Since most concentrations of the chemical parameters were not normally distributed, non-parametric analysis was performed. Mann-Whitney U-test was used to determine differences in concentrations between wet and dry seasons. A probability value of $p < 0.05$ was considered as statistically significant in this study.

In order to determine the diversity of the plant species in their groupings, the Shannon-Wiener diversity index method was applied to the data. The Shannon's Diversity Index (H) and Species Evenness (E) were calculated for each of the different growth forms of plants measured and between the three sampling events (1991, 1998 and 2007).

In ecological studies, knowing the number of individuals present in each species may not provide a full understanding of the ecosystem. To consider all the attributes of the species in a study including the disparities in their size, structure and niche, suggests that simple counts could be misleading. One way around this problem, however, is to describe the community in terms of the species per unit area (Begon *et al,*. 2006), and the Shannon-Wiener diversity index is one tool that can be used. According to Begon *et al,* (2006), Shannon-Wiener diversity index is the simplest measure of the character of a community that takes into account both abundance (or biomass) patterns and the species evenness.

Species diversity, represented by Shannon's Diversity Index (H) is the number of different species in a particular area, Species Richness (S) is the weighted measure of abundance such as number of individuals or biomass, while another measure of species diversity is the Species Evenness Index (E), which is the relative abundance with which each species is represented in an area (Shannon and Wiener, 1963).

Measuring diversity has been historically significant, and due to the obvious declines in habitat diversity these data are still valuable. The Shannon-Wiener Diversity Index is one measure that is used to draw information from samples in the field. Historically, the index has been used to measure the effects of habitat quality, such as effects of pollution. The Shannon-Wiener index

provides a good tool for comparing two distinct habitats because it combines two quantifiable measures i.e. the species richness and species evenness.
Shannon's diversity index $\mathbf{H} = -\{\sum(\mathbf{Pi\ lnPi})\}$

Where **Pi** is the proportion of the total number of specimens **i** expressed as a proportion of the total number of species for all species in the ecosystem. The product of **Pi lnPi** for each species in the ecosystem is summed, and multiplied by −1 to give **H**. The species evenness index (**E**) is calculated as $\mathbf{E = H/H_{max}}$. $\mathbf{H_{max}}$ is the maximum possible value of **H** and is equivalent to **lnS**.

Thus $\mathbf{E = H/lnS}$

2.6 Results

2.6.1 Inventory of aquatic macrophytes and their life-forms

According to deGraft-Johnson (1999), when the Kpong Headpond was closed for filling in 1981, there were only 15 species of aquatic macrophytes present (3 submerged, 3 free floating, 5 emergents and 4 sudd-formers) (Table 2.1), but the number increased rapidly and by 1988, there were 53 aquatic plants (7 free floating, 43 emergent and 3 submerged) (Table 2.1) (Gyimah-Amoako, 1988; de-Graft Johnson, 1999). The current study recorded 65 species, an indication that the number of species and their diversity is increasing in the Kpong Headpond (Table 2.1). The newly identified species are made up of five rooted emergent plants including *Cyperus papyrus* and seven free-floating species including *Nymphaea lotus* and *Eichhornia crassipes*. The current study identified 49 emergent, 12 free floating and 4 submerged species. This means that the increase in new plant species invading the headpond is across all the life-forms, but there were more free-floating species than emergent and submerged species. More invasive alien species (e.g. *Eichhornia crassipes, Cyperus papyrus* and *Salvinia molesta*), which were hitherto not there, have also invaded the headpond.

The study revealed that the headpond also has mats of mixed vegetation which grow around the banks, islands and over shallow areas including the intake point of the Kpong head works of the Ghana Water Company Limited (GWCL) and parts of the landing sites. The sudds are impenetrable masses of floating vegetation of about 70 cm thick and 450 to 900 kg per square metre of surface. These sudds require an infestation of either water hyacinth or salvinia onto which other vegetation grows. There is then a succession of species that colonise mats of these invasive species until they form a permanent sudd.

All the plant species found in the headpond at the time it was closed for filling were indigenous except *Pistia stratiotes*. The emergent plants constituted 60%, the free-floating, 20% and the submerged 20% of the total number of weed species present (Table 2.1).

In 1988, there was a huge increase in the number of emergent plants - from 15 to 43 - and thus the percentage of the emergent plants rose from 60% to 81%. The percentage of the free-floating plants declined from 20% to 13% while that of the submerged declined from 20% to 6% (Table 2.1).

In 2007, the number of emergent plant species increased from 43 to 49, but their percentage contribution to the total dropped from 81% in 1988 to 75%. The number of free-floating plants increased from 7 in 1988 to 12 in 2007 and the percentage rose from 13% to 19%. The number of submerged plants increased by one from 3 in 1988 to 4 in 2007 and the percentage of the total rose from 5.7% to 6%. However, at this time, there has been an invasion of the headpond by the notorious waterweeds *Eichhornia crassipes*, *Cyperus papyrus*, *Salvinia molesta* and *Azolla filliculoides*.

Table 2.1 Aquatic macrophyte species recorded in the Kpong Headpond at the filling of the dam in 1981 (deGraft-Johnson, 1999), in 1988 (Gyimah-Amoako) and in December 2007.

Name	Family	1981	1988	2007
Emergent species				
Acroceras zizanoides (Kunth) Dandy	Poaceae		x	x
*Aeschynomene elaphroxylon** Guill. & Perr.	Fabaceae			x
*Aeschynomene indica** L.	Fabaceae			x
Alternanthera sessillis L. R. Br. Ex Roth	Amaranthaceae		x	x
Aponogeton pectinatus L.	Asteraceae		x	x
Brachiara mutica (Forssk.) Stapf	Poaceae		x	x
Burnatia enneandra (P.Micheli)	Alismataceae		x	x

Ceratopteris cornuta (P. Beauv.)	Parkeriaceae		x	x
Chasmopodium caudatum (Hack) Stapf	Poaceae		x	x
Chloris robusta Stapf	Poaceae		x	x
Commelina diffusa Burm. f.	Commelinaceae		x	x
Crinum natans (Baker)	Amarillydaceae		x	x
Cyclosorus striatus (Schum.)	Thelypteridaceae	x	x	x
Cyperus articulatus L.	Cyperaceae		x	x
Cyperus distans Linn. f.	Cyperaceae		x	x
Cyperus nudicaulis (Poir)	Cyperaceae		x	x
*Cyperus papyrus** L.	Cyperaceae			x
Echinochloa pyramidalis (Lam.) Hitchc. & Chase	Poaceae	x	x	x
Echinochloa stagnina P. Beauv.	Poaceae		x	x
Eichhornia natans (P. Beauv.) Solms-Laub	Pontederiaceae		x	x
Eleocharis acutangula (Roxb.)	Cyperaceae		x	x
Enydra fluctans (Lour.)	Asteraceae	x	x	x
Fuirena umbellata (Rottb.)	Cyperaceae		x	x
Heteranthera callifolia Rchb. Ex Kunth	Pontederiaceae		x	x
Hydrolea glabra Schumach & Thonn	Hydrophyllaceae		x	x
Ipomoea aquatica (Forssk.)	Convulvulaceae		x	x
Ipomoea asarifolia (Desr.) Roem & Schult.	Convulvulaceae		x	x
Leersia hexandra Sw.	Poaceae	x	x	x
Ludwigia hyssopifolia (G.Don) excel	Onagraceae		x	x
Ludwigia leptocarpa (Nutt.) Hara	Onagraceae		x	x
Ludwigia stolonifera (Guill. & Perr.) Raven	Onagraceae		x	x
Mariscus lingularis L.	Cyperaceae	x	x	x
Neptunia oleracea (Lour.)	Mimosaceae			x
*Oxycaryum cubense** (Poeppig & Kunth.)	Cyperaceae	x	x	x
Paspalum orbiculare Forst	Poaceae		x	x
Pentodon pentandrus (Schumach & Thonn.) Vatke	Rubiaceae		x	x
Polygonum salicifolium Willd	Polygonaceae		x	x
Polygonum senegalense (albo tomentosum) Meisn	Polygonaceae		x	x

Phragmites karka (Retz) Trin. Ex Steud.	Poaceae	x	x	x
Pycreus mundtii Nees	Cyperaceae		x	x
Pycreus polystachyos (Rottb.) P. Beauv.	Cyperaceae		x	x
Pycreus pseudodiaphanus S. S. Hooper	Cyperaceae		x	x
Rhynchospora corymbosa (Linn.) Britt.	Cyperaceae		x	x
*Sesbania sesban** L.	Leguminosae			x
Sphenoclea zeylanica Gaertn.	Sphenocleaceae		x	x
Struchium spargonophorum (L) Kuntze	Asteraceae		x	x
Torulinium odoratum L. S. Hooper	Cyperaceae		x	x
Typha domingensis (Persoon) Steud	Typhaceae	x	x	x
Vossia cuspidata (Roxb.) Griff.	Poaceae	x	x	x
Free floating				
Azolla pinnata subspecies *africana* Desv.	Azollaceae	x	x	x
*Azolla filliculoides** Desv.	Azollaceae			x
*Eichhornia crassipes** (Mart) Solms	Pontederiaceae			x
Lemna paucicostata Hegelm	Lemnaceae	x	x	x
*Pistia stratiotes** L.	Araceae	x	x	x
*Salvinia molesta** D.S. Mitchell	Salviniaceae			x
Salvinia nymphellula Desv.	Salviniaceae		x	x
Spirodella polyrrhyiza L. Schleid	Lemnaceae		x	x
*Nymphaea maculata** Schum & Thonn.	Nymphaeaceae			x
*Nymphaea micranta** Guill. & Perr.	Nymphaeaceae			x
Nymphaea lotus* L.	Nymphaeaceae			x
*Wolffia arrhiza** L. Horkel. Ex. Wimm.	Lemnaceae			x
Submerged				
Ceratophyllum demersum L.	Ceratophyllaceae	x	x	x
Potamogeton octandrus Poir	Potamogetonaceae	x	x	x
Utricularia inflexa (Forsk.)	Lentibulariaceae		x	x
Vallisneria aethiopica Fenzl.	Hydrocharitaceae	x	x	x
Total		**15**	**53**	**65**

*Invasive alien species x - denotes presence

The numbers of invasive aquatic plant species on the Kpong Headpond increased dramatically from 1 to 10 species between 1981 and 2007. The highest increase was between 1981 and 1988. The emergent plants recorded the highest number of plants between 1981 and 2007. The increase in the number of submerged plants within the period was just marginal (Figure 2.2).

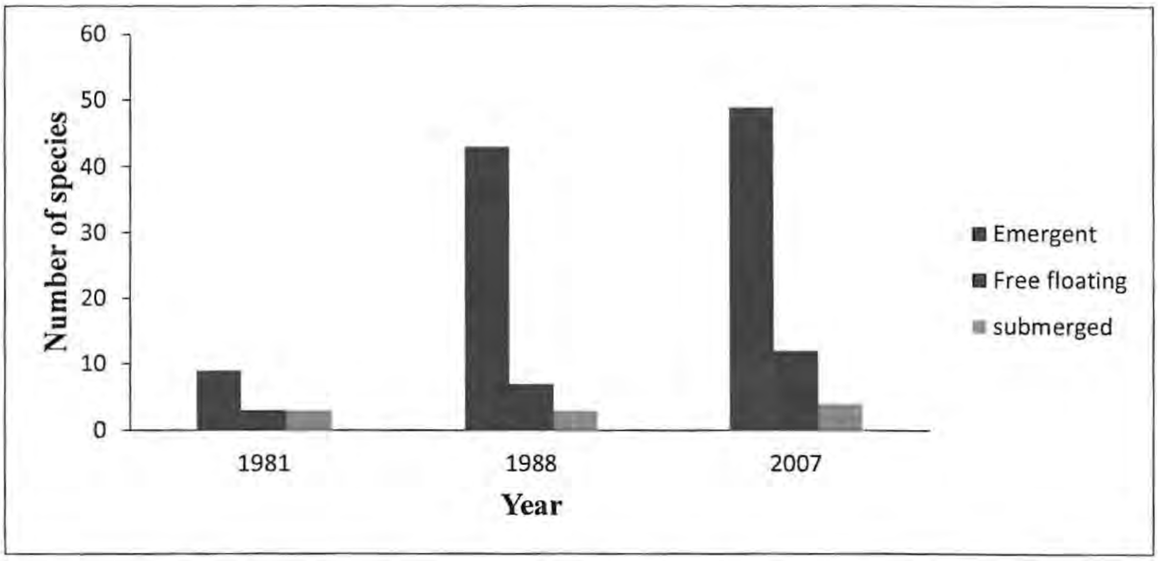

Figure 2.2 The life-forms of aquatic plants and the number of species on the Kpong Headpond

2.6.2 Species diversity for identified life-forms

In 1981, the free-floating and submerged plants both showed the highest diversity of 0.3219 each, while the emergent plants recorded a diversity index of 0.3065. The overall diversity index for 1981 was 0.9503 and species evenness of 0.3509 (Table 2.2).

Table 2.2 Diversity Index and Species Evenness for plants at the filling of the dam in 1981.

Life form	Number present	Pi	ln(Pi)	Pi ln (Pi)
Emergents	9	0.6000	-0.5108	-0.3065
Free floating	3	0.2000	-1.6094	-0.3219
Submerged	3	0.2000	-1.6094	-0.3219
Total	15	1.0000		-0.9503

From the table, H = - (-0.9503) therefore, H = 0.9503

The total number of species, also known as species richness **(S) = 15.**

lnS = 2.7080

Therefore, Species Evenness (E) = H/lnS

= 0.9503/2.7080

E = 0.3509

In 1988, the free-floating plants had the highest diversity index of 0.2673, followed by the emergent plants with diversity index of 0.1696 and the submerged plants with diversity index of 0.1625. The overall diversity index for the plants in 1988 was 0.5994 and species evenness of 0.1509 (Table 2.3).

Table 2.3 Diversity Index and Species Evenness for the study by Gyimah-Amoako (1988).

Life form	Number present	Pi	ln(Pi)	Pi ln (Pi)
Emergents	43	0.8113	-0.2091	-0.1696
Free floating	7	0.1321	-2.0241	-0.2673
Submerged	3	0.0566	-2.8717	-0.1625
Total	53	1.0000		-0.5994

From the table, H = - (-0.5994) therefore, H = 0.5994

The total number of species, also known as species richness **(S) = 53.**

lnS = 3.9702

Therefore, Species Evenness (E) = H/lnS

= 0.5994/3.9702

E = 0.1509

In 2007, the free-floating plants had the highest diversity index of 0.3119 followed by the emergent plants with diversity index of 0.2131 and submerged plants with 0.1715 as their diversity index. The total diversity index of the plants for 2007 stood at 0.6965, with species evenness of 0.1669 (Table 2.4).

Table 2.4 Diversity Index and Species Evenness for current study (2007).

Life form	Number present	Pi	ln (Pi)	Pi ln (Pi)
Emergents	49	0.7539	-0.2826	-0.2131
Free floating	12	0.1846	-1.6895	-0.3119
Submerged	4	0.0615	-2.7887	-0.1715
Total	65	1.0000		-0.6965

From the table, H = - (-0.6965) therefore, H = 0.6965

The total number of species, also known as species richness **(S) = 65.**

lnS = 4.1744

Therefore, Species Evenness (E) = H/lnS

= 0.6965/4.1744

E = 0.1669

The highest diversity index was recorded in 1981 (0.9503) followed by 2007 (0.6965) and 1988 with (0.5994). Again, 1981 recorded species evenness of 0.3509 followed by 2007 with 0.1669, and 1988 with 0.1509 (Table 2.5).

Table 2.5 The Shannon-Wiener Diversity index (H) and Species Evenness (E) for the aquatic macrophytes on the Kpong Headpond from 1981, 1988 and 2007.

Year	Diversity Index (H)	Species Evenness (E)
1981	0.9503	0.3509
1988	0.5994	0.1509
2007	0.6965	0.1669

2.6.3 Physico-chemical parameters and ions

Results of the physico-chemical analyses are shown in Table 2.6a for wet and 2.6b for dry seasons respectively. Results are compared with the World Health Organization (WHO) guidelines for drinking water (WHO, 1996; 2004), since communities within the catchment area of the Kpong Headpond use the untreated water for domestic purposes. The concentrations that were above the guideline values were identified and discussed.

Generally, values of pH (6.4-9.8) were within or close to the range expected for most natural waters, which is 6-9 (Mihelcic, 1999). Statistically, there was no difference between wet and dry seasons ($p>0.05$). Most values were within the recommended range of 6.5-8.5 for potability (WHO, 2004) and could sustain aquatic life. The type and concentration of suspended matter influenced the turbidity and transparency of water. In the present study, mean turbidity value recorded was 3.4 NTU (Nephelometric Turbidity Unit) for both wet and dry seasons and well below the WHO guideline value of 5 NTU.

The ionic content measured by conductivity was low in the Kpong Headpond (mean value of 67.9 and 65.0 μS/cm for wet and dry seasons respectively) and comparable to a study undertaken on Lake Volta (mean value of 79 μS/cm) (Ofori-Danson and Ntow, 2005). Conductivity exhibited pronounced temporal variation between dry and wet seasons ($p = 0.027$).

KPONG RESERVOIR PROJECT

Table 2.6a: Physico-chemical characteristics of the Kpong Reservoir (Wet Season)

MONTH	LOCATION	pH	Conductivity	Turbidity	Colour	Alkalinity	Total Hard.	Calcium	Chloride	Nitrite-N	Nitrate-N	Phosphate	Sulphate	Ammonia-N	Fluoride	DO	BOD
MAY	SITE 1	7.69	64.3	3.1	7.5	30.0	10.0	3.2	2.5	0.004	0.176	0.116	1.48	0.647	0.005	5.4	2.4
	SITE 2	7.46	61.7	1.7	2.5	30.0	10.0	3.2	2.0	0.002	0.391	0.181	0.448	0.307	0.005	5.0	4.1
	SITE 3	7.34	61.4	1.8	5.0	30.0	10.0	4.0	2.5	0.001	0.348	0.118	1.71	0.473	0.263	5.0	0.7
	SITE 4	7.64	67.4	1.8	5.0	36.0	10.0	4.0	2.5	0.010	0.144	0.116	1.00	0.327	0.005	NA	NA
JUNE	SITE 1	7.06	65.3	3.7	2.5	34.0	22.0	4.0	2.0	0.005	0.768	0.171	4.13	0.540	0.005	5.9	3.2
	SITE 2	7.07	67.2	2.7	5.0	36.0	22.0	4.0	2.5	0.002	0.736	0.097	3.55	0.128	0.005	NA	NA
	SITE 3	7.35	70.7	5.8	7.5	36.0	20.0	5.6	2.0	0.003	0.488	0.160	4.24	0.436	0.619	6.3	4.5
	SITE 4	7.02	64.7	3.4	5.0	36.0	20.0	4.8	2.5	0.010	0.757	0.100	2.40	0.211	0.005	NA	NA
AUGUST	SITE 1	6.76	58.4	3.8	2.5	34.0	22.0	7.2	5.0	0.016	1.13	0.223	17.9	0.463	0.506	8.7	5.5
	SITE 2	6.82	67.0	3.2	2.5	42.0	26.0	5.6	2.5	0.046	2.19	0.727	4.31	0.534	0.361	NA	NA
	SITE 3	7.43	71.1	5.8	2.5	34.0	20.0	6.4	2.0	0.013	0.687	0.249	6.09	0.543	0.309	5.6	2.8
	SITE 4	6.61	70.1	2.9	2.5	34.0	18.0	4.8	10	0.011	1.59	0.180	4.64	0.708	0.479	NA	NA
SEPTEMBER	SITE 1	6.80	74.7	3.0	2.5	32.0	12.0	4.0	2.5	0.001	0.221	0.210	4.69	0.405	1.09	6.5	1.9
	SITE 2	6.42	66.3	2.4	2.5	32.0	10.0	3.2	2.5	0.001	0.164	0.256	4.69	0.317	1.04	NA	NA
	SITE 3	7.20	79.5	4.3	5.0	38.0	14.0	4.8	3.0	0.001	0.139	0.217	3.75	0.326	1.06	8.1	2.4
	SITE 4	6.41	66.6	2.5	2.5	32.0	12.0	4.0	2.5	0.001	0.169	0.228	4.59	0.285	1.16	NA	NA

Table 2.6b: Physico-chemical characteristics of the Kpong Reservoir (Dry Season).

MONTH	LOCATION	pH	Conductivity	Turbidity	Colour	Alkalinity	Total Hard.	Calcium	Chloride	Nitrite-N	Nitrate-N	Phosphate	Sulphate	Ammonia-N	Fluoride	DO	BOD
APRIL	SITE 1	6.76	60.3	4.7	7.5	38.0	16.0	5.6	2.0	0.001	0.001	0.298	4.93	0.245	0.548	5.6	3.1
	SITE 2	6.73	63.8	3.6	7.5	36.0	16.0	4.8	3.0	0.007	0.001	0.109	12.5	0.187	0.356	NA	NA
	SITE 3	6.60	60.3	2.3	5.0	36.0	22.0	6.4	4.0	0.018	0.499	0.185	15.0	0.264	0.556	6.1	3.0
	SITE 4	6.68	62.0	3.0	5.0	34.0	16.0	4.8	3.0	0.001	0.001	0.187	6.31	0.169	0.437	NA	NA
OCTOBER	SITE 1	7.37	79.6	3.8	2.5	36.0	22.0	4.8	1.0	0.001	0.462	0.244	3.98	0.345	0.666	8.6	1.5
	SITE 2	6.91	69.1	2.5	2.5	34.0	20.0	4.0	2.0	0.009	1.156	0.199	1.00	0.088	0.304	NA	NA
	SITE 3	7.15	72.4	4.2	2.5	32.0	20.0	4.0	2.0	0.009	0.132	0.118	5.76	0.414	0.749	8.8	1.9
	SITE 4	6.73	65.8	1.9	2.5	32.0	20.0	4.8	2.0	0.001	1.561	0.078	4.20	0.216	0.169	NA	NA
NOVEMBER	SITE 1	6.74	61.2	3.1	2.5	30.0	24.0	4.4	1.0	0.001	0.196	0.578	3.90	0.401	0.566	5.6	1.2
	SITE 2	6.64	61.4	2.7	2.5	30.0	20.0	4.0	1.0	0.001	0.644	0.001	1.00	0.08	0.289	NA	NA
	SITE 3	6.83	62.2	3.5	2.5	30.0	22.0	4.0	1.0	0.004	0.001	0.829	4.90	0.366	0.65	7.6	0.5
	SITE 4	6.59	61.9	2.3	2.5	32.0	24.0	4.0	1.0	0.006	0.196	0.001	1.00	0.181	0.144	NA	NA
DECEMBER	SITE 1	6.81	65.4	3.8	25	40.0	22.0	4.8	3.0	0.001	0.825	0.254	11.1	0.366	0.558	7.8	2.6
	SITE 2	6.55	59.0	2.9	25	34.0	22.0	4.0	2.0	0.001	0.356	0.147	1.00	0.341	0.411	NA	NA
	SITE 3	7.78	64.6	2.8	25	32.0	20.0	4.4	2.0	0.001	0.175	0.289	1.00	0.411	0.398	5.4	1.1
	SITE 4	6.70	59.2	2.5	25	32.0	24.0	4.8	2.0	0.001	0.495	0.274	1.00	0.606	0.599	NA	NA

The waters of the Kpong Headpond could be classified as soft in view of the low concentration of calcium and chloride (Table 2.7) and total hardness. Significant differences between wet and dry seasons were observed for chloride ($p = 0.009$) and total hardness ($p = 0.001$). The relatively high chloride values measured during the wet season could have resulted from run-offs from within the environs of the reservoir. Total alkalinity averaged 33.7 and 32.8 mg/L respectively, for wet and dry seasons, and thus the contributions of carbonates and bicarbonates were low (Quarcoopome *et al.*, 2007). Higher total alkalinity indicates higher buffering capacity since total alkalinity is known to buffer pH changes that occur naturally as a result of photosynthetic activity of plants (Wetzel, 1983).

Table 2.7 Average ionic composition of surface water of some water bodies (mg/L) adapted from (Quarcoopome *et al.*, 2007).

Ion	**Kpong Headpond (current study)**	**Weija Reservoir (Ghana)**	**Lake Volta (Ghana)**	**Lake Kariba (Zimbabwe/Zambia)**
Na^+	No data	38.4	12.1	3.60
K^+	No data	2.30	9.6	No data
Ca^{2+}	4.70	18.4	9.4	9.30
Cl^-	2.50	48.6	7.1	No data
Mg^{2+}	No data	10.1	1.6	1.90

Source: Lake Volta (Ofori-Danson and Ntow, 2005), Lake Kariba (Marshall, 1984), Weija Reservoir, (Asante *et al.* 2008).

The Kpong Headpond is well oxygenated and dissolved oxygen (DO) levels were 81.5% and 90.1% saturation for wet and dry seasons respectively, which are higher than the minimum (30%, 2.43 mg/L DO at 25.1°C) required for protection of aquatic life (DeZuane, 1997). The high DO levels maintained in the waters could also be a result of mixing and re-aeration due to wind action (Straskaba and Tundisi, 1999) as well as photosynthetic activity. Particularly, the relatively high DO levels measured during the dry season (mean of 7.3 mg/L) could be attributed to photosynthetic activity. Thus, the oxygen levels in the Kpong Headpond were above the 5 mg/L threshold needed to support fish life (Hynes, 1970).

Mean biochemical oxygen demand (BOD) levels recorded for the wet and dry seasons were 3.4 mg/L and 1.9 mg/L respectively, and there was no significant difference between the seasons. The relatively higher BOD measured during the wet season could have resulted from runoff from communities or settlements along the reservoir. This implies that seasons, may have a slight although not significant influence on BOD. This observation suggests that organic pollutants accounting for BOD in the reservoir are discharged at rates proportional to the discharges of runoff into the reservoir (Quarcoopome *et al.*, 2007).

Nutrients

Though the natural background levels of phosphate (P-PO_4^{3-}) in inland waters usually range from 0.005 to 0.05 mg/L (Dunne and Leopold, 1978), the phosphate levels at all the four sites in the Kpong Headpond were in excess of 0.1 mg/L. This could be due to anthropogenic activities witnessed along the banks of some sampling sites during the study. The highest phosphate concentration of 1.56 mg/L was measured at site 3 where there is a fish market and where the effluent from a slaughter house was being discharged.

Ammonia is known to be toxic to aquatic life (especially fish) even at very low concentrations (McNeely *et al.*, 1979) and can cause odour and taste problems at concentrations above 1.5 and 35 mg/L respectively (WHO, 1996). At all four sampling sites, concentrations of ammonia-nitrogen were below the lower limit but there was significant difference ($p = 0.043$) between wet (mean of 0.576 mg/L) and dry seasons (mean of 0.377 mg/L).

Nitrate-nitrogen levels exceeded the global average of 0.1 mg/L for nitrate in freshwater (Meybeck and Helmer, 1989). This could be due to run-off from fertilized farm lands and domestic waste. Mean concentrations measured were 0.622 and 0.358 mg/L for the wet and dry

seasons respectively. The results were statistically significant (p = 0.027). Concentrations of nitrite-nitrogen were also significantly different (p = 0.031) between wet and dry seasons.
The mean concentration of sulphate for the dry season slightly exceeded the global average of 4.8 mg/L for freshwater (Meybeck and Helmer, 1989). Mean concentrations measured were 4.35 mg/L (wet season) and 5.42 mg/L (dry season). It may thus be inferred that sulphate is abundant in the Kpong Headpond.

Low concentrations of nitrite, nitrate and phosphate were observed compared to other reservoirs such as the Weija Reservoir (Table 2.9). The lower levels of nutrients detected reflect relatively low levels of agricultural activity and absence of industries around the catchment. The dissolved oxygen values also indicate that the Kpong Headpond is not polluted. The low levels of nutrients measured confirm the results of an earlier study by Ansa-Asare and Asante (1998) which compared the nutrient status of Weija and Kpong Headponds.

Seasons could have a significant effect on water chemistry, especially ammonia-nitrogen and nitrate-nitrogen due to runoff. However, most of the physico-chemical constituents did not exhibit pronounced variations, probably because of their sources, which are relatively independent of seasonal influences (Quarcoopome *et al.*, 2007).

Trace elements

Trace elements measured (cadmium, zinc, iron, manganese, lead and copper) did not reveal any significant results. The absence of industries within the catchment area could account for the low levels of elements recorded. Although trace elements occur naturally, they are also by-products of many industrial processes and are non-degradable. They enter the water environment through atmospheric and land-based effluent sources (Robson and Neal, 1997). They are found in the water, biota and sediment compartments of a water body, but potentially, the most hazardous environmental effects on human health arise when they enter the food chain (Beijer and Jernelöv, 1986).

2.7 Discussion

Assessment of the aquatic macrophytes during the study revealed that 65 species comprising 49 emergent macrophytes, 12 free-floating macrophytes and 4 submerged macrophytes were present. This shows a marked increase from the results of Gyimah-Amoako (1988) who recorded 53 species comprising 43 emergent macrophytes, 7 free-floating macrophytes and 3 submerged macrophytes at the same headpond. The increase can be attributed to the increase in human activities in and around the catchment area over the years (1981-2007). The growth of weeds on the Kpong Headpond was prolific soon after closure of the dam. The Kpong Headpond submerged several settlement villages along the then lower Volta River, displacing about 6,650 people. During the filling of the dam, large quantities of biomass were destroyed including termites, insects, spiders, reptiles, mammals, grasses, trees, bacteria, fungi and other microbes. The decomposing tissues of the billions of organisms provided huge quantities of mineralized nutrients which were subsequently used by aquatic plants, animals and micro-organisms for their own growth. Additionally, nutrients entered the headpond from the inundated soils which in many instances were rich alluvial deposits from past natural flood events in the river. More recently, activities such as washing and bathing in the lake, dumping of waste from the fish market close to the headpond, the draining of untreated effluent from the main slaughter houses of Atimpoku and Kpong Townships and fertilizer seepage into the headpond changed the nutrient status of the water. Guts and scales of fishes were also thrown into the headpond. All these activities lead to increased nutrient load and sedimentation which favours the growth of aquatic macrophytes (Mustapha 2006).

According to Walmsley (2000) and Byrne *et al.* (2010), the linkage between aquatic plant production, nutrients and human activity was first noted in the early part of the 1900s. Increasing concentrations of nitrogen and phosphorus result in increases in water hyacinth biomass accumulation, ramet production, shoot:root ratio and plant height (Reddy *et al.,* 1989, 1990). Phosphorus is one major plant nutrient that can potentially positively affect growth and nutrient storage by water hyacinth (Byrne *et al.*, 2010). Reddy *et al.* (1990) showed that, with increasing phosphorus, all measures of water hyacinth growth increased. The rate of increase was not proportional to the increase in phosphorus, but phosphorus deficiency was found to be a limiting factor for growth and reproduction. Haller and Sutton (1973) found that if the concentration of phosphorus fell below 0.1 mg/l, active growth of water hyacinth stops, but concentrations above this allowed for growth as well as the uptake of nutrients in excess of the plant's requirements. Below 0.06 mg P/l, the plants will be expected to die; between this value and 0.1 mg P/l, the plants will survive but will not grow. Between 0.1 mg P/l to 1.06 mg P/l, water hyacinth will actively grow but above 1.06 mg P/l (Haller and Sutton 1973), no additional growth is expected for increasing levels of phosphorus. These values represent the upper and lower limits within which the growth of water hyacinth can be predicted. From the results of the current study, the phosphate levels at all the sites on the Kpong Headpond were in excess of 0.1mg P/l, but not above the 1.06 mg P/l threshold, and thus will not limit water hyacinth growth.

In an earlier study on the Kpong Headpond by Ansa-Asare and Asante (1998), the pH values were found to range between 6.7 and 7.0 in comparison with the 6.4 and 9.8 in the current study. The earlier work recorded a mean value of 0.3 mg/l for nitrate, now 0.53 mg/l; 0.02 mg/l for nitrite, now 0.006 mg/l. A mean of 0.44 mg/l was recorded for ammonia but now it is 0.35 mg/l. Phosphate was 0.08 mg/l but now 0.22 mg/l and 0.4 mg/l was recorded for sulphate and now it is 4.6 mg/l. The DO and BOD were 7.5 mg/l and 3.2 mg/l respectively and now they are 6.75 mg/l and 2.46 mg/l. Ansa-Asare and Asante (1998) recorded 0.4 mg/l for sulphur with the current study recording a mean of 4.88 mg/l. The nutrient status of the Kpong Headpond, however, fluctuates with the rainy and dry seasons but does not appear to be changing with time.

Mustapha (2008), working on the Moro Reservoir in Ilorin, Nigeria, which was infested with the aquatic weeds *Cyperus iria, Eichhornia crassipes, Heteranthera callifolia, Ludwigia abyssinica, Ludwigia hyssopifolia, Nymphaea lotus, Pistia stratiotes,* and *Salvinia nymphellula* recorded the following: temperature-(23°C-28°C) pH-(6.8-7.3), now, a mean of 29.5°C was recorded. Conductivity- (62.4-78.8 µS/cm), in the current study, the conductivity ranged from (65.0-67.9 µS/cm). DO- (3.2-5.2mg/l), now, a mean of 7.3mg/l. BOD-(3.0-4.6 mg/l), now, it ranged between 1.9-3.4 mg/l. Nitrate-22.4 mg/l, now, a mean of 0.53 mg/l and phosphate-(0.3-0.5 mg/l), now has a mean of 0.22mg/l. He attributed the weed infestation to the conductivity of the water which reflects the amounts of dissolved salts, i.e. cations and anions, in the water. According to him, the conductivity values obtained in the reservoir fell within the range which supports massive growth and crowding of aquatic macrophytes. Bini *et al.* (1999) recorded the conductivity between 36 and 260 μS/cm and this is the range which supports massive growth of macrophytes, while Khedr and El-Demerdash (1997), reported that the distribution, growth and abundance of emergent and floating aquatic species in drainage canals in the North Eastern Nile Delta was correlated with electrical conductivity of the water.

The increase in the aquatic macrophytes from 15 in 1981 to 53 in 1988 could also be attributed to the change in hydrology. According to the Volta Basin Research Project (VBRP, 2000), the impoundment of the river at the two sites at Akosombo and Kpong, caused an alteration of the existing ecological and biophysical processes in the river basin, such as a slowing of the flow of the river, both upstream and downstream, and flooding of cultivated fields upstream. These changes in the natural processes resulted in an invasion of aquatic weeds which created conditions for promoting the silting and closure of the estuary, as well as other more subtle effects.

The number of 65 species identified at Kpong headpond is higher than the ones identified in other water bodies in Ghana. Ameka (1987) recorded 34 species in the Weija reservoir and Adams (2007) and Nkansah (2007) observed six species of macrophytes in the Owabi reservoir. These differences in abundance of species could be attributed to the differences in conditions prevailing in these areas. Sculthorpe (1967) suggested that the abundance of aquatic macrophyte is fundamentally influenced by turbulence (wind and wave action). The distribution and abundance of aquatic plants in a lake is also dependent upon the lake's chemical and physical properties, including the amount of light available, water levels, water temperatures, type of Lake Bottom sediments, current or wave action, and the concentration of dissolved gases and nutrients (Smith, 1982).

In 2003, the most problematic aquatic weeds, *Eichhornia crassipes* and *Cyperus papyrus* were reported from the Kpong Headpond (VRA, 2003) and confirmed by this study. These observations, which were confirmed during the current study, are an indication that with time new aquatic plant species (invasive alien species) are invading the headpond. It must be noted, however, that neither the altered hydrology of the headpond nor the increased nutrient status of the water could increase the number of aquatic plant species. But these factors could lead to an increase in the density of the individual populations. The increase in number of species could therefore be traced to the migration (immigration and emigration) of fishermen from one infested water body to the next in response to increased fish catches. For example, according to Odei (1983), the creation of the headpond was also immediately accompanied by an increase in fish population. The news of greater catches on the new headpond attracted a number of fishermen, especially from behind the Akosombo Dam and from the area of the Volta Delta.

The Shannon-Wiener Diversity index is used to calculate aquatic and terrestrial biodiversity. As the number and distribution of taxa (biotic diversity) within the community increases, the value of H' increases (Gerritsen, 1998). It is postulated that given a large sample size, with more than 5 species, the Shannon-Wiener index values can range from 0 to ~4.6. All values recorded during the study period were near 0, which means that the life-forms of the plants were not evenly distributed in the Kpong Headpond in 1981, 1988 and 2007 due to the dominance of *Eichhornia crassipes* and *Cyperus papyrus*. It is believed that the invasion and density of these plants could have been underestimated due to the continuous removal of *E. crassipes* infestations.

This study has shown the value of long-term ecological datasets that facilitate the early detection and hopefully control of introduced species with invasive potential.

Chapter 3

The social, economic and health impacts of *Eichhornia crassipes* (Mart) Solms-Laubach (Pontederiaceae) in the Oti River Arm of Lake Volta

3.1 Introduction

Recently, through the efforts of the World Bank, the Global Invasive Species Programme (GISP) and other partners, research has been conducted on the impacts and socio-economic implications of invasive species for developing countries with particular attention to Africa. For example, the introduction of Nile tilapia (*Oreochromis niloticus* L. for aquaculture has decimated native fisheries; triffid weed (*Chromolaena odorata* L. King and Robinson (Asteraceae)) causes severe impacts in natural areas as well as agriculture; and water hyacinth has negatively affected local fisheries, transport and hydropower (Wise *et al*., 2007). These studies are important and justify expenditure on control options for the invasive alien species.

3.1.1 Economic impacts of water hyacinth

From a socio-economic perspective, water hyacinth invasion into freshwater systems presents a problem for many human activities. Water hyacinth has been shown to have severe economic impacts, including reduction in the ability to access waterways, thereby increasing the cost of transport and impeding water access, increase the number of disease harbouring mosquitoes, snails and other vectors, impacting directly on human health. It also results in a reduction in the amount of oxygen exchange causing death or stress to fish, and thus increasing the cost of fishing and reducing the yield per hectare. Water hyacinth has been shown to increase the rate of evapotranspiration which reduces the amount of water available for household use and also increases the cost of irrigation and watering livestock (GISP, 2006).

The costs (direct and indirect) of water hyacinth on human suffering in underdeveloped nations and subsistence communities are immeasurable in monetary terms (Charudattan, 2001a). The socio-economic impacts of water hyacinth fall into two broad categories: market impacts (e.g., changes in prices), and non-markets impacts (e.g., changes in ecosystem services). Market impacts imply reduced production of commodities sold within the marketplace. For inland water ecosystems affected by water hyacinth, these production losses include decreases in fisheries and aquaculture production, decreases in the availability and accessibility of water for industries, decreases in the navigability of lakes and rivers (or costs for clearing and re-establishing navigability) and declines in property values (Ciruna *et al.*, 2004).

Non-market impacts due to water hyacinth in inland waters can include potential risks to human capital due to premature deaths, declines in social capital due to increased transaction costs (Social capital is typically thought of as the relationships between people integral to sustain trust in societies. These relationships facilitate the building of social institutions, such as non-governmental organizations, new government institutions, etc. Invasive Alien Species reduce ecosystem services and can cause greater demands on governments, as a result weakening social capital. This can have adverse impacts in countries that are already weak in social capital) and declines in natural capital due to the loss of ecosystem services. Estimating the value of these non-market impacts can be difficult and costly. Nonetheless, the potential impacts of alien species introductions and the reversibility of these impacts should be considered even if they are not quantifiable (Ciruna *et al.*, 2004). Evidence from the literature on the impacts of water hyacinth on various economic activities is presented in Table 3.1.

Table 3.1 Evidence of economic impacts of water hyacinth (after GISP, 2006 and Wise *et al.*, 2007).

Study	Economic impact	Estimated degree of negative impact	Country
Agriculture and Environment			
Wise *et al,* (2007)	Species richness, diversity and abundance	Significantly negatively impacted	South Africa
Transport			
Chikwenhere *et al.* (undated A)	Impact on transport time	50% (increase)	Zimbabwe
De Groote *et al.* (2003)	Impact on household income from trading food crops	39%	Benin

Chikwenhere *et al.* (undated A)	Impact on the amount of agricultural products sold	50%	Zimbabwe
Wise *et al.* (2007)	Palmwine collectors using river for transport	Decreased productivity by 14%	Central African Republic
Fuel			
De Groote *et al.* (2003)	Impact on household income from trading wood	73%	Benin
Overall impact on income			
De Groote *et al.* (2003)	Impact on household income overall	66%	Benin
Fishing			
Joffe and Cooke (1997)	Impact on fishing yields	40-50%	Niger and Malawi
De Groote *et al.* (2003)	Impact on household income from fishing	69%	Benin
De Groote *et al.* (2003)	Impact on household income from trading fish	74%	Benin
Chikwenhere *et al.* (undated B)	Impact on fishing yields	30%	Zimbabwe
Wise *et al.* (2007)	Gill net fishing	Decreased catch by 26%	Central African Republic

Wise *et al.* (2007)	Fish and wild life losses	Decreased productivity of fisheries	6 S.E. States of USA and Uganda
Infrastructure			
Wise *et al.* (2007)	River weir	Washed away due to pressure from water hyacinth	Nseleni River, South Africa
Wise *et al.* (2007)	1 of 5 turbines of hydropower generation dam closed	Metal surfaces corroded due to build up of sulphur dioxide under a water hyacinth mat	Kafue River, Zambia
Human health			
Wise *et al.* (2007)	Malaria	Increase in vector borne diseases	Uganda

3.1.2 Health impacts of water hyacinth

The objective of creating water impoundments in developing countries is to improve the economic conditions of the local people. In the long-term, however, such projects may be associated with adverse impacts on the health status of the people living in the surrounding area. This is due principally to the infestation of the water bodies by invasive aquatic plant species. The diseases associated with the presence of aquatic weeds in tropical developing countries are among those that cause the major public health problems, but this is seldom quantified. The dense floating mats of water hyacinth, for example, impede water flow and create good breeding conditions for vectors of animal and human diseases (Grodowitz, 1998), such as malaria, encephalitis, filariasis, and schistosomiasis (Gopal, 1987; Richardson and van Wilgen, 2004).

In tropical countries, it has been hypothesized that water hyacinth contributes to an increase in populations of the snails that transmit schistosomiasis, a disease that afflicts 83 million people globally (Gay, 1960; Dazo *et al.*, 1966; Batanouny and El-Fiky, 1975; Bond and Roberts, 1978; World Health Organization [WHO], 1985; Badejo *et al.*, 1988; Crompton, 1999; Ntiba *et al.*, 2001). Many schistosome snail species thrive in the presence of aquatic vegetation (Obeng, 1966; Odei, 1973; Klumpp and Chu, 1980; Ndifon and Ukoli, 1989; Woolhouse and Chandiwana, 1989) and/or prefer the low water velocities and light intensities that occur under dense, mat-forming vegetation (WHO, 1957; Malek, 1958;

Muirhead-Thomson, 1958; Mitchell and Thomas, 1972). However, the schistosome host snail species can vary widely in their ecological requirements. For example, in Lake Victoria, East Africa, *Biomphalaria sudanica* Martens (1870) prefers still, shallow waters with muddy substrates and vegetation, whereas *B. choanomphala* Martens (1879) prefers deeper, sandy, non-vegetated waters offshore (Webbe, 1966; Baalawy, 1971; Magendantz, 1972; McCullough *et al.*, 1972).

The dynamics among invasive pathogens, human behaviour and economic development are complex and depend on interactions between the virulence of the disease, infected and susceptible populations, the pattern of human settlements, and their level of development. Large development projects, such as dams, irrigation schemes, land reclamation, road construction and population resettlement programmes have contributed to the invasion of diseases such as malaria, dengue, schistosomiasis and trypanosomiasis. For example, the prevalence of lymphatic filariasis in the southern Nile Delta has increased 20-fold since the building of the Aswan Dam in the 1960s (McNeely *et al.*, 2001). This increase has been due primarily to the increase in breeding sites for the mosquito vector of the disease, following the rise in the water table caused by the extension of irrigation. The problem has been exacerbated by increased pesticide resistance in the mosquitoes due to heavy agricultural pesticide use and by rural-to-urban commuting among farm workers. Thus invasive species combined with variations in rainfall, temperature, human population density, population mobility and pesticide use all contribute to one of the most profound challenges of invasive species (McNeely *et al.*, 2001).

3.2 Aims and Objectives

The aim of the study was to estimate the socio-economic and health impacts of current and potential infestations of water hyacinth in the Oti River Arm of Lake Volta in Ghana. In addition, the study will also investigate the costs and benefits of management actions and prevention strategies.

3.3 Materials and Methods

3.3.1 Study site

The Oti River or Pendjari takes its source from the Atakora hills in the Republic of Benin at about 600 m above sea level. It is shared by Benin, Togo and Ghana. The tributaries in the upper catchments include the Doudodo, the Singou and Kompienga. The other tributaries to the river are Koumongou, Keran, Kara, Mo, Kpanle, Wawa Menu and Danyi rivers (Figure 3.1). The Oti River has a permanent flow; however, most of the tributaries dry up during the year. The mean annual inflow of the river into Ghana is about 276 m^3 /s and constitutes about 75% of the total Oti basin. The portion of the Oti basin in Ghana forms only about 18% of the total catchment of the Volta system but contributes between 30 and 40% of the annual flow of the Volta River system (Ghana Country Report, 2002).

Annual rainfall varies across the basin from about 1600 mm in the southeastern section in Ghana to about 400 mm in the northern part of Mali. Three types of climatic zones can be identified in the region. The humid south, below latitude 7^{o} 30'N, with two distinct rainy seasons; the tropical transition zone between latitude 7^{o} 30'N and latitude 9^{o} N with two seasons of rainfall very close to each other and the tropical climatic north of latitude 9^{o}N with one rainfall season that peaks around August (Ghana Country Report, 2002).

Annual mean temperatures vary from about 27°C to 30°C, with, daily temperatures varying between 32°C and 44°C. Observed mean rainfalls and temperatures may not remain stable due to climate change. Studies using Global Circulation Models (GCMS) and simple climate models indicate that mean daily temperature will increase by 2.5° C to 3.2°C over the 1961-1990 baseline by the year 2100. Further it was projected that annual rainfall totals, using medium sensitivities would decrease by about 9% to 27% by the year 2100 in parts of the basin (Ghana Country Report, 2002).

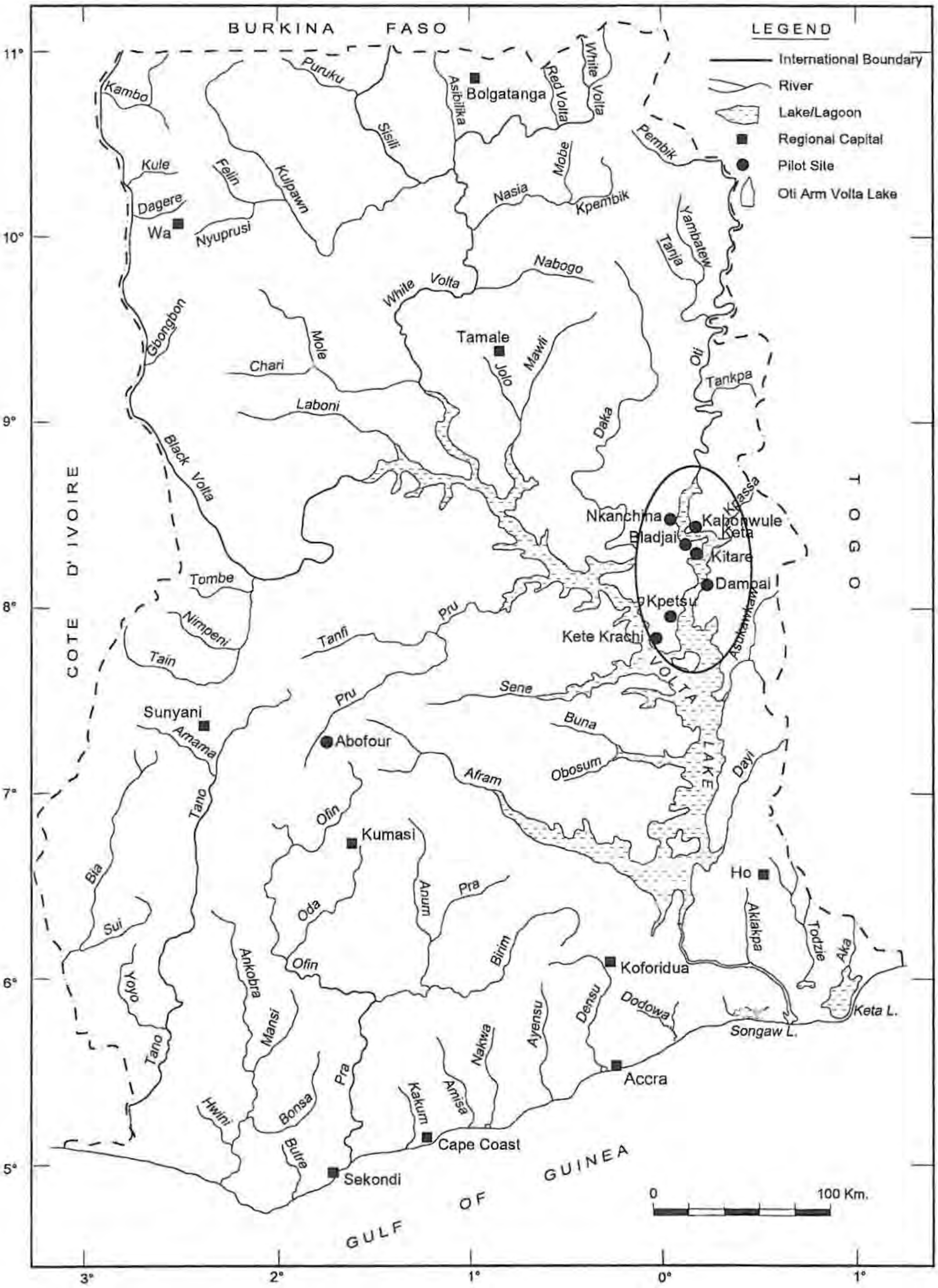

Figure 3.1 Map of Oti River on Lake Volta showing study sites highlighted by the circle.

Water hyacinth was detected in the Oti River Arm of Lake Volta in 1998. Soon after the invasion, it was realised that the weed invasion would reach the main lake if there was not a rapid response to check its spread. Ghana's Volta River Authority (VRA) working together with experts from the Council for Scientific and Industrial Research (CSIR-Ghana), and Environmental Protection Agency (EPA-Ghana) and other national and international stakeholders initiated chemical and manual control measures in April 1999 with the aim of keeping the water hyacinth infestation from entering the main body of Lake Volta. The area of control was about 6 km^2. This was followed by the initiation of biological control, with the release of the water hyacinth weevils *Neochetina eichhorniae* and *Neochetina bruchi* in 2004 (Figure 3.2; chapter 4).

In spite of control efforts the area of infestation continued to expand. In December 2000 the infestation was estimated to cover 10,000 ha and it stretched over 100 km between Adakponu (8 km south of Dambai) to Nkanchina in the north (Table 3.2).

Table 3.2 Water hyacinth locations and qualitative cover in the Oti River Arm of Lake Volta, November, 2003.

Segment of water body	Coverage	
	Shoreline	**Water surface**
Adakponu-Kitare	Infestation sparse, as isolated rosettes	1,000 ha
Dambai-Kitare	Infestation sparse; Intermittent cover of 1-2 m wide	1,000 ha
Kitare-Domkpai	Infestation moderate; 2-3 m wide	1,000 ha
Domkpai-Kabonwule	Infestation fairly intense; Continuous band of 3-4 m wide	2,000 ha
Kabonwule-Nkanchina	Infestation intense; 4-6 m wide	5, 000 ha

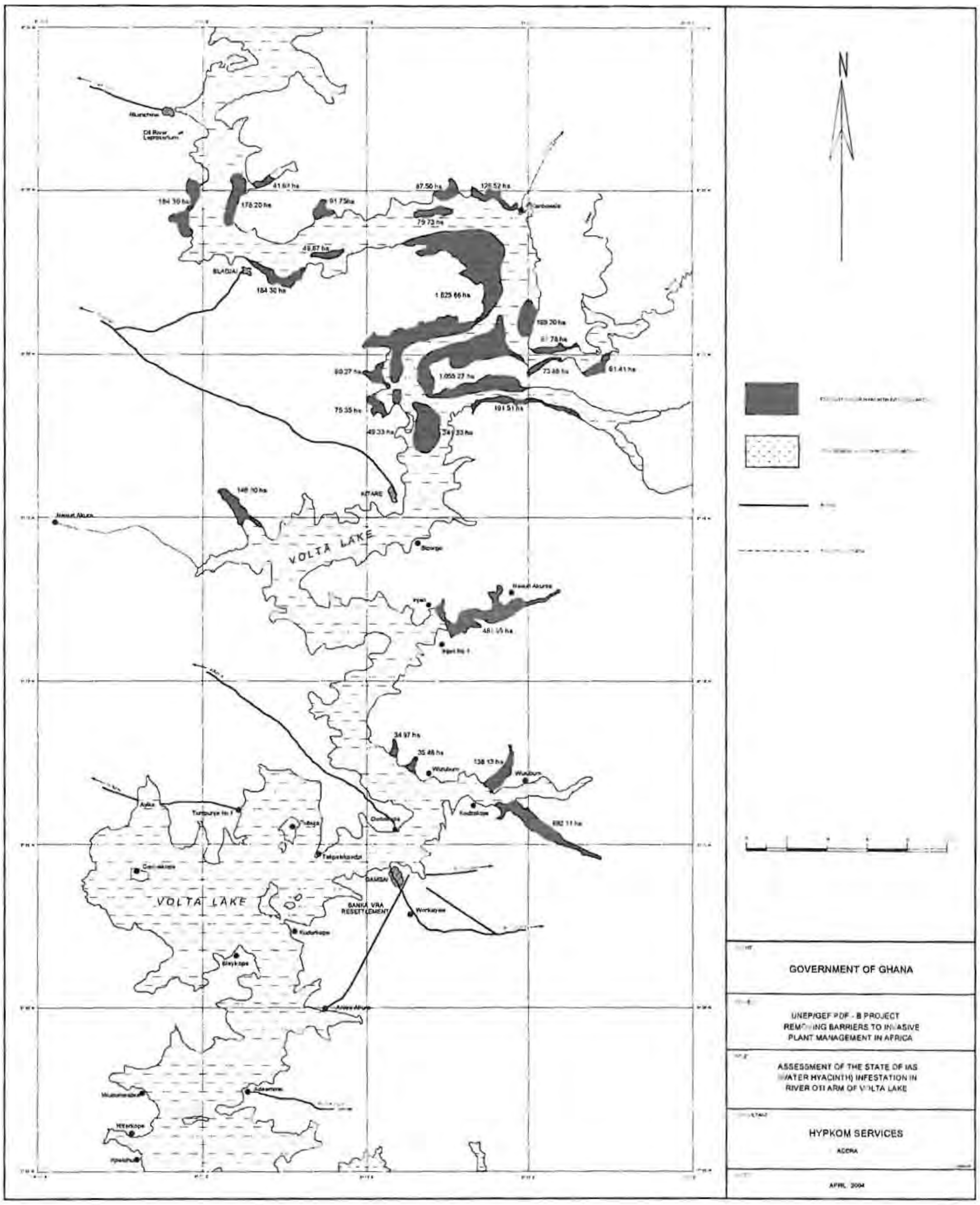

Figure 3.2 Water hyacinth infestation on the Oti River Arm of the Lake Volta as at 2003. (green cover denotes water hyacinth infestation).

During this period, over 20 islands, which served as sanctuaries for offshore infestations were identified. However, further north of Nkanchina, the intensity of infestation was considerably less. A few streams that served as tributaries of the Oti from neighbouring Togo were identified to be probable sources of re-infestation, while most of the infestation sites were also not easily accessible due to presence of tree stumps in the lake. Water hyacinth infestations reach their peak between February and March every year.

3.3.2 Socio-economic survey

The Oti River Basin had a population of at 591,223 in 2000 and was projected at 698,615 in 2005 along the Oti River Arm of Lake Volta, (Ghana Statistical Service, 2005). The most common occupations of the people living along the Oti River are fishing, farming and trading. The main objective of this survey was to evaluate the socio-economic impact of water hyacinth on the incomes of the people living along the Oti River.

To meet the objectives of the study both primary (in the form of questionnaires) and secondary data (from different sources of literature, mainly project reports) were sourced. During the survey, 60 people were interviewed randomly in the 9 villages visited. These communities were selected based on accessibility and population. The respondents included fishermen, farmers, traders, teachers, coxswains, chiefs, assemblymen and students. Individual interviews and Focal Group Discussions were also conducted. While the secondary data provided a feel of the context within which the study was carried out, primary data formed the bulk of the data collection activity. The method for collecting primary data was divided broadly into two approaches, namely quantitative and qualitative surveys. The qualitative surveys did not follow any set of questions. Rather, a checklist of issues relating to the community was considered, since public services, systems of social sharing as well as the general environment were considered as factors that could influence the welfare of individuals. The checklist was therefore followed as a guide, being revised as and when found necessary.

Data analysis consisted of a blend of statistical analyses based on the quantitative and qualitative survey results. Two sets of data analyses were carried out. They were descriptive and statistical analyses. The descriptive part was based on information from the qualitative survey and descriptive statistics from the quantitative survey data. However, the lack of record keeping by fisher folk was a major limitation of the study. Responses were therefore based on respondents' recall. For instance, net cash income was obtained directly by questioning the fishermen. It could be underestimated if the respondent suspected the interviewer of being linked to tax agencies or overestimated if the respondent failed to subtract certain costs. The figures obtained represent broad approximations only to facilitate comparisons. A more rigorous calculation of net incomes should include computation of costs and revenues from fishing and non-fishing activities and the allocation of rental prices of fixed fishing and non-fishing assets. Similarly, responses regarding consumption expenditure could either be under estimations or over estimations as Scott and Amenuvegbe (1990) found that on average respondents forgot 2.9 % for each day.

3.4 Results

The highest number of respondents were fishermen (26), followed by traders (14) and then farmers (10). Forty-three were male (71.67%) and 17, (28.33%) female. The highest numbers of traders were in Dambai because it is a major marketing centre. There was only one traditional ruler, one assemblyman and a student (Table 3.3).

Table 3.3 A breakdown of the number of respondents during the socio-economic survey.

	SEX		OCCUPATION							
Villages	M	F	**Fishermen**	**Farmers**	**Traders**	**Teachers**	**Cox swain**	**Chiefs**	**Assembly men**	**Students**
Dambai	7	3	3	0	4	1	1	0	0	1
Njari	4	1	3	1	1	0	0	0	0	0
Kitare	6	2	4	1	2	0	1	0	0	0
Bladjai	5	2	3	1	1	1	0	0	1	0
Kapite	3	3	2	1	2	0	1	0	0	0
Kabonwule	4	2	2	1	1	0	1	1	0	0
Papaye	4	1	3	1	1	0	0	0	0	0
Nkanchina	6	2	4	2	1	1	0	0	0	0
Bi-Zongo	4	1	2	2	1	0	0	0	0	0
TOTAL	**43**	**17**	**26**	**10**	**14**	**3**	**4**	**1**	**1**	**1**

3.4.1 Social impacts of water hyacinth infestation in the Oti River basin

A common problem in these lakeside villages is the lack of basic health and sanitary amenities, such as clean water supply, toilets and waste disposal systems. Moreover, the children play barefoot along the lake-shore and in the water, thereby exposing themselves to health hazards. There are no potable water supply systems in most of the communities visited and the people rely mainly on raw water from the lake despite the extensive provisions that were made by the VRA for the supply of pumps and wells in the lakeside villages. However, without proper maintenance, most of these eventually failed, and as a result village inhabitants depend completely on lake water for their domestic use (Zakhary, 1997). No proper human waste disposal system currently exists, and the inhabitants freely urinate and defaecate at the lake shore, perpetuating the cycle of schistosomiasis transmission. In some communities, inhabitants have no access to the lake to draw water at certain times when the shore becomes heavily infested with water hyacinth. The people had to do physical removal of the weeds to be able to draw water and even under those circumstances the water was often dirty and smelly because of the rotting mass of the weed.

Ghana and five other countries share the Volta River Basin and as a result there is the need to address priority trans-boundary concerns in integrated ecosystem management of the basin. In that regard, Ghana proposed an initiative on the environmental and socio-economic effects of waterweed invasion including alien species as one of the issues requiring attention. Due to the cross-border nature of the water hyacinth infestation in the Oti River, there is collaboration between Ghana and Togo under the aegis of the Volta Basin Commission, which is based in Ouagadougou, Burkina Faso. The commission seeks to bring researchers, policy makers and opinion leaders of riparian communities of neighbouring countries with common problems together to facilitate the search for solutions.

One of the more obscure benefits of water hyacinth is that it has opened up the area for research and academic work. Due to the presence of water hyacinth, researchers are making efforts to deal with the deeper and systemic problems that are the real causes and impacts of the weed explosion in the Oti River environment. The expertise in the region is not adequate to handle the weed problem so there is a need to mobilise other expertise in time and equip them (the experts) appropriately towards the task. Handling the immediate crisis would have been a straightforward issue if current knowledge were sufficient. Now that expertise is lacking, it should be remembered that what has brought researchers to Oti River basin is the need to identify ways of improving the capability of communities. Authorities and supporting organizations should respond to, and effectively handle the water hyacinth problem and improve communication and interaction among other researchers. Decision-makers and representatives of other stakeholder groups must also be involved. Only in this way can water hyacinth in the Oti River be brought under control. Researchers and other academics, who hitherto had nothing to do in the River Oti basin are now seriously engaged in research work, interacting with the locals and sharing ideas with them. These interactions are serving as motivation to the people, since innovative ideas are continually being exchanged. It is also educating the community on the impacts of the weed infestation and the role of individuals and communities in the effort to manage the incidence of the infestations. Also the community is being sensitized on the need for them to know that clean and safe water, access to good hygienic practices and knowledge of good hygienic practices are necessary components of public health. They have been educated to understand that inclusion of water and sanitation into their community development programmes was a necessity.

Through research and collaboration, the area has also been opened up to the international community. Research findings from the area are now being discussed in international fora and researchers from other countries are visiting the area to learn at first hand some of the management practices that have been put in place.

3.4.2 Impacts of water hyacinth on economic activities in the Oti River basin

The main economic activities in the Oti River include agriculture (the growing of rice and other vegetables), fishing, trading and transportation (passengers, carting goods, trucks) across to the other bank by the large ferry boat and transportation of traders to marketing centres along the lake by smaller motorized boats.

3.4.2.1 Impact on agriculture

Agriculture is the principal economic activity within the Volta Basin. The dominant agricultural land-use form is rain-fed land rotation, producing largely basic food staples including yam, cassava, maize, rice, other cereals and vegetables. The rice and vegetables are cultivated mainly in the drawdown of Lake Volta. However, water hyacinth invaded and completely took over the rice fields and vegetable farms, thereby competing with the crops for both space and nutrients. These are subsistence farmers cultivating the area in the drawdown of the lake. There are 10 farmers, each cultivating between 0.5 and 1.5 hectares, depending on the water level of the lake. According to these farmers, about a third of their yields, about US\$ 30 ha^{-1}, are used to pay for labour costs in removing water hyacinth every season. It thus reduces productivity of the farm and increases labour costs. The farmers spend more time (and even hire more labour) to maintain the farms, thereby increasing production costs. A farmer cultivating a vegetable farm of one hectare expects to harvest crops that will give him approximately US\$ 100, but because of the costs involved, ends up getting about US\$ 65.

3.4.2.2 Impact on fishing

Socio-demographic profile of fishing households

Although the basic unit of analysis was the fishing household, the study mostly focused on the socio-demographic profile of heads of households since this is closely related to the socio-economic condition of the entire household. Forty household heads were interviewed and included in the analysis.

Sixty percent of the respondents were Ewes, 20% Ga-Adangbes, 10% Nchumurus, 5% Akans, and the other tribes constituted the remaining 5% (Figure 3.3). The unit of analysis as indicated was the head of household who, with few exceptions, was an adult male. No woman was found to be participating in direct fishing operations. A combination of patriarchy and the nature of fishing occupation may explain the predominance of men as head of fishing households.

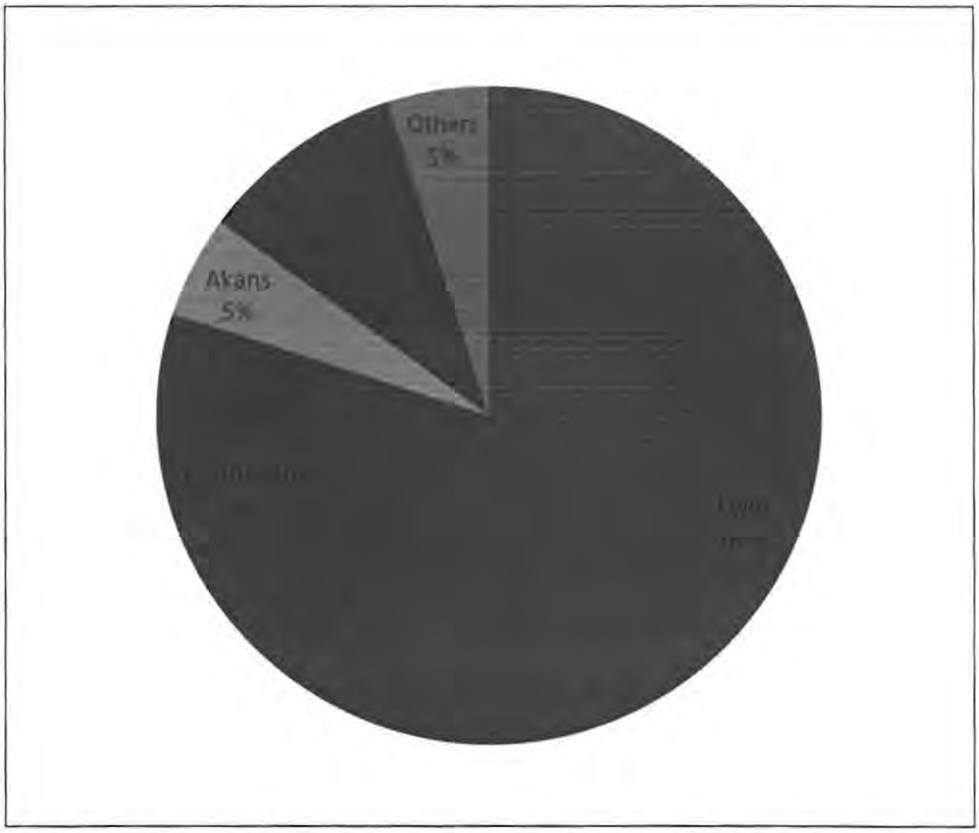

Figure 3.3 The percentage of people from different ethnic groups (tribes) used in the water hyacinth impact on fisheries questionnaire.

The sample was dominated (60%) by the 31-50 year age group. The minimum age of a fishing household head was 20 years and the maximum 55 years, whilst the average was 38.3 years. The relatively low percentage of fishermen below 31 years suggests that the youth are not attracted to fishing. Important considerations are the requirement of physical fitness and/or the lack of adequate capital to purchase fishing gear. In terms of occupational mobility, it is clear that the 31-50 age group tend to cling to their ancestral profession whilst the more adventurous youths feel no commitment to fishing. This is consistent with the general observed migration of rural youth to urban areas in search of employment.

The average household size of 5.9 persons was slightly higher than the national average of 5.4 (Ghana Statistical Service, 2005). Sampled household size varied from 2 to 20 persons. Unlike the situation in rural sectors where large families were found among lower income groups (Ghana Statistical Service, 2005), in the sample studied there was a relationship between household size and their incomes. The larger the household the more members are engaged in fishing or other activities, hence the higher the family income.

About 40 % of fishing household heads interviewed have never had formal education or have attained a low level (at most 6 years) of formal education. The majority (55.8%) had middle, junior secondary, senior secondary or vocational school education. Only two (1.7%) of the respondents had tertiary education.

Fishing activities

Fishermen use various gear and methods. Gill nets were normally set in the evenings and retrieved in the mornings. Harpooning, cast and mosquito nets (illegal gear) were used by individuals throughout the day and (sometimes) in the night to catch fish. The passive gear: traps, acadja/atidza (a traditional fishing method employed in the coastal areas of Ghana, Togo and Benin - see Table 3.4), hook and line were deployed and retrieved over variable periods (Table 3.4). The craft used by the fishermen are motorised boats and traditional planked canoes that take the crew and equipment several kilometres out to the river where the gear is deployed.

Table 3.4 Description of fishing methods employed on the Oti River.

Method/Equipment	Procedure
Acadja/Atidza	This method provides food and refuge for young fishes trapped and confined within a delineated area made of twigs and branches of plants. The trapped fish are usually harvested after 4-5 weeks by first surrounding the delineated area with a large fishing net. After removing the decayed twigs and branches the fish are hauled in.
Cast net	Cast nets used in the Oti River vary in type of materials and mesh sizes when fully stretched.
Gill net	Monofilament or multi-filament gill nets are commonly used. They vary in material used and range in size from meshes 25 to 40 mm when fully stretched.
Harpooning	This involves the use of a harpoon to stab fish especially in crevices created between tree stumps in the Oti River.
Hook and line	These are made up of long lines with several hooks or a single hook and are baited with the flesh of fish and weighted down with lead-stones at the bottom.
Mosquito net	Nets of very fine laterally stretched mesh sizes of 2.5 mm are used to seine through the water from canoes.
Traps	Traps woven with palm branches are baited and secured in the water to catch fish.

Unlike full time fishermen whose main and usually only occupation is fishing, respondents undertake a variety of supplementary occupations concurrently. Other income generating activities such as farming, trade and wage labour are referred to in this study as non-fishing activities. Among the non-fishing occupations farming was most important (particularly at Kabonwule and Papaye where land was relatively abundant for arable crop and cattle grazing and vegetable farming in the drawdown of the lake) followed by trading for other household members. Farming and trading together accounted for an overwhelming proportion of non-fishing employments/occupations for heads (75%) and for other household members. Kabonwule had the highest share of farming households, possibly because of land availability. At Dambai, and Kapite households were trade-minded and opportunities for commercial activities were most important due to the presence of important markets at these locations. Fish retail trade starts at the landing beaches, where fish are cleaned by women and young girls, extracting and separating the offal (gill, gut and fin) for a fee. Substantial volumes of offal are left at the beaches to rot or thrown back into the water after the day's activities when buyers have come for their wares. In some instances, other family members carry the catch home for cleaning and subsequent processing.

Income levels

Household incomes were derived from fishing and non-fishing activities. In the study, the disposable cash income was considered the sum of fishing and non-fishing incomes earned by the household minus taxes. Mean total monthly fishing and non-fishing incomes as well as total monthly income for all respondents were slightly above the prevailing national monthly minimum wage of US$ 4.99. Ghana Living Standards Survey V classified households with annual incomes below US$ 1076.13 per annum as poor (Ghana Statistical Service, 2007). This translates to US$ 89.67 per month, which is far higher than the US$ 30.00 per month (based on US$ 1.0 per day, exchange rate of GH¢0. 93 to the US dollar and 30 days per month) threshold criteria adopted by the National Development Planning Commission in 2007.

On average, fishing income amounted to 71.3% of total household income in Dambai and 61% at Kapite. In contrast, fishing incomes contributed only 33.1% of total household incomes at Kitare. Among the three sub samples, however, Nkanchina fishing households had the highest total income of over US$ 247.31 per month, compared to US$ 204.30 per month at Bladjai and US$ 193.55 at Kitare. Important differences due to location of the fishermen were not identified. Fishing households' incomes in comparison with the national average gives an idea of the relative standard of living of the fishermen. In terms of *per capita* disposable monthly income, the fishing *per capita* income of US$ 44.08 was found to be less than that of the average Ghanaian of US$ 47.31 (Government of Ghana (2005).

About 98% of inland fish products within the country are derived from the river and lake resources of the Volta Basin (Ghana Country Report, 2002). Apart from the direct fishing activities from the rivers and lakes, there is a considerable amount of aquaculture development going on in Lake Volta. Water hyacinth did present many problems for the fishermen. Access to sites became difficult when weed was excessively present, loss of fishing equipment often resulted when nets or lines became tangled in the root systems of the weed and the result of these problems was more often than not a reduction in catch and subsequent loss of livelihood. In areas where fishermen make meagre living from their trade, this can present serious socio-economic problems. Fishermen also complain that crocodiles and snakes have become more prevalent in water hyacinth infested waters.

In the Oti River, traditional fishing grounds have been taken over by water hyacinth and fishermen have to travel longer distances to un-infested areas to fish. This means there is lack of access to and loss of fishing grounds. According to Kateregga and Sterner (2009), lack of access to fishing grounds seriously affects fish catchability, delayed access to markets (affecting the quality of fish) and increased costs (effort and materials). Fishing nets and other gear were destroyed by the water hyacinth, so some fishermen tended to use unauthorized gear (active gear such as winch nets attached to boats) for fishing. Water hyacinth mats have also blocked the breeding grounds of economically important species such as tilapia and Nile perch. Fishing has thus become more time consuming and laborious.

In the Tano Lagoon, fish catches have dropped by 80-90%, since 1991, and this has been attributed to the water hyacinth invasion (Holcik, 1995). This has significantly affected the livelihood of fishermen in the area. Water hyacinth decreased fish catches and fishing grounds in the Nveye Lagoon Complex on the South-western border of Ghana with Côte d'Ivoire in 1991. Pre-water hyacinth infestation fish catches of 2-3 metric tonnes/day decreased to 200-500 kg/day at Asukro on the Nveye Lagoon. Twice as much fish were caught in terms of weight and numbers in open surface water as against those under the water hyacinth mats (Holcik, 1995).

Water hyacinth infestation in the Tano River led to loss of job opportunities. For instance, up to 30% of fishermen from Asukro on Nveye Lagoon were forced to leave and look for work elsewhere due to loss of fisheries revenue (Holcik, 1995). Fishermen also use more fuel, up to three times as much, to push their boats through the heavy weeds (Akinyemiju, 1987). These increased costs are then reflected in consumer prices.

Water hyacinth also created impediments to trade and commerce, i.e. the important port and border post as well as the market centre at Jewi Wharf was occasionally cut off by floating mats of water hyacinth, curtailing commercial activities and subsequently leading to loss of revenue to traders, traditional authorities, boat owners, the Jomoro District Assembly and the National Revenue Agency (Customs Excise and Preventive Service) (Julien, 1995). Whenever the landing site at Jewi Wharf was blocked by water hyacinth, it created considerable problems. People coming to the market got stranded and their perishable goods were spoilt because boats could not ply through the thick mats of water hyacinth to the landing site. Those whose livelihoods depend on the market are thus deprived of their social and economic survival.

The water hyacinth infestation also created jobs for some people. Manual removal of water hyacinth, although very labour-intensive, was useful in controlling small infestations. For example, community groups using rakes and pitchforks removed over 100 tonnes of the weed from landing beaches in the Oti River Arm of Lake Volta in one year. The total membership of the site management committees was 60. The breakdown was: Dambai 15, Kabonwule 15, Kitare 10, Bladjai 10 and Nkanchina 10. There is an attendant at the biological control agents (*Neochetina eichhorniae* and *Neochetina bruchi*) rearing facility at Dambai. All the members of the pilot site management committee and the attendant were paid $10 per month and this worked out to $610 ($10 x 60 members + $10 for attendant) a month and $7,320 per annum (for the total membership). All these people came from the local communities. They were recruited, trained and given the task of maintaining the biological control agents' rearing facilities and to serve as members of pilot site community management teams who manually harvested the weeds from boat landing sites and community water accessing points.

3.4.2.3 Impact on trading and transport

The Oti River basin in Ghana is generally deprived and has only few or no access roads at all. The most common means of transport between villages is therefore by boat, from one person dug-outs to motorized boats. The boats are the means by which children are transported to school daily and women with their goods (agricultural products, especially vegetables and fresh or processed fish) were conveyed to the markets. However, the infestation by water hyacinth delayed or sometimes prevented the children from going to school and the women from taking their goods to the markets.

During the peak of the water hyacinth infestation in 1999, the large ferry boat *Ndewura Jakpa* could also not ply the route thereby bringing all economic and social activities to a halt. This incident brought the then Head of State of Ghana to the site who on the advice of the Environmental Protection Agency (EPA-Ghana), asked the Water Hyacinth Control Committee to spray the infestation with glyphosate (Round up®) in order to ease the discomfort of both residents and travellers. This operation and other related activities cost the Volta River Authority (VRA) approximately US$60,000.00.

The Oti River is obstructed with many dead tree stumps as a result of the damming of the Volta River. Most of these stumps are covered by invading water hyacinth and other aquatic macrophytes, making it difficult for boat operators, who sometimes have to meander their way through to avoid them. The inability of the coxswains to locate these stumps has led to serious accidents that claimed many human lives and loss of merchandise.

A major road runs from Accra through Kadjebi and Dambai in the Volta Region to Tamale in the Northern Region (Eastern Corridor). This road is truncated by the Oti River at Dambai where there is no bridge. The only links are a ferry boat that transports vehicles, passengers and goods across from Dambai to the opposite bank, and motorised canoes operated by individuals. Interviews were conducted among the boat operators and travellers on the boats. Below is a breakdown of the price build up of the amount of money realised from these operations by both the Volta Lake Transport Company Limited, a subsidiary of the Volta River Authority, and the private individuals operating the passenger boats.

3.4.2.4 Cost breakdown for operating individual passenger boat service at Dambai

Cost of boat transportation of one person from Dambai – opposite bank = $3.30/person/trip

Average number of passengers/trip = 50

Amount realised/trip = $165.00

Number of ordinary days = 5 (Wednesdays to Sundays)

Number of market days = 2 (Mondays and Tuesdays)

Number of trips/day (ordinary days) = 4. Therefore total/day = 165 x 4 = $660.00

Total for 5 days = $3300.00

Number of trips/day (Market days) = 8. Total/market day = 165 x 8 = $1320.00

Total for 2 market days = $2640.00

Total amount for one week = $5940.00

Number of boats operating passenger service at Dambai = 7

Total income generated by passenger boats/annum = **$1,866,980.00**

3.4.2.5 Cost breakdown for operating the Volta Lake Transport Company Limited ferry boat service at Dambai

Cost of transporting one person by ferry from Dambai – overbank = $4.67/person/trip

Average number of passengers/trip (ordinary days) = 50

Amount realised/trip (ordinary days) = $233.50

Number of ordinary days = 5 (Wednesdays to Sundays) Average number of passengers/trip (market days) = 80

Amount realised/trip (market days) = $4.67 x 80 = $373.60

Number of market days = 2 (Mondays and Tuesdays)

Number of trips/day (ordinary days) = 4. Total/ordinary day = 233.50 x 4 = $934.00

Total for 5 days = $934.00 x 5 = $4670.00

Number of trips/day (market days) = 8. Total/market day = 373.60 x 8 = $2988.80

Total for 2 market days = $5977.60

Total amount for one week = $10,647.60

Average number of vehicles ferried across/week = 540

Average cost/ferrying a vehicle = $7.00

Total amount realized from ferrying vehicles/week = $3780.00

Total amount realized from the ferry boat operations/annum = **$493,899.00**

Grand total of revenue generated by both ferry boat and motorized passenger service boats/annum = **$ 2,360,879.20.** **Note:** Calculation is based on 300 days in a year.

Table 3.5 The costs for operating individual passenger boat service and Volta Lake Transport Company Limited ferry boat service at Dambai

Duration	Days/wk	Trips/ day	No. of boats	No. of ferries	Income/ day for boats (US$)	Income /day for ferry (US$)	Annual income/ boat owner (US$)	Annual income for all 7 boat owners (US$)	Annual income for ferry (US$)
Ordinary days	5	4	7	1	660	934	129,360	905,520	183,064
Market days	2	8	7	1	1320	2968	366,640	960,960	310,835
Total							496,000	1,866,980	493,899

The average total number of passengers ferried across per week by both the private passenger boats and the ferry boat is approximately 14,880. The average number of vehicles ferried across per week is approximately 540. These passengers include government officials, teachers, school children, students, traders, researchers, medical doctors, nurses, patients and other people.

Whenever mats cover a beach or bay, they impact on the community living along its shoreline. Two most notable impacts that were reported by most people interviewed were: disruption of boat-transport due to the blockage of the navigable routes and the interference these blockages create to the fishing industry. If water hyacinth infestation blocks the movement of the boats and the ferry boat and stops them from moving for a day or two or for a week, one can imagine the considerable social and economic loss suffered by the large number of people whose daily lives depends on the movement of these boats will suffer. The transportation industry in the Oti River supports more than 1 million people and is estimated to be worth about US $2.4 million per annum

3.4.3 Impacts on health

Medical records gathered from the Dambai Clinic indicate that malaria is the most prevalent disease, followed by schistosomiasis and diarrhoea. There are also, occasional outbreaks of cholera and typhoid fever. A survey conducted among school children (through interviews and urine analysis by VRA Health Services Department) at Dambai showed that over 95% of the children are infected with schistosomiasis. However, since almost all the school children have either blood in their urine or faeces, they believe that it is a normal phenomenon and thus, not report it to the clinic. The health statistics from the lakeshore communities should be interpreted with great caution as these represent only the cases that were reported to the health centres as against the larger group that do not report.

The water hyacinth mats, according to the communities, provide breeding grounds for mosquitoes (malaria), and vectors (infested snails of *Biomphalaria* sp. and *Bulinus* sp.) of diseases such as the schistosomiasis, as well as snakes. Perhaps the most serious aspect of aquatic weed growth is its direct impact on the incidence and spread of water borne diseases such as schistosomiasis, encephalitis and filariasis (Odei, 1975). Incidence of malaria increased, for example, at Mepe/Battor, 82.7% of the respondents suffered periodic attacks of malaria before the construction of the Akosombo Dam, as compared to 98.7% post construction, while the corresponding data for Adawso/Okradjei were 58.4% and 65.82%, pre- and post-, respectively (Sam, 1993).

According to a survey by the then Water Resources Research Institute (Sam, 1993), the Akosombo hydroelectric project is linked to increases in the incidence of some common endemic water-borne diseases such as schistosomiasis (bilharzia), malaria and other less common ones. These increased disease transmissions could be associated with inadequate sanitary measures in the lakeside settlements and the proliferation of aquatic weeds.The survey data for both pre- and post-project phases were obtained from field interviews, and were complemented with others obtained from questionnaires sent to some selected public institutions on some specific topics. The surveys were undertaken between 1986 and 1988 by a team from the then Water Resources Research Institute. The interviews were directed at opinion leaders, including chiefs and other randomly selected elderly members of the communities between the ages of 25 and 99 years who experienced both the pre- and post-project conditions. The increase in incidence of water-borne diseases could be attributed to the change in the hydrology of the lake, which also increased the rate of proliferation of the weeds.

3.4.3.1 Schistosomiasis control

In Ghana, a schistosomiasis control programme which delivered praziquantel mass treatment in affected villages was started to control the increase of schistosomiasis after the completion of the Akosombo Dam in the Volta Region in 1964. In other parts of the country no official control programmes exist. In Mali, control efforts started in 1982 with the establishment of a national schistosomiasis control programme (Brinkmann *et al.*, 1988). After 1987, activities were decentralized to the district and regional health teams and schistosomiasis control was integrated in primary health care (Traore′, 1996).

3.4.3.2 Demand for praziquantel for schistosomiasis treatment

According to WHO's estimates, Ghana is ranked as the third country in the world (in the order of estimated national "need" for praziquantel) and requires approximately 28 million tablets of praziquantel annually, which is about 6.5% of the estimated global need. The Ghana government has procured praziquantel through UNICEF and WHO, though the procurement has been irregular, and the annual supply has never exceeded 100,000 tablets. In 1993, however, the Ghana Partnership for Child Development project in the Volta Region procured 200,000 tablets of praziquantel (Table 3.6). Reportedly, praziquantel is available in the private market in Ghana along with metrifonate, and Ambilhar (niridazole), a drug not officially recommended for schistosomiasis, although the volume of private sales is unknown.

According to WHO (1993), starting in 1983, a total of 24 countries have established schistosomiasis control programmes. These countries are: Algeria, Brazil, Botswana, Burundi, China, Dominican Republic, Egypt, Ghana, Indonesia, Laos, Madagascar, Malawi, Mali, Mauritius, Morocco, Nigeria, Philippines, Saudi Arabia, Sudan, Suriname, Tunisia, Tanzania, Zanzibar, Venezuela and Zimbabwe (WHO, 1993). WHO provides technical assistance to these programmes, but does not become involved in the funding of control programmes or in the procurement of drugs for the programmes. As part of a global monitoring effort, a computerized global database has been established in the Schistosomiasis Control Unit of WHO, with information on the epidemiology of schistosomiasis, control activities and people responsible for control, water resources, and chemotherapy for each endemic country (WHO, 1993).

Table 3.6 Estimated need and availability for praziquantel in the top 30 countries

Country	Tablets needed	% of global need	Cumulative % of global need[a]	Availability in 1993	% of need met[b]
1. Nigeria	61,827,176	14.6%	14.6%	negligible	negligible
2. Tanzania	31,409,269	7.4%	22.0%	160,000	0.5%
3. Ghana	27,611,179	6.5%	28.5%	200,000	0.7%
4. Mozambique	27,311,159	6.4%	35.0%	n/a	
5. Egypt	26,316,941	6.2%	41.2%	10 million	38.0%
6. Zaire	23,945,287	5.7%	46.8%	n/a	
7. Brazil	19,680,000	4.6%	51.5%	negligible[c]	negligible
8. Madagascar	15,413,514	3.6%	55.1%	n/a	
9. Mali	13,962,618	3.3%	58.4%	607,000[d]	4.3%
10. Uganda	13,900,410	3.3%	61.7%	125-200,000	1.4%
Nos. 11-20	99,642,543	23.5%	85.2%		
21-30 (incl. China)	43,035,263	10.1%	95.4%		
China	2,826,355	0.7%		24 million[e]	850%
Availability in the Republic of Korea[f]				1-1.2 million	
Total estimates (for top 30)	**404,124,000 need**			**(36,367,000 accounted for)**	
Total global estimates	**423,609,839 need**			**89,000,000[g] availability**	**21.0%**

Source: Estimated need is for use of praziquantel in treatment of schistosomiasis, based on a case treatment strategy, from Utroska *et al.*, (1989); estimates of praziquantel availability are mostly for 1993, and are based on various sources, including a survey distributed to governments and schistosomiasis experts, as part of this study.

[a] The cumulative % of global need refers to the percentage of total global need accounted for by that country and all countries above.

[b] The % need met is based on the highest estimate of availability as a percentage of the estimated need.

[c] Brazil has wide availability of oxamniquine, which is produced in Brazil and is used for treatment of *S. mansoni.*

[d] The data for Mali are for 1995 and include purchases for projects and for the Ministry of Health.

[e] This figure for China is based on import and production estimates; the high volume is partly explained by China's strategy of mass treatment for schistosomiasis in endemic areas, not only for infected cases, and by China's treatment of cattle (which require large dosages of praziquantel).

[f] the Republic of Korea is included because praziquantel is widely available (for treatment of schistosomiasis and liver fluke).

[g] This figure of 89 million probably overestimates the global supply of praziquantel for human usage, since it includes the quantity used in China for both human and veterinary treatment.

Due to the proliferation of aquatic weeds in Lake Volta, the incidence of water borne and water-related diseases increased (Zakhary, 1997). Also movement of people in the communities was curtailed as a lot of effort is needed to move from one place to the other using canoes. In order to bring health care nearer to the communities, the Volta River Authority (VRA), as part of its social responsibility to the riparian communities, procured a medical boat (*Onipa Nua*) which it uses in health outreach programmes along the lake. Because of the absence of easy access to the national health infrastructure by the people along the lake, health problems persist and many communities can only be visited by boat as there are no road networks.

During 2006, SwissGha Foundation, a non-governmental organization (NGO) in collaboration with the Volta River Authority undertook three outreach trips successfully. In all, 7,213 inhabitants of these villages with various diseases were treated, all free of charge. The records showed the disease distribution to be: 23% malaria, 13.1% intestinal helminthiasis and 12% respiratory infections. Others were various joint and muscle pain conditions, skin sepsis, eye, nose and throat conditions (ENT), Urinary Tract Infections (UTI), hypertension and pregnancy-related illnesses. The third trip focussed especially on the treatment of diseases of the eye. It was made up essentially by the same team, but this time with a "7-man Eye Team" in addition. The aim was to study eye problems in the communities along the lake to treat as many of them as possible. The third trip had a similar disease profile, with malaria still being 24% and eye diseases being 11%.

3.4.3.3 Donation for health care

A donation of medical equipment, disposables and consumables amounting to US$15,000 was presented by the foundation towards the project "Medical Boat on the Volta Lake" and also to the Akosombo Hospital. It was inaugurated on December 14, 1990 and also serves as a training centre for medical staff and other health professionals, both Ghanaians and foreigners, in community health care delivery. The donation is to help alleviate the suffering of the people living along the banks of Lake Volta due to the negative impacts of water hyacinth.

3.5 Management of water hyacinth infestations in the Oti River Arm of Lake Volta

Due to the water hyacinth infestation of Lake Volta, the VRA and other stakeholders became aware of the need to maintain the water hyacinth management programme. The management programme was designed to prevent the explosive growth of the weeds and to prevent them from entering the main Lake system. The effort paid off and is now being supported by the UNEP/GEF Project: "*Removing Barriers to Invasive Plant Management in Africa*" that is being hosted by the CSIR-Ghana and co-ordinated by CABI Africa, Nairobi. Kenya. This project is working in close collaboration with an African Development Bank-funded project on water weed management in West Africa "*Integrated Management of Invasive Aquatic Weeds Project*" that is being hosted by EPA-Ghana.

3.5.1 Control and management of water hyacinth on the Oti River

During the survey to assess the level of infestation of the water hyacinth and to interact with the inhabitants of the lakeshore communities on ways to manage the weeds due to the problems they cause, all ten people interviewed at Dambai and all five at Njari said they have no use for the weed so it must be controlled and prevented from expanding its coverage. At Kitare, of the eight people interviewed, five opted for eradication and three said they had no opinion since they had nothing to do with the weed. At Bladjai, Kapite, Kabonwule and Papaye, all the twenty-four people interviewed opted for the eradication of the weeds since according to them, the weeds interfered with their work. At Nkanchina, of the eight people interviewed, six wanted the weeds to be controlled while two people said they had no opinion. At Bi-Zongo, of the five people interviewed, four wanted eradication, and one person had no opinion (Figure 3.4). These opinions were directly linked to the seriousness of the weed in that particular area. Further, most respondents, although they removed the weed themselves, felt that water hyacinth control should be a government initiative.

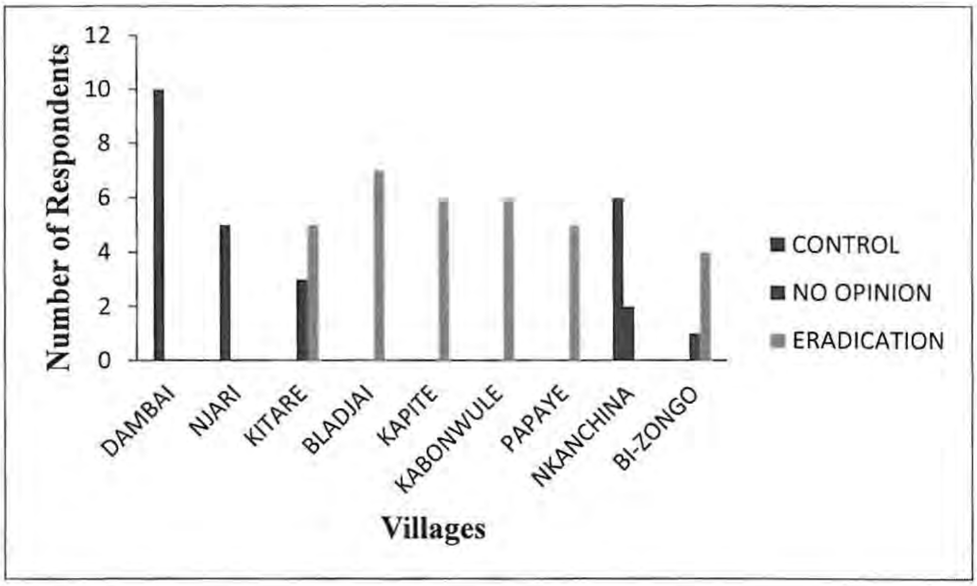

Figure 3.4 Water hyacinth management options recommended by respondents in the ecological survey.

On the discovery of water hyacinth in the Oti River Arm of Lake Volta in October 1998, VRA sponsored physical, chemical and biological control programmes at this new infestation site. A combination of herbicides and manual management programmes for water hyacinth, carried out by VRA, resulted in 90% success. Within the period from October 1998 to December 1999, total eradication was achieved along approximately 550 km of the shoreline. An area covering 650 ha was reclaimed, leaving approximately 60-100 km of the shoreline infested. A total of approximately US$54,167 was invested in this period.

Water Weed Management in West Africa/Ghana Water Bodies 2000-2002 was funded by the FAO at the cost of US$2,000,000. This regional project continued the management programmes on aquatic weed problems in the sub-region with training programmes for personnel from Ghana, Togo and Burkina Faso by Ghanaian specialists. Biological control agents were supplied to Togo and Burkina Faso. The project also enhanced bio-agent rearing facilities for water hyacinth. A biological control rearing facility was built along Lake Volta at Dambai for the rearing of *Neochetina* weevils.

The UNEP/GEF Project "Removing Barriers to Invasive Plant Management in Africa" 2005-2010 costing US$1.5 million is currently operating. This is an African regional project involving Ethiopia, Ghana, Uganda and Zambia. It is aimed at addressing and removing barriers or bottlenecks such as weak policy environment, non-availability of critical information, lack of or inadequate capacity in implementation and then enhancing the building of both human and infrastructural capacity by management programmes on invasive plant problems in pilot countries. Under this project, the biological control rearing facilities have been rehabilitated; training programmes are being organized for selected stakeholders to bring them in line with prevailing management expertise in the field. Also, quarantine facilities are being provided for the Plant Protection and Regulatory Services Directorate of the Ministry of Food and Agriculture in Ghana (PPRSD of MoFA) and students are being trained at tertiary level to build capacity for the management of invasive alien species in Ghana.

Four institutions (grouped into three) are engaged in the water hyacinth management activities. These include the Volta River Authority (VRA), Environmental Protection Agency (EPA-Ghana), the Department of Zoology of the University of Ghana and the CSIR Water Research Institute. The VRA are seen as the custodians of Lake Volta and have their own monitoring and control programmes each year. Their activities are complemented by the routine visits by the EPA-Ghana regional office in the Volta Region where River Oti is located, while the Department of Zoology of the University of Ghana and the CSIR Water Research Institute provide technical support to the programme by visiting the site to evaluate the infestation level and make recommendations to the water hyacinth control committee for the necessary remedial action to be taken. Table 3.7 highlights the activities of the water hyacinth management committee, the individuals and groups involved, the amount of money needed to keep the work going and the equipment required for the job.

Table 3.7 Estimates of baseline control and management costs of water hyacinth in the Oti River Arm of Lake Volta, Ghana.

ITEM	BREAKDOWN	COST (US$)	NOTES
VRA Monitoring	1Research Officer	26,667	VRA team carries out
	2 Technicians	32,000	water hyacinth
	1 Coxswain	16,000	monitoring for two
	Cost of one Fibre glass boat	21,333	weeks each month
	Cost of one 4x4 field vehicle	57,600	
	Overheads	46,060	
EPA Monitoring	1 Regional Officer	2,000	Twice a year for one
	1 Technician	1,556	week each time.
	Field equipment	556	Water samplers, maps,
	1 Coxswain	1,333	reagents and audio-visual
	Hiring of boat	2,667	equipment.
	Hiring of vehicle	5,600	
	Overheads	2,742	
UG and WRI Monitoring	2 UG and 2 WRI staff	4,444	UG and WRI team
	1 VRA Research Officer	1,111	carries out monitoring
	1 Technician	622	for one week per year
	1 Coxswain	667	
	Hiring of boat	889	
	Hiring of vehicle	2,800	
	Overheads	3,160	
Physical Control of new infestations	Physical removal of new water hyacinth infestations by hired labour gangs	88,889	2 months twice per year at 100m each time at the Oti river.
Bio-control agents rearing facility and maintenance	1 full time staff	1.600	
	2 part-time assistants	2,133	
	Facility maintenance	2,667	Includes release costs
	Overheads	1,920	
TOTAL		<u>**US$ 327,036**</u>	Amount of money needed for one year operations only

3.6 Discussion

Quantifying the impacts of alien invasions on biodiversity in economic terms is an especially difficult task and was not undertaken in this study. It would be illuminating to consider the cumulative effects of the steady replacement of a large number of indigenous species by a small number of invasive alien species over time (chapter 2), and not simply take each case study on its own - the latter approach seldom provides an adequate reflection of impacts (Ing-Marie Gren *et al.*, 2007). The economic costs of invasion are easier to quantify. Damage costs of aquatic weeds is defined as changes in total net welfare in society caused by that species. Quantification of such a change is obtained in two steps: *i)* identification and quantification of all effects and *ii)* assessment of the effects in monetary terms. The first step requires information on the impact of the weeds on humans and on ecosystems *in situ,* that is, direct impacts, and impacts on surrounding ecosystems and dispersal of its effects in the entire economy, denoted as indirect impacts. Direct and indirect effects of aquatic weeds are illustrated in Figure 3.5 below.

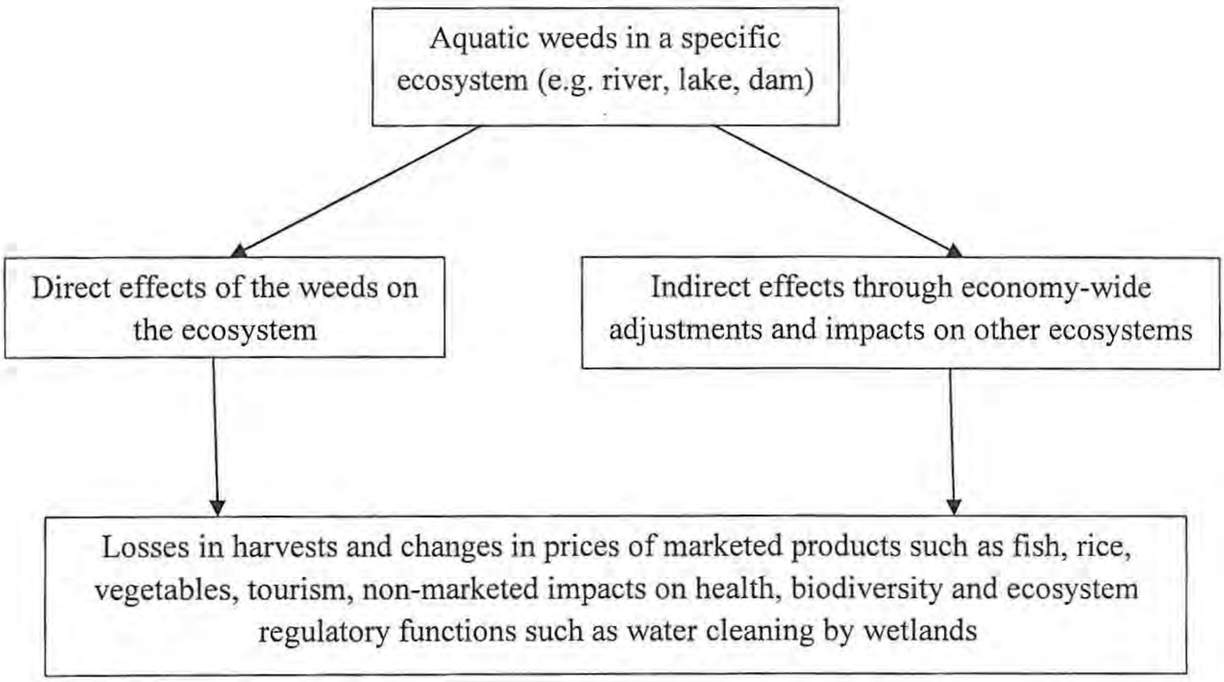

Figure 3.5 Illustration of Economic impacts of aquatic weeds in a water body.

Monetary values can be assigned to the impacts perceived by humans, which are exemplified by fish harvest losses and health impacts (Figure 3.5). Some of these values can be specific in specific ecosystems. Monetary values for products traded on the market, such as losses in fish, vegetable crops and rice harvests, can then be obtained by means of market prices. Other values, such as improved health and biodiversity, cannot be traded and their assessments need to be obtained in other ways.

According to Gutiérrez *et al.,* (2001), it is accepted that water hyacinth growth is close to logistic growth. Sato and Kondo (1983) established that the biomass increase (fresh weight per surface unit) closely approximates the logistic equation and Del Viso *et al.* (1968) demonstrated that the annual growth cycle of water hyacinth plants in Argentina can be represented by a sigmoid curve. Reddy and Debusk (1984), in growth evaluations with plants cultivated in a pond with unlimited nutritional conditions, determined the growth characteristics of water hyacinth in the central part of Florida, USA. They obtained a growth curve characterised by three phases: a delay phase followed by exponential growth; a linear growth phase, and a slow exponential growth phase. These are the characteristics of a sigmoid curve. The carrying capacity of the system (K) will be reached during the periods when maximum biomass will be obtained.

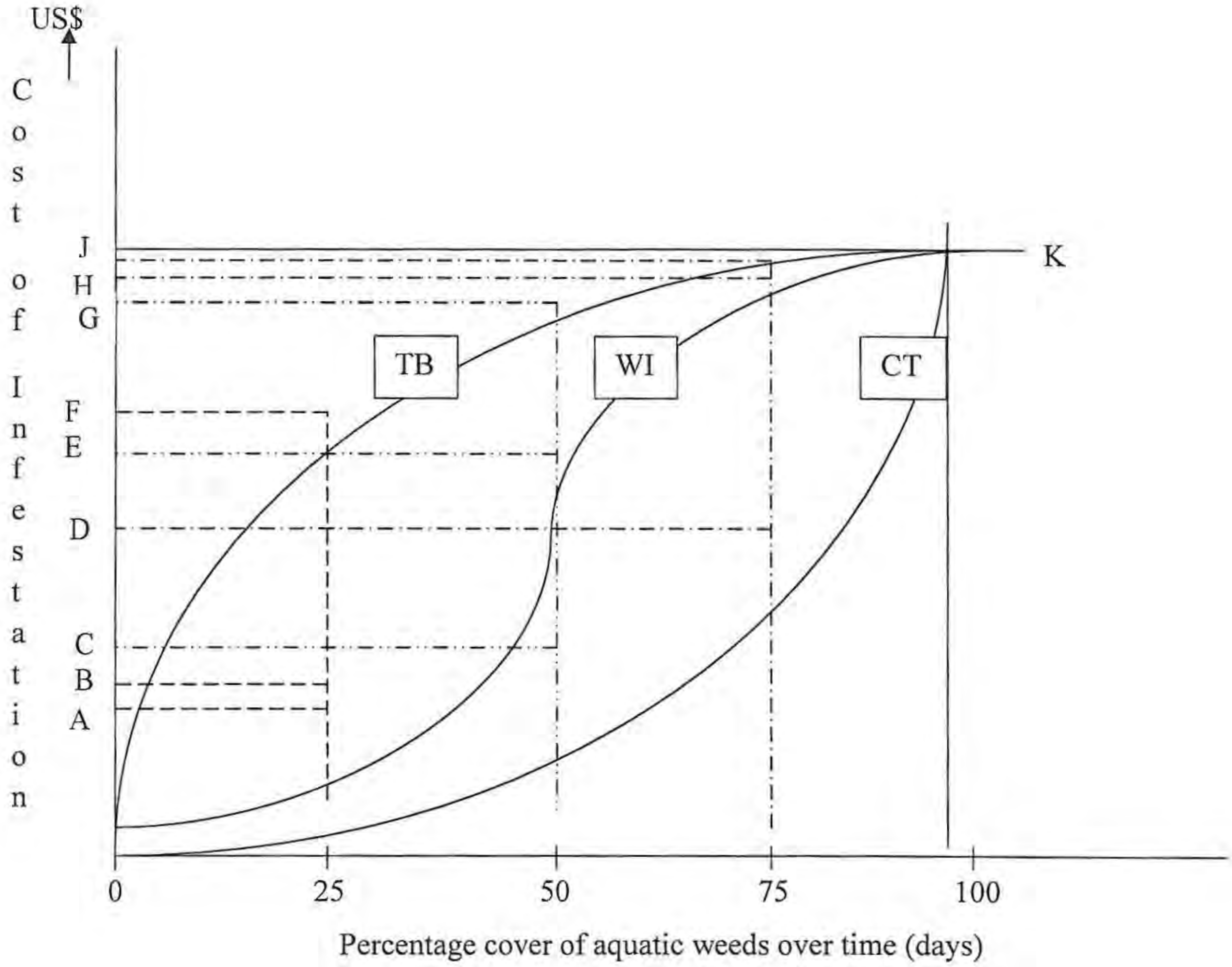

Figure 3.6 Percentage (%) cover of aquatic weed infestation at a site and the cost of 'control' or 'no control'. TB: total benefit, WI: weed infestation, CT: weed control effect (adapted from (Ing-Marie Gren *et al.*, 2007)

In Ghana there are different scenarios that the government can take with regards to whether water hyacinth (and this probably applies to other waterweed species) infestation can be controlled or left uncontrolled. If it is controlled, then to what extent should it be controlled? All of the options have cost implications and are presented in Figure 3.6. The curve TB represents the total benefit the country gains from the use of the water body (Figure 3.6). WI is the level of weed infestation, and CT the effect of controlling the weed infestation on the water body. K is the carrying capacity of the system; i.e. the level at which aquatic life in the water body can be sustained and above which the whole system will crash. From the diagram (Figure 3.6), when the level of infestation is at 25%, the total socio-economic, ecological and biodiversity cost of the infestation to the country if nothing was done about the infestation will be US$ B. If control measures were put in place, then the cost of infestation would become US$ A. The total benefit accruing to the state because of the control measures would be US$ (F-A). At 50% level of infestation, the cost to the country becomes US$ E. If control measures were in place, the cost would come to US$ C and the benefit would be US$ (G-C). At 75% level of infestation, total cost to the country would stand at US$ H. If measures were in place to control the infestation, the cost would have been US$ D with the country benefitting to the tune of US$ (J-D).

The costs of aquatic weed infestation to the country are from both direct and indirect sources. This means that neglecting to control the weed infestation is not going to affect only the socio-economic wellbeing of the people but would encompass a wide range of issues. If the weed infestation was left at 25%, the government might have saved some money and the socio-economic status of the people would have been compromised, but the benefits of controlling it would have been about eight-times the amount saved. At 50% level of infestation, the cost of the infestation was about five-times the cost when it was at 25% whereas if it were under control, the cost would have been just the amount lost to the state at 25% level of infestation but the benefit would have been double the amount needed if it were under control. At 75% level of infestation, because of the exponential growth of the weeds, the whole system would be near the carrying capacity (K) which means the whole water body will be near saturation point from the weeds and at that level, the amount of money that will be needed to control the weeds and restore the system will be about ten-times the initial amount needed to start the control when the infestation first started. This shows that the economic, social and ecological loss due to the uncontrolled water hyacinth infestation will far outweigh any savings on part of government not committing funds into control projects. If the infestation is not controlled, the water body faces imminent danger of total degradation. Timely control interventions will bring immense benefits to the country and especially the people whose livelihoods depend on the water body. Late interventions come along with huge financial investment therefore it is always better to implement control and other management options early.

A survey was conducted in Benin in 1999 (De Groote *et al.* 2003) to demonstrate the economic impacts of water hyacinth on local economies before and after water hyacinth was controlled using the biological control agents, mottled water hyacinth weevil (*Neochetina eichhorniae*) and chevroned water hyacinth weevil (*Neochetina bruchi*). The principal activities of the men surveyed were fishing and agriculture. They reported that water hyacinth impacted fishing. The women, whose principal activities were transport and trading, reported that trade was most affected. In addition, many of the women said that the time that it took to trade was increased because water hyacinth slowed river navigation, making it take longer to get to the market. During the height of the water hyacinth infestation, men reported their annual income dropped from US$1,984 to US$607. After the control of water hyacinth their *per capita* income rose to US$1,160. Women were most impacted in trading of fish; they saw their *per capita* income drop from US$519 to US$137 during the major infestation. Trade in food crops was reduced from $310 to US$193 per person. At the time of the survey, the fish trade had not recovered, while the food crop trade had dropped to 92% of its pre-water hyacinth infestation level. The researchers estimated that the economic loss due to water hyacinth was US$2,151 per household, while the benefit from the biological control was US$783 per household. This study clearly demonstrates the costs of invasive aquatic weeds can have significant impacts on local economies and that when invasive aquatic weeds are controlled it improves not only the ecosystem but also the economy (De Groote *et al.,* 2003). Based on the findings of this chapter, this example is applicable to Ghana.

Chapter 4

Post-release evaluation of the biological control agents *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) and *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae) on *Eichhornia crassipes* (Mart) Solms-Laubach (Pontederiaceae) infestations in the River Tano and the Tano/Abby/Ehy lagoon complex, southwestern Ghana

4.1 Introduction

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Pontederiaceae) is one of the most prominent aquatic weeds found throughout the tropical and subtropical areas of the world (Sculthorpe, 1967; Holm *et al.,* 1969; chapter 1). Water hyacinth forms dense impenetrable mats across water surfaces, limiting access by man, animals and machinery. Navigation and fishing are obstructed, and irrigation and drainage systems become blocked. The consequences are devastating for those communities reliant on water bodies for water, food, sanitation and transport (Julien *et al*., 1999; chapter 3). To combat the problems caused by the weed, efforts to control its spread and to reduce its biomass have been many and varied, and include weed management methods such as physical removal, application of herbicides and release of biological control agents (chapter 1). It is now generally recognised that physical and chemical controls have very limited application in most countries because of their high cost and low sustainability (Julien, 2001). Utilisation of the weed for commercial and subsistence purposes has also been widely considered. Utilisation has never developed into a sustainable industry other than localised cottage industries or to support very poor communities in subsistence existences, such as the production of biogas (Julien, 2001). Only small amounts of water hyacinth can be utilised in such activities, which should never be confused with control. Neither should the potential for utilisation prevent the implementation of control strategies (Harley *et al.,* 1996; Julien *et al.,* 1996). The cost of water hyacinth to communities far outweighs the benefits that might occur through utilisation.

Many studies have explored the use of water hyacinth for sewage and waste water treatment. Its fast growth rate and high rate of nutrient and heavy metal absorption make the weed a cheap and largely environmentally benign tool for decontamination (Hill *et al.,* 1999a; Zhu *et al.,* 1999). However, as Gopal ended his review, "Developing countries should not encourage the propagation of this weed for utilization. The interests of mankind can only be safeguarded by seeking effective control of water hyacinth and not by its utilisation" (Gopal, 1987). The one control technique that continues to show promise, can be developed further, is affordable, environmentally friendly and above all sustainable, is biological control (Julien, 2001).

Dramatic successes with biological control have been reported from other parts of Africa and elsewhere in the world, most notably on Lake Chivero, Zimbabwe (Chikwenhere and Phiri, 1999); Lake Victoria, Kenya (Ochiel *et al.*, 1999); Louisiana, USA (Goyer and Stark, 1984); Mexico (Gutiérrez *et al.*, 1996), Papua New Guinea (Julien and Orapa, 1999) and Benin (De Groote *et al.*, 2003; Ajuonu *et al.*, 2003). But one of the challenges for biological control is in most cases the lack of effective post-release evaluation.

Evaluation of biological control programmes is essential to justify continued expenditure (Blossey *et al.,* 1996) and to test the predictions from pre-release studies. In the past, there has been little follow-up evaluation of biological control programmes (Blossey, 1995) chiefly because financial sponsors took the view that it was unnecessary. As a result, one of the criticisms of biological control is that there has been little evaluation of the impact of the agents on both the target and non-target species (Howarth, 1991)

Most post-release evaluation may be limited to monitoring the presence and spread of the agents, without evaluation of impact on the weed and its population dynamics (McClay, 1995). Laboratory experiments may demonstrate that insect feeding significantly affects the plant, but the relevance to weed population dynamics in the field may not be shown (Crawley, 1989; Spollen and Piper, 1995). The impact of biocontrol can be determined experimentally in the field by artificially excluding the agent(s) through insecticides or exclusion cages. Until recently, there have been few such experiments (Crawley, 1989) mainly because of the requirement for long-term treatment with insecticides or maintenance of cages. Increasing numbers of such experimental studies are appearing (Lonsdale *et al.,* 1995; McEvoy *et al.,* 1991; Sheppard, 1996). Long-term experiments and monitoring that assess the long-term impact of biological control on the host, its environment and eventually the welfare and economics of the concerned population are the most valuable but are difficult and expensive. The ultimate goal of the release of biological control agents is the restoration of invaded ecosystems. Uninvaded reference sites or long-term documentation of communities before release of biological control agents thereby provide useful benchmarks (Blossey 1999). The current poor availability of biological inventories will make true assessments of indirect impacts on food webs and species difficult. Monitoring protocols need to be able to detect the extent to which the release of biological control agents can drive population fluctuations or changes in ecosystem function. Natural ecosystems are immensely complex, although invaded systems may have lost a degree of their original complexity. However, the prevalence of organism interactions makes it difficult to predict the response of even well-understood systems to environmental change or perturbations (Yodzis, 1988; Polis and Strong, 1996). Consequently, arguing with confidence that ecological conditions have improved or deteriorated, or are simply different due to changes associated with spread of biological control agents, is impossible unless such impacts can reliably be distinguished from natural oscillations or plant succession. Lag effects make the detection and mitigation of impacts even more challenging (Byers and Kendall, 1982; Parker *et al.*, 1999). Laboratory and small-scale field experiments cannot adequately replicate interactions occurring in the field. The only way to capture the full range of ecological effects of the release of biological control agents is by detailed observations in actual ecosystems.

Despite a fairly long history of biological control of water hyacinth in the world and the number of successful programmes now reported, much additional research is needed. As new agents are released there will be a need to quantify their impacts. In addition, some available agents have not been fully evaluated. Lack of a quantitative evaluation of *O. terebrantis*, for example, has resulted in it possibly being underrated as a control agent despite its significant effect on water hyacinth on the Shire River in Malawi (Hill, unpublished data). A literature review for biological control of insects showed that data on post-release impacts were reported for less than 2% (of over 5,000) of classical biological control introductions (Lynch *et al.*, 2001). The majority of these are insect biological control examples and there are also many weed biological control programmes that remain unevaluated.

A classic example of post-release evaluation of water hyacinth was the one done on Lake Victoria in East Africa. At the peak of the infestation of water hyacinth in Lake Victoria in the late 1990s, data from Albright *et al.* (2004) showed through satellite imagery that up to 20,000 hectares of the water surface were covered by mats of water hyacinth. To control the weed, classical biological control agents (*Neochetina bruchi* and *Neochetina eichhorniae*) were imported to the Great Lakes Region and were released from 1995 onwards onto different parts of the lake. This resulted in a reduction of infestation to less that 2,000 ha by

1997. However, weed biological control frequently suffers from a lack of quantified post release evaluations in which controlled experiments are used and weed biological control scientists resort to the classical "before and after" analyses to show impact. In the Lake Victoria example, Williams *et al.*, (2007) argued that only an "overriding metascale process" could have altered the ecosystem of a lake as large as Lake Victoria and that the intensity of the 1998 El Niño event resulted in decrease in water hyacinth. They noted that low sunlight levels rather than weevil numbers would have caused the decline in the weed. Wilson *et al.*, (2007) assert that weevil introduction was the primary factor in the decrease in water hyacinth in Lake Victoria. They concluded that biological control using *Neochetina* weevils released from 1995 through 1997 was the main cause in the water hyacinth decrease and that abnormal weather only partially accounted for this reduction (Wilson *et al.*, 2007). This example further highlights the need for long-term post-release evaluation.

4.2 History of biological control of water hyacinth, in the Tano River and Lagoon complex

In 1986, the National Biological Control Committee (NBCC) was established to study, monitor and develop strategies for the control of the water hyacinth and other invasive species that threaten the country's water bodies. The committee comprised experts from 13 institutions including Zoology Department of the University of Ghana, Environmental Protection Agency (EPA), Volta River Authority (VRA), National Disaster Management Organisation (NADMO), Ghana Navy, Plant Protection and Regulatory Services Directorate (PPRSD) of Ministry of Food and Agriculture (MoFA), Crops Research Institute (CRI) and Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR). This was followed by the National Biological Control Programme (1992-1994), which started the biological control of water hyacinth in Ghana, with the importation of the two species of *Neochetina* weevils from the International Institute of Tropical Agriculture (IITA) in Cotonou, Benin in 1993. The weevils were released into the western region in the Tano Lagoon complex in 1994 (Wilson and deGraft-Johnson, 1994, 1995; deGraft-Johnson, 1996). Weevil-rearing facilities were established at the Department of Zoology, University of Ghana and at Jewi Wharf along the Tano River complex in the Jomoro District of the Western Region.

Between 1994 and 1996 the Integrated Control of Aquatic Weeds programme was established. This continued the work on the biological control of aquatic weeds in Ghana, with the importation of *Niphograpta albiguttalis* against water hyacinth, *Cyrtobagous salviniae* for salvinia and *Neohydronomous affinis* for water lettuce (*Pistia stratiotes*) from South Africa in 1996. These agents were released in the Tano lagoon in 1996; only the *Niphograpta albiguttalis* did not establish (deGraft-Johnson, 1996).

The International Mycoherbicide Programme for *Eichhornia crassipes* control in Africa (IMPECCA) ran between 2001 and 2002. This was a collaborative work with IITA/PHMD/IMPECCA. In this collaboration, host specific pathogenic fungi were identified from the Tano River and lagoon complex. These were *Alternaria eichhorniae* and *Acremonium zonatum*. Other pathogenic fungi identified included *Rhizoctonia solani, Myrothecium roridum* and *Cercospora rodmanii*. *Myrothecium roridum* was the most common fungus with *Alternaria eichhorniae* the least common. Although the role of pathogens in the control of water hyacinth has not been quantified, it appears to be minimal and the results of the IMPECCA were never implemented.

Finally, the Integrated Management of Invasive Aquatic Weeds Project was established and was to run from 2006 to 2011. This was an ECOWAS sponsored project funded in part with a loan and part as a grant from the African Development Bank (AfDB). This project was to contribute towards controlling the invasive aquatic weeds in seven shared water bodies of West Africa and Mauritania. The countries include: Ghana, Nigeria, Senegal, Benin, Niger, Mali and Gambia. The outcome of this project was considerable capacity building in these countries with regards to the identification and control of invasive alien species, including aquatic weeds.

4.3 Aims of this study

The aim of this study was to assess the populations of the biological control agents *Neochetina bruchi* and *Neochetina eichhorniae* on water hyacinth infestations in the Tano River and the Tano/Abby/Ehy/Lagoon complex, southwestern Ghana. While this does not present a manipulated experiment in which insect-free controls are compared to insect-fed treatments, it is intended to establish a benchmark for future evaluation. A further aim was to determine if additional agents are required to reduce water hyacinth infestation in this system.

4.4 Materials and Methods

4.4.1 Study site

The Tano River and the Tano/Abby/Ehy Lagoon complex lies between the republics of Côte d'Ivoire and Ghana on 5° 5' 23'N; 2° 51' 3° 21'W (Ghana has about 25 km of shoreline along the Tendo-Ehyportia but no actual lagoon surface area). Nveye Lagoon (5°07'N/2°55 'W) has a surface area of 200 ha and is entirely situated within Ghana. It opens into Ehy Lagoon in Côte d'Ivoire, which is part of the Abby Lagoon complex. Close to it, and opening to the sea at 2°47'W, is the small Domini Lagoon, which with its peripheral zones of inundation covers some 400 ha. A few kilometres inland, the Ghana-Côte d'Ivoire border is delineated by the channel of the Tano River, which discharges into Ehy Lagoon, but north of the lagoon, permanent forested swamps cover 7,500 ha in Ghana (Figure 4.1). The Tano Lagoon complex covers a distance of about 52 km and surface area of about 410 km^2, a depth of 14.9 m at the deepest point and a mean depth of 5 m. It has an annual fluctuation level of between 0.3 and 0.5 m. Jewi Wharf is an important port and border post as well as a market centre in Ghana located along the Tano River. It is occasionally cut off by floating mats of weeds, curtailing trade and other commercial activities there and leading to loss of revenue (Julien, 1995; chapter 3).

The Tano River rises from Techiman in the dry semi-deciduous forest belt in the Brong Ahafo Region. It flows through the tropical rain forest for about 400 kilometres into the Ehy/Tendon and the Abby lagoons which lie in the coastal vegetation (largely mangrove swamps), from where it enters the Atlantic Ocean at Assini in Côte d'Ivoire. The Jomoro District in the Western Region, where the lagoon complex is located, experiences two rainy seasons/year: April to July (major) and September to November (minor) with a short dry spell in August and a longer dry period from December to March. The district is the wettest part of Ghana with average annual rainfall of about 1,732 mm. Relative humidity is high (above 75%) throughout the year and annual average temperatures range between 22°C and 37°C. There is flooding of the Tano River during the rainy seasons of April to July and September to November each year. The flood waters move into the Nveye and Tano lagoons before eventually entering the sea through the Ehy Lagoon in Côte d'Ivoire, and this has implications for biological control (see below).

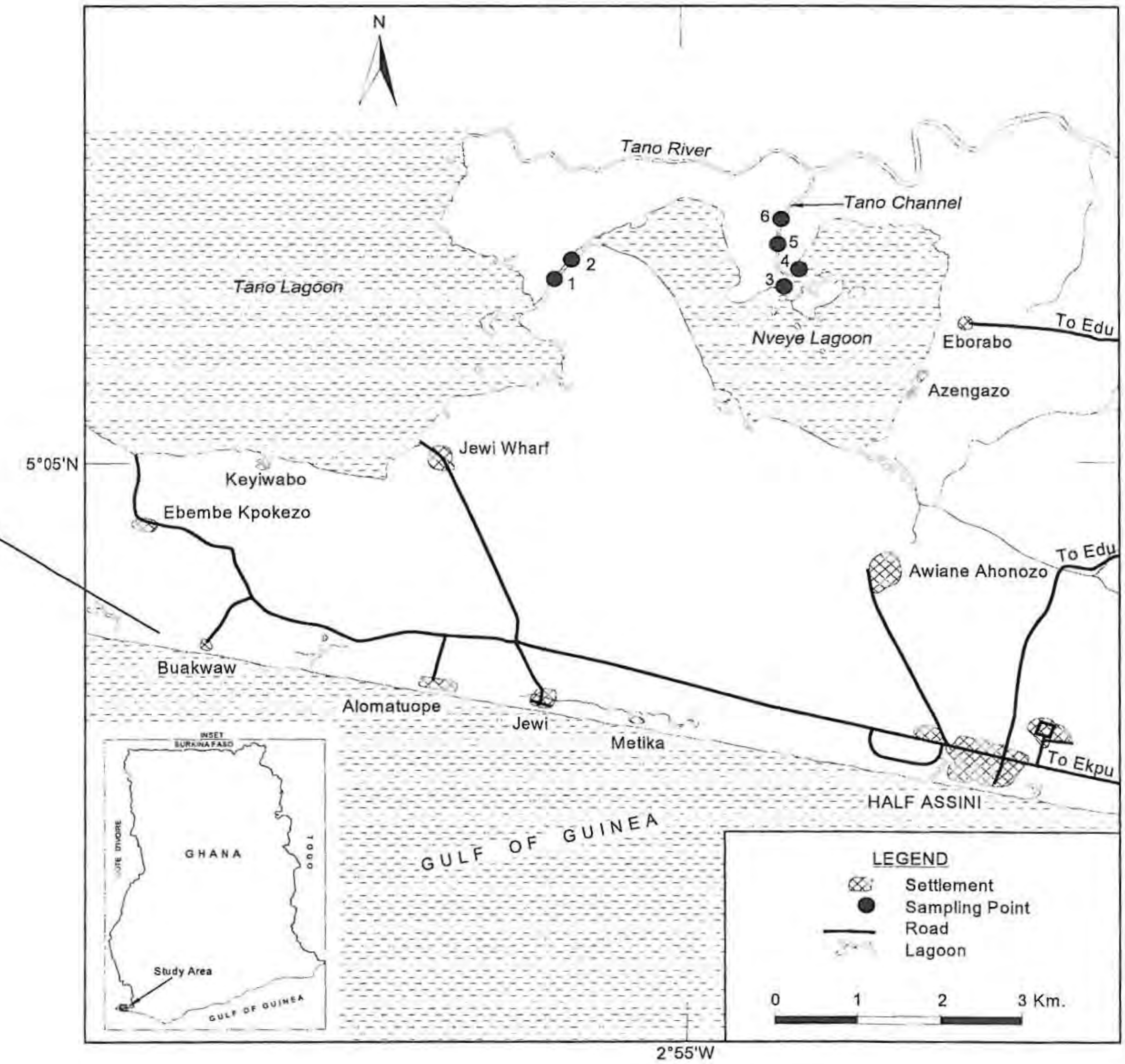

Figure 4.1 The Tano River and Lagoon complex showing sampling points

4.4.2 Assessment of the impact of biological control of water hyacinth

Qualitative monitoring of water hyacinth and *Neochetina* weevils was carried out every month from January to December, 2008. Six sites were selected (Figure 4.1), sites 1 and 2 (Zone TL) were located in the Tano Lagoon (seaward), sites 3 and 4 in the Nveye Lagoon (zone NV) and sites 5 and 6 in the main Tano River channel (zone TC) (riverine portion).

At each of the selected sites, three 0.25 m^2 quadrats were placed randomly on the water hyacinth mats and all the plants in each quadrat collected into separate polyethylene bags, labelled and transported to a site along the bank. Ten other plants were randomly selected from the mat. The following were recorded: leaf 2 petiole length, leaf 2 lamina area, number of leaves, root length, number of feeding scars and number of adult weevils per plant. Size of the water hyacinth infestation at each site and percentage of infestation sampled were also recorded. Measures of plant characters such as petiole and leaf length as well as weed cover are important in evaluating the impact of biological control of water hyacinth (Julien *et al.*, 1999). Adult weevil feeding scars were counted on the second fully expanded leaf of each plant in the sample. This is an indirect method of estimating weevil population in the field (Wright and Center, 1984). As an indicator of plant vigour, the lengths of the longest leaf blade and the petiole were measured (Delfosse, 1978). To estimate the water hyacinth coverage of the entire water body, the lagoon complex was observed from the fixed sampling sites, from where the percentage water hyacinth cover of the respective site of the lagoon complex was estimated. During sampling, the total percentage cover of water hyacinth infestation at a particular site was estimated on every occasion. The plant and insect parameters measured here are similar to those measured in other water hyacinth programmes throughout the world (Hill and Julien, 2004) and thus provide a means of comparison.

Bagged plants were washed, blotted dry, and divided into biomass components. Above water biomass consisted of all live leaf laminae and petioles and the central rhizome of the rosette (not including connecting stolons). Dead biomass consisted of leaves that were 50% or more dead (determined by visually estimating the brown portion of total laminar and petiole area) and the petiole bases of dehisced leaves. Root biomass consisted of all available root matter. The roots were detached and placed into one container, the dead parts into a second container and the leaves and stem into a third container. The roots, leaves and dead parts were weighed separately using a Camry manual spring balance, and the masses recorded.

The sampling was designed to evaluate water hyacinth growth parameters, quantify weevil feeding damage and estimate weevil populations. Rapid assessment of weevil populations was done by counting the number of *N. eichhorniae* and *N. bruchi* adult weevils separately from each of the ten plants randomly selected at each site. Larval and pupal populations were not assessed.

4.4.3 Statistic analyses

The non-parametric Kruskal-Wallis (KW-H) ANOVA by ranks and median test was used to compare the data between the sites and over the duration of the study. This was because the data did not conform to normality and/or homogeneity of variances. The Kruskal-Wallis

(KW-H) ANOVA is the non-parametric equivalent of a one-way ANOVA. As it does not assume normality, the KW-H ANOVA tests the null hypothesis of no difference between three or more group medians, against the alternative hypothesis that a significant difference exists between the medians. In a Kruskal-Wallis analysis, the *H* statistic is the actual value of the test. The value of $p<0.05$, indicates there is significant difference between the medians. The non-parametric Kruskal Wallis (KW-H) ANOVA by ranks and median test was also used to compare the feeding score data. The Statistica software (Version 6.0) package was used.

4.5 Results

Originally, the three zones (= 6 sites) were infested with water hyacinth and had populations of *Neochetina* weevils; however, there was a lower weevil infestation in the Tano channel (TC) than in Nveye Lagoon (NV) and the Tano Lagoon (TL) (Awuah, 2004). The Tano Channel is the riverine portion of the complex and is located northwards, the Nveye Lagoon, in the middle and the Tano Lagoon southwards towards the sea (Atlantic Ocean). The Tano Channel was characterized by big plants with relatively short roots; the Nveye Lagoon had a mixture of both big and medium plants, whereas the Tano Lagoon had mostly small plants (stunted) with long roots and a few big ones. These three zones were chosen because they have more than ten years of history of water hyacinth biological control.

The total percentage cover of water hyacinth in the study area fluctuated with the flooding regime of the Tano River. The floods usually lag behind the rains so although the rains started in April, it was not until June that the water hyacinth mats were flushed down towards the sea with the weevils attached. The percentage water hyacinth cover therefore also followed the flooding regime of the Tano River and Lagoon complex. The percentage cover varied between 65% and 70% (January to May) and 25% in June, decreased further to 22% in July before rising gradually to a peak of about 48% in December (Figure 4.2).

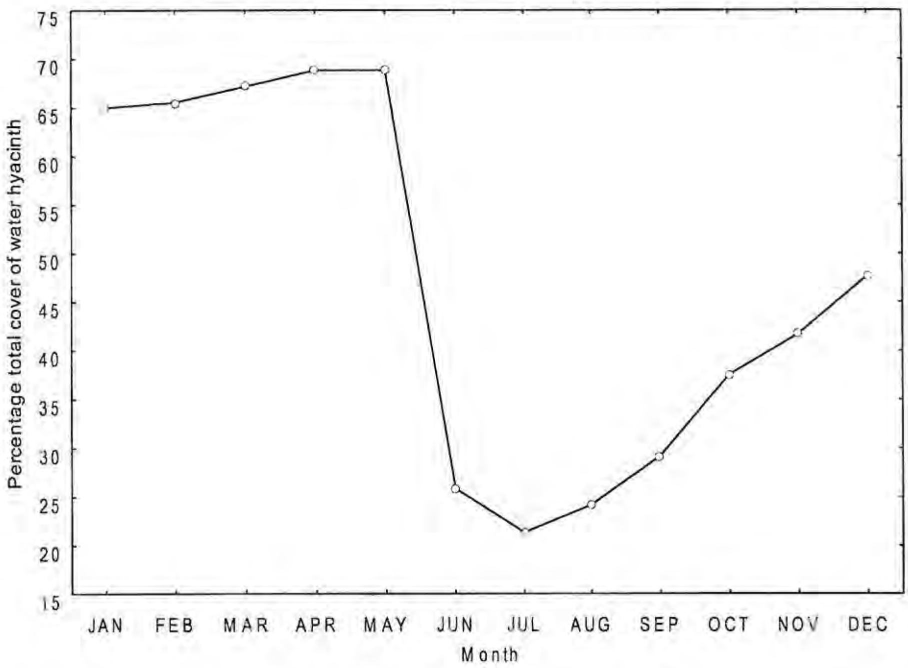

Figure 4.2 A 'typical' annual fluctuation of weed cover 15 years after the first release of biological control agents showing percentage total area of water hyacinth infestation in the Tano Lagoon, Nveye Lagoon and Tano Channel, Jan.-Dec. 2008.

4.5.1 Leaf 2 petiole length

The second leaf, and petiole, is the most actively growing part of the water hyacinth plant and the part that is favoured by the *Neochetina* weevils. It is thus routinely used as an important plant parameter. There was significant difference in the leaf 2 petiole lengths at the various sites (H (60, N = 718) = 238.4773; p <0.0001) (Figure 4.3). The longest leaf 2 petiole was recorded in December at Tano Channel (59 cm) while the shortest (17 cm) was recorded in January at Nveye Lagoon.

Tano Channel is the riverine portion of the Tano River and the weevil infestation here was not as high as in both the Nveye Lagoon and Tano Lagoon. There was therefore significant reduction in the petiole length of the plants in both the Nveye and Tano lagoons as compared to the long petioled plants in the Tano channel. Reduction in petiole length therefore could be ascribed to the feeding habits of the *Neochetina* weevils. However, the site experiences two rainy seasons/year: April to July (major) and September to November (minor), with a short dry spell in August and a longer dry period from December to March. During the rainy seasons, the volume of water in the Tano River increases and flood waters overflow their banks, dislodge and scatter water hyacinth plants and carry them downstream while the volume of the river reduces in the dry season. The shorter petioles at this site could therefore be due to regrowth from plants remaining. This illustrates the need to understand the dynamics of the ecosystem and for long-term monitoring. It would be easy to ascribe short petioles at the Tano River sites to the weevil damage but this might not be the case.

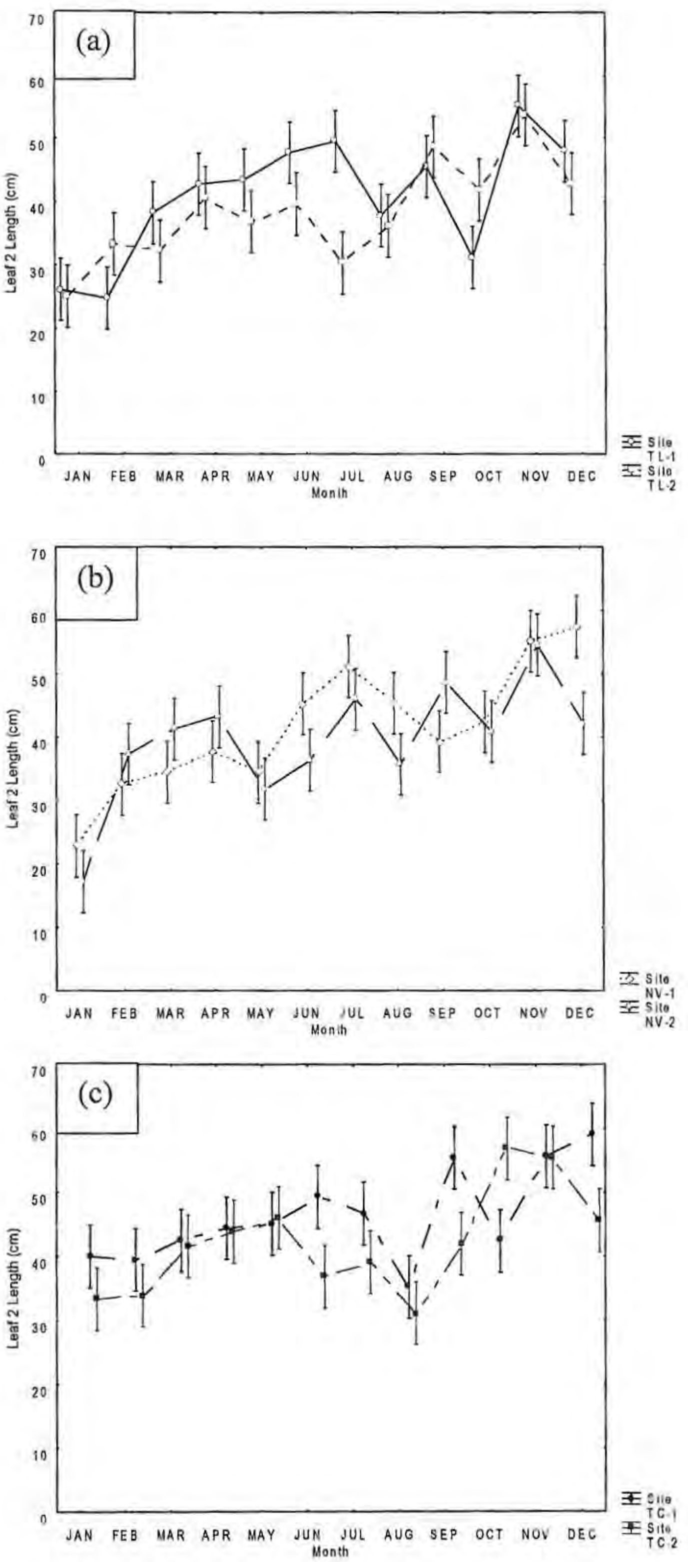

Figure 4.3 Mean Leaf 2 petiole length (cm)/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.2 Leaf 2 Area

There were significant differences between the lamina areas of the leaves at all the sites. (H 5, N = 720) = 87.8708; $p = 0.0001$) (Figure 4.4). The biggest leaf 2 surface area recorded was 240 cm^2/plant in September at site TC, while the smallest surface area was recorded at site NV in January and was 98 cm^2. The weevils thus caused significant reductions in the leaf lamina areas of the water hyacinth plants in both the Nveye Lagoon (215 cm^2) and Tano Lagoon (220 cm^2) lagoons as compared to the Tano Channel, where weevil activities were not as intense (See section 4.6.7). In general, the small leaf surface areas suggest the presence of stress from abiotic factors (Gopal and Sharma, 1981), such as weevil feeding (DeLoach and Cordo, 1983; Center *et al.* 1999b), and/or pathogen infection (Charudattan *et al.* 1978). The reduction in the leaf lamina size associated with herbivory means that the plant has far less surface area for photosynthesis.

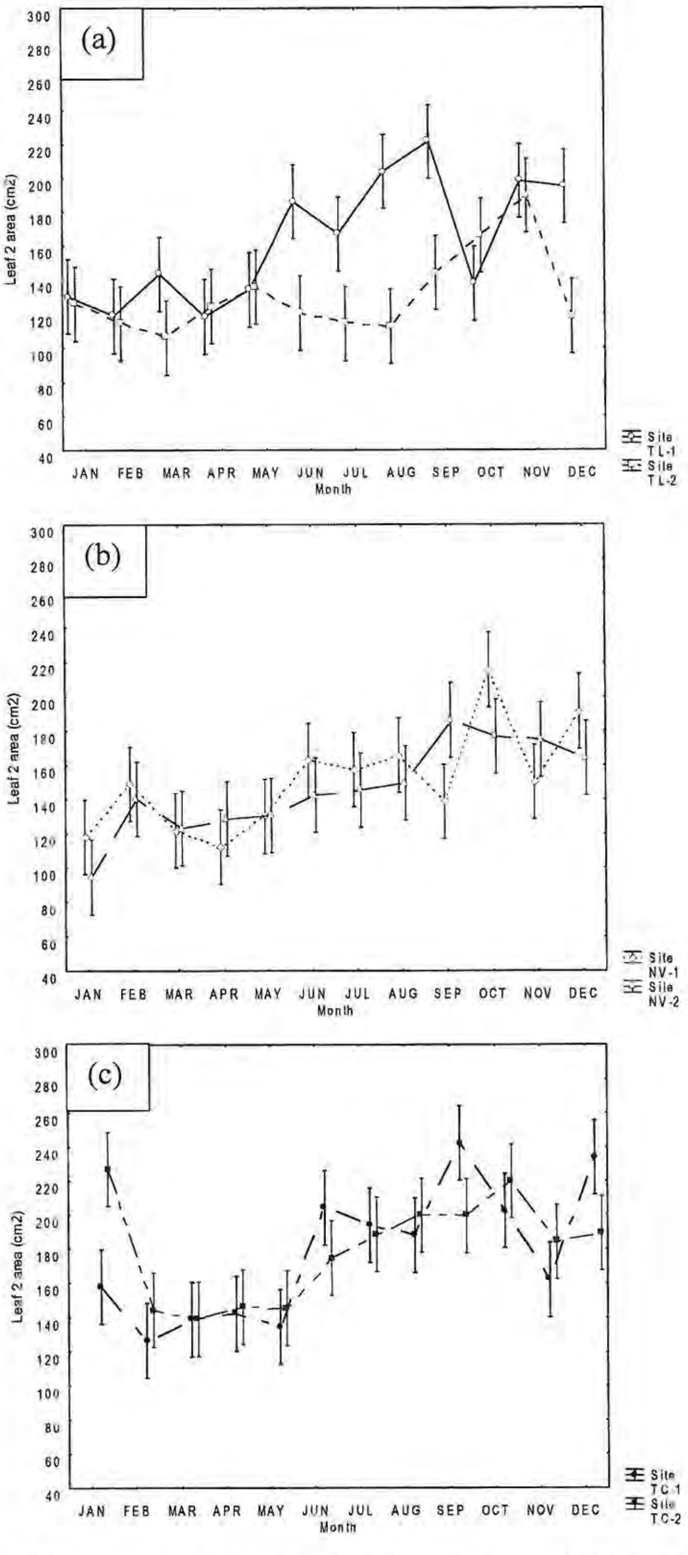

Figure 4.4 Mean Leaf 2 area (cm^2)/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.3. Maximum root length

There was significant difference in the maximum root lengths of the water hyacinth plants in the various sites. H (40, N = 720) = 66.03468; $p = 0.0059$ (Figure 4.5). The maximum root length recorded during the study was in March (37 cm) and at the site NV, 34 cm at TL in May and 34 cm at TC in April while the shortest was recorded at site TC in October (15 cm) with TL (18 cm) in June, and NV (20 cm) in November. Root length is determined by water quality and is not influenced by herbivory. According to Soti and Volin (2010), biomass allocation response of water hyacinth grown in low nutrients supported the expectation that plants experiencing nutrient limitation will produce more roots to increase their capacity to absorb nutrients. There are varying degrees of nutrient loading in the Tano River and lagoon complex at different times of the year, so the water hyacinth plants respond appropriately at the various sample sites. The flood waters from the rising Tano River deposit more nutrients in the rainy season at Tano Channel site first, hence the shortest value for root length was at site TC in October, which is within the minor rainy season while both the TL and NV sites recorded the highest mean root lengths. Thus root length is purely an indication of water quality and has no relationship with levels of biological control.

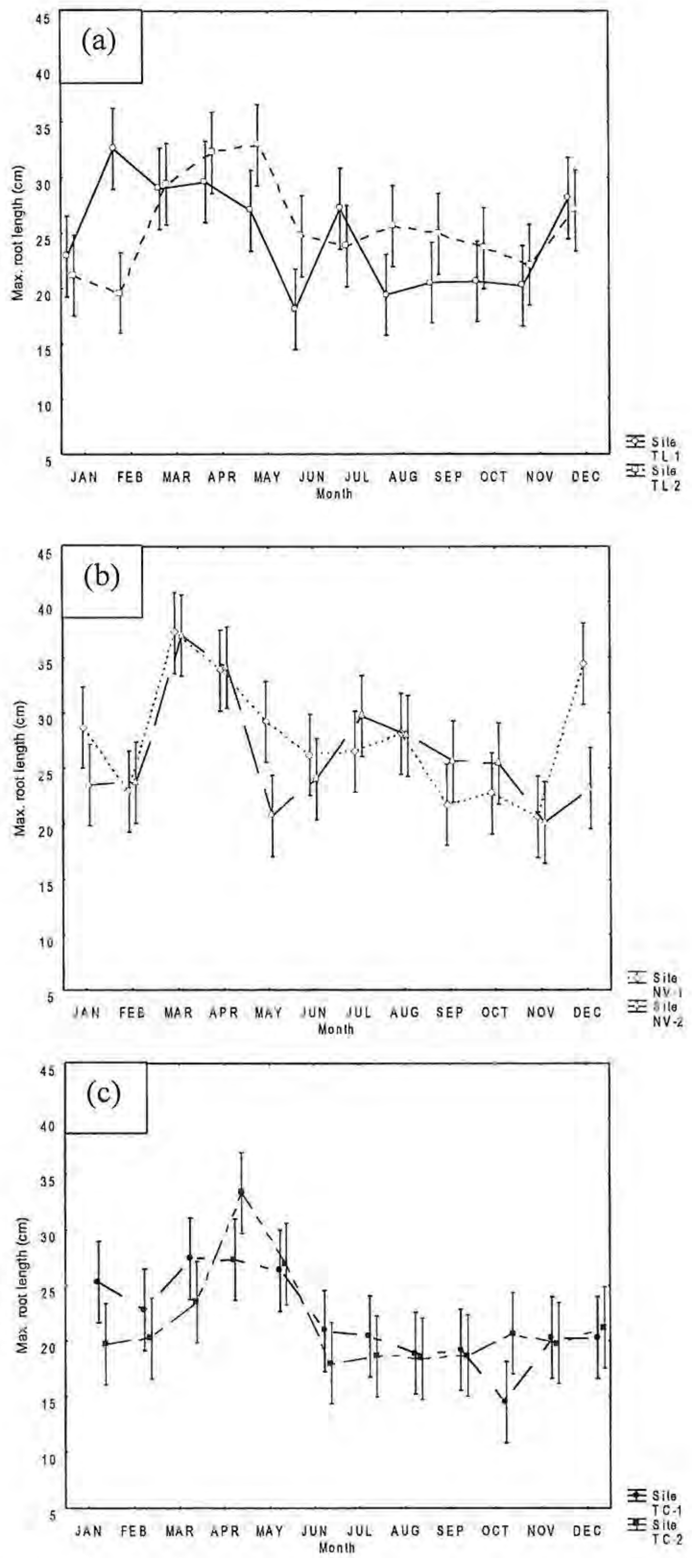

Figure 4.5 Mean of maximum root length/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.4 Number of ramets (daughter plants)

The number of ramets per plant was significantly different at all the three sites. (H 8, N = 720) = 39.03498; $p < 0.0001$) (Figure 4.6). The highest mean number of ramets produced was 3.5/plant at TL in August, followed by 3.0/plant in July at site TC and 2.5/plant at site NV in January and November. The lowest mean number of ramets was 0.3/plant at sites TL in May and NV in February. In normal growth, large numbers of both leaves and ramets are produced per plant, but the weevils, through their activities, reduced the mean numbers of leaves and ramets produced per plant. In heavy infestations, the meristematic tissues (i.e., new leaves and daughter plants) are destroyed, resulting in less overall productivity and growth. As damage increases, plant growth rate is reduced and the production of new leaves and new stolons is reduced. Plant size (height, weight, size of leaves, size of stolons) declines. According to Bownes (2009), herbivory suppresses daughter plant production, albeit by different agents whereas plants not subjected to herbivory will continue to reproduce vegetatively. Asexual reproduction by water hyacinth is affecting importantly density and spread of water hyacinth populations, therefore a reduction in productivity would reduce expansion of water hyacinth mats and reduce its invasive potential.

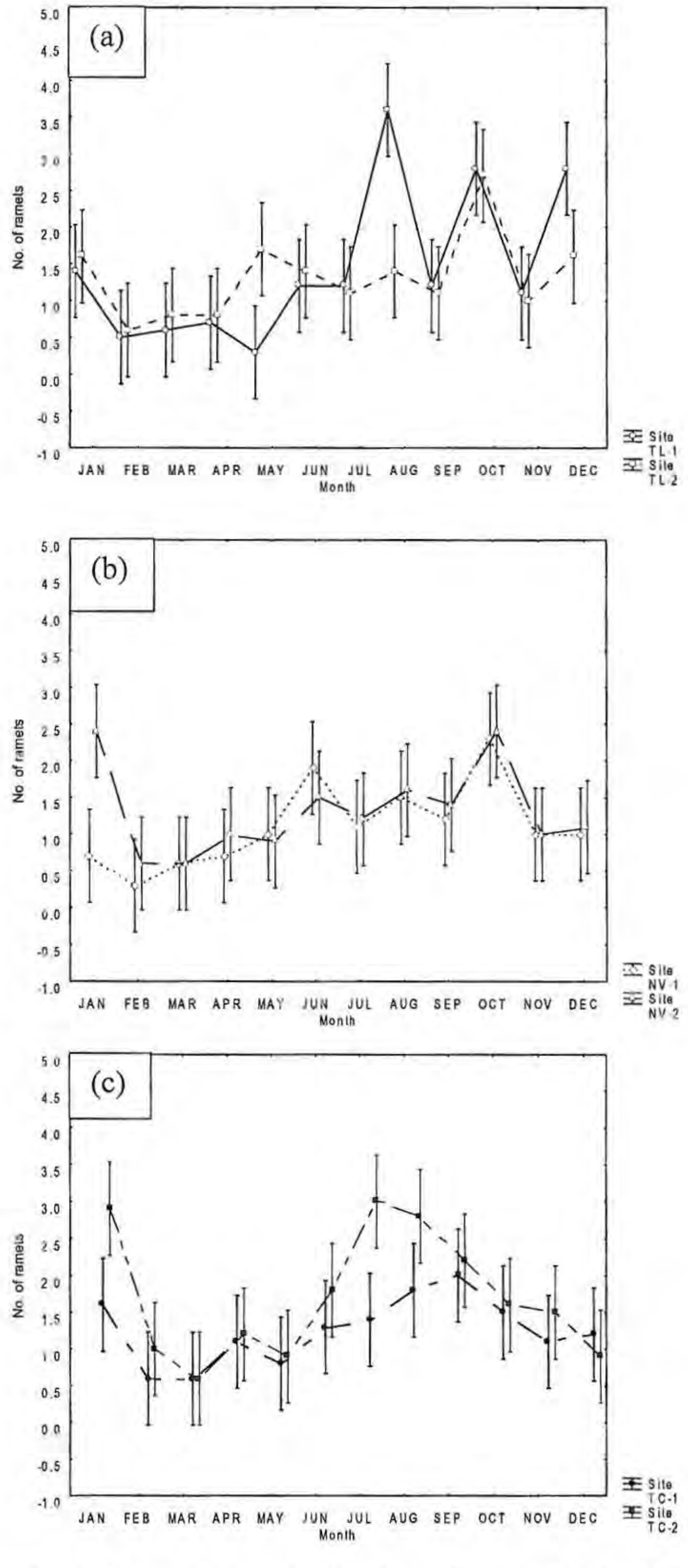

Figure 4.6 Mean number of ramets/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano channel (TC) (c), Jan.-Dec. 2008

4.5.5 Number of flowers

The distribution of the number of flowers per plant was not significantly different between the three sites. (H 5, N = 720; = 0.649336; p = 0.9856) (Figure 4.7). The mean highest number of flowers produced was 1.1/plant at site TL in June, 1.0/plant at site NV in May and 0.2/plant at site TC in January (peaks). In biological control of water hyacinth, destruction of seeds is vital. This is because the seeds remain in the mud and cause regeneration of new infestations long after initial control has been achieved. The sexual reproductive phase of the plant, however, requires considerable energy. Flower production therefore lowers both leaf and ramet production. Pieterse *et al.* (1976) observed that non-flowering plants produced over twice the number of ramets and nearly double the biomass compared with flowering plants. Flowering appeared to be stimulated by nutrient-stress in Coetzee *et al.*'s (2007) study, but was not significantly reduced by herbivory at any of the nutrient levels tested.

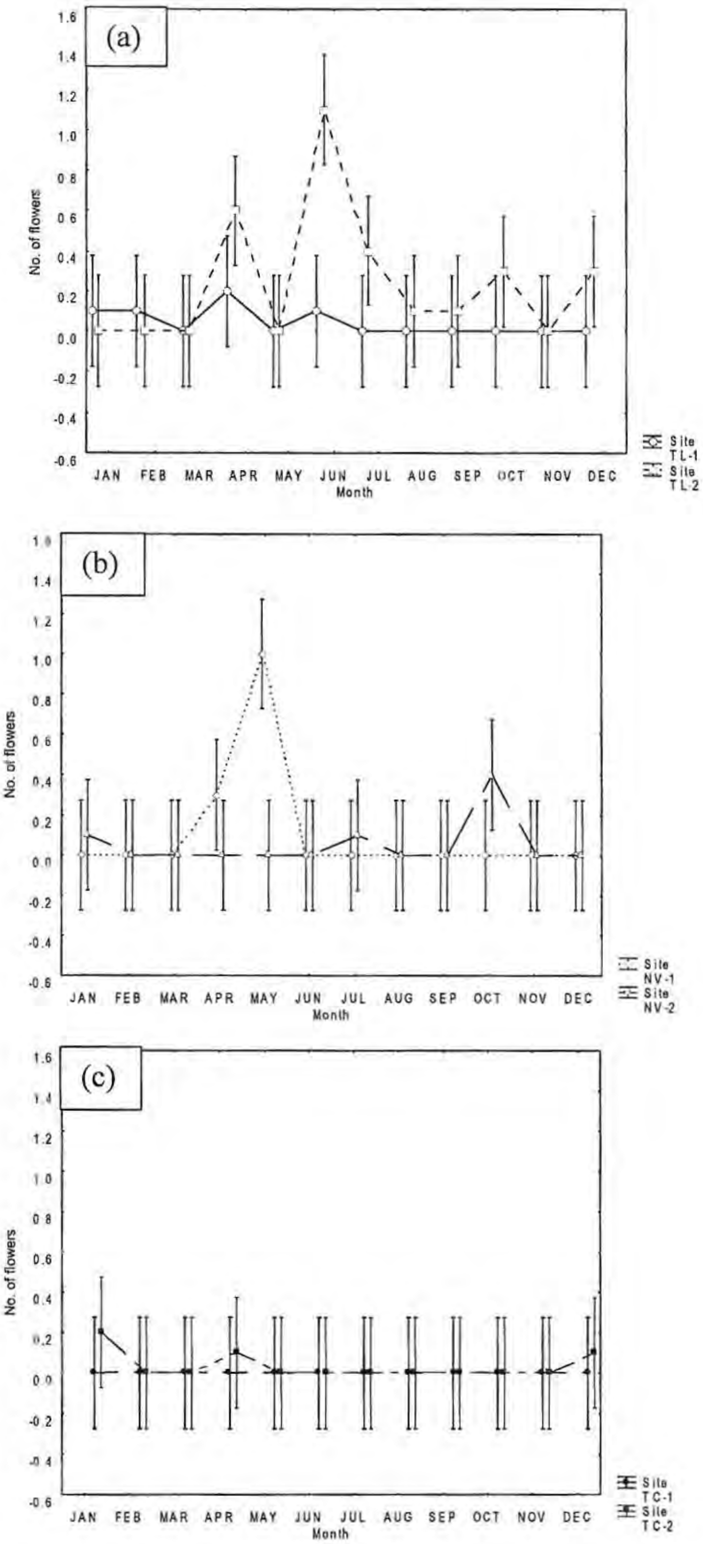

Figure 4.7 Mean number of flowers/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.6 Number of leaves

The distribution of the number of leaves per plant was significantly different for all the three sites. (H (13, N = 720) = 148.5992; $p < 0.0001$) (Figure 4.8). The mean numbers of leaves per plant was higher at the NV site (10.2) than at the TL (9.2) and TC (9.0) sites. The mean least number of leaves recorded was TL (4.9), NV (4.4) and TC (3.9). It must be noted that though the TC had the least number of leaves, it also had the largest surface area of leaves. The number of leaves per water hyacinth plant determines the health status of the plant. A number of green leaves borne by the water hyacinth is an indication that the plant is healthy and is under no stress at all, but few mottled and curly leaves indicate stressed condition Center and Spencer (1981). *Neochetina* adults feeding results in a reduction in the number of leaves per plant, and more specifically it reduces leaf turn-over rate. Center and Spencer (1981) showed a consistency in the number of water hyacinth leaves and report that a range of 6-8 functional leaves is the normal complement for a mature water hyacinth plant and leaf production and senescence reach an equilibrium resulting in the retention of a nearly constant leaf complement. The leaves are responsible for giving the plants buoyancy and an upset in the balance between leaf production and mortality rates will compromise the ability of plants to stay afloat, and therefore their survival (Center and Van, 1989).

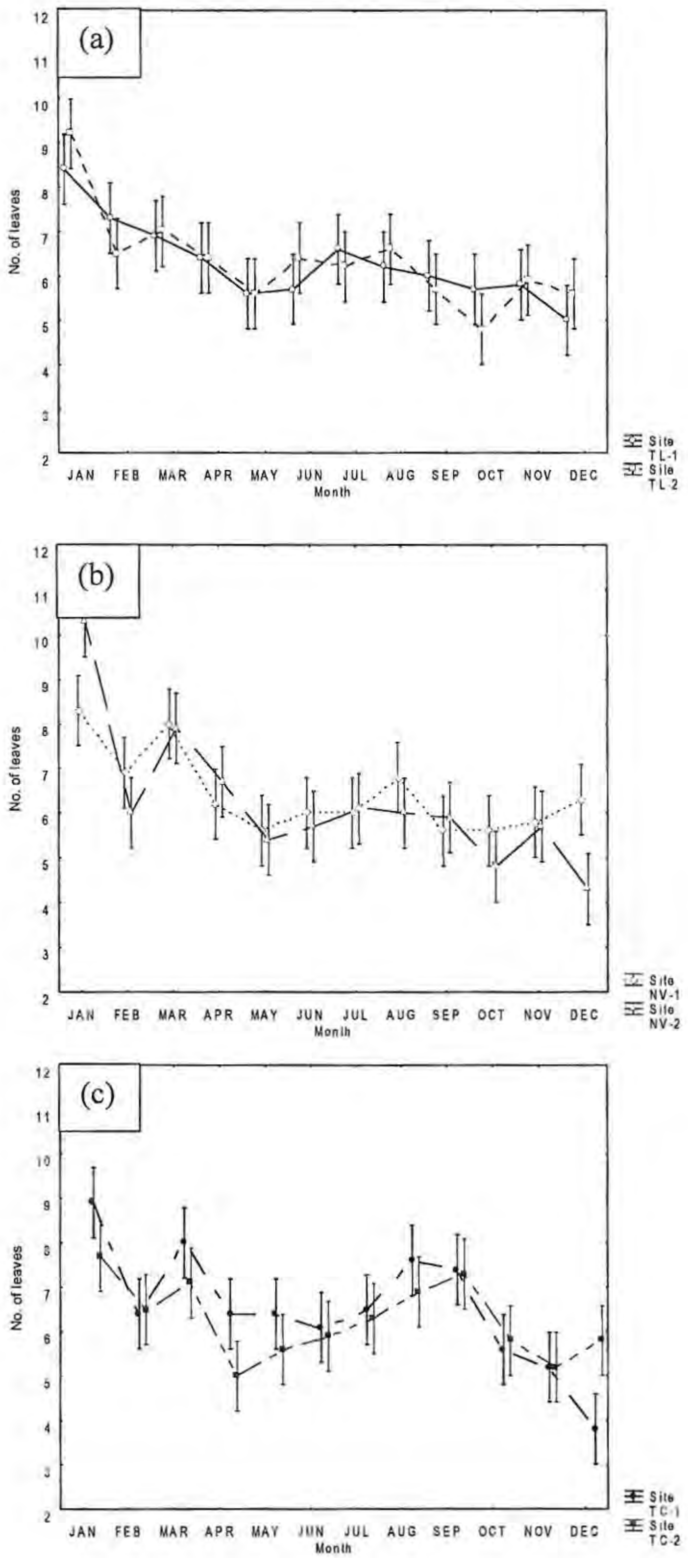

Figure 4.8: Mean number of leaves/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.7 Number of *Neochetina eichhorniae* weevils

The distribution of the number of *Neochetina eichhorniae* weevils per plant was significantly different for all three zones. H (4, N = 720) = 10.38706; $p = 0.0344$ (Figure 4.9). The highest mean number of weevils per plant was 1.3 at the site NV, 1.1 in the TC and 0.6 in the TL. The density of the weevils (i.e. the number of weevils per plant) determines the level of damage that is inflicted on the plant by the weevils. The higher the weevil density, the greater the impact of the weevils will be on the plants. For significant impacts the weevils must establish and their numbers must increase to thresholds that will impact negatively on the water hyacinth population build-up. In this study the number of larval mines per plant was not recorded and should be done in future. The larvae are the most damaging part of the life cycle and their feeding on meristematic tissue significantly impacts plant growth and leaf turnover rate. Adult feeding on the young, unfurled wrapper leaf can cause structural damage to the leaf resulting in incomplete development. Thus measuring adult populations is also important.

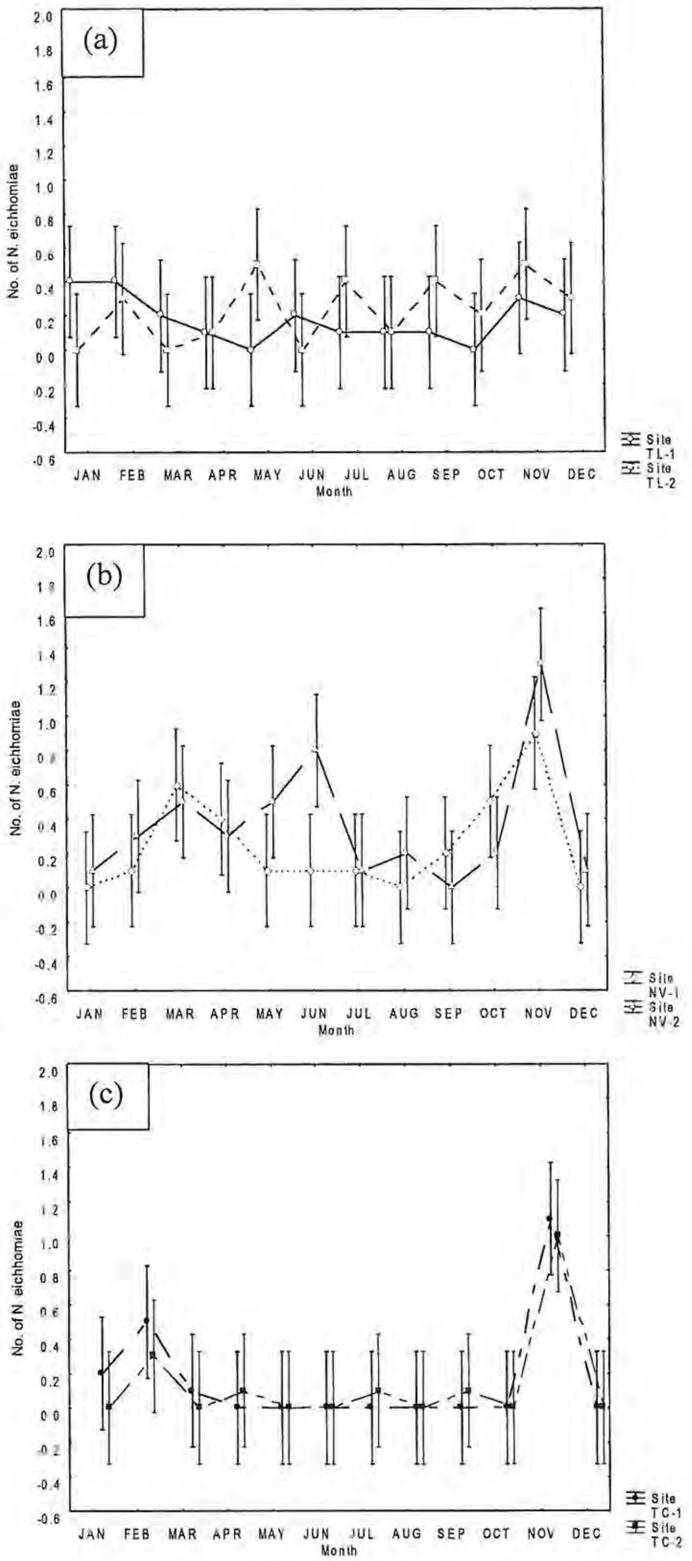

Figure 4.9 Mean number of *Neochetina eichhorniae* weevils/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.8 Number of *Neochetina bruchi* weevils

The distribution of the number of *Neochetina bruchi* weevils per plant was not significantly different for all three sites. (H (5, N = 720) = 1.033902; p = 0.9598) (Figure 4.10). The highest mean numbers of weevils per plant was 1.2 at the site NV, 0.9 in the TC and 0.8 in the TL. The number of *N. bruchi* per plant appears to be similar to that for *N. eichhorniae*.

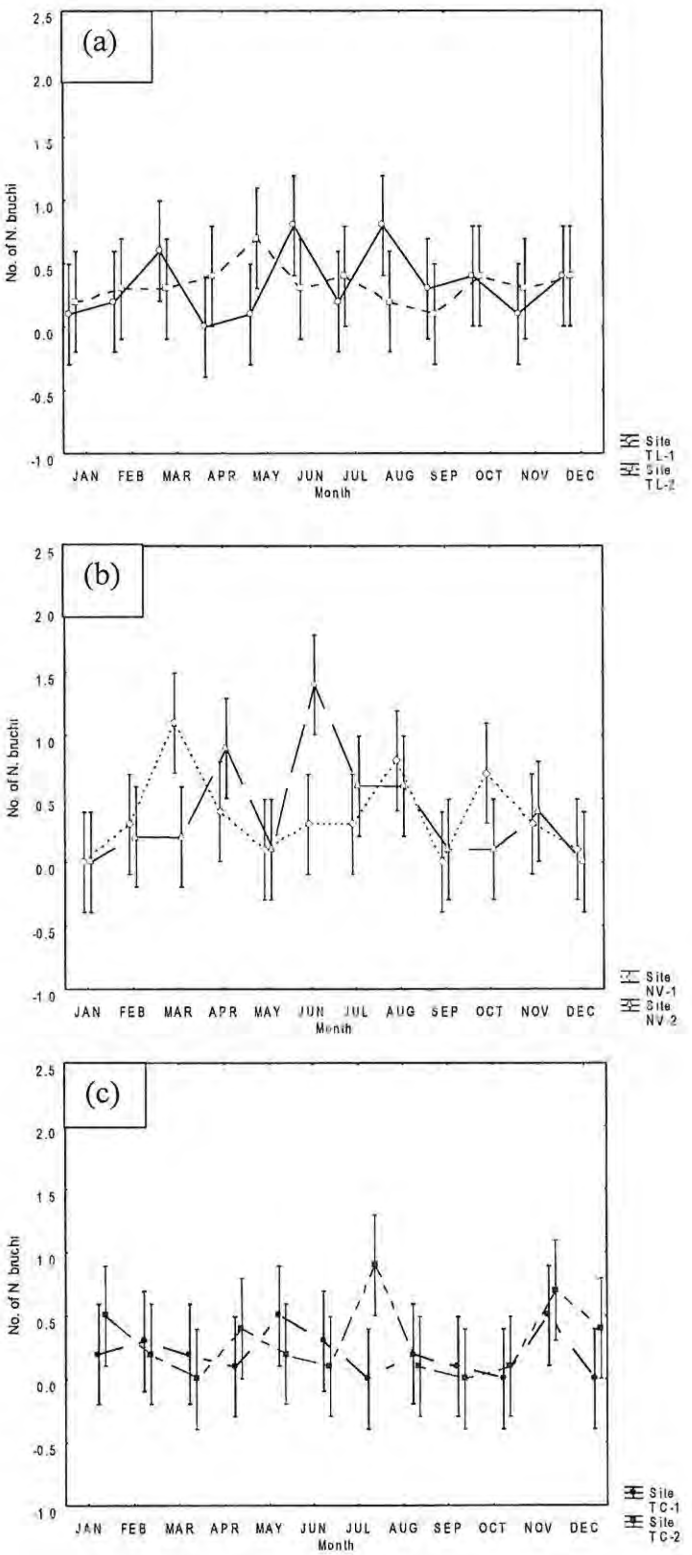

Figure 4.10: Mean number of *Neochetina bruchi* weevils/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.5.9 Number of feeding scars

The distribution of the number of feeding scars per plant was significantly different for all three zones. (H (138, N = 720) = 241.7872; $p < 0.001$) (Figure 4.11). Unfortunately the adult feeding scars of the two weevil species are indistinguishable. The highest mean numbers of feeding scars per plant was at the site NV (152/plant), followed by TL (150/plant) and then TC (90/plant). The distribution of the number of feeding scars/cm^2 is not significantly different for all three zones (H (2, N = 61) = 2.86925; $p = 0.2382$) (Figure 4.12). The highest mean numbers of feeding scars/cm^2 was at site NV (1.3/cm^2) in April, followed by site TL (1.1/cm^2) in December and then TC (0.65/cm^2) in both February and November.

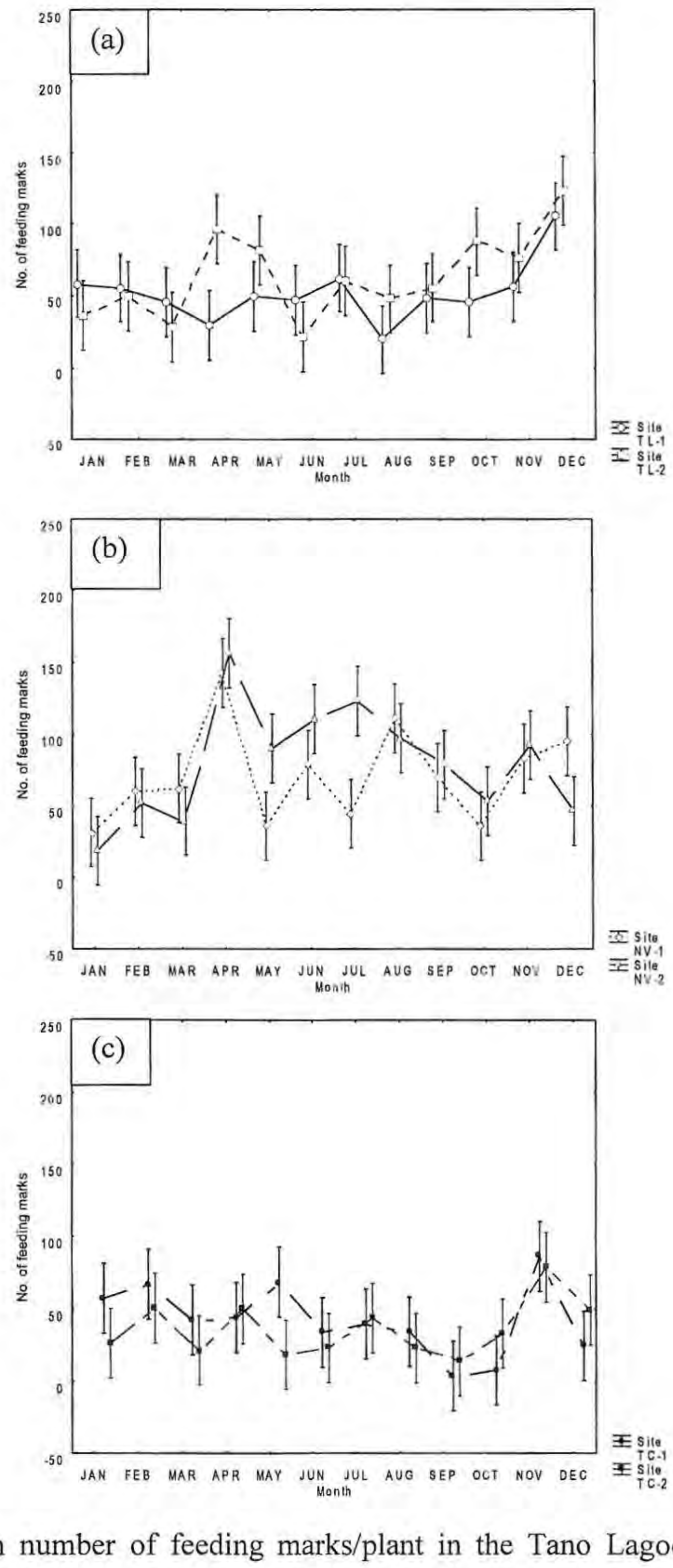

Figure 4.11: Mean number of feeding marks/plant in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

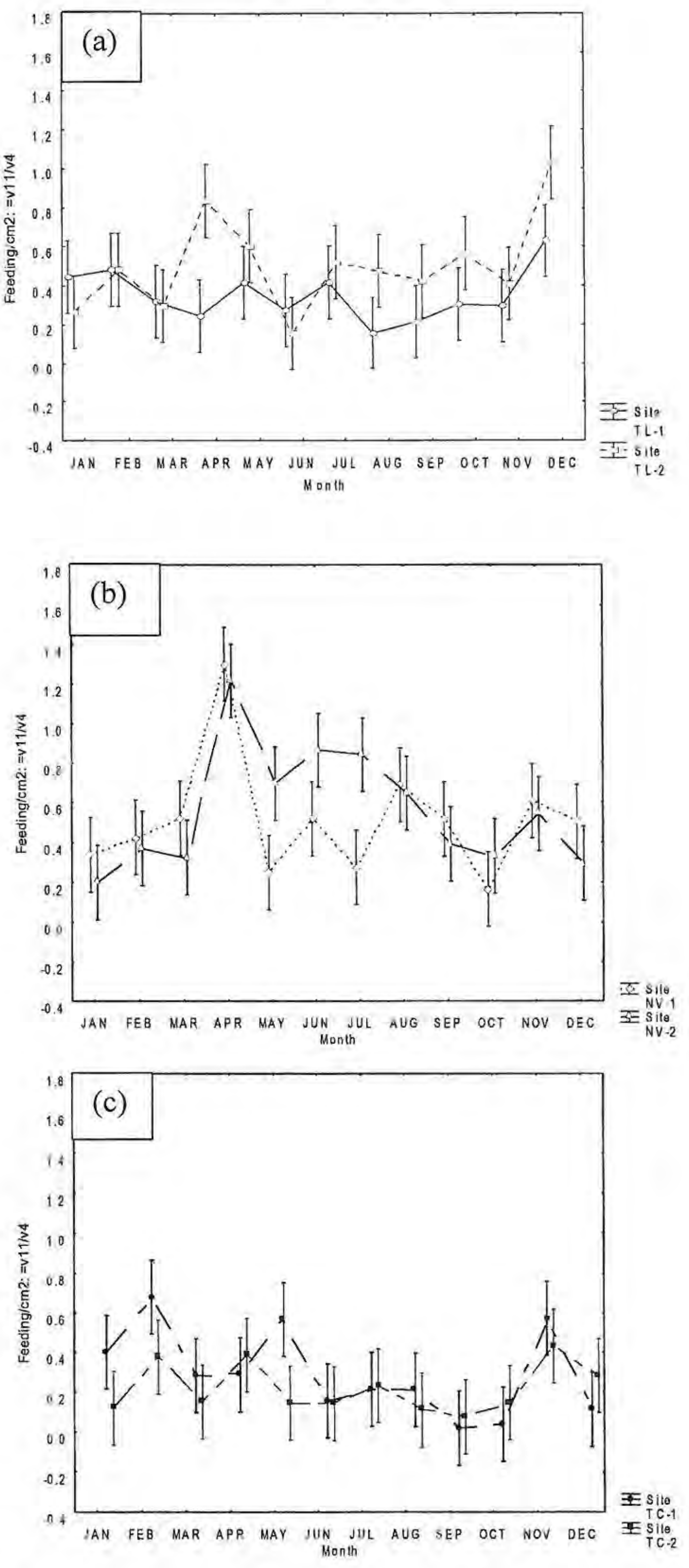

Figure 4.12: Mean number of feeding scar/cm^2 of leaf area by *Neochetina* weevils in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.6 Weed biomass

The weed biomass is defined as the amount of weed mass in a particular area or volume. The effect of a water hyacinth population over the water ecosystem depends on this variable. According to Wilson (2002), the problems caused by water hyacinth are due to the quantity of vegetation, and only biomass density gives an accurate measure of this. Plant biomass was obtained by weighing samples from the field and estimating the weight of the population. The three components of water hyacinth biomass (roots, dead plant parts, and total live above-water plant parts) varied significantly between field sites across all sampling times (Figures 4.13 - 4.15).

4.6.1 Biomass above water

The distribution of the biomass of water hyacinth parts above water was significantly different for all three zones (H (71, N=216) = 124.7441 $p < 0.0001$) (Figure 4.13). The biomass of water hyacinth parts was highest (12.2 kg/m^2) at site TL-2 in October, 12.1 kg/m^2 at site NV-1 in November and 12.1 kg/m^2 at site TC-1 in November (peaks). The lowest mass was 3.0 kg/m^2 recorded at site NV-1 in September, 3.8 kg/m^2 at TC-1 in July, and 4.1 kg/m^2 at TL-2 in March. The highest values for the biomass above water coincided with the rainy season (April-July and September-November), while the lowest values also coincided with the dry season (August and December - March). This can be attributed to the massive growth experienced during the rainy season due to the availability of nutrients and the reduction in growth during the dry season due to a reduction in the availability of nutrients. Above water-biomass consisted of all living leaf laminae and petioles and the central rhizome of the rosette (not including connecting stolons). It is described as the cover and defined as the space covered by the weed as seen from above (Brower and Zar, 1977). Maintaining leaf biomass also maintains the capacity for carbon acquisition which is needed for growth and survival. Leaf biomass also increases with nutrient supply therefore plants in the rainy season (high nutrient treatment) had a greater capacity for carbon gain with greater overall surface area for photosynthesis and higher photosynthetic rates that correspond with high levels of nitrogen availability (Ripley *et al.*, 2006).

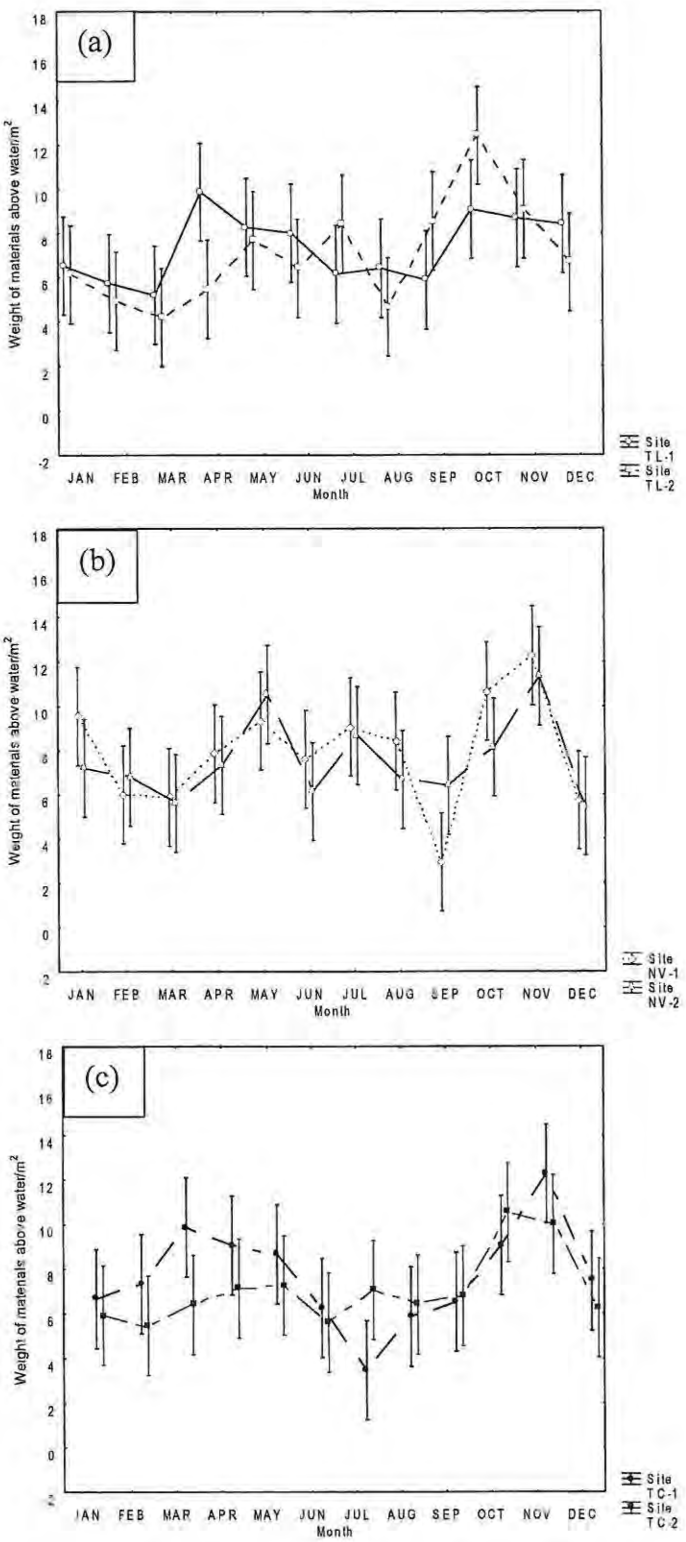

Figure 4.13: Mean biomass of plant parts above water in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (a) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.6.2 Biomass below water (root biomass)

The distribution of the biomass of water hyacinth parts below water was significantly different for all three zones (H (71, N=216) = 148.0327; $p < 0.0001$) (Figure 4.14), and corresponds with root length. The highest values for the biomass below water recorded were 9 kg/m^2 in November at site NV-1 and NV-2. 8 kg/m^2 in July at TL-2 and 6.5 kg/m^2 in April at TC-1. The low values recorded were 1.8 kg/m^2 in September at site TL-1, 1.7 kg/m^2 in September at NV-1 and 1.5 kg/m^2 in July at TC-1. Root biomass consisted of all available root matter. The value of the root biomass is an indication of the nutrient status of the water. The high values were recorded in the rainy season while the low values were recorded in the dry season.

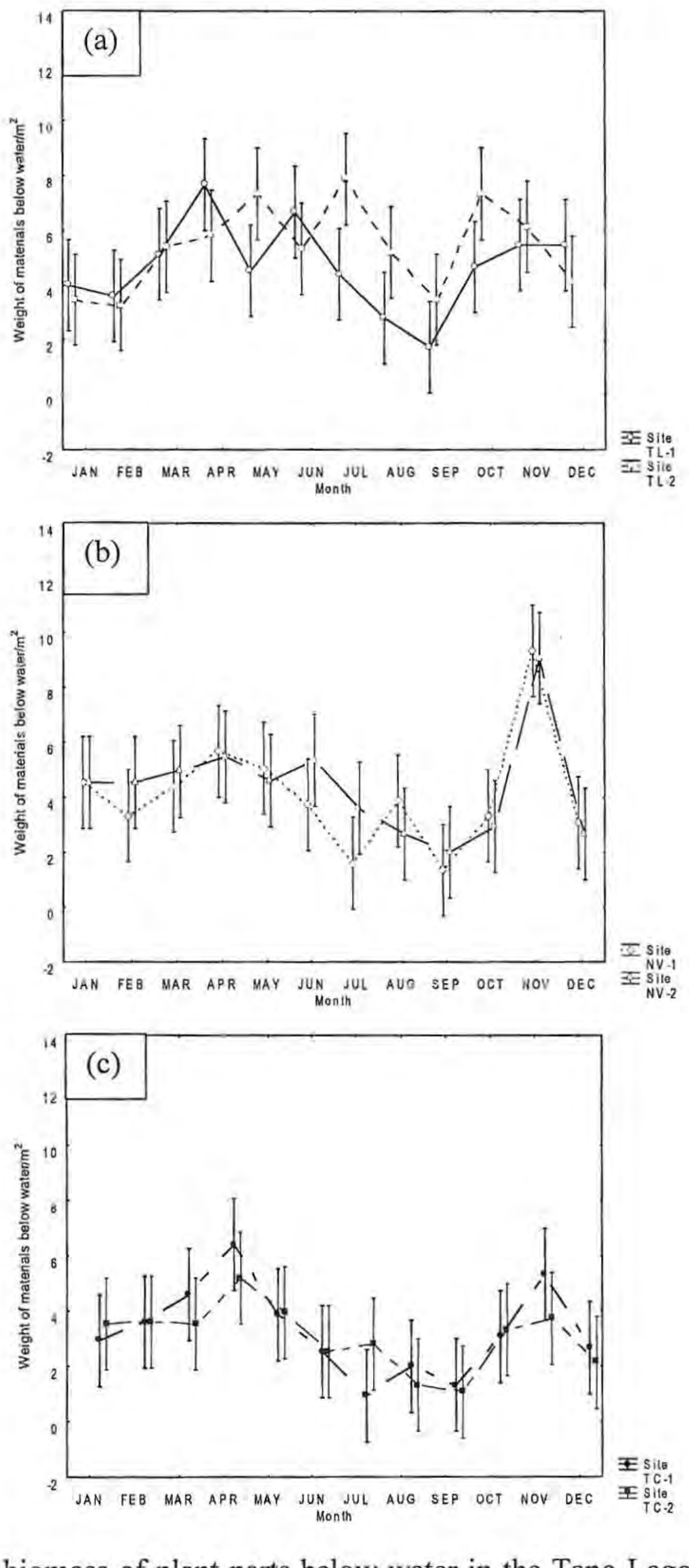

Figure 4.14: Mean biomass of plant parts below water in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.6.3 Biomass of dead plant matter

The distribution of biomass of dead water hyacinth parts was significantly different for all three zones (H (71, N=216) =148.6866 $p < 0.0001$) (Figure 4.15). The values of the mean biomass of the dead matter were higher than the biomass of the above water parts at NV-13kg/m^2 in December, 9.0kg/m^2 at TL in August and 6.9kg/m^2 at TC in May. Dead biomass consisted of leaves that were 50% or more dead (determined by visually estimating the brown portion of total lamina and petiole area) and the petiole bases of dehisced leaves.

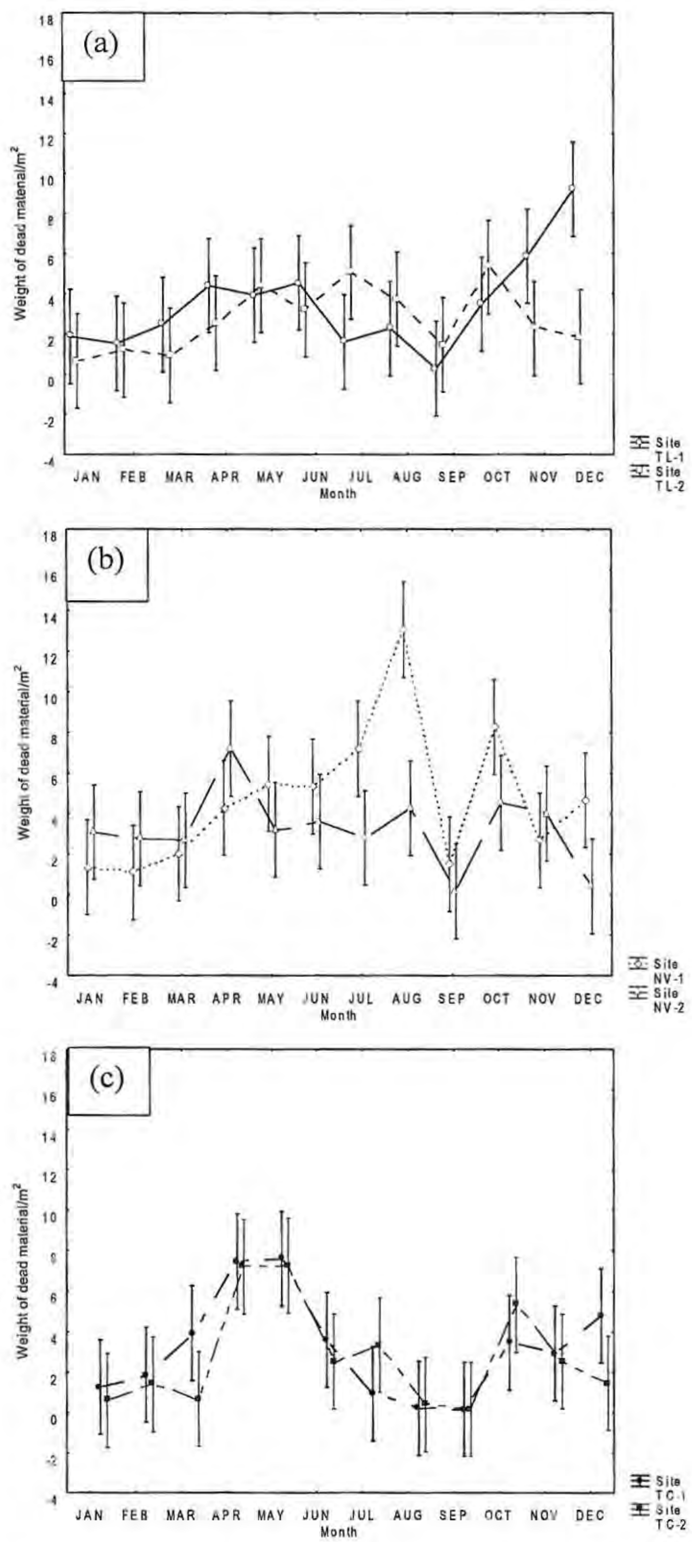

Figure 4.15: Mean Biomass of dead plant parts in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.6.4 Ratio of above-water biomass to below-water biomass

The distribution of the ratio of biomass of water hyacinth parts above water to parts below water was significantly different for all three zones (H (71, N=216) = 139.6364; $p < 0.0001$) (Figure 4.16). Above-water biomass was divided by root biomass to estimate shoot-to-root ratios. The ratio of above-water biomass to below-water biomass at all the sites appears to be uniform (2.5), except in September, where the value was 7 at site TL-1, 25 at site NV-1 and 11 at site TC-1.

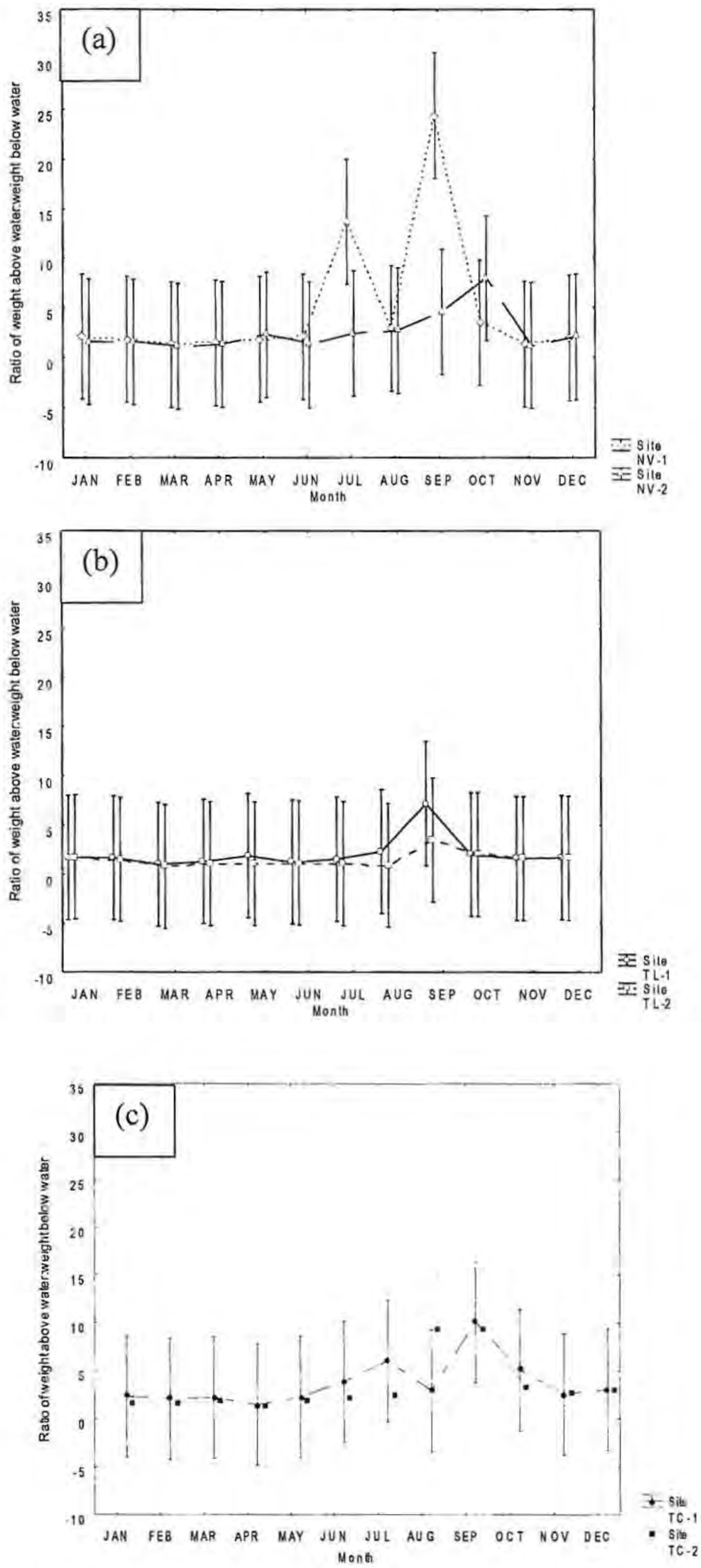

Figure 4.16: Ratio of biomass of plant parts above water to plant parts below water in the Tano Lagoon (TL) (a), Nveye Lagoon (NV) (b) and Tano Channel (TC) (c), Jan.-Dec. 2008.

4.6.5 The relationship between feeding/cm^2 on leaf 2 of water hyacinth plants by the *Neochetina* weevils by seasons

According to Wright and Center (1984), an indirect method of estimating adult weevil populations on water hyacinth in the field is by counting the number of feeding scars on the 2nd fully expanded leaf of each plant in the sample. In this study, the density of weevil scars (feeding/cm2) was compared at each of the zones (NV, TC, TL) during the dry season (November-April) and the wet season (May-October). There was a significantly higher density of scars and thus adult weevil population at NV, TC and TL during the dry season, and TC during the wet season than NV and TL during the wet season (Fig. 4.17).

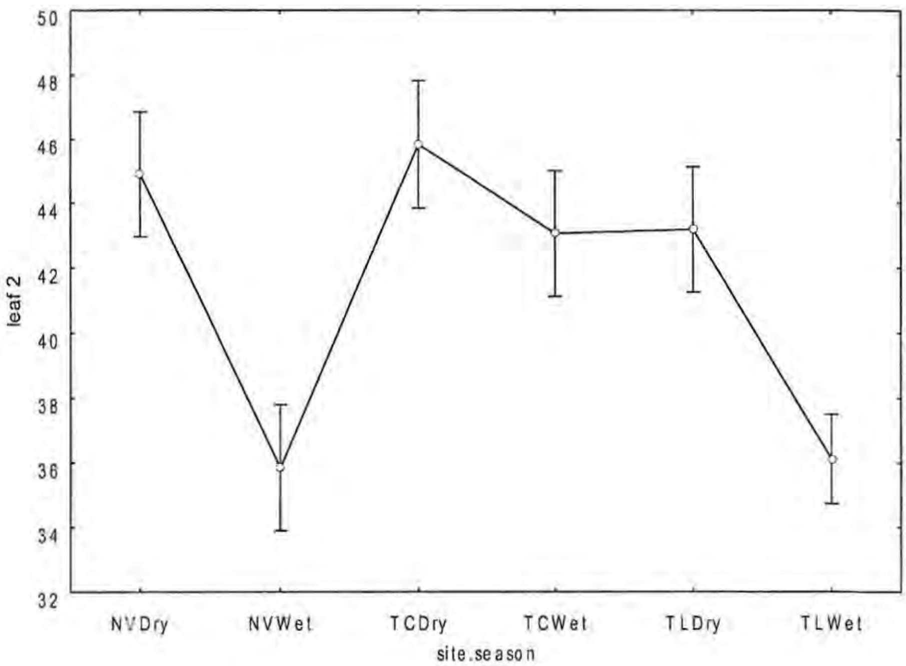

Fig. 4.17: The relationship between feeding/cm^2 on leaf 2 of water hyacinth plants by the *Neochetina* weevils by seasons (or feeding/cm^2 on leaf 2 against the seasons and sites) as a function of increasing or decreasing levels of herbivory ($F_{5;831} = 23.775$, $P < 0.0001$).

Although significant, the relationship between weevil feeding density and plant height at each site during each season was weak (Table 4.1), suggesting that adult feeding had no effect on plant vigour.

Table 4.1: Regression analysis of the effects of herbivory by *Neochetina eichhorniae* and *Neochetina bruchi* on leaf 2 during the wet and dry seasons at the 3 zones (TC, TL and NV).

Site	Season	R	R^2	p-value	F-value
Tano Channel	Wet	0.172682	0.029819	0.059291	3.626801
	Dry	0.145981	0.021310	0.111623	2.569392
Tano Lagoon	Wet	0.176169	0.031035	0.054265	3.779474
	Dry	0.198996	0.039599	0.029338	4.865396
Nveye Lagoon	Wet	0.210331	0.044239	0.021121	5.461869
	Dry	0.128384	0.016482	0.162280	1.97750

4.7 Discussion

Successful biological control has occurred in various locations in the world, and where biological control of water hyacinth is demonstrably successful, it has been a result of the activities of either *N. eichhorniae* or *N. bruchi* or both (Julien, 2001). Successful controls have been recorded in Argentina, Australia, India, USA, Papua New Guinea, Zimbabwe, the three Lake Victoria countries (Uganda, Tanzania and Kenya), South Africa and Thailand (Harley, 1990; Julien *et al.* 1999; Hill and Olckers, 2001). In the USA, Center and Durden (1986) identified characteristics of water hyacinth infestation in a state of decline due to attack by *Neochetina* sp. and noted that adult feeding had destroyed over 35% of the lamina area in some cases. They observed that colonization by *Neochetina* sp. first reduces plant size and then decreases the coverage of water and provided the weevils are well distributed over the infestation, control may be expected in three years. Again, in Louisiana in the USA, *Neochetina* sp. have reduced the height, density and biomass of water hyacinth and the area under infestation has decreased from 445,154.21 hectares in 1974 to 121,850.85 hectares in 1980 after their initial release between 1972 and 1977 (Cofrancesco *et al.,* 1985). High levels of control by *Neochetina* sp. have been achieved at many water hyacinth infestation sites in the tropical regions of Australia and Africa. The first reported collapse of water hyacinth was in 1978, three years after their initial release in 1975, following severe damage by *N. eichhorniae* at an infestation site at Rockhampton (Wright, 1979) and also in Benin (De Groote *et al.*, 2003; Ajuonu *et al.*, 2003).

In Ghana, according to Wilson and deGraft-Johnson, (1995) and deGraft-Johnson and Hoevers (1998), one year after the initial releases, the *Neochetina* sp. spread unassisted and reached water hyacinth infestation areas some 150 km from the nearest release sites. The attributes that made these control programmes successful in Ghana are: they are subtropical or tropical areas, the weed mostly grew as a monoculture and the weed was free to sink once damaged and was not supported by other plants; nor were the roots resting in mud beneath water, the weed was not subjected to regular removal by periodic or annual flows and so insect density increased unabated to damaging levels, the mats were stable for long periods so that insect numbers could build up. In some instances, the action of wind and waves assisted the rate of damage and sinking of mats, e.g. Lake Victoria, Uganda (Julien, 2001). It is probable that control would have occurred regardless, although the level of control may have been less, or simply have taken longer. In other locations, the lack of the additional stresses on the damaged plants imposed by wind and wave buffeting may limit control (Hill and Olckers, 2001). In other instances, the reduction in plant growth and stature, resulting from insect attack, caused mats to disintegrate into smaller components that could be flushed from lagoons via narrow channels and hence to the ocean, e.g. lagoon of the Sepik River in Papua New Guinea. This flushing-out accelerated the rate of removal of water hyacinth from the system, but it is likely that the heavily damaged plants would have been destroyed and sunk anyway, as occurred at other impounded locations, e.g. Lake Phayao, Thailand and Crescent Lagoon, Australia (Julien, 2001).

In the current study, it was realised that the weevils are well established after 15 years, however, there were some differences in the numbers per square meter (density) at the various sites. This could be attributed to the differences in the hydrology of the sites and the morphology of the plants. There has been, in general, a suppression of growth of the water hyacinth plants as indicated by their shorter heights (stunted growth; less that 50 cm) especially in the Tano and Nveye lagoons. However, this cannot be an absolute indication of the effect of the weevils on the plants since there was no control to compare with. An important part of most, if not all, experiments is a set of tests referred to as "controls". There were numerous feeding marks of the adult weevils per plant and the inference is that the weevils have now not only established but have spread, increased their populations considerably and are exerting control on the water hyacinth. However, from the analyses of the data, it was found that the mean density of the weevils per plant was very low (1.3/plant for *N. eichhorniae* and 1.2/plant for *N. bruchi* as the highest means). These low numbers will not exert any meaningful control on the water hyacinth infestations in the Tano River and lagoon complex. There is therefore the need to do some augmentative releases to increase the numbers, or introduce a new biocontrol agent to complement the efforts of the *Neochetina* weevils. For example, during the control of water hyacinth on Lake Victoria, on the Kenyan shores of the lake, some four years after introduction, adult weevil numbers varied from 0 to 32 per plant, with an average of six adults per plant. Weed coverage was reduced by up to 80% (Ochiel *et al.*, 2001).

If the biomass of the above-water parts is higher than the dead matter, it can be deduced that although the biological agents are inflicting damage on the water hyacinth plants, it will take a very long time for control to be achieved, unless the numbers of the agents are increased through repeated releases, or other agents are released to augment the effects of the earlier ones. According to Wilson (2002), biomass density of a water hyacinth infestation gives an accurate measure of the problem and it also determines whether or not to institute a control programme or not. The values of the mean biomass of the dead matter were higher than the biomass of the above-water parts at NV-13kg/m^2 in December, 9.0kg/m^2 at TL in August and 6.9kg/m^2 at TC in May. The situation in the Tano River channel was, however, different. Here, the water hyacinth plants were generally over 50cm in height, healthy and with little weevil damage, suggesting that control is not significant. It must be noted that, in the Tano Channel, the water hyacinth plants were subjected to regular removal by periodic or annual floods by the river overflowing and so insect density did not increase. Due to the periodic flooding which flushes out plants as well as biocontrol agents that are established, re-infestation of water hyacinth is rapid and plants quickly reach pest proportions when released from herbivore pressure (Center *et al.*, 1999a).

Factors militating against successful control of water hyacinth include catastrophic reductions of the weevil populations by periodic or annual floods (Hill and Cilliers, 1999). When this happens, the weed populations can recover much faster than the insect populations and hence control is delayed. Sudd formation prevents damaged water hyacinth from sinking, and provides a floating receptacle for seeds and a seedling bed. In shallow water where roots are embedded in mud and debris, it may limit pupation, prevent damaged plants from sinking and encourage the growth of other plant species.

Interactions between the many environmental factors affect survivorship and population dynamics of each biological control agent, and hence the level of damage and control. As a consequence, for each control agent, there is likely to be a range of control outcomes, from areas where excellent control is achieved to those where biological control may have no impact. For those locations where water hyacinth continues to grow at greater than acceptable levels, management should aim to make best use of the cheapest and most sustainable control method, normally biological control, in synergy with other available tools-herbicides, physical removal, manipulation of flows, and reductions of nutrient input.

It is unrealistic to think that biological control on its own will solve all water hyacinth problems. Hence, there is a need to develop integrated management strategies. This means selecting the most appropriate control techniques available and implementing those techniques so that they complement each other in time and space. The objective should be to obtain the best level of control that is affordable and sustainable while considering environmental impacts. Since affordability and sustainability are major considerations in the management of most water hyacinth problems, biological control should be the base component of all strategies.

There could be the addition of other compatible biological control agents or the combination of agents such as *Neochetina* weevils and *Eccritotarsus catarinenesis*, *Neochetina* weevils and fungi such as *Acremonium zonatum* or *Cercospora piaropi.* These biocontrol agents have a specific impact on water hyacinth, so if research indicates that the combination of these control agents on one site will not elicit antagonistic behaviours towards each other, either in their mode of feeding or at their oviposition sites, their complementary impact would lead to more effective control than each of them going it alone. An integrated management approach to controlling water hyacinth including inundative releases of all available agents, could result in a reduction in the extent of water hyacinth infestations.

In the current study, it was realised that the flooding regime of the Tano River did not allow weevil population growth at sites due to the flushing of the water hyacinth plants from their locations each time the river is in flood. Since the river is continually flowing, it affects the nutrient status of the water at the different sites. Some sites (e.g. the Tano Channel) get nutrient- enriched waters from time to time while others (e.g. Tano Lagoon) are deprived of nutrients, thereby affecting the feeding patterns of the *Neochetina* weevils. Since the numbers of weevils per plant are low, there is the need to do augmentive releases of the weevils regularly especially after every rainy season. The mirid *Eccritotarsus catarinensis*, which has shorter generation times than the weevils and a better disperser (Hill *et al*., 1996) has just been released in the Tano River and lagoon complex as an additional biocontrol agent. It is hoped that it will complement the control efforts of the *Neochetina* weevils.

This study could serve as the baseline of biocontrol evaluation in the Tano River and lagoon complex, which should be continued in the long-term. Also, it would provide a good platform to assess how other agents will perform should they be introduced. Without long-term evaluations, it is impossible to increase success rates, gain predictability of outcomes or move away from trial-and-error approaches that still dominate weed biocontrol programmes (Lawton, 1990; McFadyen, 1998; McEvoy and Coombs, 1999).

Chapter 5

Retrospective host specificity testing of *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) and *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae) in Ghana.

5.1 Introduction

In natural systems, host range of phytophagous insects is ecologically constrained by the behavioural, neurophysiological and physiological traits shared by members of a population, by the suite of plant species that have been and are currently within the geographic range of the population and by the intensity of inter- and intraspecific competition, predation, and parasitism that the population must endure (Tallamy, 2000). Changes in host specificity are most likely to occur when one or more of these constraints are relaxed during periods of allopatric (geographic) isolation (Mayr, 1963) or allochronic (temporal or seasonal) isolation (Wood and Keese, 1990). Unfortunately, a successful biological control introduction relaxes these constraints. The agent is transported to a new environment, isolated from gene flow with the parent population, released from constraining interactions with predators, parasitoids, and interspecific competitors, and exposed to communities of novel plant species. If successful in reducing the population density of the target weed species, the agent faces diminishing host availability and in turn increasing intraspecific competition (Marohasy, 1996). Consequently, selection to oviposit or feed on plant species outside the normal range of acceptability becomes intense.

The discovery of water hyacinth in some Ghanaian water bodies in the late 1980s prompted several control and management options, including physical removal, chemical treatments and biological control (chapter 4). The weevils *Neochetina eichhorniae* and *Neochetina bruchi* were introduced into Ghana in 1994. Both species were imported from IITA, Benin, in July 1993, reared at the Zoology Department of the University of Ghana, Legon, and released into the Abby-Ehy-Tano River and Lagoon complex in southwestern Ghana from March 1994. During monitoring, it was observed that the weevils reduced the level of water hyacinth infestation in the River Tano and Lagoon complex (chapter 4). When the weevils were imported into Ghana, no host specificity tests were conducted on them before release, relying on host specificity results from elsewhere in Africa and the rest of the world (Julien *et al.*, 1999).

Serious concerns about the non-target effects of biological control agents are increasingly being expressed by ecologists, the wider scientific community and biological control practitioners themselves (Thomas and Willis, 1998; Anonymous, 1999). Many of these warnings call for biological control practitioners to better understand the effects of releases of biological control agents. The best way of predicting both direct and indirect non-target effects is to understand the host specificity of agents (Secord and Kareiva, 1996). Host specificity testing provides the primary information for making decisions on whether to release an agent.

Host specificity is an intrinsic property of an insect and is the consequence of behaviour, post –ingestive constraints, nutritional needs and morphology (Zwölfer and Harris, 1971; Scriber, 1984; Slansky and Rodriguez, 1987; Courtney and Kibota, 1990; van Klinken, 2000a). As such, it is a function of genotype and can therefore vary considerably between individuals within a species (Wiklund, 1981; Singer *et al.*, 1993) and within populations (Funk, 1998). Host specificity is a combination of host range breadth, the level of preference for each host for feeding or oviposition and the rate of growth and reproductive performance on each host (van Klinken, 2000a). Therefore, two herbivores with identical host ranges could differ dramatically in their host specificity because one species does not distinguish hosts whereas the other species utilises one in strong preference to the remainder.

Therefore, the necessity for detailed host-specificity testing of all agents before field release has been an accepted doctrine since the biological control of prickly pear (*Opuntia stricta* (Haw.) Haw. (Cactaceae) in Australia in the 1930s (Dodd, 1940). The aim is no longer to demonstrate that a group of valued plants will not be attacked, but rather to determine the potential host range of the agent and therefore which plants if any will be at risk in the field (Wapshere, 1989; Cullen, 1990; Blossey, 1995; McClay, 1996). An understanding of host specificity is greatly improved when the insects attacking a complete taxonomic group of plants are known (Goeden & Palmer, 1995; McClay *et al.*, 1995; Sheppard *et al.*, 1995; Briese, 1996), or where the host relationships of a taxonomic group of insects is studied (Anderson, 1993; Futuyama *et al.*, 1995).

Neochetina bruchi and *N. eichhorniae* have undergone extensive host specificity testing in numerous countries before their release (Julien *et al.*, 1999). These two weevils were tested against a long and diverse list, covering 274 plants species in 77 families, representing a wide range of terrestrial, aquatic, economic, exotic and native plant species which were taxonomically related and taxonomically unrelated to water hyacinth, but which were of economic or agricultural importance (for example: Harley (1975); DeLoach (1976), Argentina and USA;, Nagarkatti and Jayanth (1984), India; Jayanth and Nagarkatti (1987), Forno and Wright (1990), Australia; Sastroutomo *et al.* (1991), Malaysia; Ogwang and Molo (1997), Uganda; Cam (1997), Vietnam; Ding *et al.* (1998), China; Y.H. Fayad, (pers. comm.), Egypt; S.S. Tjitrosoedirdjo, (pers. comm.), Indonesia; G. Ochiel, (pers. comm.), Kenya; B. Napompeth, (pers. comm.), Thailand; G. Chickwenhere, (pers. comm.), Zimbabwe).

During host specificity testing, it was observed that adult *N. bruchi* fed to some extent on 50 species of test plants, but the feeding was significantly less on the non-target plants than on water hyacinth. However, the most consistently damaged plant species were those in the same family as *Eichhornia crassipes*; Pontederiaceae. Others were in the families Commelinaceae, Araceae, Asteraceae and Brassicaceae (Julien *et al.,* 1999). *Neochetina bruchi* laid one or several eggs on 22 plant species, of which 9 were in the Pontederiaceae and Commelinaceae. The total numbers of eggs laid on non-target plants were very low and no larvae completed development. Similarly, eggs or larvae placed on plants other than water hyacinth failed to develop and invariably survived for only a few days.

Neochetina eichhorniae made one or several exploratory feeding scars on the foliage of 25 test plants (Julien *et al.*, 1999). However, feeding on these plants was much less than on water hyacinth and caused no serious damage to the plants. Eggs of *N. eichhorniae* were laid on 7 species of test plants, of which more than half were in the families Pontederiaceae or Commelinaceae. Most of the eggs were infertile and if hatched, the larvae died soon after. Similarly, larvae inserted into stems of test plants did not feed and died within a short period. *Pontederia cordata* L. (Pontederiaceae) was the only other plant apart from water hyacinth on which any larval development was observed, but even then, no larvae completed development on the plant during testing.

Based on the above evidence, Julien *et al.* (1999) stated that releases of the *Neochetina* weevils into new countries could be carried out without undertaking exhaustive host specificity testing. They did, however, intimate that testing, including both multiple choice and no-choice oviposition and larval development trials, should still be carried out on native members of the Pontederiaceae family if they had not already been tested. Center *et al.* (2002) also suggested that post-release evaluations of natural enemies in countries of introduction will provide additional host specificity data and could render further quarantine-based trials unnecessary if non-target species were also evaluated.

The Pontederiaceae is a small, exclusively palustrial and aquatic family of herbaceous monocotyledons. It comprises 6-9 genera and 30-35 species, the majority of which are native to the New World Tropics (Eckenwalder and Barrett, 1986). A few species extend to cool temperate regions such as Southern Canada and Japan. *Pontederia* (6 species) and *Hydrothrix* (1 species) are exclusively New World in their natural distribution, whereas *Monochoria* (5 species) and *Scholleropsis* (1 species) are restricted to the Old World. *Eichhornia* (7 species) and *Heteranthera* (11 species) are predominantly Neotropical, but *Eichhornia natans* and *Heteranthera callifolia* are native to Africa (Eckenwalder and Barrett, 1986). In Africa, the flora of the Pontederiaceae family includes three indigenous and two introduced plants. These are *Eichhornia crassipes* (introduced), *Eichhornia natans, Heteranthera callifolia, Monochoria africana* and *Pontederia cordata* (introduced).

The long-held and most widely accepted view among biological control practitioners is that there is a very low risk of post-release evolution resulting in increased non-target attack, because evolution will favour increased specialisation (Huffaker, 1959; Harris and Zwölfer, 1968; McFadyen, 1998), particularly if "host range is integrated with many features of biology" (Zwölfer and Harris, 1971). The possibility of rapid evolution nonetheless raises important issues for the practice of classical biological control, where herbivores (both insect and pathogens) are released into totally new environments free of specialist natural enemies and often exposed to potential new hosts and different selection pressures (van Klinken and Edwards, 2002).

5.2 Objectives of the study

The focus of this chapter is on the fact that, although *N. eichhorniae* and *N. bruchi* have been released all over the world and have been particularly successful in controlling water hyacinth in Africa (Cilliers *et al.*, 2003), very little host specificity testing has been carried out in Africa, and none in Ghana. Therefore, the aim of this study was to conduct laboratory host specificity trials on *N. eichhorniae* and *N. bruchi* on indigenous plants within the Pontederiaceae in Ghana some 15 years and approximately 45 generations (assuming 3 generations per year (DeLoach and Cordo, 1976)) after release, since recent evidence demonstrates that significant changes in host use can occur in the field within 10s or 100s of generations (Thompson, 1998). The results of the laboratory host specificity trials were then compared to field surveys on species in the Pontederiaceae.

5.3 Experimental plant species

Three plants from the Pontederiaceae family were used in the experiment. These were *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.* Plant species should be chosen for host range screening on the basis of their taxonomic relationship to the target species (Wapshere, 1989; Harley and Forno, 1992). The agents are exposed to progressively less related plant species (i.e. to different varieties of the target host, then to different species in the same genus, then to different genera in the same tribe).

5.3.1 Taxonomy, morphology and biology of *Eichhornia natans* (P.Beauv.) Solms: Pontederiaceae

Eichhornia natans is an aquatic herb with submerged or floating leaves and branched stems that are mostly rooted in the soil. Leaves are alternate and are of two kinds: submerged leaves that are sessile, linear, acute, measuring 3-6.5 cm long and 10 mm broad (Figure 5.1). The floating leaves are petiolate, ovate or orbicular, obtuse or rarely acute at the apex, cordate with small rounded overlapping lobes, minutely pustulate above and measuring 1.3-3 cm long, 1-2 cm wide; with true petioles which are about 4-10 cm long. The stipules range from 2 mm in the submerged leaves to 3.2 cm long in the floating leaves. They are membranous, obtuse and sheath the stem. Inflorescences are usually 1-flowered, shortly pedunculate, arising from a tubular membranous obtuse l.3 cm long spathe, apparently arising from below the middle of the petioles of the floating leaves but actually terminating in the short lateral 1-leaved branches of the main stem. The perianth is somewhat irregular, blue or mauve and the lobes are small, obovate, up to 4.5 mm long and 2 mm wide. It forms a tube 1.0-1.2 cm long, elongating after anthesis to 2.2 cm long. There are 6 stamens, unequal and glabrous. The style is long and filiform while the capsule is narrowly fusiform, about 1.0-1.2 cm long. The seeds are numerous, oblong with many very fine longitudinal ribs up to 1 mm long (http://plants.jstor.org/flora/ftea.002052: Accessed June, 2010).Electronic reference (Er-1).

Figure 5.1 *Eichhornia natans. Photo Credit:* Akobundu and Agyakwa, *(1998). A handbook of West African weeds.*

5.3.2 Taxonomy, morphology and biology of *Heteranthera callifolia* Kunth: Pontederiaceae

Heteranthera callifolia is a glabrous aquatic plant about 13-50 cm tall; lower stems are creeping and rooting in the mud, sometimes free-floating; stoloniferous. Leaves are erect or ascending or sometimes floating (Figure 5.2). The leaves are broadly ovate, sub-obtuse or short and obtusely pointed, cordate about 2.5-7.5 cm long and 1.3-5 cm wide. The petioles are 5-20 cm long. The flowering stems are 3 to 10 cm long with an apical leaf similar to the ordinary leaves. The inflorescence is a spike measuring 5-10 cm long and made up of 7-20 small sessile flowers with a membranous spathe at its base subtended by the leaf-sheath. This spathe contains a basal cleistogamous flower. The perianth is white, blue or purple with the lobes spreading.The lobes are oblong, obtuse, 4-5 mm long and forming a cylindrical tube 5-10 mm long. The stamens are 3 and shortly exserted, sometimes only one in cleistogamous flowers. The capsule is oblong, trigonous, 0.8-1.2 cm long or (in the cleistogamous flower) 1.2-1.8 cm long (http://plants.jstor.org/flora/ftea.002052: Accessed June, 2010). Electronic reference (Er-1).

Figure 5.2 *Heteranthera callifolia. Photo credit:* Wikipedia, the free encyclopedia

5.4 Materials and Methods

5.4.1 Collection of plants

Eichhornia crassipes was harvested from the River Tano in southwestern Ghana (N05° 05; W002° 56), *Eichhornia natans* from a marshland within the Kpong Headpond in the Eastern Region of Ghana (N06° 0.09; E000° 0.04) and *Heteranthera callifolia* from a rice field at Essienimpong (near Kumasi) in the Ashanti Region of Ghana (N06° 39; W001° 26).

5.4.2 Laboratory host range testing

Twenty-one plastic tubs (diameter: 20 cm, depth: 25 cm) were set up with 2 litres of tap water with a pH of 7.50 and a conductivity of 550 μs. A nutrient solution of cow dung was prepared and added to the water. Two plants of each species were added to each tub. The plants were left for two weeks to stabilise in the insect proof-net greenhouse and covered with gauze. This was to prevent outside contamination from other insects such as aphids, whiteflies and lepidopteran larvae which normally attack plants grown under glasshouse conditions (Chikwenhere, 2000). The inoculation of weevils was initiated soon after stabilisation.

The experiment lasted for six weeks, from 3rd of August to 13th of September 2009 in a mini-tunnel (greenhouse) erected on the premises of the CSIR-Water Research Institute in Accra. Ghana. The two weevils (*Neochetina eichhorniae* and *Neochetina bruchi*) were sexed and then combined; i.e. they were not separated. Although this might confound the results, the combination of the two species is representative of the field situation. This allowed a comparison between the results of the laboratory and field trials. This means that larval mining and development could not be used as an indicator of host specificity, but adult mortality and feeding scars were attributed to species. Three replicates of seven treatments (5 weevils) + 1 plant *E. crassipes* + cover net; 5 weevils + 1 plant *E. natans* + cover net; 5 weevils + 1 plant *H. callifolia* + cover net; 5 weevils + 1 plant each of *E. crassipes* + *E. natans* + *H. callifolia* + cover net (choice trial); 1 plant *E. crassipes* with no insects + cover net; 1 plant *E. natans* with no insects + cover net; 1 plant *H. callifolia* with no insects + cover net were used in this experiment (Table 5.1). The cover net was white gauze curtaining wrapped around the tubs with an elastic cord to maintain weevils either in or out of the tubs for the six weeks duration. Only five weevils were used because of the relatively small sizes of *Eichhornia natans* and *Heteranthera callifolia* plants. If more weevils had been used, the damage to *Eichhornia crassipes* would have been severe and the plants would not have survived for the duration of the experiment.

Table 5.1 The treatments used in the no-choice and one multi choice trial host specificity testing for *Neochetina eichhorniae* and *Neochetina bruchi* on three species within the Pontederiaceae.

Treatment (abbreviations)	Treatment (in full)
5WCNEc	5 Weevils + *E. crassipes* plants, cover net
5WCNEn	5 Weevils + *E. natans* plants, cover net
5WCNHc	5 Weevils + *H. callifolia* plants, cover net
5WCNEcEnHc	5 Weevils + *E. crassipes*, *E. natans*, *H. callifolia* plants, cover net
EcCN	*E. crassipes* plants, cover net
EnCN	*E. natans* plants, cover net
HcCN	*H. callifolia* plants, cover net

5.4.3 Temperature

The daily temperatures and relative humidity were recorded using a mercury-in-glass thermometer and a Model 116 Whirling hygrometer respectively, at 08h00, 12h00 and 17h00 daily for the duration of the experiment (Table 5.2).

Table 5.2 Means of temperature and relative humidity (±S.D. and S.E.), N = 42 during the experiment at 8am, 12 noon and 5pm.

Temperature °C (Mean Max. ± S.E.)			**Relative humidity % (Max. ± S.E.)**		
08h00	12h00	17h00	08h00	12h00	17h00
28.50 (0.94)	31.60 (0.53)	30.10 (0.31)	88.02 (0.86)	62.18 (1.92)	67.56 (0.94)

5.4.4 Monitoring

Insect and plant parameters were measured six weeks after introduction of the weevils to the different treatments. Insect parameters measured were survival of the adults and the number of feeding scars on leaf two of the plants. Larval mines in the petioles were recorded, but it is accepted that as the adults were not separated into species, this was not a sound parameter. Plant parameters measured were; leaf 2 petiole length, leaf 2 lamina area, root length, number of ramets (daughter plants), number of flowers and number of leaves. The insect parameters provided an indication of utilization of the three plant species by the weevils, while the plant parameters provided a measure of the impact of the weevils on the plants in comparison to the no-insect control treatments.

5.4.5 Statistics

The non-parametric Kruskal-Wallis (KW-H) ANOVA by ranks and median test was used to analyse the data and to investigate differences between the 7 treatments (4 with insects and the 3 controls without insects but with cover net). The Kruskal-Wallis (KW-H) ANOVA is the non-parametric equivalent of a one-way ANOVA. As it does not assume normality, the KW-H ANOVA tests the null hypothesis of no difference between three or more group medians, against the alternative hypothesis that a significant difference exists between the medians. Levene's Test of homogeneity of Variances at $p < 0.05$ was conducted on the data. The Statistica software (Version 6.0) package was used.

5.4.6 Field host range

At each field site (Kpong Headpond for *Eichhornia natans*, Essienimpong for *Heteranthera callifolia* and Tano River for *Eichhornia crassipes*) three subsites were chosen randomly and ten plants of each species were selected in each of the subsites (30 plants per site). Each plant was inspected for weevil feeding damage on the leaves and larval damage in the petioles. Plants were surveyed twice, once in May and again in August, 2009.

5.5 Results

5.5.1 Laboratory host range testing

5.5.1.1 Insect parameters

The weevils showed a high level of specificity to *E. crassipes* over *E. natans* and *H. callifolia*. There was no significant difference (Figure 5.3) between the feeding damage on *Eichhornia crassipes* in the 5WCNEc and *E. crassipes* in the choice experiment of 5WCNEcEnHc, in the choice trial, feeding damages were only recorded from *E. crassipes*. There were feeding damages seen on the treated plants (5WCNEc and 5WCNEcEnHc) while there were non on the untreated plants (EcCN, EnCN and HcCN) and 5WCNEn, 5WCNHc, (KW-H (8, N = 81) = 60.0051; p <0.0001) (Figure 5.3). In the (no-choice) treatments, some weevil mortality was recorded on *E. natans* and *H. callifolia* treatments, while all five adults survived for the duration of the trials in which *E. crassipes* was present. Larval mines were recorded on *E. crassipes,* but not on *E. natans* or *H. callifolia* in either the choice or no-choice trials.

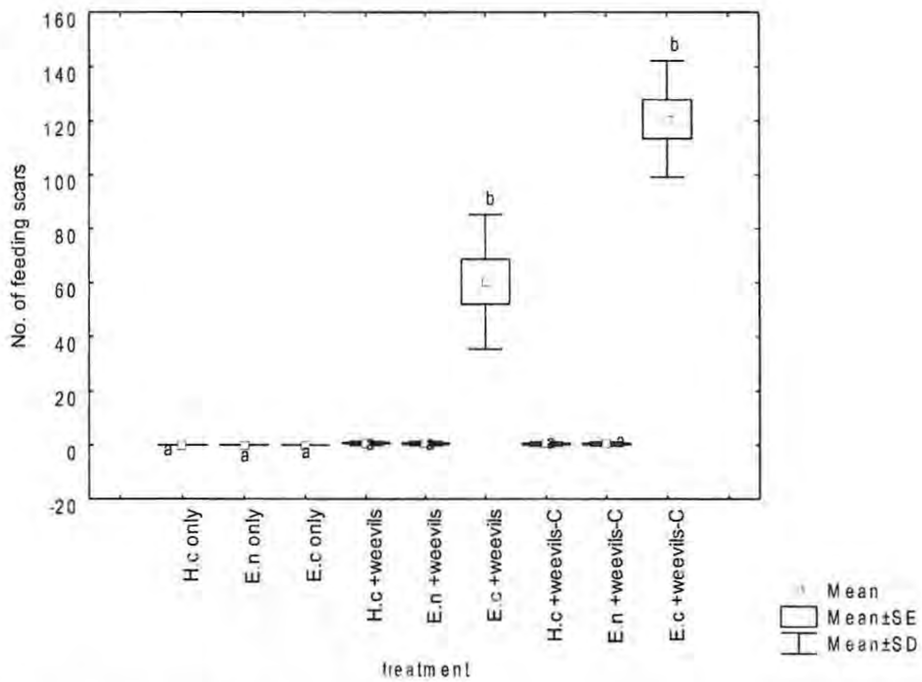

Figure 5.3 Mean number of feeding scars on *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia* in the no-choice and choice host specificity trials. The C in the x-axis legend refers to the choice trial.

5.5.2. Plant Parameters

5.5.2.1. Mean number of daughter plants (ramets)

There were no significant differences between the numbers of daughter plants produced by the various plants during the experimental period (KW-H (8, N = 81) = 13.21267; p = 0.1047) (Figure 5.4). This is probably due to high variability in the data, and herbivory appeared to stimulate daughter plant production but the differences were not significant.

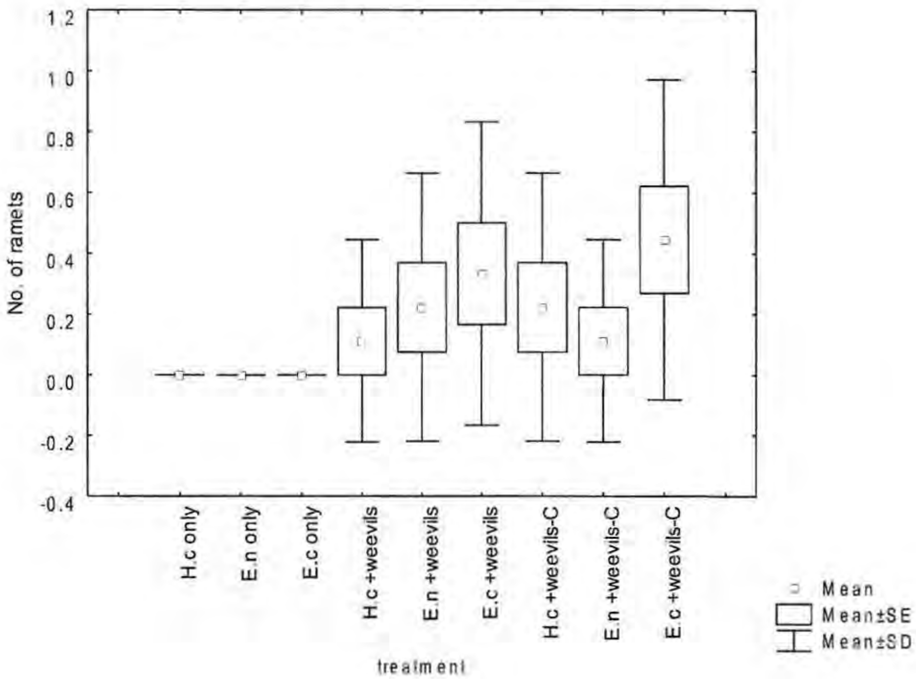

Figure 5.4 Mean number of daughter plants produced by *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.*

5.5.2.2 Mean number of flowers

Flowers were only recorded on *E. crassipes* and one of the *H. callifolia* plants during the experiment and there were no significant differences between the numbers of flowers produced (KW-H (8, N = 81) = 9.8701; p = 0.2743) (Figure 5.5). *Eichhornia crassipes* produced flowers in the herbivory treatment and not the controls, but differences were not statistically significant. However, in herbivory, production of flowers, leaves and offshoots is reduced, and plant growth is stunted (Julien *et al,* 1999).

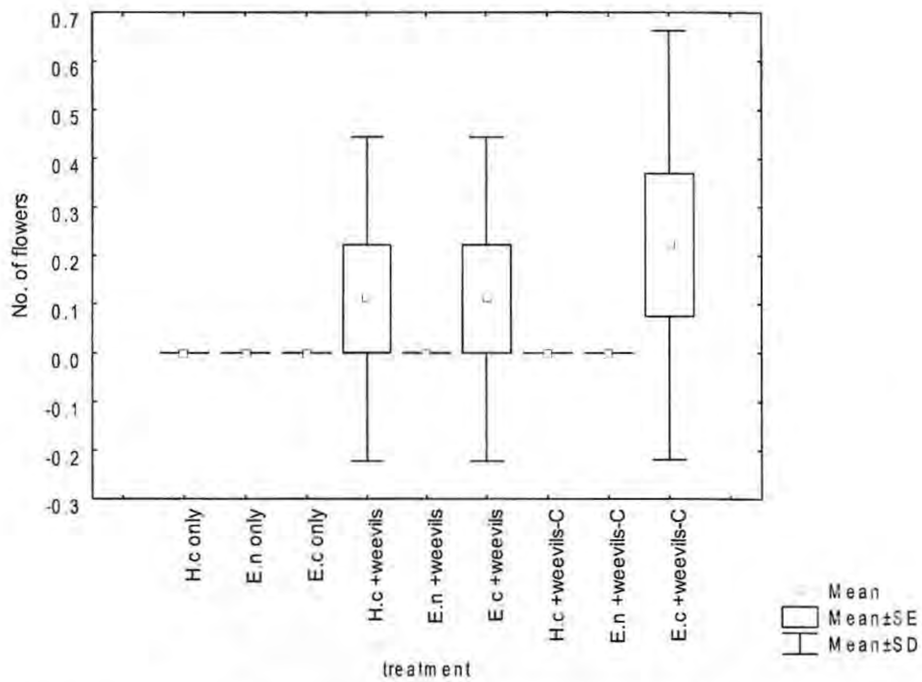

Figure 5.5 Mean number of flowers per plant produced by *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.*

5.5.2.3 Mean number of leaves

There was a significant difference in the number of leaves of *Eichhornia crassipes* in EcCN and *Eichhornia natans* in 5WCNEcEnHc (KW-H (8, N = 81) = 23.6071; $p = 0.0027$). The number of leaves on *Eichhornia crassipes* in EcCN and on *Eichhornia natans* in 5WCNEcEnHc were also significantly different from the number of leaves in HcCN, EnCN, 5WCNHc, 5WCNEn, 5WCNEc and the leaves of *E. natans* and *H. callifolia* in 5WCNEcEnHc (Figure 5.6).

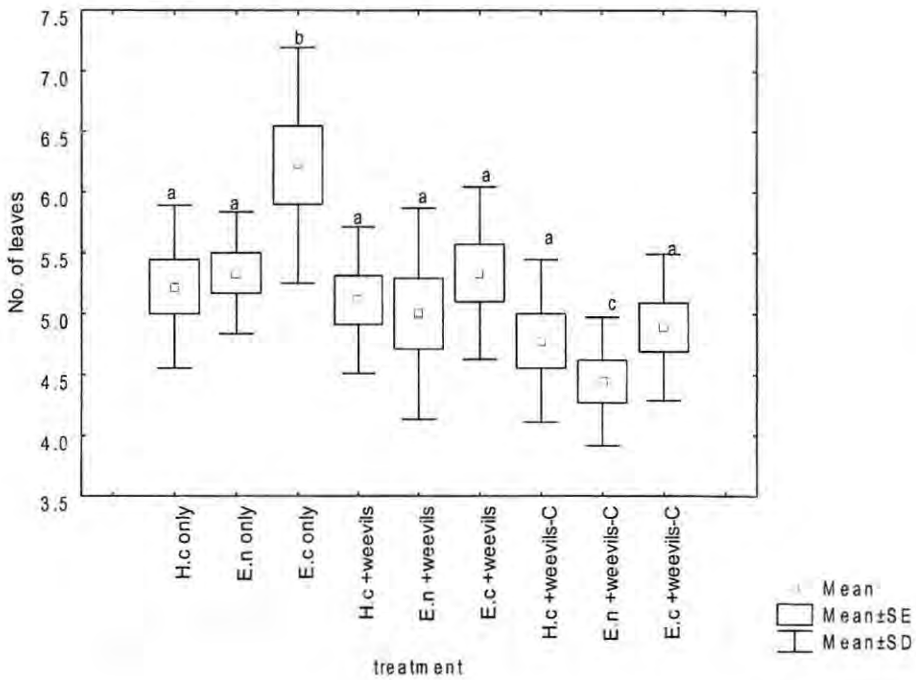

Figure 5.6 Mean number of leaves produced by *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.*

5.5.2.4 Mean leaf 2 area

Eichhornia crassipes plants had significantly larger surface area of leaves than the leaf surface areas of both *Heteranthera callifolia* and *Eichhornia natans* (KW-H (8, N = 81) = 63.3772; p <0.0001) (Figure 5.8). Herbivory by adult weevils had no effect on leaf surface area of *E. crassipes* since other plants were not fed on.

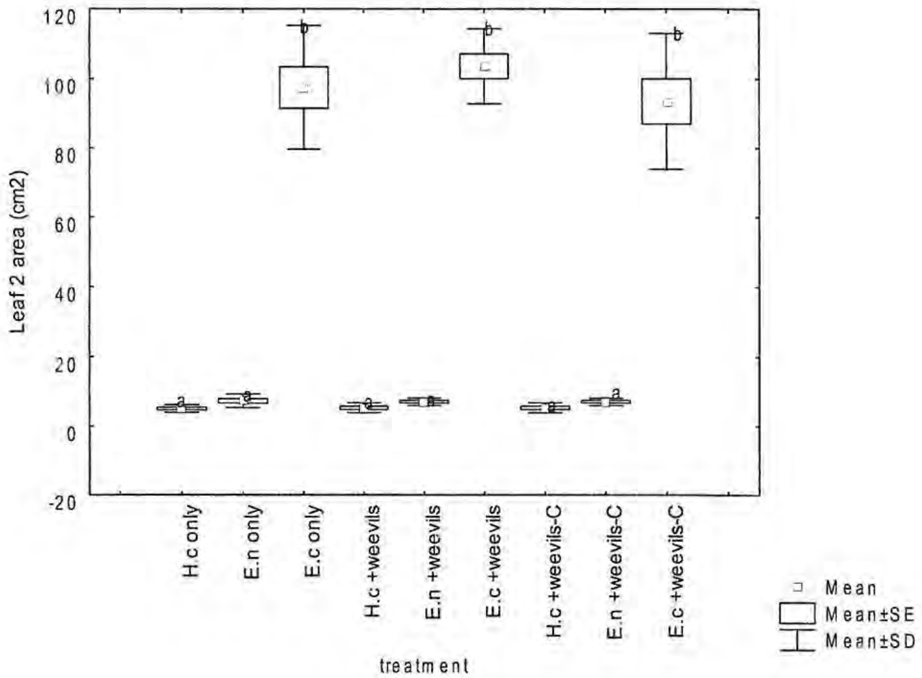

Figure 5.7 Mean leaf 2 areas of *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.*

5.5.2.5 Mean leaf 2 petiole length

The mean leaf 2 petiole lengths also followed the trend shown by the leaf. Thus the leaf 2 petiole lengths of EcCN, 5WCNEc and the *Eichhornia crassipes* plants were significantly taller than *Heteranthera callifolia* and *Eichhornia natans.* Herbivory did significantly affect petiole length (KW-H (8, N = 81) = 66.6722; p <0.0001) (Figure 5.9).

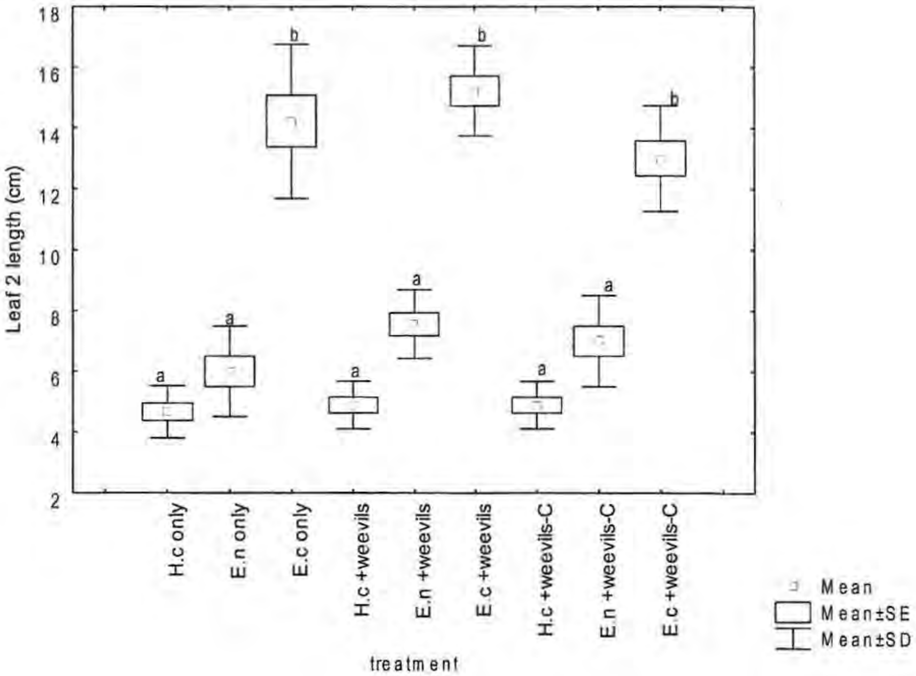

Figure 5.8 Mean leaf 2 petiole lengths of *Eichhornia crassipes, Eichhornia natans* and *Heteranthera callifolia.*

5.5.3 Field host range

Adult weevil feeding scars (both *N. eichhorniae* and *N. bruchi*) were found on all of the 60 *E. crassipes* plants inspected at the Tano River site on both sampling occasions. The numbers of feeding scars on leaf 2 varied between 48 and 153 scars in May and 36 and 122 scars in August, 2009. Furthermore, most of the plants at this site (> 65%) had larval mines in the petioles. In contrast, none of the *Eichhornia natans* and *Heteranthera callifolia* showed any signs of adult feeding or larval mining, suggesting that both the *Eichhornia natans* and *Heteranthera callifolia* are 'no hosts' for the *Neochetina* weevils. *Eichhornia natans* was collected from the Kpong Headpond where the weevils are well established on *E. crassipes.* The results of the field surveys thus confirmed the results from the laboratory host range testing.

5.6 Discussion

Damage to water hyacinth comes from both the adults and the larvae. Adult feeding causes distinctive feeding scars on the leaf surface, which are clearly visible and easily recognized, but indistinguishable between species. Larvae are rarely seen, as they tunnel and remain within the plant tissue from shortly after hatching. Their presence can be determined from the presence of streaks of necrotic tissue just beneath the epidermis of petioles. Heavy feeding by adult weevils on the lamina causes leaves to desiccate and curl. Under pressure from this damage and from larval feeding the petioles become thin, spindly and brittle, plants become waterlogged and gradually sink. Leaf-turnover rate, which is a good indicator of plant stress, was not measured in this experiment.

As a science, biological control of invasive alien plants has undergone changes in approach and practice over the last decade. Biological control agents are non-indigenous species in their recipient environments therefore there is some degree of ecological risk associated with their introduction (McEvoy and Coombs, 1999). It is therefore an ethical requirement that future biocontrol agent releases are safe and, as far as can be predicted in pre-release screening, efficacious. Efficacy testing in the laboratory or even in the field in the native range can never guarantee success or be completely reliable predictors of the outcome of complex interactions that are likely in the new environment. However, this type of approach will ultimately allow for selection of a smaller number of agents that have the potential to control the target weed (Pearson and Callaway, 2005).

The results of this experiment confirmed that the *N. bruchi* and *N. eichhorniae* weevils showed a high level of specificity to *E. crassipes.* This high level of specificity has been confirmed by researchers in several other countries. At least 15 countries in Africa have introduced the weevil without any adverse consequences (Julien and Griffiths, 1998). Further, this study shows that despite the fact that the two weevils have been in Ghana for at least 45 generations, the level of host specificity has not changed. This finding is supported by the work of Arnette and Louda (2002) and van Klinken and Edwards (2002) who also found no evidence for rapid evolutionary change in host plant finding by insects used as biological control agents.

Numerous studies have shown that under laboratory conditions, insects show an expanded host range, referred to as the fundamental host range, and that in the field they show a much more restricted host range, the realized host range (e.g. Baars and Neser, 1999, Olckers *et al*., 1995; Sheppard *et al.,* 2005). This phenomenon has led to the rejection of a significant number of potentially safe insects and has led to the questioning of the validity of pre-release host specificity trials that are carried out under quarantine conditions (Louda *et al.,* 2003). In this study, the laboratory host range of the two weevils was consistent with the field host range indicating that, in this case, results from the laboratory could be extrapolated to the field.

Efficacy testing in the laboratory can never guarantee success or be completely reliable predictors of the outcome of complex interactions that are likely in the new environment (Pearson and Callaway, 2005). Based on this study, it was not evident that the weevils were in fact damaging agents for water hyacinth. These results contradict what has been shown in the field at many sites around the world, where the weevils are considered to be excellent and damaging agents (Coetzee *et al*. 2009). However, the study presented above was carried out over a short period of time (six weeks), and had the length of the trial been extended to include larval development, significant impacts would have been recorded.

The host-specificity of these insects has been demonstrated during extensive host testing and confirmed by observations after their release. Despite being released widely there are no reports of these weevils seeking out and damaging plants other than water hyacinth. In Australia, feeding and larval damage were observed on *Pontederia cordata* (Pontederiaceae) in the field, but only when plants of this species were placed amongst water hyacinth under heavy attack from *Neochetina* sp. (Stanley and Julien unpublished data). Damage has never been observed in other situations. Further support for their specificity comes from knowledge of the life-history of the *Neochetina* sp. The pupation behaviour of these insects, whereby they make a pupal cocoon in the roots of floating water hyacinth, makes it highly unlikely that any substrate-rooted plant could provide a suitable host.

There is some risk that exotic species which are used to control exotic pest species can become pest species themselves. The main instrument regulating the trade and use of biocontrol agents is the Code of Conduct for the Import and Release of Exotic Biological Control Agents (FAO 1995 - http://www.fao.org/docrep/x5585E/x5585e0i.htm: Accessed May 2011). Electronic reference (Er-2). The Code of Conduct is intended to facilitate safe import, export and release of biological control agents and introduce internationally acceptable procedures, especially where national legislation is inadequate or non-existent. In addition, the IPPC has developed a standard (revised International Standard for Phytosanitary Measures #3) on Guidelines for the Export, Shipment, Import and Release of Biological Control Agents and Other Beneficial Organisms (e.g. pollinators) (www.acfs.go.th/sps/downloads/76047_ISPM_3_E.pdf -Accessed May, 2011). Electronic reference (Er-3).

Clearly there are dangers inherent in releasing control agents with known broad host ranges (this practice is not acceptable anymore), but the benefits associated with the release of more host specific agents need to be remembered. For instance, the weevil *N. eichhorniae* is one of the most successful control agents released against water hyacinth in the USA, where numerous studies have documented its beneficial effects (e.g. Goyer and Stark, 1984; Center and Van, 1989; Grodowitz *et al.*, 1991; Center *et al.*, 1999b). There is usually insufficient evidence to validate the safety or risk of biological control because monitoring of damage by introduced control agents to non-target species is often minimal (Simberloff and Stiling 1996a). Both proponents and opponents of biocontrol recommend that extensive pre- and post-release evaluations on environmental effects of control agents be conducted to assess the risk of introduced agents (e.g. Simberloff and Stiling 1996b; Thomas and Willis 1998; McEvoy and Coombs 2000). Completing such evaluations efficiently and thoroughly is a daunting prospect due to the vast amount of time and resources they require. While this is not an acceptable excuse not to conduct post-release evaluations, there are few examples of such analyses. Studies such as this one (e.g., Hill *et al.* 2000; Coetzee *et al.* 2003, 2005, 2007; Ajuonu *et al.*, 2003) go some way to addressing these concerns in that they provide ideal opportunities to perform what many researchers have suggested, such as Louda's (2000) insights to minimise the risk of biological control agents.

Field studies in the Tano River and Lagoon complex in Ghana (Chapter 4) revealed that some water hyacinth infested sites where the performance of the *Neochetina* weevils were being evaluated were deprived of nutrients, thereby affecting the feeding patterns of the *Neochetina* weevils. It was also observed that the numbers of weevils per plant were low and there was the need to do augmentive releases of the weevils regularly, especially after every rainy season. Since much of pre-release testing of *E. catarinensis*, as well as a substantial amount of post-release assessment, pertinent to its use in Ghana, had been conducted in South Africa (Coetzee *et al.*, 2011), thereby providing further data regarding the need for and safety of this agent. It was recommended that *E. catarinensis* be considered for release as an additional control agent of water hyacinth in Ghana. The determination that the mirid reduces the vigour of water hyacinth, in terms of growth and competitive ability (Coetzee *et al.*, 2005, 2007), further justifies consideration of this insect for release in Ghana. The mirid, which has shorter generation times than the *Neochetina* weevils and is a better disperser (Hill *et al.*, 1996; Ajuonu *et al.*, 2007), was thus released in the Tano River and lagoon complex as an additional biological control agent in 2009. It is hoped that it will complement the control efforts of the *Neochetina* weevils.

Chapter 6

General Discussion

6.1 Introduction

As already stated in this thesis, the invasion of ecosystems by alien species is a large and growing threat to the delivery of ecosystem services (Drake *et al.*, 1989). Invasive alien species are a product of the on-going and increasing human re-distribution of species to support agriculture, forestry, mariculture, horticulture and recreation, as well as a by-product of accidental introductions. They include disease organisms, agricultural weeds, and insect pests. These species are known to erode natural capital, compromise ecosystem stability, and threaten economic productivity. The problem is growing in severity and geographic extent as global trade and travel accelerate, and as human-mediated disturbance, global changes in climate and biogeochemical cycling, and increased dissemination of propagules makes ecosystems more susceptible to invasion by alien species (Le Maitre *et al.*, 2004). Besides their impacts on agriculture, forestry and human health, biological invasions are also widely recognised as the second-largest global threat (after direct habitat destruction) to biodiversity (Mooney and Hobbs, 2000). Thousands of alien species from other parts of the world have been (and continue to be) introduced to Africa, both intentionally for a range of economic and ornamental purposes, and accidentally. Those that become invasive often bring considerable costs to the economy and the environment (Neuenschwander *et al.*, 2003; Wise *et al.*, 2007).

Waterweeds and in particular water hyacinth, remain problematic and pose serious economic, social and environmental threats (Chapter 3). Considerable effort has been made to document these impacts. As this study has shown, however, this is difficult and there is the need for biologists, sociologists and economists to work more closely together. The need for a multidisciplinary approach in aquatic weed control cannot be overemphasised. It is our hope that the control strategies already adopted in Ghana will continue to reduce deleterious impacts and allow sustained development in the Volta Basin.

The main rivers and water bodies used for fisheries are concomitantly used also for transportation. In fishing communities along lakes and rivers, water transportation is the only means of transportation for people and goods. Children often use canoe transport to go to school. Transport efficiency may decline markedly in situation of heavy infestation of aquatic plants, as was reported in Benin (Ajuonu *et al.*, 2003). Motorboats require more operating time, in the order of 40%, to cross an infested water body. This leads to a decline of the number of operational days by 55%, and ultimately to financial losses. It is not possible to make an accurate estimation of the total losses, which are produced in the transport sector. However, these conditions of dense stands of weeds are reported to lead to increases in the cost of transportation of between 200 and 500%, because there is the need to procure stronger motors, not less than 80 hp (African Development Fund, 2004). However, the lack of statistical data in the field makes it difficult to estimate the total losses. Invasive aquatic plants also contribute to the corrosion of bridge pillars, which lead to increased costs of maintenance and diversion of financial resources from other demanding sectors (African Development Fund, 2004).

This thesis has several "take home messages" that could assist in reducing the impact of invasive alien species in Africa. According to the CABI led UNEP/GEF Project "Removing Barriers to Invasive Plant Management in Africa", countries in sub-Saharan Africa have thus far done little to implement Conference of Parties (COP) decisions on Invasive Alien Species (IAS). In most countries there is a weak policy and institutional environment, critical information is unavailable, there is inadequate implementation of prevention and control, and there is a lack of the necessary capacity.

The Global Invasive Species Program (GISP) Synthesis Meeting (September 2000) identified management of IAS in Africa as a priority because IAS are adversely affecting local and globally significant biodiversity and are also threatening agricultural production and food security (which continues to be the main priority for most African governments). Under current trends, the situation in Africa will deteriorate because on one hand the pathways through which IAS invade are becoming more numerous (Chapter 1) and on the other there are a number of barriers that are constraining countries in Africa from addressing the problem effectively. Countries participating in the GISP meeting identified invasive plants as the greatest current threat to biodiversity on the continent. Invasive plants were therefore considered to be the first priority in the development of management strategies for all IAS.

Four categories of barriers were identified which form the basis for this intervention:

- Weak policy and institutional environment
- Knowledge gaps
- Inadequate implementation of prevention and control
- Lack of capacity

6.1.1 Weak policy and institutional environment

There are gaps, overlaps and inconsistencies in existing policies, regulations, strategies and institutional arrangements concerning IAS in African countries. Most countries give more prominence to IAS issues in their national biodiversity strategy and action plans than in their national environmental action plans and policies.

For example, until recently, Ethiopia, Ghana and Zambia had authorities that had overall responsibility for the coordination of IAS issues. In Uganda, the National Environment Management Authority (NEMA) has this responsibility but, it currently lacks the means to effectively implement its mandate. Conflicting recommendations regarding IAS by different authorities are commonplace. This is exemplified by Ethiopia, where *Prosopis* planting is recommended as a means of controlling desertification under the National Plan to Combat Desertification, while being acknowledged as a threat to biodiversity resources under the Forestry Research Strategy. The same applies to water hyacinth in many countries in Africa where the conflict between control and utilization continues.

While implementation of the CBD is generally a responsibility of the environmental sector, historically it has been the agricultural sector that has addressed IAS issues. However, the starting point for agriculturalists is that IAS cause economic damage to agriculture, with the environmental damage they cause being of secondary concern. There is now increasing cross-sectoral cooperation at the international level, such as between CBD and the International Plant Protection Convention (IPPC), but in most African countries there is no institutional coordination mechanism for ensuring that IAS issues are addressed with the necessary broad, multi-sectoral ecosystem approach.

6.1.2 Knowledge gaps

The weak policy and institutional environment results in critical information for decision making being unavailable. Three categories of information and communication have been identified as lacking. First, there is inadequate sharing and exchange of information between the different stakeholders, including the different arms of government, the private sector, civil society and the general public. For example information about the invasive potential of *Mimosa pigra* L. (Mimosaceae) existed in Zambia from the early 1980s but it is only in the last few years that this has became widely known by the relevant authorities. The recent introductions of water hyacinth to the feeder waters for Lake Mburo (Uganda) and to a pool at Adenta near Accra, Ghana are further examples of a lack of awareness of the IAS issues. This is despite the fact that there is a Global Working Group for the Biological and Integrated Control of Waterweeds, under the auspices of the IOBC and the numerous attempts to set up a regional clearing house for information and expertise on water hyacinth impacts and control.

Second, there is shortage of information regarding the biodiversity of a country, and the status of alien species present (Chapter 2). The most comprehensive species lists available are for mammals and birds. Plant lists exist for some key biodiversity areas in some countries but with a few exceptions, e.g. the Budongo Forest Reserve in Uganda, these lists are not comprehensive and non-native species are often not included. Even in well studied areas such as Budongo the severity of the impact of invasive plants is poorly understood. Studies have been carried out on Paper Mulberry (*Broussonetia papyrifera*) L. Hert. Ex Vent. (Moraceae) in Budongo but not on *Senna spectabilis* (DC.) Irwin and Barneby (Leguminosae) which following reconnaissance works undertaken during a project is believed to be exerting relatively greater biodiversity impacts (NARO/UNEP/GEF-IAS project, Uganda, 2009). However, considerable efforts that have been made in the last ten years which resulted in a series of comprehensive Floras for Ghana, Benin, Guinea and probably others, which are gradually complementing older compilations like the fascinating and underrated Flora of West Tropical Africa by Hutchinson and other collaborators.

Third, globally there is an increasing body of relevant information, (for example on effective IAS control and management techniques), that national organisations need to access and contribute to, but the wherewithal to do this is lacking. In spite of the fact that some African countries have websites, not all of them are linked to global information sources such as those of GISP and the IUCN ISSG. Problematic species for which there exists a considerable global body of knowledge that has been poorly accessed by relevant stakeholders in some countries to date, include *Lantana camara* L. (Verbenaceae), *Mimosa pigra, Prosopis juliflora* (Sw) DC (Fabaceae) and water hyacinth. However, we need to acknowledge the efforts being made by the Inter-African Phytosanitary Council, which needs more support.

6.1.3 Inadequate implementation of preventive and control measures

Prevention of the introduction of IAS is practiced to some extent in some African countries through their plant quarantine organisations. The focus is primarily on the prevention of agricultural pests, and the countries implement basic risk analyses. However, capacity is limited, including the assessment of environmental risks, which is now included in International Standards for Phytosanitary Measures No.11 on Pest Risk Analysis for Quarantine Pests. When an alien invasive species breaches the defences and enters a country, early detection and rapid response should provide an opportunity for eradication. Most of the countries in Africa do not have the mechanism for monitoring and detecting invasive species except in agriculture and only a few of them (e.g. South Africa) have rapid response plans to allow for eradication of new invasions.

Control programmes in some countries have been slow or inadequate, but there are some examples of successful control of invasive species, primarily through the use of classical biological control, in which another alien species is introduced that attacks the invasive. Properly executed, this is a safe approach that has led to successful control of water hyacinth in several countries (Chapters 4 and 5). However, control often takes a long time to be implemented. Water hyacinth was first reported from Lake Victoria in 1989, but it was not until 1995 that available biological control agents were released. This is despite an enormous body of literature on the efficacy and safety of this approach (Julien *et al.,* 1999). Ethiopia, on the other hand, has a water hyacinth problem but has never introduced the available biological control agents despite evidence that they have been effective and safe in other countries in Africa and beyond.

Many invasive species have been introduced because of anticipated benefits, and this can present a conflict when control is proposed. *Prosopis* has been and is still promoted as a beneficial tree and was introduced to Ethiopia in the 1970s. While it provides benefits to some, it is now highly invasive. It currently covers thousands of hectares in the Middle and Upper Awash Valley and Eastern Harerge, with damaging impacts on local biodiversity and the potential for much further spread. Approaches for addressing such conflicting perceptions and objectives, including a regulatory framework and scientific methods for evaluating costs and benefits, are generally absent.

6.1.4 Lack of capacity

Institutional, human and physical resources to address IAS problems are inadequate in most countries. Ghana, for example, has 48 official national entry points, most of which are inadequately staffed to prevent unwanted introductions. The national plant protection organisations of some countries have received some capacity building support, but these need to be enhanced. In Ethiopia the Ministry of Agriculture and Rural Development (MoARD) has been given extensive powers to control imports and exports, disposal, inspection and survey and treatment of land with regard to imported plants and plant products (under the Plant Quarantine Council of Ministers Regulation No. 4/1992). However, it lacks the means to implement the regulation.

Some national plant protection organisations in Africa apart from Ghana have received some capacity building as technical cooperation projects through FAO. While such efforts are starting to be translated into procedures such as risk analysis in the crop pest sector, such procedures have yet to be adopted for potential IAS despite the fact that the International Institute of Tropical Agriculture (IITA), in collaboration with national programmes in sub-Saharan Africa and other international organizations, has during the past 20 years given courses in biological control to people working on the biological control of several exotic pests, which have threatened the production of major commodities and the livelihoods of millions of people (Arega *et al.,* 2005). It must also be noted that the IITA has also helped establish strong national biological control programmes and built the biological control capability of these countries.

There are examples of potentially effective control efforts that have so far failed to be translated to the field scale. In Uganda current approaches to the management of *Cymbopogon nardus* L. Rendle (Poaceae) in infested rangelands cost approximately US$175/hectare/year. Integrated control, conducted on a small scale, could reduce these costs to US$25/hectare/year. However, adoption of such approaches has been poor due to a lack of capacity for follow up trials and information dissemination.

There also exists some capacity in biological control. Uganda, Ghana and Zambia have implemented a number of national and regional biological control strategies. Some efforts such as water hyacinth biological control on Lake Victoria have been very successful, while others such as *Chromolaena odorata* L. King & Robinson (Asteraceae) control in Ghana have been less so. Some capacity in biological control of floating water weeds has been built up in Zambia, Malawi, Kenya, Uganda, Tanzania, Benin, Nigeria, Congo Republic, Democratic Republic of Congo and Senegal. However, this has never been translated into a systematic investigation into the possibilities for biological control on invasive alien species affecting terrestrial ecosystems (e.g. *Lantana*) and floodplain ecosystems (e.g. *Mimosa*).

Only a few impacts have been quantified and even then, only in limited areas. It is difficult to estimate the rates of spread and the densities of species invasions, especially over large areas. While it is possible in many cases to estimate the rate of spread of a species over short distances, invasive alien species experts are of the view that the mechanisms and rates of spread at larger infestations might be a bit too difficult. In addition, spread rates are not the only determinants of impact and the population densities of a species at a site also need to be considered. It is thus, difficult to carry out accurate economic assessments. Even with limited data, and other constraints, it appears that control of invasive species will deliver positive benefits and that control operations, if carried out effectively, will be worth the effort.

Socially, there is total lack of basic health and sanitary amenities, such as clean water supply, toilets and waste disposal systems, however, children play barefoot along lake-shores and in the water and thereby exposing themselves to a lot of health hazards. Also, water hyacinth invaded and completely took over rice fields and vegetable farms thereby competing with the crops for both space and nutrients. Fortunately the VRA and other stakeholders are aware of the need to maintain the water hyacinth management programme. Their efforts are now being augmented by the UNEP/GEF Project: "*Removing Barriers to Invasive Plant Management in Africa*" which is being hosted by the CSIR and co-ordinated by CABI Africa, Nairobi. Kenya. This project is working in close collaboration with an African Development Bank-funded project on water weed management in West Africa "*Integrated Management of Invasive Aquatic Weeds Project*".

Evaluation of biological control programmes is essential to justify continued expenditure (Blossey *et al.,* 1996). Most evaluation is undertaken after agent release and establishment, but it may be limited to monitoring the presence and spread of the agents, without evaluation of impact on the weed and its population dynamics (McClay, 1995). Laboratory and small-scale field experiments cannot adequately replicate interactions that occur in the field. The only way to capture the full range of ecological effects of the release of biological control agents is by detailed observations in actual ecosystems. In assessing the impact of the biological control agents, *Neochetina bruchi* and *Neochetina eichhorniae* weevils on water hyacinth infestations in the Tano River and Lagoon complex, it was found that the weevils were inflicting serious damage on the water hyacinth plants but the whole system (plants and weevils) was subject to seasonal flooding of the Tano River. Greater control was achieved in the dry season when weevils abound and the plants more stationary than in the rainy season when the plants and attached weevils are flushed out into the sea. There has been in general, a suppression of growth of the water hyacinth plants as indicated by their shorter heights, (less that 50 cm.) especially in the Tano and Nveye lagoons. However, this cannot be an absolute indication of the effect of the weevils on the plants. It is suggested that more work needs to be done to draw absolute conclusions.

6.2 Recommendations

There is need for a body or an institution to co-ordinate activities of existing and new establishments dealing with invasive species, and also to formulate policies for governments which should be multi-sectoral and must strengthen institutional linkages through coordination and cooperation. This should follow the South African and United States models. The institution being proposed should have adequate powers to deal with the challenge of invasive species and all other waterweeds. That institution should:

- Provide national leadership on invasive species; ensure that national efforts are co-ordinated and effective; promote action at local, district and regional levels and ensure international co-operation.
- Increase resource allocation to institutions to enable them to carry out their mandates relating to the prevention and control of invasive species.
- Provide leadership in regional and international co-operation and develop sub-regional invasive species management plans, including phytosanitary measures.
- Provide guidance on prevention, early detection and rapid response, control and management, restoration, research, information management, leadership and co-ordination.
- Develop a policy for managing all invasive alien species pathways. Trade blocks must be at the heart of such a policy. For example the ECOWAS trade block can facilitate the prevention of trading and transportation of invasive alien species.
- Strengthen education and awareness creation, and also develop participatory management approaches involving stakeholder communities and District Assemblies.
- Provide institutions and stakeholders dealing with invasive alien species in the country with financial and technical support and also assist them to develop the

necessary human resources required for the effective management of invasive alien species.

- Strengthen human resources development programmes in the tertiary education institutions to make them more responsive to Ghana's invasive alien species challenges.
- Finally, update existing laws of the country and those of the Inter-African Phytosanitary Council of the African Union and bring them in line with current developments, national aspirations and existing challenges in relation to the invasive alien species and make these laws work.

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QUESTIONNAIRE

UNEP/GEF PROJECT-"Removing Barriers to Invasive Plant Management in Africa"

Sex......... Age........ Occupation.................. Marital status.....................Location.....................

1. Are you aware of the existence of any plants/Invasive Alien Species (IAS)?
   Yes ....   No...........

2. If yes, what species do you know?

   a Water hyacinth

   b Hippo grass

   c Water fern

   d Water lettuce

   e Other (specify)..

3. Where are they found?

   a Rivers/streams

   b Ponds

   c Wetlands,

   e Lagoons

   g Other (specify)..

4. Are they prevalent in any specific locations in this area? Yes.....   No......

5. Name any three specific locations

....

....

....

6. When was/were this/these plant (s)/IAS first noticed in this area?

   a. Less than 5 years ago,

   b Less than10 years ago,

   c. Less than 20 years ago,

   d Over 20 years ago

e Cannot recall

7 Do you know any folklore about the introduction of this plant/IAS? Yes..... No....

8 If yes, what is/are the prominent ones?

a Seed in imported grain (specify)

b Fishing gear

c Contaminated Boats

d Drift

e As fishing aid

f Ornamental

g Other (specify)

9. Do you have an idea of the origin of the plant/IAS? Yes.... No......

10. If yes where did it come from?

a Neighbouring Country (Specify),

b Asia,

c America,

d Somewhere in Africa (specify),

e Europe,

f Other (specify)...

11 Are there any economic uses for the plant/IAS in your community? Yes ..... No.....

12 If yes what uses do you put it to?

a Medicinal,

b Mulch,

c Compost,

d Fodder Crop,

e Mushroom production

f Handicraft

g Other (specify)...

13. How do you rate it against other weeds that occurred in abundance before its arrival in terms of its usefulness?

a Better,

b Worse,

c Cannot tell

14. Has the plant/IAS been noted to cause any problems since it was detected?
Yes, No

15. If yes what are some of the problems

a Reduction in fish species

b Reduction in Catch per unit Effort (CPUE),

c Harbours vermin (Snakes etc),

d Blocking water ways,

e Blocking fishing gear,

f Causing siltation and water loss,

g Other (specify)……………………………………………..

16. Do you know how the plant/IAS is propagated? Yes..... No.......

17. If yes, how?

a by seed

b stems

c roots

d leaves

e Other (specify)……………………………………………..

18 Does the mature plant/IAS flower and produce seeds? Yes.... No....

19 If yes, how are they dispersed?

a animals

b Water

c Wind

d man

e Other (specify)……………………………………………..

20 Have you ever attempted to control the plant/IAS in any way? Yes.... No.....

21 If Yes, what did you do or do you normally do?

a Remove and burn

b Remove and use

c Application of herbicides

d Abandoning the settlement

e Other (specify)……………………………………………..)

22 Are the practices adopted successful? Yes..... No........

23 If No, why do you think the practices are not successful?

a The plant rejuvenates too fast,

b Seeds germinate and grow very fast,

c The weed is resistant to herbicides

d Sprouts from cuttings of all parts,

e Other (specify)……………………………………………..

24 With your experience how else do you intend to deal with the problems of the plant/IAS?

a Seek Extension advice,

b Report the situation to District Assembly or

c Seek assistance from NGOs

d Seek communal involvement in its management,

e Apply more herbicides at higher doses,

f Work harder to contain the situation,

g Other (specify)……………………………………………..

25 Will you like to see the plant/IAS controlled or eliminated? Yes..... No.....

26 If yes, what in your view is the most appropriate option to manage the plant/IAS?

a Chemical treatment with herbicides,

b Physically remove all and burn regularly,

c Introduce natural enemies to suppress the IAS,

d Other (specify)…………………………………………….

27 Do you see yourself as a partner in the control of the plant/IAS? Yes...... No.....

28 If yes how do you intend to contribute to the control of the plant/IAS?

a Financial contributions,

b Cooperation with and support for Researchers and extension staff,

c Reporting the occurrence of the weed,

d Protection and dispersal of control agents,

e Propagation of the methodology of control,

f Other (specify)…………………………………………….

29 Will you welcome the introduction of any new plants in your area?
Yes....... No.........

30 If No, why not ?

a They may pose health problems,

b They may take over the environment and damage biodiversity,

c They reduce fish populations and diversity,

d They may reduce water quality,

e They may impede water utilisation,

f They could increase cost of water treatment

g They may introduce pests and diseases

h Other (specify)…………………………………………….

31 If yes, Why?

a They may enhance fishing,

b they provide herbs for medicines,

c they are food for domestic animals and wild life,

d they can be used as botanicals pesticides

e they may possess aesthetic value

e Other (specify)…………………………………………………..

32 What will you do to prevent the recurrence of the plant/IAS in your community?

a Refrain from introduction of plants without the necessary quarantine certification and advice colleagues to do same,

b Report strange plants to extension officers, NGOs, District assemblies etc

c Physically remove and destroy strange plants before they spread,

d Other (Specify)