AN ENVIRONMENTALLY-FRIENDLY AND PARTICIPATORY APPROACH TO THE MANAGEMENT OF AN INVASIVE AQUATIC WEED

BY

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A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE, UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE MASTER OF PHILOSOPHY (M.PHIL) DEGREE

JUNE, 2010

DECLARATION

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere. References cited in this work here however have been fully acknowledged.

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DEDICATION

I dedicate this work to my late parents, Ex-Sgt. Amoatanga Awuni and Madam Comfort Laadi Awuni (RIP). They are always remembered with a heart-felt gratitude.

ACKNOWLEDGEMENT

My gratitude goes to Dr. D. D Wilson my Principal Supervisor and Co-supervisors, Messrs. K. A. A. deGraft-Johnson and F. J. K. Akpabey. I acknowledge with gratitude the facilities put at my disposal by the Department of Animal Biology and Conservation Science (DABCS), University of Ghana Legon and by Officers of Customs, Excise and Preventive Services and Plant Protection and Regulatory Services Directorate (PPRSD) at Jewi Wharf Border Post, Jomoro District in the Western Region. Again, the contribution of my family and friends in this endeavour will always be remembered. May God bless you

ABSTRACT

Biological control of water fern, *Salvinia molesta* was studied in concrete tanks of area 4 m^2 each at the insectary of the Department of Animal Biology and Conservation Science (DABCS), University of Ghana, Legon and Jewi Wharf in the Western Region. The impact of *Cyrtobagous salviniae* on *S. molesta* was studied in Legon and Jewi Wharf. Results show that there was damage inflicted on *S. molesta* by the *C. salviniae* which manifested with increase in percentage and area damage of *S. molesta* with time in both locations (correlation coefficient = 0.99 in both cases). The damage became evident when leaves turned brown due to infestation, with the leaves being more likely to fall off during handling. The rate of multiplication of *C. salviniae* was also studied through the numbers recovered per quadrat. Population estimation using a 0.25 m × 0.25 m quadrat during sampling yielded up to 525 adult weevils in the tank at Legon in two months, giving a 6.4 fold increase in population and a density of 131 adult weevils per square metre, that of Jewi Wharf yielded 608 adult weevils in the tank by the third month giving a 16.4 fold increase in population and a density of 152 adult weevils per square metre. The results indicated that *C. salviniae* was able to survive and reproduce on *S. molesta*. The results also indicated that *S. molesta* reduced in area coverage due to damage and the population of *C. salviniae* also reduced in a predator-prey relationship pattern. Assessment of biological control potential of a closely related species, *Salvinia nymphellula* in a large plastic pool at DABCS and on the lower Volta (Big Ada) in the Greater Accra Region was also carried out. The impact of *C. salviniae* released was monitored over a five month period in Legon and in the lower Volta. Sampling was done to determine the percentage damage of *S. nymphellula* by *C. salviniae*. The results indicated that *C. salviniae* could not survive and reproduce on *S. nymphellula*. As a result, there was no

damage characterized by *C. salviniae*. The results confirm the fact that *C. salviniae* is host-specific to *S. molesta* and will not even feed on a closely related species, *S. nymphellula*. The results of the community perceptions on invasive weeds and their control indicated that the communities prefer manual control of weeds to any other method. The Jewi Wharf community was aware of biological control of weeds but not that of the lower Volta. Jewi Wharf community however had mixed perceptions of biological control and did not prefer the method. It was again indicated that perceptions on the invasive water weeds were based on the socioeconomic effects which they encounter from the spread of the weeds, as it has always been the case in other parts of the world where the weeds are prevalent.

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CHAP TER ONE

1.0 INTRODUCTION

1.1 INVASIVE WATER WEEDS

The menace of invasive aquatic weeds is reaching alarming proportions in many parts of the world especially in tropical nations where environmental conditions coupled with increasing number of dams and irrigation projects foster aquatic plant growth. Introduced aquatic plants in Africa represent one of the largest threats to the socioeconomic development of the continent (Cilliers, 2003). According to Cilliers *et al.,* (2003), five aquatic weeds are especially problematic in Africa: They are *Eichhornia crassipes* (Mart) Solms-Laubach (Pontedericeae) (water hyacinth); *Azolla filiculoides* Lam. (Azollaceae) (red water fern); *Myriophyllum aquaticum* (Vell.) Verdc. (Haloragaceae) (Parrot feather); *Pistia stratiotes* L. (Araceae) (water lettuce or Nile cabbage) and *Salvinia molesta*, Mitchell (Salviniaceae) (Kariba weed).

Eichhornia crassipes and *Salvinia molesta* are native to South America and except for the rooted *M. aquaticum*, are free-floating macrophytes. The exact date and mode of introduction of these plants in some countries is not clear. However, water hyacinth has been present in Africa since the late 1800s, while water lettuce was used as a medicinal plant in ancient Egypt (Holm *et al.,* 1977). In the last half of the twentieth century, they spread widely throughout the tropics and subtropics, moved in part by the trade in ornamental plants for fish tanks and ponds, which would have aided their dispersal to new areas. However, in the absence of natural enemies and in, nutrient enriched tropical waters, these aquatic weeds have proliferated and become problematic (Cilliers *et al.,* 2003).

The invasive aquatic weeds in West Africa were of three main species: (1) *E. crassipes*; (2) *S. molesta* and (3) *P. stratiotes*. The first two were reported in West Africa in the early 1980's whiles the third was first reported in the early 1960's. They have increasingly developed dense stands on the surface of West African water bodies, and have rapidly become a major problem, against which the Council of Ministers of Economic Community of West African States (ECOWAS) adopted, in 1987, a regional floating weeds program (AfDB, ECOWAS/IAS Project, 2003). The other two invasive aquatic weeds introduced in West Africa were *Azolla filiculoides* and *Myriophyllum aquaticum*. *Azolla filiculoides* was first reported in Ghana on the Tano lagoon in 1997. Though *Myriophyllum aquaticum* has been reported in Ghana, the exact date of it first introduction is not all that clear (deGraft- Johnson, pers.com, 2010).

Increased global trade and travel are significantly increasing the rate at which new species are intentionally and unintentionally introduced around the world. Agriculture, forestry, fisheries, the pet trade, the horticultural industry and many industrial consumers of raw materials today depend on species that come originally from other parts of the world. The challenge, however, is to identify how the Invasive Alien Species (IAS) influences ecosystems and brings about changes that are inimical to the environment, to biodiversity, economy and social aspects of society (McNeely *et al.*, 2001; UNEP/CBD, 2007).

Apart from the Volta River system, Ghana has some seven major river systems, namely, the Tano, Ankobra, Pra, Kakum, Oti, Ayensu and Densu. Some of these river systems have been dammed for potable water production, irrigation and fisheries.

However, in nearly all the impoundments, serious aquatic mycrophyte infestations have developed affecting the proper use of the water resources and management of the impoundments (deGraft-Johnson, 1991, 1996).

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 in Zimbabwe, where an explosive development of *S. molesta* covered 22% of the surface of the reservoir in the early 1960s (Boughey, 1963).

However, since then, the development of the problem of aquatic weeds to nuisance proportions has been reported in a number of water bodies in Ghana. These include those recorded for Volta Lake (Hall and Pople, 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); Kpong Headpond (Gyimah-Amoako, 1988) and the irrigation reservoirs at Dawhenya, Ashaiman, Okyereko and Mankesim (deGraft-Johnson, 1991).

1.2 Significance of the study

Invasive plants according to the United States Department of Agriculture (USDA) National Invasive Species Information Center, are introduced species that can thrive in areas beyond their natural range of dispersal. These plants are characteristically adaptable, aggressive, and have a high reproductive capacity. Their vigor combined with a lack of natural enemies often lead to outbreak populations. Invasive aquatic plants are included in the invasive plant species. These invasive aquatic plants are introduced plants that have adapted to living in, on, or next to water, and that can grow either submerged or partially submerged in water (wwww.invasivespeciesinfo.gov).

The ECOWAS sub-regional strategy put in place in 1982 in the Agriculture and Natural Resources sector identified programmes on the exploitation of surface and ground water resources, the development of fisheries and the control of floating water weeds (AfDB, ECOWAS/IAS Project, 2003).

These policy and development strategies are in line with the African Development Bank Group vision for poverty reduction, which focuses on agriculture and rural development as the prime building block; given the dominant role agriculture plays as the key employer of the people and the main contributor to Gross Domestic Product (GDP), rural transformation, and economic growth (AfDB/ECOWAS/ IAS Project, 2003).

Data from the Global Invasive Species Programme (GISP) report (Anonymous, 2006 as cited in UNEP/CBD, 2007) on invasive species and poverty show the enormous amount of money lost through IAS. In 1993, the Office of Technology Assessment of the United States Congress estimated that the 79 most harmful invasive species had caused damage of United States Dollars (US$) 97 billion in the USA since 1906. These estimates were subsequently updated and extended to other countries. Annual losses to pests were estimated at US$ 6.24 billion in Australia, US$ 42.60 billion in Brazil, US$ 78.50 billion in USA, US$ 5.56 billion in the UK, US$ 91.02 billion in India and US$ 4.30 billion in South Africa. Globally, the costs of damage caused by invasive species have been put at US$ 1.4 trillion per year, close to 5% of global GDP. These figures provide an interesting comparison between developed and developing countries. Estimated damage caused by invasive species was equal to 53% of agricultural GDP in the USA, 31% in the UK and 48% in Australia. By contrast, the damage in South Africa, India and Brazil amounted to 96%, 78% and 112% of agricultural GDP of these developing countries respectively.

Losses caused by floating weeds are experienced worldwide and in several key sectors of the economies of the ECOWAS countries, including, irrigated agriculture (blocking of channels and pumps), fishery (reduction of catch and increased costs), health (water-borne vector-disease treatment e.g. malaria, encephalitis and filariasis) and reduction in drinking water quality, energy (interfere with hydroelectricity production), transport (hindering boat traffic), wasting water in evapotranspiration, spoils the aesthetic value of water for recreation and tourism and finally threatens the existence of wildlife populations (Mitchell, 1979; deGraft-Johnson, 1996).

As a result of the menace floating water weeds posed to the ECOWAS sub-region, the Council of Ministers of ECOWAS, again adopted in 1987, a regional floating weeds program. The actual project proposal was largely concerned with biological and physical means of control, which were to be combined in an integrated control program.

Four water bodies were included in the project, namely: a) coasts of Benin and Nigeria; b) the Middle and Upper Niger River Basin (Benin, Nigeria, Niger, and Mali); c) the Tano River and reservoirs in Cote d'Ivoire and Ghana (Cote d'Ivoire, Ghana, and Togo); and d) the Senegal River System (Mali, Senegal, Mauritania, and The Gambia) (AfDB, ECOWAS/ IAS Project, 2003).

Following the ECOWAS sub-regional floating weeds program adopted in 1987, a workshop was held on the 24-27 June 1991 in Harare, Zimbabwe. The workshop considered the increasing socioeconomic impact of water weeds to national economies and measures for their control. The meeting was organised by the Commonwealth Science Council (CSC) in collaboration with the International Institute of Biological Control (IIBC) and with the active participation of Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia. Delegations from eight African countries attended the workshop including Benin, Botswana, Ghana, Kenya, Malawi, Nigeria, Uganda, Zimbabawe, as well as experts on water weed control and representatives from the Economic Community of West African States (ECOWAS) and the International Union for Conservation of Nature and natural resources (IUCN) (Commonwealth Science Council, 1993).

The workshop made the following recommendations for action towards their control at the national and regional level:

1. Floating water weeds grow extraordinarily rapidly, so action taken now will limit damage to affected areas and slow the spread of these weeds to new areas.
2. Preference should be given to integrated biological, physical, chemical and other methods of control.

3. As a general rule, biological control should be implemented as soon as infestation is confirmed. Biological control is the only cost-effective, permanent and environmentally-friendly method to combat floating aquatic weeds (Commonwealth Science Council, 1993).

In Ghana, a two-year biological control programme for water hyacinth funded by the Austrian government with support from International Institute of Tropical Agriculture (IITA), Plant Health Management Division, Cotonou, was initiated in 1993 (deGraft-Johnson, 1996). In 1994, another two-year project was instituted on integrated control of aquatic weeds in Ghana supported by European Economic Commission (EEC) through Food and Agricultural Organization (FAO). The emphasis was on the biological control of floating water weeds, *Eichhornia crassipes, Salvinia molesta* (Kariba weed) and *Pistia stratiotes*. The Alien Invasive Species (IAS) recorded were *Eichhornia crassipes* in 1994 in Accra and 1990 in Tano lagoon and *Salvinia molesta* in 1994 in Tano lagoon (deGraft-Johnson, 1996; deGraft-Johnson and Hoevers, 1998). *Pistia stratiotes* and *Salvinia nymphellula* both native to Ghana were first recorded on the Volta lake in the early 1960's (Hall *et al.*, 1975). However, *S. nymphellula* was known to have caused the death of Aku lagoon (borders between Akuse and Amedeka) in the early 1980's (deGraft-Johnson, pers. com, 2009).

An integrated Management of Invasive Aquatic Weed Project was also initiated by EPA-Ghana. This involves essentially biological control to achieve permanent solution, while physical control is employed as a vanguard and short-term solution to infested small-localized areas. This resulted in the removal of 150 hectares of aquatic weeds from two major water bodies – the Volta and Tano Rivers. However, the 150 hectares "is like a drop in the ocean" considering the fact that there is an estimated 6,000 hectares of water weed occupying substantial and critical portions of the Volta, Tano and Oti Rivers (EPA, 2009).

As a result of the problems posed, there is an ongoing Integrated Management of Invasive Aquatic Weed Project by EPA-Ghana which targets the removal of 700 hectares of water weeds from the Volta and Tano Rivers. A separate project is being implemented by the Council for Scientific and Industrial Research (CSIR) on the Oti River (EPA, 2009).

According to EPA-Ghana (2009) stated that the Integrated Management of Invasive Aquatic Weed Project include current collaboration among eight West African countries including Ghana (EPA, 2009). The project is being funded with a 2.5 million dollar loan facility from the African Development Bank. It has a $320,000 grant component, while the Ghana government is expected to contribute $625,000. Considering the enormous financial resources voted for the project in the ECOWAS sub region, it gives an indication that the menace of these weeds is being recognized and much attention and seriousness is being attached to the control of the weeds in order to overcome the numerous socioeconomic problems that result from the invasion of the weeds.

It is in response to the need to curb the water weeds menace on Ghana's water bodies that this study is being initiated to use a recommended environmentally-friendly approach in the management of *Salvinia molesta* and *Salvinia nymphellula*, so that appropriate recommendations will be made to help fight the menace.

1.3 Objectives

The objectives of this study were as follows:

- To compare the production rate of *Cyrtobagous salviniae* (salvinia weevil) on *Salvinia molesta* in bio-agents rearing facilities at Jewi Wharf in the Western Region and at the University of Ghana, Legon.

- To determine the effectiveness and extent of damage caused by *C. salviniae* on the *Salvinia molesta* compared to *Salvinia nymphellula*.

- To assess the level of awareness of the local community of biological control as well as their involvement in the control of the weeds in the Jewi Wharf and the lower Volta.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 MORPHOLOGY, BIOLOGY AND ECOLOGY OF *SALVINIA MOLESTA*

2.1.1 Plant forms

Salvinia molesta is a free-floating aquatic fern with a horizontal rhizome just beneath the water surface (Bonnet, 1955; Room, 1983). Each plant is a colony of ramets. Each ramet comprises an internode, a node, a pair of floating leaves, the submerged 'root,' and associated buds. The "root" is a modified leaf that looks and functions like a root (Croxdale, 1978; 1979; 1981).

Salvinia molesta is morphologically variable, primarily in response to the level of crowding and availability of nutrients. These two factors are largely independent of one another. There are three growth forms, namely; primary, secondary and tertiary. These growth forms grow with a continuum among them and are associated with the degree of crowding experienced by the plant (Mitchell and Tur, 1975).

The primary form occurs as isolated plants in the initial 'invading' stage of an infestation. This form has small, oval leaves less than 15 mm wide that lie flat on the water surface (Plate 1).

Plate 1. The primary form of *Salvinia molesta* D.S. Mitchell.

The secondary form occurs when plants have been growing over open water for some time, either freely or on the edge of stable mats. Internodes are longer, with larger, boat-shaped (slightly keeled) leaves that have rounded apices and are variable in size, but are normally between 20 mm and 50 mm wide. The entire lower leaf surface is in contact with the water (Plate 2).

Plate 2. The secondary form of *Salvinia molesta* D.S. Mitchell

The tertiary form occurs when plants are growing in crowded mat conditions associated with mature infestations. Internodes are short with large heart-shaped, or oblong and deeply keeled leaves up to 60 mm in width when fully opened. The undersides of adjacent leaves are in contact with each other. (Plate 3).

Plate 3. The tertiary form of *Salvinia molesta* D.S. Mitchell

2.1.2 Growth and reproduction

Salvinia molesta is pentaploid, with a chromosome number of 45, and is incapable of sexual reproduction (Loyal and Grewal, 1966). Each node bears a series of up to three axillary buds that develop successively under normal growing conditions (Room, 1988), and up to six in response to damage (Julien and Bourne, 1986). The number of axillary buds that grow, the rate of growth, and plant size are largely dependent on available nutrients. Growth is apically dominant and progresses by expansion of apical and axillary buds, the latter forming branches. New plants form when older plants break apart due to senescence or damage (Room, 1983).

Salvinia molesta is a perennial plant with no seasonal periodicity, although changes in growth may be related to seasonal variations such as changes in temperature. The fact that the plant is asexual and perennial means that millions of tonnes of the plant worldwide may be clones of a single genetic individual (Werner, 1988; Barrett, 1989). The plant is well adapted to growth in low nutrient waters and can take up nutrients quickly when they become available (Room and Thomas, 1986).

The proportion of axillary buds that develop is correlated with the nitrogen content of the plant (Room, 1983; Julien and Bourne, 1986), and the nitrogen content increases following removal of buds by insects or other agents (Room and Thomas, 1985; Julien and Bourne, 1986; Forno and Semple, 1987). At low levels of nitrogen leaves are larger, 'roots' longer, sporocarps occur more frequently, and rhizome branching is reduced (Room, 1983; Julien and Bourne, 1986; Room, 1988; Room and Julien, 1995). The nitrogen content of salvinia ranges from 0.6 to 4.0% dry weight (Room and Thomas, 1986). The maximum rate of nitrogen uptake, calculated from rates of growth, is near 8 mg nitrogen/g dry weight of salvinia/day or about 6,000 kg nitrogen/ha/year (Room, 1986). Actual measurements at a sewage treatment lagoon indicated an uptake of 1,580 kg nitrogen/ha/year (Finlayson *et al.*, 1982).

The optimum temperature for growth is 30°C. Room (1986) described the effect of temperature, above and below 30°C, on relative growth rates and predicted no growth below 10°C and above 40°C. Temperature does not affect the proportion of axillary buds that expand to initiate new branches (Room, 1988). Exposure to temperatures below –3°C or above 43°C for more than two hours kills *S. molesta* (Whiteman and Room, 1991). However, sometimes leaf temperatures that approached 50°C for the hottest parts of days did not obviously affect growth, probably due to water acting as a heat sink for the plants (Storrs and Julien, 1996).

Mats of *S. molesta* can grow in water bodies with conductivities ranging from 100 μS/cm to 1,400 μS/cm (Mitchell *et al.*, 1980; Room and Gill, 1985). In water with 10% of the salinity of seawater (4,800 μS/cm), growth was reduced by 25% (Divakaran *et al*, 1980); at 20% salinity, growth was very slow; while at 30%, plants died after 30 minutes of exposure (Room and Julien, 1995). Optimum pH for growth is 6.0 (Cary and Weerts, 1984). In the field the plant grows at pH values from 5.2 to 9.5 (Holm *et al.*, 1977; Mitchell *et al.*, 1980).

Salvinia molesta compensates for the destruction of buds by initiating growth of dormant buds. Complete compensation occurs only when high levels of nitrogen are available (Julien and Bourne, 1986; Julien *et al.*, 1987). Destruction of leaves (Julien and Bourne, 1988) and rhizomes (Julien and Bourne, 1986) does not induce compensatory growth.

Salvinia molesta combines a high growth rate with a slow rate of decomposition (Sharma and Goel, 1986). Doubling times of leaves of 3.4 days have been recorded in sterile culture and on Lake Kariba, Zimbabwe, numbers of leaves (ramets) doubled in 8 to 17 days (Gaudet, 1973; Mitchell and Tur, 1975). In the Kakadu National Park, Australia, dry weight doubled in 5 to 30 days (Storrs and Julien, 1996). In green house studies, leaf doubling time as low as 2.2 days has been reported (Cary and Weerts, 1983). Under ideal growth conditions, biomass and numbers of ramets typically double in 2 to 3 days (Mitchell and Tur, 1975; Cary and Weerts, 1983). Kammathy

(1968) stated that in the backwaters, canals and rice paddies of Kerala, India, it successfully competes with and even replaces water hyacinth and water lettuce.

Gaudet (1973) found that when *S. molesta* and naturalized species of common salvinia were grown together, *S. molesta* maintained a greater dry weight and larger leaf area. The larger leaf area corresponds to a greater light absorptive area and is a factor in the success of *S. molesta* as a troublesome aquatic plant.

Densities from as high as 2,500 large tertiary form ramets per m^2 (in nutrient-poor water) to 30,000 small tertiary form ramets (in nutrient-rich waters) have been noted. *Salvinia* is 95% water by weight and biomass of living shoots can exceed 600 g/m^2 of dry weight, while biomass of living and dead shoots and 'roots' may exceed 1,600 g/m^2 of dry weight or 400 t/ha of fresh weight (Room and Julien, 1995).

2.1.3 Spread

Salvinia molesta has been introduced to other parts of the world as an aquarium plant (Room *et al.*, 1981). It continued to spread within and between aquatic systems by man to other warm regions of the world. For example, in the Sepik River flood plain of Papua New Guinea, a few plants introduced in 1972 grew in 8 years into mats covering 250 km^2 and weighing 2.2 million tons (Thomas and Room, 1986b; Room, 1990). Mitchell and Tur (1975) also reported that 3 years after the formation of the Kariba reservoir in Africa, *S. molesta* blanketed 21.5% or 1,003 km^2 of the reservoir surface area.

The plant has been discovered and eradicated in several botanical gardens and was detected and destroyed at two aquatic plant nurseries in Florida, where it had apparently been part of a contaminated aquatic plant shipment from Sri Lanka (Nelson, 1984). It is spread accidentally when equipment or boats are moved and deliberately when it is used in a pond, aquarium, or water-garden plant or as a biological weapon (Gewertz, 1983). As a biological weapon, it is capable of doubling in size in a few days and capable of covering an entire waterbody. This prevents sunlight from entering the water, and which in turn prevents plant and animal life from surviving. To make matters worse, it is difficult to kill the plant because small pieces of the plant can regenerate into a new plant. It is carried on animals as they move from infested water bodies to other water bodies (Forno and Smith, 1999). Dispersal within a water body or catchment is by wind and water currents (Room and Julien, 1995).

2.1.4 Habitats

Salvinia molesta grows preferably in stagnant or slow-flowing waters such as lakes, natural freshwater, artificial dams, wetlands, ditches, ponds, drainage canals, and along margins of rivers (Forno and Harley, 1979).

2.2 TAXONOMY OF *SALVINIA*

The aquatic fern family Salviniaceae is placed within the order Hydropteridales and consists of a single genus, *Salvinia* (Mitchell, 1972). *Salvinia molesta* was named after Antonio Maria Salvini (1633-1729), University of Florence in Italy. The specific epithet *molesta* originates from the Latin *molestus* meaning 'troublesome,''annoying,' referring to its weediness (Parsons and Cuthbertson, 2001).

Salviniaceae family in the "world species list" consists of 10-12 species (Hassler and Swale, 2002). *Salvinia molesta* was given recognition as a species in 1972 (Mitchell, 1972) and is grouped within the *Salvinia auriculata* complex, together with *Salvinia auriculata* Aublet, *Salvinia biloba* Raddi, and *Salvinia herzogii* de la Sota (Mitchell and Thomas, 1972). Species within this complex are characterized by the presence of divided but apically joined "basket" hairs on the abaxial surface, which produce an "egg-beater-like" appearance (Plate 4) (Mitchell and Thomas, 1972; Forno, 1983). *Salvinia molesta* can be distinguished from species within the *S. auriculata* complex by the arrangement of sporangia, the shape of sporocarps (Mitchell and Thomas, 1972; Mitchell, 1972), and by the pattern of leaf venation (Forno, 1983).

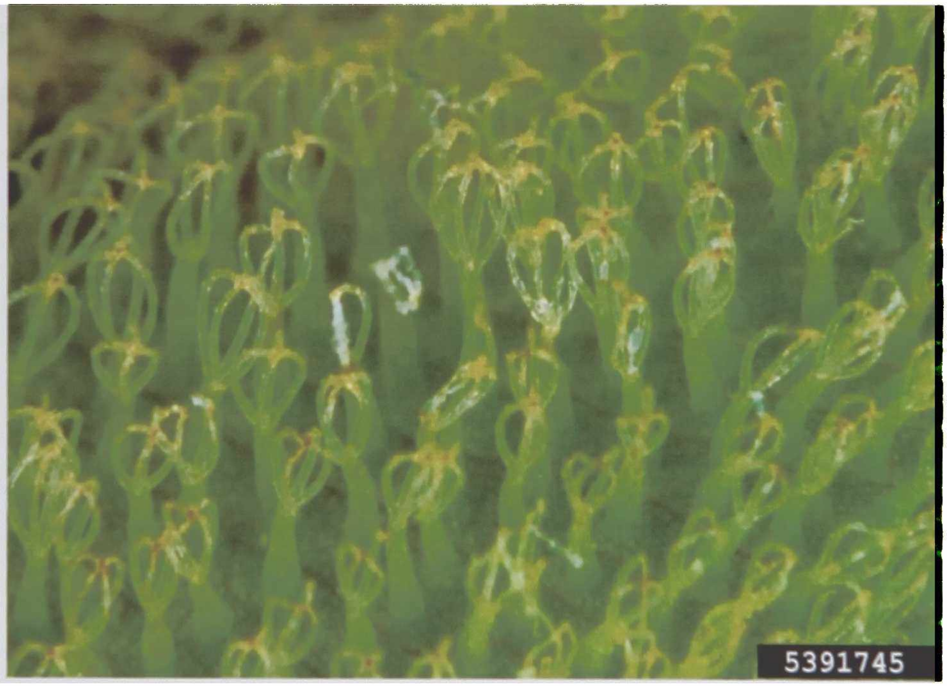

Plate 4. In *Salvinia molesta,* the leaf hairs form an 'eggbeater' shape at the tips. Culled from www.invasive.org

2.2.1 Scientific classification of *Salvinia molesta*- Mitchell

Kingdom: *Plantae* - Haeckel, 1866 – Plants.

Phylum: *Tracheophyta* - Sinnott, 1935 Ex Cavalier-Smith, 1998 - Vascular Plants.

Class: *Filicopsida* - Cronquist *et al.*, 1966.

Order: *Hydropteridales* - Britton, 1901.

Family: *Salviniaceae* - Lestiboudois, 1826.

Genus: *Salvinia* - Floating fern, water spangles [for A. W. Salvini (1633--1729)].

Species: *molesta*- D.S. Mitchell.

Botanical name: - *Salvinia molesta*- Mitchell.

2.2.2 Members of the genus *Salvinia*

Hassler and Swale (2002) in their study "World species list" stated 12 species of *Salvinia*:

1. ***Salvinia auriculata*** Aubl.; *Hist. Pl. Guian* 2: 969. t. 367 (1775).
2. ***Salvinia biloba*** Raddi; *Pl. Bras.* 1: 1, t. 1, f. 4 (1825).
3. ***Salvinia cucullata*** Roxb. ex Bory; *Bot. Voy. Bot.* 26 (1833).
4. ***Salvinia cyathiformis*** Maxon; *Journ. Wash. Acad. Sci.* 12. 401 (1922).
5. ***Salvinia hastata*** Desv.; *Prod.* 177 (1827).
6. ***Salvinia minima*** Baker; *J. Bot.* 24: 98 (1886).
7. ***Salvinia molesta*** Mitch.; *Br. Fern Gaz.* 10. 251 (1973).
8. ***Salvinia natans*** (L.) All.; *Fl. Pedem.* 2: 2 (1785).
9. ***Salvinia nymphellula*** Desv.; *Prod.* 177 (1827).
10. ***Salvinia oblongifolia*** Mart.; *Ic. Cr. Bras.* 128, t. 75, f. 2, t. 76 (1834).
11. ***Salvinia radula*** Baker; *J. Bot.* 24: 98 (1886).
12. ***Salvinia sprucei*** Kuhn in Mart.; Fl. Bras. l(2): 655 (1884).

2.3 ORIGIN AND GEOGRAPHICAL DISTRIBUTION

The native range of *Salvinia molesta* includes a relatively small area (20,000 km^2) in southeastern Brazil, including the states of Sao Paulo, Paraná, Santa Catarina and Rio Grande do Sul. It occurs between the latitudes 24° S and 32° S; at altitudes 0 to 500 m and up to 900 m inland (Forno, 1983; Forno and Harley, 1979). In its native range, *S. molesta* is not especially abundant. Its first recorded exotic establishment was in Sri Lanka in 1939 (Williams, 1956). It has since become established in India (Cook and Gut, 1971), Australia (Room and Julien, 1995), Papua New Guinea (Mitchell, 1979), Cuba, Trinidad, Guyana, Columbia (Holm *et al.*, 1979), South Africa (Cilliers, 1991), Botswana (Edwards and Thomas, 1977), Kenya and Zambia (Mitchell and Tur, 1975), Namibia (Forno and Smith, 1999), Madagascar (Room and Julien, 1995), Ghana and Cote D'Ivoire (de-Graft Johnson, pers. obs.), Indonesia (Java, Borneo, Sulawesi), Malaysia (mainland Sabah, Sarawak) (R. Chan, pers. comm.), the Philippines (Pablico *et al.*, 1989), Fiji (Kamath, 1979), and New Zealand (Randall, 1996).

2.4 NEGATIVE IMPACTS OF *SALVINIA MOLESTA*

The rapid growth of *S. molesta* on water bodies imposes negative effects on the environment, human health and the economies of affected countries. On the basis of environmental, economic and human health problems, *S. molesta* is ranked second to *E. crassipes* on the list of the world's most noxious aquatic weeds (Barrett, 1989).

Mats of *S. molesta* impede access to, and use of waterways for commercial and recreational purposes and degrades waterside aesthetics. The mats reduce habitats for game birds, limit access to fishing areas, and probably alter fisheries, all with negative economic consequences. *Salvinia* can clog water intakes and interfere with agricultural irrigation, water supply, and electricity generation. It provides habitats for vectors of human disease with serious socioeconomic impacts (de-Graft-Johnson 1996; Mitchell 1979). For example, human health costs in Sri Lanka have been increased by *S. molesta* since infestations provide an ideal environment for the reproduction of disease-carrying organisms. It is an important plant host of Mansonia mosquitoes which serve as one of the principal vectors of rural elephantiasis (Pancho and Soerjani, 1978). Other mosquito species sheltered by *S. molesta* have been responsible for the transmission of encephalitis, malaria and dengue fever (Creagh, 1991/1992). In Lake Kariba, small habours have been clogged and the mats aided in spreading snails which are the intermediate vectors of Schistosomiasis (Thomas and Room, 1986a).

Again, in Papua New Guinea, as a result of a few plants infestation in 1972, in 8 years, the level of colonization and the extent of area covered affected the lives of about 80,000 people who were almost entirely dependent on canoes for transport and food (Thomas and Room, 1986b; Room, 1990).

In developing countries, the impact of *S. molesta* can be devastating because weed mats block the use of waterways for transportation, cutting off access to important services, farm lands, and hunting grounds. The harm from salvinia mats to fisheries also can be very significant to communities dependent on fish for local consumption (sometimes as the main source of protein) or in areas where fish sales are the main source of cash income (Bennett, 1966).

Creagh (1991/1992) wrote "A single small plant may grow to form a thick mat covering more than 100 km^2 in just three months, thereby choking lakes and waterways, reducing populations of aquatic plants and animals and in some countries threatening the livelihoods of thousands of people".

The ability to grow very quickly and blanket water bodies makes *S. molesta* an aggressive and competitive weed (Cary and Weerts, 1983; Mitchell and Tur, 1975; Mitchell, 1978/9; Room, 1986). Initially, salvinia forms a single layer over water, but with continued growth, the mats become multi-layered and can reach up to 1 m in thickness (Thomas and Room, 1986). Thick mats support other colonizing plants, and the high biomass and stability of such mats make them difficult to dislodge and destroy (Storrs and Julien, 1996).

Plants and animals dependent on open water to gain sunlight, oxygen, and space for sustenance and growth, or for landing, fishing, nest building, or mating, are displaced by dense *S. molesta* infestations. Water under mats of *S. molesta* has a lower oxygen concentration due to reduced surface area of water available for oxygenation, inhibition of photosynthesis by submerged plants, and consumption of dissolved oxygen by decaying *Salvinia*. This results in higher carbon dioxide and hydrogen sulphide concentrations, lower pH, and higher temperatures than nearby open water (Mitchell, 1978; Thomas and Room, 1986b).

Through high growth rates and slow decomposition rates, *S. molesta* reduces the concentration of nutrients that would otherwise be available to primary producers and organisms that depend on them (Sharma and Goel, 1986; Storrs and Julien, 1996).

Thus *S. molesta* potentially alters the nutrient dynamics of water bodies which it colonizes.

The most detailed assessment of costs caused by salvinia was conducted in Sri Lanka using 1987 as the base year (Doeleman, 1989). Paddy rice losses, fishing losses, other losses (power generation, transport, washing and bathing, etc.), health costs, abatement costs, and economic benefits were considered. No environmental costs were included, but they were recognized as important. There were no identified benefits from *S. molesta*. Total costs associated with *S. molesta* were estimated to be between 0.9 and 2.1 million Australian dollars for 1987. This information was used to determine the benefits from biological control over the following 25 years.
Room and Julien (1995) used the above information as a guide and estimated that the annual benefits gained from successful biological control of salvinia worldwide were approximately $150 million U.S.

2.5 UTILISATION OF *SALVINIA MOLESTA*

Despite the problems posed by *Salvinia* on water bodies, researchers have identified some good uses of the plant.

Research conducted in the USA has shown that *Salvinia molesta* could be used as a feed supplement or as an ingredient in the diets of the herbivorous fish, *Oreochromis niloticus* (King *et al.* 2004). However, Moozhiyil and Pallauf (1986) stated that the plant is not suitable as a sole source for fodder because of high contents of crude ash, lignin and tannins which tends to reduce digestibility.

There are also prospects in the use of dried *Salvinia* material in the manufacture of paper and when used in combination with rice straw could be used to manufacture packaging materials in addition to other uses (Bambie & Bhardwaj, 1979). Again, salvinia has been used in biogas generation which is also an important alternative energy source (Abasi & Nipaney, 1984).

2.6 CONTROL METHODS OF *SALVINIA MOLESTA*

Solutions to the problem of the water weeds infestations are many and varied, and depend upon the particular situation in which the weeds have appeared, the level of infestation, and the kinds of communities and facilities that are being affected. However, they are usually divided into three major categories namely, biological, chemical and physical controls.

2.6.1 Chemical control

The application of herbicides for control of aquatic weeds has been carried out for years. The herbicides most commonly used to control *Salvinia molesta* include diquat at 1-2 kg/ha, fluridone at 20 parts per billion, diquat at 3% plus copper at 5 % (Westerdahl & Getsinger, 1988).

In Australia, repeated applications of paraquat at an unspecified treatment rate and a wetting agent have been used successfully to control *S. molesta* (Miller and Pickering, 1980). However, Glyphosate was reported to be ineffective in controlling the plant (Mitchell, 1979) and Fluridone was also not effective (Wells *et al.*, 1986). Diquat was reported by Mitchell (1979) as only one-eighth as effective as paraquat, however, in

Malaysia, diquat at 4.5kg/ha was effective in controlling the plant (Kam-wing and Furtado, 1977).

The main concern on the use of herbicides is the environmental and health related effects, especially where people drink from the water (AfDB, ECOWAS/ IAS Project, 2003). Large scale application of herbicides may result in rapid loss of oxygen from water bodies due to the exceedingly large amount of dead plant materials that sink to the bottom. This will interfere with aquatic life (Brooker and Edwards, 1975; Culpepper and Decell, 1978; Madsen, 1997). The method does not give a permanent solution to weed infestation (AfDB, ECOWAS/ IAS Project, 2003).

2.6.2 Physical control

Manual: Manual removal of aquatic weeds is suitable only for very small areas. It is also difficult, labour intensive and could involve serious health risks associated with the work, such as snakes, crocodiles and bilharzias. Transportation of the harvested weeds, for example, is also costly because of it very high water content. However, this method induces capacity building through involvement of the local people, and could also create income generation opportunities through uses of the harvested weeds (AfDB, ECOWAS/ IAS Project, 2003).

Cook (1976) reported that manual control was successful in controlling 1,500 hectares of the plant on an Indian hydroelectric reservoir. Thirty men removed about half of the infestation over a three-month period and it required annual repetition to maintain acceptable levels of control (Murphy, 1988).

Again, in the Adelaide River, Australia, hand removal and erection of nets at the water surface were used in the management of *S. molesta* (Miller and Pickering, 1988). This was used alongside with spraying remaining plants with herbicides such as diquat and 2, 4-D along the edges of the Adelaide River, Australia (Miller and Pickering, 1988).

Mechanical: Mechanical removal of aquatic weeds is generally seen as the best short-term solution to the problems created by the weeds. It is however costly, involving either land-based bucket cranes, draglines or booms, or alternatively, water-based machinery such as mowers, dredges, barges or specially designed aquatic weed harvesters. Even then, such methods are suitable only for relatively small areas; and many of these techniques require the support of water and land-vehicles for transporting the large quantities of the weed that is removed. Plants may regenerate from small fragments and rapidly reinfest cleared areas (AfDB, ECOWAS/ IAS Project, 2003).

The relatively high costs of the purchase and maintenance of the machinery are likely to outweigh the positive but limited and temporary impact of the method (AfDB, ECOWAS/ IAS Project, 2003).

In Ghana, the management of aquatic weeds has been mostly on adhoc basis and involves manual or mechanical removal and limited application of herbicides. These methods have often either no long-term advantage, being too expensive or invariably unacceptable particularly in impoundments for potable water production (de-Graft Johnson, 1996; Annang, 2009).

2.6.3 Biological control

Biological control is the use of host specific natural enemies to reduce the population density of a pest. Several insects and fungi, including a variety of weevils and moth have been identified as control agents for aquatic weeds (Ennis, 1982).

The major advantage of biological control is that the natural enemies once established can reduce and hold certain weed infestations below economic damaging levels. After the initial cost of development, the annual cost of a self-perpetuating biological control measure is much lower than the other methods which must be repeated annually. However, biological control generally provides a lower degree of control (McLaren and Amor, 1979).

The natural enemy acts strictly on its host and remains available only at the site of infestation, and tends to be self-regulating. Biological control is therefore said to be environmentally safe (AfDB, ECOWAS/ IAS Project, 2003).

2.6.4 Integrated biological and manual control

This involves essentially biological control to achieve permanent solution, while physical control is employed as a vanguard and short-term solution to infested small-localized areas. Physical control would be carried out as regular complement to biological control, thereby making it possible to achieve maximum control of the invasive weeds.

The integrated control should be supplemented with public awareness campaign (Taylor, 1999) and encourage participatory involvement of the local community in the control programme (Taylor, 1997). Local communities should be trained in the practical uses of harvested weeds, for example: compost, animal fodder, yarn and rope, baskets, mats and biogas production. Integrated control allows the use of aquatic weed during the physical control, thereby increasing economic capability, temporarily (AfDB, ECOWAS/ IAS Project, 2003).

2.6.5 Case study of integrated biological and manual control in Botswana

In Botswana, biological control of *Salvinia molesta* integrated with community participation, coupled with the rapid implementation of a well-managed action plan using a labour force of 27 to 37 men at the community level resulted in the eradication of *S. molesta* and rehabilitation of an area of the Okavango swamp within 2 years. The operational activities lasted from July, 1986 to February, 1987 (Forno & Smith, 1999).

2.6.6 Community participation in the management of weeds in Ghana

With the support of EPA-Ghana, similar eradication and rehabilitation activities is on-going on the Tano lagoon. As a result, some community members have been trained to manually remove invasive aquatic weeds as a vanguard in the short-term in the Jewi Wharf community, whiles biological control continues as a long-term and permanent measure to achieve control in the Tano lagoon.

2.7 DESCRIPTION, BIOLOGY AND ECOLOGY OF *CYRTOBAGOUS SALVINIAE*

Cyrtobagous salviniae **has been identified as a biological control agent that is host specific to *Salvinia* species (Room *et al.*, 1981; Forno, 1983 and Cilliers, 1991).**

The adult male of *C. salviniae* (1.8 x 0.9 mm) is slightly smaller than the female (2.2 x 1.2 mm). Newly emerged adults are brown, darkening to black in about 5 days. It is a nocturnal animal difficult to be seen in the field (Mitchell, 1979). Adults are found on or beneath young leaves, on or inside the developing leaves and submerged stolons or runner-like structures called rhizomes. When under water, adults respire by means of a film of air bubbles called a plastron that adheres to their ventral surface (Forno *et al.*, 1983).

Multiple matings occur 5 to 26 days after emergence. At 25.5°C, oviposition begins after 6 to 14 days. Eggs (0.5 x 0.24 mm) are laid singly in cavities excavated by adults in lower leaves, developing leaves, rhizomes, and 'roots.' At 25.5°C, females lay one egg every 2 to 5 days for at least 60 days (Forno *et al.*., 1983). Eggs hatch in 10 days at this temperature. Newly emerged larvae (1 mm) are white. They feed initially on 'roots' in or on the small buds, and later inside rhizomes, completing three instars in approximately 23 days (Forno *et al.*, 1983).

Development rate is dependent on temperature and the nutrient status of the host plant, larval development taking 13.4 days at 31°C on 'high' nitrogen plants. Larvae prefer to tunnel in young rhizomes and more tunneling occurs if plants are low in nitrogen. Larvae do not survive below 16.3°C (Sands *et al.*, 1983).

Pupation occurs in a cocoon (2.0 x 2.6 mm), which is woven from 'root hairs' and attached underwater to the 'roots,' rhizomes or leaf bases. At 25.5°C, pupae require 12.6 days for full development. Pupal duration is not affected by plant quality (Forno *et al.*, 1983; Sands *et al.*, 1983).

Oviposition does not occur below 21°C, and eggs fail to hatch below 20°C or above 36°C. Adults feed between 13°C and 33°C (Forno *et al.*, 1983). However, Forno and Bourne (1986), stated that the damage caused by the insect generally increases as water temperature increases from 16 to 30°C. The lower lethal temperature at which 50% of the adult population would be expected to die is -5.2°C (Reaney 1999). Population densities of *C. salviniae* are capable of reaching 300 adults and 900 larvae per m^2, levels estimated as necessary for control (Room and Thomas, 1985; Room, 1988, 1990).

2.7.1 Scientific classification of *Cyrtobagous salviniae*- Calder & Sands

Kingdom: *Animalia*

Phylum: *Arthropoda*

Class: *Insecta*

Order: *Coleoptera*

Family: *Curculionidae*

Genus: *Cyrtobagous*

Species: *salviniae*

Zoological name: *Cyrtobagous salviniae*- Calder & Sands.

A

B

Plate 5. A. The *C. salviniae* (Culled from www.invasive.org)

B. A photograph of *C. salviniae*

2.8 EFFECT OF *CYRTOBAGOUS SALVINIAE* ON *SALVINIA MOLESTA*

The Adult *C. salviniae* are found on or beneath young *S. molesta* leaves, on or inside the developing leaves and submerged stolons or runner-like structures called rhizomes. Both the adult and larvae of *C. salviniae* feed on the leave buds. The larvae eventually tunnels into young rhizomes or sometimes the petioles (Forno *et al.*, 1983). Combined feeding actions of the adults and larvae can be devastating with reported impact to field populations of *S. molesta* sometimes observed in just several months instead of years, as typically seen with other biological control agents (Sands and Schotz, 1984).

Releases of *C. salviniae* from *S. molesta* in south-eastern Brazil were made first in Lake Moondarra, Australia in 1980. By mid 1981, *C. salviniae* had destroyed the weed by more than 90% leaving few small patches (cited in Julien and Griffiths, 1998). *Cyrtobagous salviniae* now controls *S. molesta* in most tropical and subtropical areas. It has been released in 15 countries and controls the weed in at least 12 of these (Table 2.1).

Despite heavy use of herbicides, mainly paraquat, in the Kwando/Linyanti river systems on the border between Botswana and Namibia from 1975 to 1983, *S. molesta* was not brought under control until a biological control agent, the weevil *Cyrtobagous salviniae* was released on the Namibian side of Kwando/Linyanti in December 1983, following spectacular biological control of *S. molesta* in Australia (Room *et al.*, 1981). By 1986, most of the *S. molesta* was infested with the weevil and 12 months later the mats of the weed were disintegrating and declining due to damage by *C. salviniae*.

Table 2.1: The Status of releases of *Cyrtobagous Salviniae* Calder and Sands for various countries and the date of initial release (Modified from Julien and Griffiths, 1998)

Country	Initial Release Date	Status
Australia	1980	Control in tropical and subtropical areas; some control in temperate areas
Botswana	Spread from Namibia	Control in 1 to 5 years
Cote D'Ivoire	1998	Established and spreading
Fiji	1991	Successful control
Ghana	1996	Control
India	1983	Control at Bangalore and Kerala
Indonesia	1997	Status is unknown
Kenya	1990	Control except where affected by herbicide
Malaysia	1989	Control where released. Needs redistribution
Namibia	1984	Good control
Papua New Guinea	1982	Good control
Philippines	1989	Established on Panay. Impact unknown
South Africa	1985	Successful control within 2 years
Sri Lanka	1986	Successful control
Zambia	1990	Excellent control
Zimbabwe	1992	Good control within 2 years

2.9 DESCRIPTION OF *SALVINIA NYMPHELLULA* DESV

This aquatic fern consists of fronds which float freely on the surface of the water. Its stem is about 1 mm thick and hairy. It branches irregularly and bears three leaves at each node. Of the three, the two bilateral leaves are green, flattened and oblong in shape up to 10 mm long by 7 mm wide with stalks swollen by air spaces. The upper surface of these floating leaves bears simple hairs which repel the water. The lower leaf of the whorl is very different; it is divided into narrow filaments which hang down about 20 mm into the water and resemble roots in appearance and function (Hall *et al.*, 1975).

Sporocarps of about 1mm long and ovoid in shape are occasionally found attached to segments of the submerged leaves. *Salvinia nymphellula* occurs with duckweeds and *Azolla* in sheltered water among the stems of emergent sedges (Hall *et al.*, 1975).

Another species of *Salvinia* is *Salvinia molesta* which is a serious weed in many parts of the tropics. *Salvinia molesta* differs from *S. nymphellula* in its larger sized leaves of about 30 mm long and the leaves surface hairs that form an egg-beater shape at the tips unlike the latter with simple hairs on the upper surface of the floating leaves (Hall *et al.*, 1975).

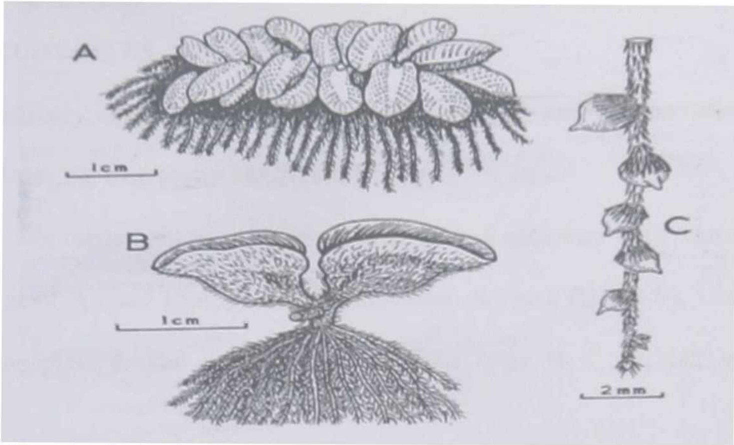

Plate 6: (A) A whole plant.

(B) Whorl of two broad floating leaves and one finely divided submerged leaf.

(C) Sporocarps on a segment of a submerged leaf.

Drawing reproduced from Hall *et al.*, 1975.

Plate 7: A Photograph of *Salvinia nymphellula* DesV

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 STUDY SITES

3.1.1 Insectary of the Department of Animal Biology and Conservation Science (DABCS), University of Ghana, Legon

The study was carried out in an open-air wire meshed enclosure with rearing pools at Department of Animal Biology and Conservation Science (DABCS), University of Ghana. See plate 8. The coordinates of the site were N 5^0 39.2662' and W 0^0 11.3261'.

Plate 8: Rearing pools at DABCS.

3.1.2 Jewi Wharf

The study area, Jewi Wharf, is a community situated in Half Assini, capital of Jomoro District in the Western Region. The district lies between latitudes 04^0 55' – 05^0 15' N and longitudes 02^0 15' – 02^0 45' W and is bordered on the north by Wassa Amenfi and Aowin Suaman Districts, to the east by Nzema East District, La Cote d'ivoire to the west and the gulf of Guinea to the south. The size of the District is 1,344 km^2 (www.ghanadistricts.com).

The district lies in the Tropical Rain Forest belt with the coastal vegetation being largely mangrove swamp and the wettest part of the country with two raining seasons and average annual rainfall more than 1,732 mm. Being tropical, there is high humidity with a uniformly high temperature that favours plant growth (www.ghanadistricts.com).

The research site was an open-air wire-meshed enclosure with rearing pools at Jewi Wharf, located along the banks of the Tano/Ehe/Nveye Lagoon complex which borders Ghana and Cote d'Ivoire and close to the Customs and Plant Protection and Regulatory Services Division (PPRSD) office. See plate 10 and Map 1. The coordinates of the site were N 05^0 05.288' and W 02^0 56.684'.

3.1.3 The lower Volta

The site is located at Big Ada, in the Dangme East District of the Greater Accra Region. The District is one of the least populated Districts in the Region. It is located on the southern coast of Ghana along the Gulf of Guinea between latitudes 5° 45' 10'' N and 6° 00'05'' N and longitudes 0° 20' 05''E and 0° 42' 00''E with Ada-Foah as the District capital with a distance of approximately 118 km east of the nation's capital, Accra (see Map 1). The relief is generally gentle with coastal savannah vegetation that consists mainly of grasses with isolated patches of shrubs and trees. The prevailing climatic condition for most of the year is dry with a mean annual rainfall ranging between 740 mm and 900 mm. Highest and lowest mean temperature in the district is 30 °C and 26 °C respectively.

The estimated population of the District is 93,193 with Ada-Foah and Big Ada being the largest localities in the District (Population Census, Ghana Statistical Service, 2000, cited in www.geohive.com).

The site where the research was carried out was along the banks of the lower Volta River at Big Ada. The coordinates of the site were N 05^0 48.872' and E 00^0 37.128'. The villages located along the banks are Kponkpo-panya, Ohorwin-panya, Korgbor-panya and Kudagbe-panya. These villages stretch for a distance of about 300 m along on the lower Volta.

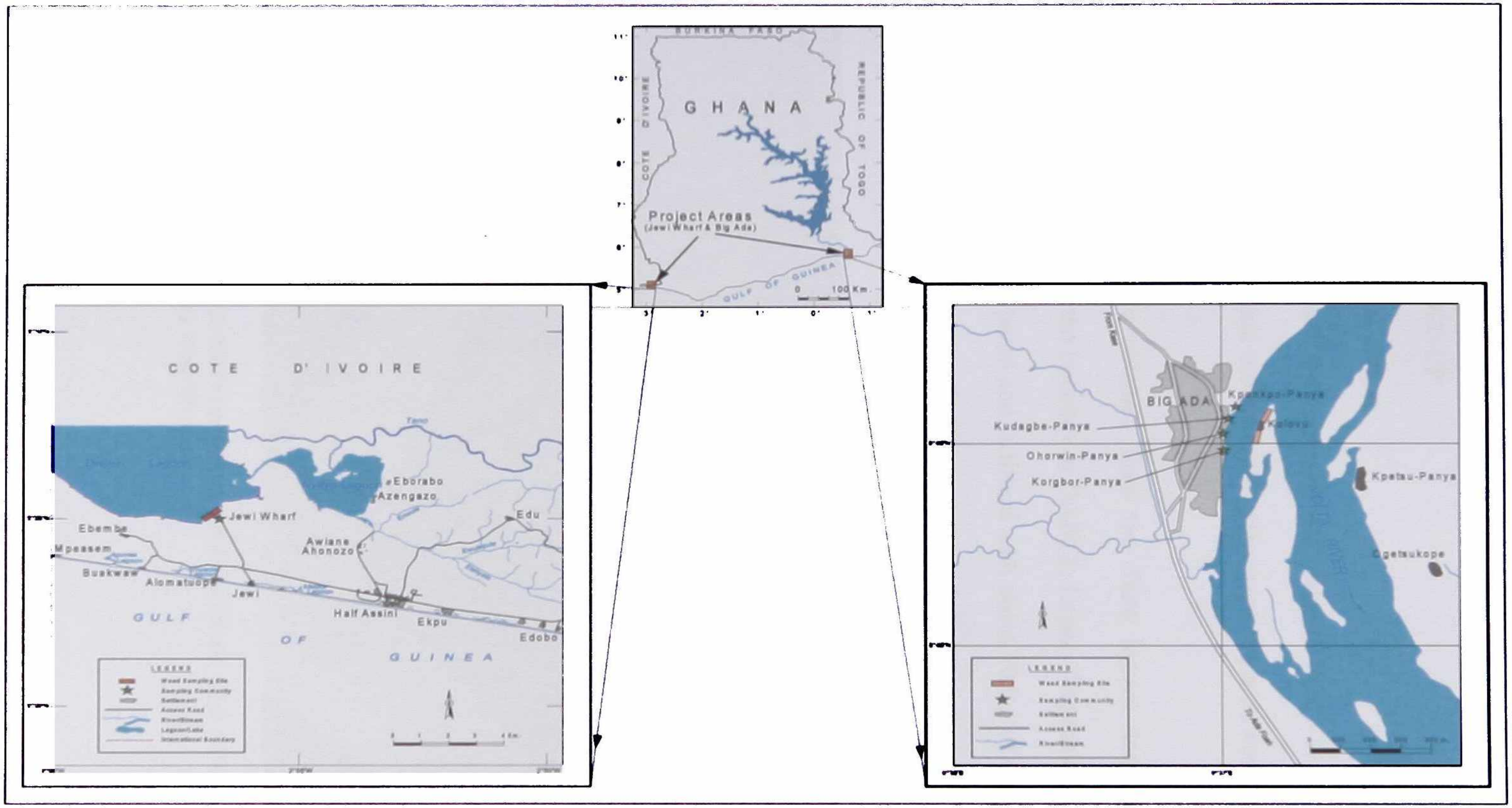

Fig. 3.1: The map of Ghana showing the study areas, Jewi Wharf and Big Ada.

On the left, above the boundary shows Cote d' Ivoire and below is Ghana.

3.2 EXPERIMENTAL SET-UP

3.2.1 The Insectary, DABCS, Legon

The site for the study is surfaced with concrete and about 15 m × 5 m (75 m^2) in area, providing enough space and good surface for the placement of plastic pools and tanks.

Salvinia molesta plants were obtained from the Tano lagoon and transported in transparent polythene bags to the insectary at DABCS, Legon. One tank with dimension 2.0 m × 2.0 m (4 m^2) was prepared and fertilized with about 20.0 g of unhydrated NPK fertilizer for the salvinia plants (plate 9). This was the source of nutrients for the plants.

Plate 9: A 4 m^2 concrete tank containing water fertilized with NPK and in which *S. molesta* was released.

The preparation involved removal of unwanted plants and plant debris. The tank was then filled with water with the aid of a water hose to a height of 1.0 m, making a volume of 4 m^3. *Salvinia molesta* plants were introduced into the tank with a bowl and within a month, the entire surface area of the tank was covered due to the proliferation of the weeds. Routine pond maintenance was carried out to remove unwanted aquatic plants including *Azolla* sp, duckweeds and tree litters with the aid of a sieve. Senescing plants were removed leaving fresh viable plants.

3.2.2 Jewi Wharf

The site is surfaced with concrete and about 5m × 3m (15 m^2) in area enclosing two concrete tanks. The enclosure is fenced with wire mesh and under lock to prevent any intrusion. See plate 10.

Plate 10: The fenced site at Jewi Wharf with rearing pools.

Another concrete tank $4 m^2$ in area was prepared and fertilized with about 20.0 g of NPK fertilizer. *Salvinia molesta* plants were introduced into the tank filled with water to a height of about 1.0 m and also making a volume of $4 m^3$. Within a month, the plants had proliferated and the entire surface area of the tank was covered.

3.2.3 The Lower Volta

Estimation of the level of infestation was about $20 m^2$ *Salvinia nymphellula* with mixed infestations of other weeds such as *Tyha* sp, *Azolla* sp and *Vossia* sp (Plate 11). The level of infestation was estimated with a rope and surveyors tape with the aid of a boat on the lake. The area of the site was rectangular. The length and the width of the site were tied with the rope and the dimensions marked on the rope and then transferred onto the surveyors tape and readings were made. The infestation was divided into two sites, site 1 had a dimension of 6 m × 2 m ($12 m^2$) and site 2 had a dimension of 4 m × 2 m ($8.m^2$). Baseline studies conducted by sampling with 0.50 m × 0.50 m ($0.25 m^2$) quadrat in replicates of 5 in each site showed no sign of *C. salviniae* infestation.

Plate 11: Infestation of the Lower Volta by *S. nymphellula* with other trapped weeds.

3.2.4 Rearing of *Cyrtobagous salviniae*

Salvinia molesta plants infested with *C. salviniae* were collected from the Tano lagoon and reared in a plastic pool of dimension 2.80 m by 0.76 m (diameter and height) and area 6.2 m^2 at the insectary, DABCS, Legon. The *C. salviniae* multiplied and served as a stock for collection and release (Plate 12).

Initial sampling in the plastic pool provided an average of 0.5 salvinia weevils per quadrat which was extrapolated to 50 weevils in the entire pool. In two to three months, the number had increased to an average of 5.0 weevils per quadrat which was extrapolated to 496 weevils in the entire pool. This provided enough stock for release in the tanks and in the lower Volta.

Plate 12: Insect rearing pool at the insectary of DABCS.

3.2.5 Collection and release of *Cyrtobagous salviniae*

To obtain the *C. salviniae*, *S. molesta* plants in the rearing pool were picked into a bowl and examined with a hand lens for the collection of the salvinia weevils (Plate 13). In certain instances, the weevils were clearly visible without the hand lens especially when they were on the leaves. The colour of the weevils sometimes blends with the dark-brown roots of the salvinia plants, making it difficult to see them with the unaided eye. A camel hair brush was used in brushing the weevils into a Petri dish with a cover.

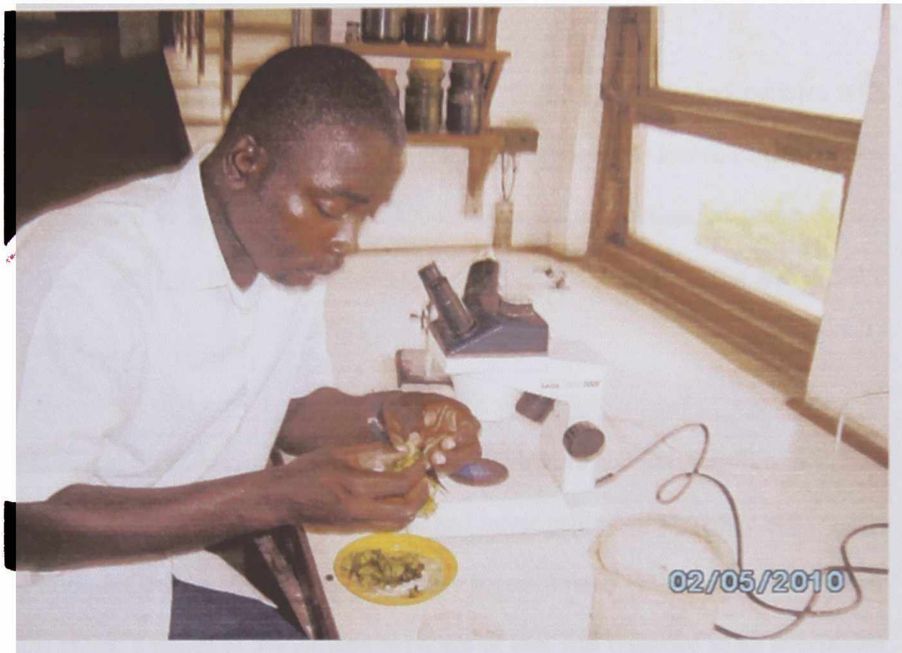

Plate 13: Observation and Collection of *C. salviniae* in the DABCS Laboratory.

The collected weevils were then carried in a well ventilated plastic container with a tiny netted lid smaller than the size of the weevil which prevented the insect from flying off. A ventilated container was chosen to ensure regular oxygen supply needed for respiration by the weevils. Some few fresh plants and water were included in the container to ensure that the weevils do not starve and obtain a simulated aquatic condition, so that they do not die off when being transported to the field.

Releases were done in the mornings and the weevils were evenly distributed on the sites. Mornings were chosen for releases to minimize heat and other stresses in the adaptation of the weevils to the new site conditions. In October 2009, 10 weevils were released, 5 in each tank at the Insectary, DABCS and Jewi Wharf.

3.3 DAMAGE ASSESSMENT

This was achieved by using a visual assessment of the leaves, buds and petioles with feeding marks or punctures in the form of irregular holes. Damaged leaves usually turned dark brown (Everitt *et al.* 2005; Awuni, 2003). Damage was estimated using ratings ranging from 0 to 1 (i.e. 0% to 100%) based on the colour change of the leaves from green to brown.

In weed biological control, equilibrium between the herbivore and the plant is maintained at greatly reduced densities over a long period and never achieving complete eradication (cited in Flores & Carlson, 2006). This point was approximated at 0% surface coverage. Thus in this study, a rating of 5% surface coverage or less was regarded as an acceptable level of control (i.e. ≅ 100% damage). There was no complete eradication as a result of new buds formation from damaged plants (Julien & Bourne, 1986). The damaged level was expressed from 0% to 100%, where 0% equals no damage and 100% equals all plants damaged.

3.4 SAMPLING OF *SALVINIA MOLESTA*

A 0.25 m × 0.25 m (6.25×10^{-2} m^2) and a 0.50 m × 0.50 m (0.25 m^2) PVC made quadrat (qdt) were used in sampling by throwing at random on the *S. molesta* plants in the tanks and on the lower Volta respectively. For every random throw, the plants within the quadrat were collected and the following parameters determined at the time of sampling:

Salvinia molesta

- Area damaged (m^2).
- Area undamaged (m^2).
- Number of *C. salviniae* recovered per quadrat (density per quadrat).
- Proportion (percentage) of *S. molesta* plants damaged per quadrat.

3.4.1 Sampling of *Salvinia molesta* at Legon and Jewi Wharf

The 6.25×10^{-2} m^2 quadrat (qdt) was thrown at random on the plants in the tanks and for every throw, the *S. molesta* plants in the quadrat were collected and number of *C. salviniae* counted by looking through the leaves and submerged stolons. The smaller dimension of the quadrat (6.25×10^{-2} m^2) was used here because of the relatively small size of the pools in which sampling was done. This ensured that enough replicates of the quadrat were sampled unlike the larger quadrat (0.25 m^2) which could have provided less number of replicates in sampling. The larger quadrat however, was suitable for field sampling since the field was relatively larger. The sampled plants per quadrat were then divided into 10, the number damaged in proportion to the number not damaged: Proportion damaged = number damaged/ 10.

Percentage damaged = Mean proportion damaged × 100%.

For example, the second month (20/11/09) of the determination of percentage damage per quadrat at Legon was as follows:

No. of quadrat	1	2	3	4	5	6	Total	Mean	Percent damaged
Proportion damaged	$^{2}/_{10}$	$^{2}/_{10}$	$^{4}/_{10}$	$^{4}/_{10}$	$^{4}/_{10}$	$^{2}/_{10}$	$^{9}/_{5}$	$^{3}/_{10}$	30%

Sampling in Legon and Jewi Wharf was carried out monthly in replicates of 6 and averages taken. Between August, 2009 and December, 2009 data collection completed in these two sites.

3.4.2 Sampling of *Salvinia nymphellula* at Legon and the lower Volta

At Legon, a 6.25×10^{-2} m^2 quadrat (qdt) was used in sampling *S. nymphellula* which took place monthly between November, 2009 and March, 2010. A cumulative total of 60 individuals of *C. salviniae* were released within the period. Sampling was done to recover *C. salviniae* within the period and assessed any damage (Plate 15).

At the lower Volta, a 0.25 m^2 quadrat (qdt) was used in sampling on *S. nymphellula* which took place monthly between January 2010 and May, 2010. A cumulative total of 180 individuals of *C. salviniae* were released between January and May, 100 on site 1 and 80 on site 2. The number of the *C. salviniae* released depended on their availability at the time of their collection and enumeration from the rearing pool. Sampling was done with the quadrat to recover *C. salviniae* within the period (Plate 16). The plants per quadrat were then divided into 10 to assess any damage in proportion to those not damaged:

Proportion damaged = number damaged/ 10.

Plate 14: *Salvinia nymphellula* pool at the insectary, DABCS, Legon.

Plate 15: Sampling *S. nymphellula* in the plastic pool with the $6.25x10^{-2}$ m^2 quadrat at the Insectary, DABCS, Legon.

Plate 16: Sampling *S. nymphellula* on the lower Volta with the 0.25 m^2 quadrat.

3.5 ASSESSMENT OF THE PERCEPTIONS, LEVEL OF AWARENESS AND COMMUNITY PARTICIPATION IN THE CONTROL OF INVASIVE AQUATIC WEEDS

Assessment of perceptions and level of awareness by the local communities of biological control as well as their level of involvement in the control of the weeds at the Jewi Wharf on the Tano lagoon and the lower Volta was done by administering 100 questionnaires, 50 at each study area (Plate 17). The questionnaires administered varied in terms of the type and species of weed infestations in the two locations. In the Jewi Wharf, the questionnaires were based on *Eichhornia crassipes* and *Salvinia molesta* because they were the major invasive weeds recorded whiles in the lower Volta, it was based on *Salvinia nymphellula* since it was the closely related species of *S. molesta* at the study site. A copy each of the questionnaires has been attached to the appendix.

Plate 17: Administration of questionnaires to some community members on the lower Volta at Big Ada.

Plate 18: EPA boats that aid community participation in weed control in Jewi Wharf

CHAPTER FOUR

4.0 RESULTS

4.1 *SALVINIA MOLESTA*

4.1.1 Baseline studies at Legon and Jewi Wharf tanks

Baseline studies in the tanks at the Insectary, Legon and Jewi Wharf revealed that *S. molesta* was already infested with *Cyrtobagous salviniae* (salvinia weevil) from the Tano lagoon. Initial sampling using the 6.25×10^{-2} m^2 quadrat estimated 77 and 32 individuals of *C. salviniae* adult populations in Legon and Jewi Wharf, respectively with negligible damage on *S. molesta*. Plants in both tanks covered an area of 4 m^2 mixed with primary, secondary and tertiary states of the plant.

4.1.2 Rearing, release and recovery of *Cyrtobagous salviniae*

Salvinia molesta infested with *Cyrtobagous sp* were obtained from the Tano lagoon and reared in a plastic pool at Legon. Initial population estimation using a quadrat yielded up to 50 adult weevils and by the thirteenth week, 496 adult weevils in the pool were recorded (Appendix Table 2) giving an estimated 10 fold increase in population.

The baseline figures indicated that *C. salviniae* established well on *S. molesta* in the release tanks at Legon and Jewi Wharf. A total of 10 individuals of *C. salviniae* adults were released from the rearing pool into the release tanks immediately after conducting the baseline studies, 5 in each tank at the time of sampling. This then added to the baseline figures totalling 82 and 37 individuals of *C. salviniae* adults at Legon and Jewi Wharf, respectively (Appendix Table 1). Population estimation using the 6.25×10^{-2} m^2

quadrat yielded up to about 525 adult weevils in the tank at Legon in a month (Appendix Table 1 & Fig 3.2), giving an estimated 6.4 fold increase in population. This indicates that *C. salviniae* was able to survive and reproduce on *S. molesta*. By the third month, the population reduced to 147 adult weevils with a severe damage to *S. molesta* (Fig 3.2 & Appendix Table 1). At this point, about 95% of the *S. molesta* plants appeared brown or yellow and majority lost their water-repelling properties and were soaked in the pool. The remaining 5% were newly formed buds from damaged plants. The colour change of the *S. molesta* plants and their decrease in surface area coverage due to damage over the three month period possibly starved some of the salvinia weevils to death since there was no nearby host for them to feed on. This could have resulted in the decrease in their population to 147 individuals. These weevils were however in the tank feeding mainly on the newly formed buds.

On the other hand, in Jewi Wharf, population estimation using a quadrat yielded 608 individuals of *C. salviniae* adults in the tank by the third month giving an estimated 16.4 fold increase in population (Fig 3.2 & Appendix Table 1).

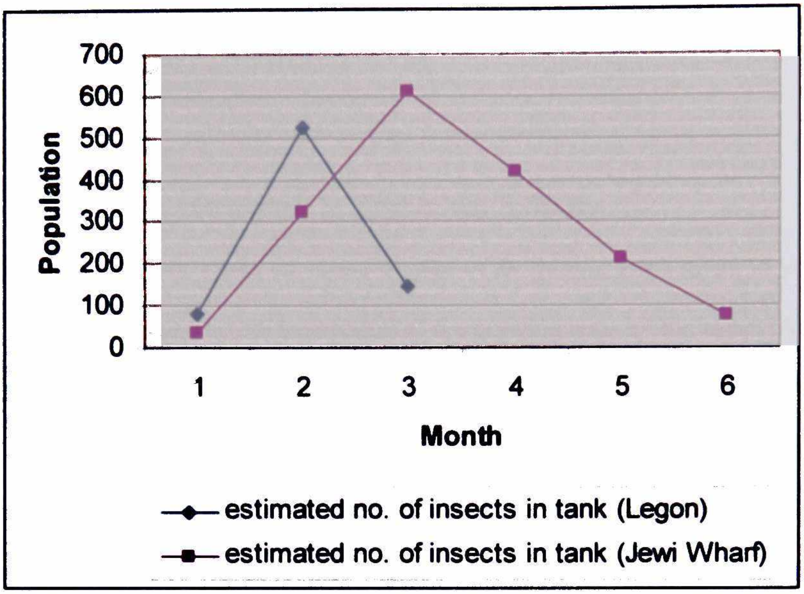

Fig 3.2: Changes in estimated *C. salviniae* population in Legon compared with Jewi Wharf.

This also indicates that *C. salviniae* was able to survive and reproduce on *S. molesta*. By the sixth month, the population reduced to 77 adult weevils (Fig 3.2 & Appendix Table 1). The colour change of the *S. molesta* plants and their decrease in surface area coverage due to damage over the sixth month period possibly starved some of the salvinia weevils to death or they flew off to the nearby host in the Tano lagoon, hence the decrease in their population to 77 individuals. These weevils were however in the tank feeding mainly on the newly formed buds. The figures given indicate that *C. salviniae* numbers increased to a peak and started decreasing over the three and six months period at Legon and Jewi Wharf, respectively. The recovery of the *C. salviniae* adults ended on the third and sixth month at Legon and Jewi Wharf, respectively because in both locations there was more than 95% colour change of the *S. molesta* to yellow or brown, signifying control of the plants in the tanks.

4.1.3 Damage to *Salvinia molesta* by *Cyrtobagous salviniae*

Damage assessment was based on colour change of *S. molesta* from green to yellow or brown. This was initiated by the destruction of the growing buds by the insect. All plants green indicate 0% damage and all plants yellow or brown in colour indicate 100% damage. Ninety-five percent colour changes to yellow or brown were approximated as 100% colour change. On this basis, in the first week of sampling *S.molesta* appeared to have a negligible or no damage (appeared green). The damage of *S. molesta* (percentage or area) increased alongside with *C. salviniae* numbers until *S. molesta* started decreasing when *C. salviniae* also decreased. The damage which manifested with a progressive increase in percentage (proportional) damage uptill the third and sixth month resulted in 95% colour change of *S. molesta* at Legon and Jewi Wharf, respectively (Fig 3.3). This point was approximated at 100% colour change of *S. molesta*. The 147 and 77 individuals of *C. salviniae* on the third and sixth month at Legon and Jewi Wharf, respectively were the numbers recovered when 95% of the *S. molesta* plants were browned. The remaining 5% were newly formed buds from damaged plants. Thus in weed biological control, there is no complete eradication as a result of new buds formation from damaged plants (Julien & Bourne, 1986). The damage also manifested in a reduction in area coverage of the plant uptill the third and sixth month when zero surface area coverage (approx. 100% damage) was achieved at Legon and Jewi Wharf, respectively (Fig 3.4, 3.5 & Appendix Tables, 3 & 4).

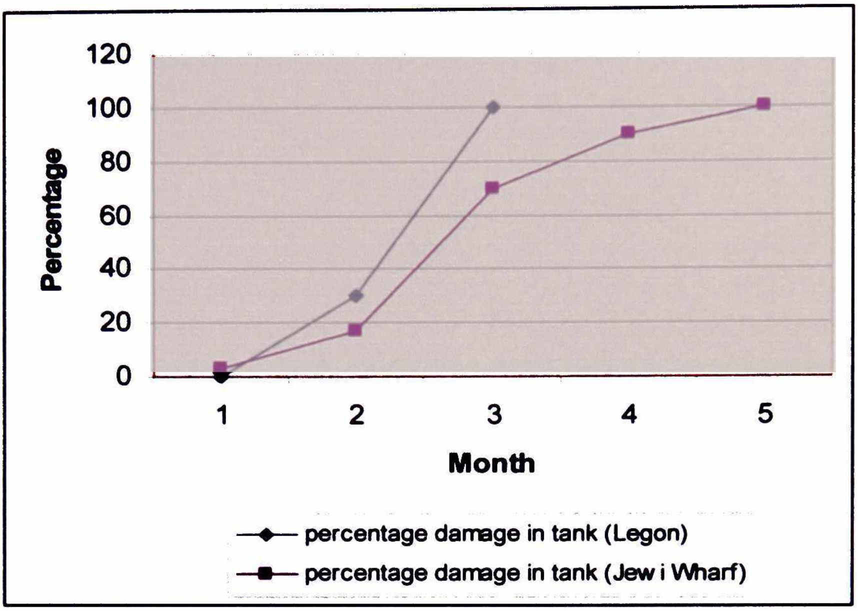

Fig 3.3: Progression in percentage damage of *S. molesta* by *C. salviniae* in Legon compared to Jewi Wharf.

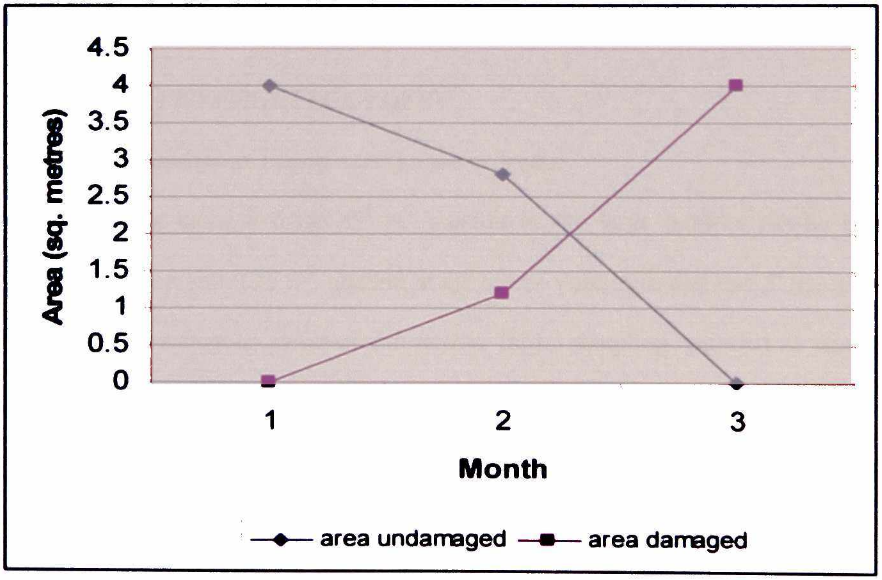

Fig 3.4: Progression of area damaged and undamaged (m^2) of *S. molesta* by *C. salviniae* over a period of three months at Legon.

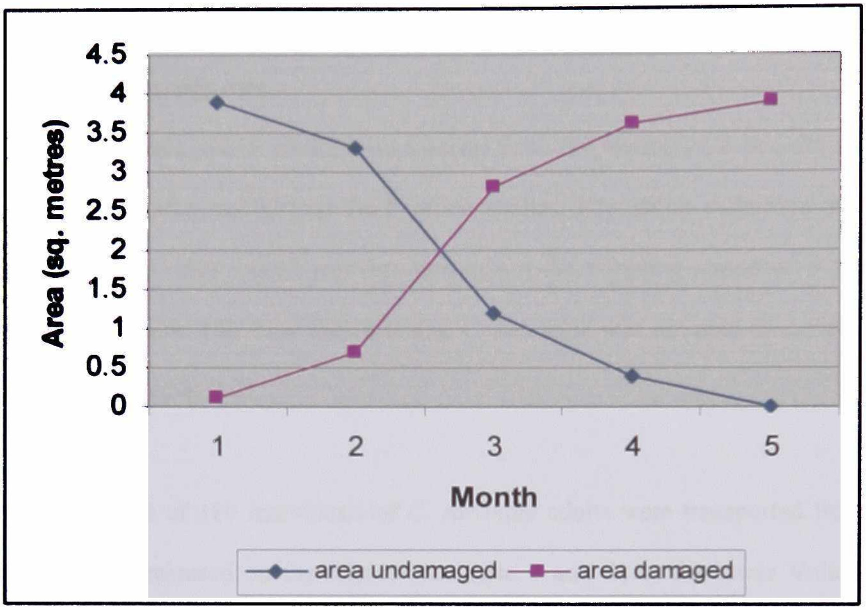

Fig 3.5: Progression of area damaged and undamaged (m^2) of *S. molesta* by *C. salviniae* over a period of five months at Jewi Wharf.

4.2 *SALVINIA NYMPHELLULA* DESV

4.2.1 Baseline studies at Legon and the lower Volta

Baseline sampling using a 6.25×10^{-2} m^2 quadrat in the large outdoor plastic pool or mesocosm at Legon and 0.25 m^2 quadrat at the lower Volta revealed that *S. nymphellula* was free from *Cyrtobagous salviniae* infestation. Initial sampling recorded no damage at the two sites. Plants in the plastic pool and at the lower Volta covered an area of 6.2 m^2 and 20 m^2 respectively, mixed with primary and secondary states of the plant. No tertiary state of the plant was recorded.

4.2.2 *Cyrtobagous salviniae* release and recovery at the Insectary, Legon and the lower Volta, Big Ada

A total of 60 salvinia weevil adults were released from the rearing pool into the release pool immediately after conducting the baseline studies. Population estimation using a quadrat yielded no adult weevil recovery throughout the sampling period of 5 months (See Appendix, Table 10). This indicates that *C. salviniae* was not able to survive and reproduce on *S. nymphellula*.

A cumulative total of 180 individuals of *C. salviniae* adults were transported from the rearing pool and released on the release sites (**site 1 and 2**) at the lower Volta after conducting the baseline studies. Cumulative totals of 100 weevils were released on **site 1** and 80 on **site 2**. Population estimation using a quadrat yielded no adult weevil recovery throughout the sampling period of 5 months. This indicates that *C. salviniae* was not able to survive and reproduce on *S. nymphellula* (See Appendix, Tables 11 & 12).

4.2.3 Damage on *Salvinia nymphellula* by *Cyrtobagous salviniae* at Legon and the lower Volta

Salvinia nymphellula had no damage in the first week of sampling in the release pool at the Insectary, Legon. Subsequent sampling using a quadrat recorded no damage due to feeding by *C. salviniae* over the five months period. Since there was no damage recorded, it did not manifest in the reduction in area coverage of the plant within the five months period (See Appendix, Table 10) in the release pool.

Salvinia nymphellula had no damage due to feeding by *C. salviniae* in the early stages of sampling at the release sites on the lower Volta. Subsequent sampling using the 0.25 m^2 quadrat recorded no damage due to feeding by *C. salviniae* over the 5 months period. Since there was no damage recorded, it did not manifest in the reduction in area coverage of the plant with time (See Appendix, Tables 11& 12) at the release sites.

4.3 STATISTICAL ANALYSES FOR LEGON AND JEWI WHARF SITES

Correlation analyses were conducted using Microsoft Excel to determine the relationship between the following:-

1. Percentage damaged of *S. molesta* in tank at Legon compared to the percentage damaged of *S. molesta* in tank at Jewi Wharf.
2. Area damaged of *S. molesta* in tank at Legon compared to the area damaged of *S. molesta* in tank at Jewi Wharf.

Comparing the two sites, Legon and Jewi Wharf, there was correlation between percentages damaged. Table (i) (Correlation coefficient = 0.99) and areas damaged. Table (ii) (Correlation coefficient = 0.99).

Table (i): Correlation of percentages damaged of *S. molesta* at Legon and Jewi Wharf

Percentage damaged at Legon (%)	Percentage damaged at Jewi Wharf (%)
0	3.3
30	16.7
100	70
	90
	100
Correlation Coefficient	0.994431146

Table (ii): Correlation of areas damaged of *S. molesta* at Legon and Jewi Wharf

Area damaged in Legon (m^2)	Area damaged in Jewi Wharf (m^2)
0	0.1
1.2	0.7
4	2.8
	3.6
	3.9
Correlation Coefficient	0.996522387

4.4 ASSESSMENT OF THE PERCEPTIONS, LEVEL OF AWARENESS AND COMMUNITY PARTICIPATION IN THE CONTROL OF INVASIVE AQUATIC WEEDS

4.4.1 INTRODUCTION

This chapter presents the results of the data collected from the lower Volta, Big Ada in the Greater Accra Region and Jewi Wharf in the Western Region. One of the objectives of the study was to investigate community participation in the control of invasive aquatic weeds in Jewi Wharf near the Tano Lagoon and on the lower Volta at Big Ada. In the pursuit of this, the study explored the following specific issues: to investigate the perceptions of respondents in the communities where invasive aquatic weeds occur, to find out their level of awareness of biological control of the weeds, and to find out their level of involvement in the control of the weeds. The data are presented under specific headings in order to address issues in a meaningful way and using Statistical Package Social Sciences (SPSS) software in the analysis. The presentation is done considering the socio-demographic characteristics of respondents and the specific objectives of the study.

4.4.2 DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

In examining community participation in weeds control, demographic features could help to determine individuals and communities approach to the control of weeds. In the write-up, attention was focused on their age distribution, gender, period of living in the community, occupation, perceptions on the methods of control and the level of involvement in weeds control at the individual and community levels. It was believed that these parameters would help inform community participation in Jewi Wharf on the Tano lagoon and Big Ada on the lower Volta. The following subsections give detailed description of the demographic characteristics of the people living in the data collection communities in Jewi Wharf and Big Ada.

4.4.3 DATA COLLECTION AT JEWI WHARF AND BIG ADA

In all, one hundred community members were interviewed, fifty each in Jewi Wharf on the Tano Lagoon and Big Ada on the lower Volta River (Table a). The sample area at Big Ada however, had a varied number of small communities along the lower Volta unlike Jewi Wharf where sampling was based on the Jewi Wharf community.

Table (a): Number of respondents in each community at Big Ada

Community	No. of Respondents	Percent of Respondents (%)
Kponkpo-panya	22	44.0
Ohorwin-panya	12	24.0
Kudagbe-panya	5	10.0
Korgbor-panya	11	22.0
Total	50	100.0

4.4.4 GENDER COMPOSITION OF RESPONDENTS

The interview was opened to both males and females based on their availability at the time of data collection in Jewi Wharf and Big Ada. However, it appeared that the proportion of males were higher than females because majority of the people who are directly or indirectly involved in the activities of the water bodies were males (Tables b and c).

Table (b): Gender profile of respondents at Jewi Wharf

Gender	No. of Respondents	Percent of Respondents (%)
Male	48	96.0
Female	2	4.0
Total	50	100.0

Table (c): Gender profile of respondents at Big Ada

Gender	No. of Respondents	Percent of Respondents (%)
Male	39	78.0
Female	11	22.0
Total	50	100.0

4.4.5 AGE DISTRIBUTION OF RESPONDENTS

The age range of respondents was between 18 to 50 years and above 50 years inclusive. In Jewi Wharf, most (25) respondents were between 18 to 30 years with 19 of them being ages 31 to 50 years. Those above 50 years were 6 in number (fig 4.1).

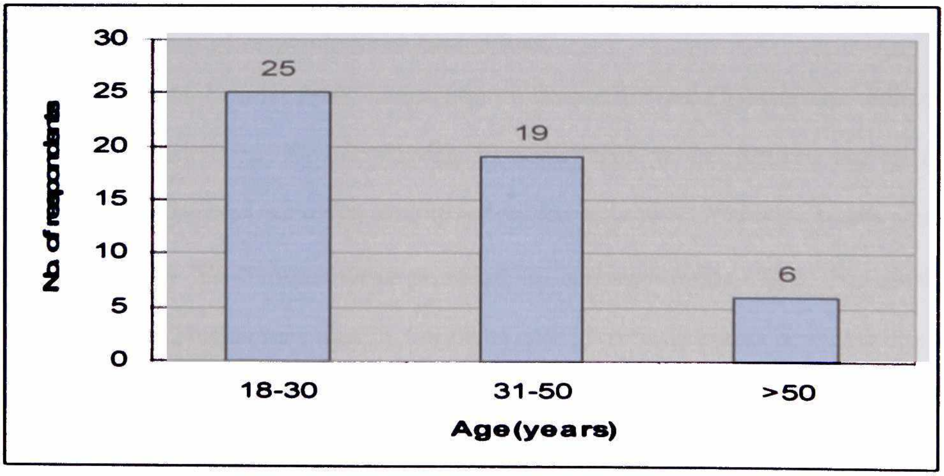

Fig 4.1. Age distribution of respondents at Jewi Wharf.

In Big Ada however, ages 18 to 30 years constituted 21 respondents and 20 of them were between ages 31 to 50 years, whiles 9 of them were over 50 years (fig 4.2).

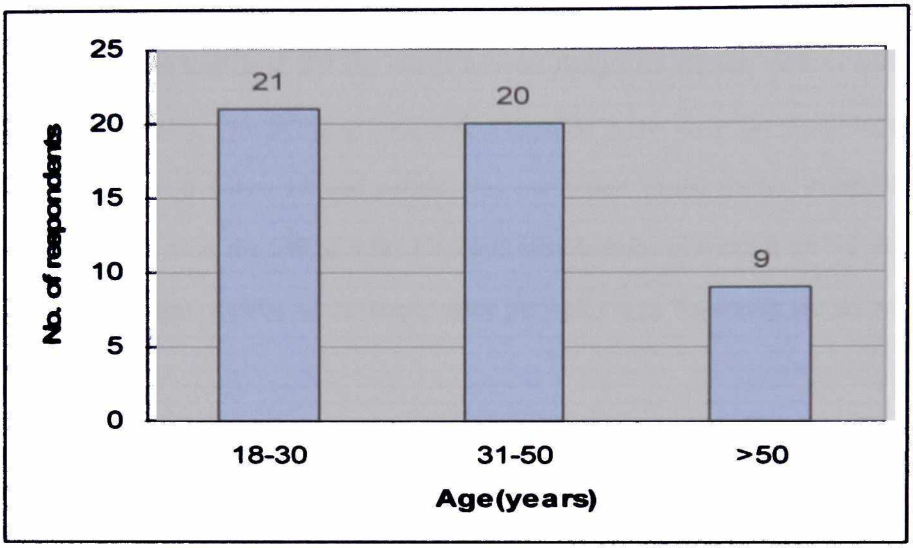

Fig 4.2. Age distribution of respondents at Big Ada.

4.4.6 PERCEPTIONS OF THE COMMUNITIES ON THE INVASIVE AQUATIC WEEDS

4.4.6.1 Perceptions of respondents at Jewi Wharf

The perceptions of the Jewi Wharf community on the weeds (water hyacinth and *Salvinia molesta*) were determined by interviewing 50 respondents. It was realized that all the respondents had perceptions which were based on socioeconomic effects the weeds posed to the community. The 50 respondents provided 127 responses on the effects they usually encounter. The 127 responses were as a result of each of the respondents providing one or more answers of the effects they usually experience from the weeds. Some of the major perceptions were that the weeds make navigation difficult by blocking boats, canals and entangling propellers of outboard motors. These delay transportation of people and goods from neighbouring communities and sometimes endanger the lives of people. About twenty-eight percent (36) responses from 50 respondents also stated that the weeds affect fish catch by entangling fishing nets and carry trapped fishing nets away. A total of 21 (16.5%) responses explained that the weeds habours dangerous reptiles such as snakes, causes skin diseases, breeds mosquitoes and evaporates water from the Tano lagoon. They explained that fishermen and people who participate in the manual removal of weeds usually do so at the risk of snake bites and skin diseases as water from the weeds touches their bodies. Details on the respondents perceptions on the weeds are shown in Table (d).

Table (d): Adverse effects of weeds at Jewi Wharf

Adverse effects	No. of responses from respondents	Percent of responses from respondents (%)
Affect fish catch	36	28.3
Makes navigation difficult	70	55.1
Habours Snakes	9	7.1
Skin Diseases	3	2.4
Breeds mosquitoes	4	3.1
Evaporates water	5	3.9
Total	127	100.0

4.4.6.2 Perceptions at Big Ada

The perceptions in the communities at Big Ada on the invasive weed- *Salvinia nymphellula* were determined. This was done because *S. nymphellula* is a closely related species to *S. molesta*. There were no *E. crassipes and S. molesta* recorded at the time of data collection in the community. In contrast to perceptions in Jewi Wharf where all respondents (50) stated various socioeconomic problems, Big Ada on the other hand, was not the case (38 respondents). In Big Ada, out of the 50 respondents, 8 (16.0%) expressed that the weed poses problems and 30 (60%) stated that the weed does not pose any problem to them. However, the remaining 12 (24.0%) respondents had no idea with regards to the adverse effects of the weed. The problems detected by the 8 respondents were mainly social and not linked directly to the economy. These were production of a bad odour as the weed decomposes at the shore (5 respondents) and the ability of the weed to cover water surface making water fetching difficult (3 respondents). Here, a total of 42 respondents neither had an idea nor detected any socioeconomic effects.

With regards to the perceptions in the two data collection areas, it could be noticed that *E. crassipes* and *Salvinia molesta* posed more serious socioeconomic problems in Jewi Wharf, whiles *Salvinia nymphellula* poses little or no effects in Big Ada. The high number of respondents who could not identify any socioeconomic effects in Ada shows that there are no noticeable problems by majority of the inhabitants on the weed or the effects are only detected in some few locations.

4.4.7 COMMUNITY PARTICIPATION IN WEED CONTROL

In assessing the peoples involvement in weed control, an important factor to look at was weed management at the individual and community level. As a result, data was collected from the various methods of weed control and the method(s) employed by the communities.

4.4.7.1 Individual level of weed control at Jewi Wharf

At the individual level of weed control in Jewi Warf, out of the total of 57 responses from the 50 respondents, it was realized that majority (86%) depended on manual removal, whiles 12.3% and 1.8% depended on wind drift to carry the weeds away and biological control respectively. The results show that there was poor patronage of biological control and a high patronage of physical removal of weeds at the individual level (Fig 4.3). The 57 responses were as a result of each of the 50 respondents showing preference to one or more than one control methods.

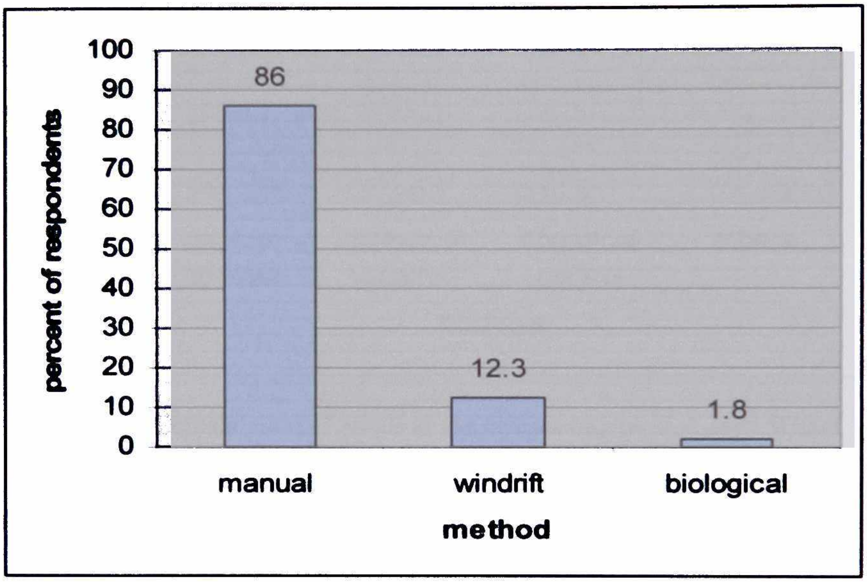

Fig 4.3. Management of weeds at the individual level at Jewi Wharf.

4.4.7.2 Community level of weed control at Jewi Wharf

At the community level in Jewi Wharf, it was realized that out of the 90 responses from the 50 respondents, manual control dominated with 54.4%, followed by biological (34.4%) and others (6.6%). Respondents however, did not show much preference to chemical control (4.4%). Considering the weeds control at the community level, it was realized that manual control was highly embraced by the respondents followed by biological control (fig 4.4). The other means of control (6.6%) was the use of the weeds in composting and feed for farm animals (section 4.4.7.6).

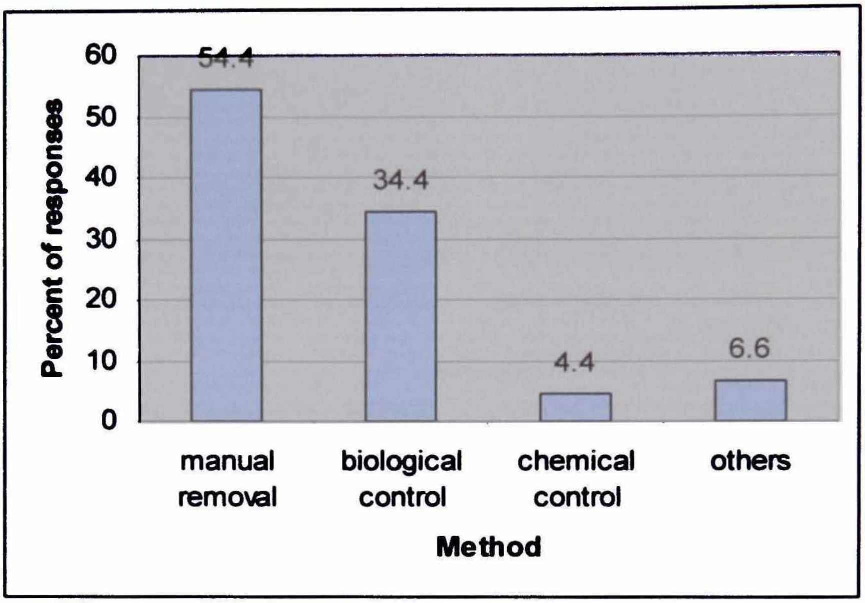

Fig. 4.4: Management of weeds at the community level at Jewi Wharf

4.4.7.3 Reasons for the adoption of control strategy at Jewi Wharf

The reasons given for the adoption of the methods both at the individual and community levels in Jewi Wharf were that, they were effective, environmentally friendly, cheaper and cost effective. However, relatively more responses were provided for the selected methods effectiveness (58.2%) and environmentally friendliness (33%) out of 79 responses from the 50 respondents (Fig 4.5). Here again, the 79 responses came about as a result of each of the 50 respondents providing one or more answers to the reasons of adoption of control strategies. The study shows that the use of physical control was the highest both at the individual and the community levels.

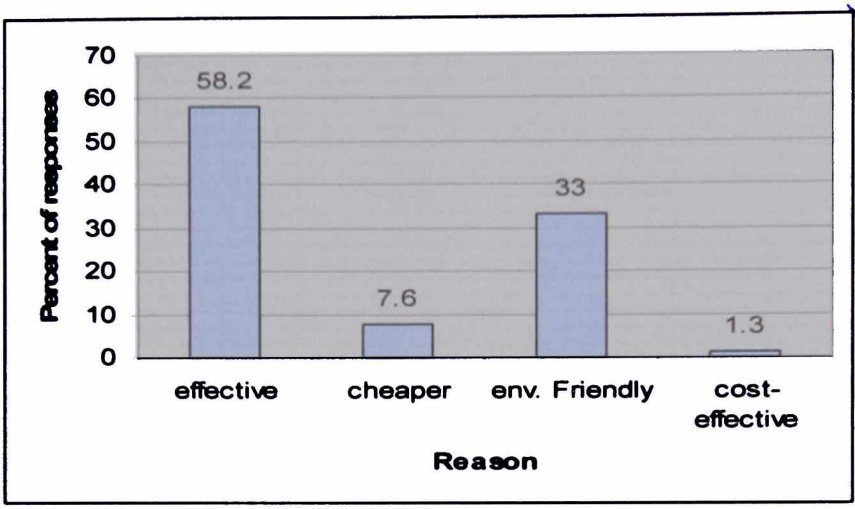

Fig. 4.5: Reasons for using the selected method by respondents at Jewi Wharf.

4.4.7.4 Individual level of weed control at Big Ada

Responses in Big Ada, however showed that weed management was only done at the individual level unlike Jewi Wharf where the weeds were managed both at the individual and community level. The method employed by 24 respondents at Ada was manual removal, whiles 26 showed no interest in the control of the weeds, therefore no method of control employed by them.

4.4.7.5 Reasons for the adoption of control strategy at Big Ada

The reasons for the adoption of the methods at the individual level (no community level existed) in Big Ada were that it was effective, environmentally friendly and cheaper. However, relatively more responses were provided for the selected method effectiveness (52.4%) and environmentally friendliness (31%) out of 42 responses from 24 respondents (Fig 4.6). The study shows that the use of manual control was the only method available at the individual level.

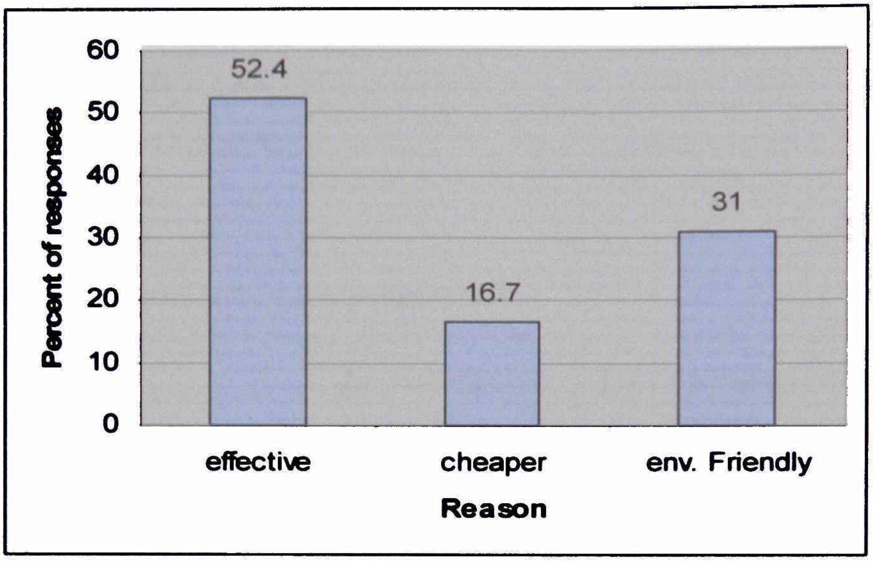

Fig. 4.6: Reasons for using the selected method at Big Ada.

4.4.7.6 Utilization of weeds as a means of weed management

As part of the ways to manage aquatic weeds and getting some benefits from them and despite the numerous problems perceived by respondents on the weeds, some important uses of the weeds were mentioned by respondents. Ninety-four percent of the respondents stated a number of uses of the weeds as detailed in Table (e). The uses of the aquatic weeds in Jewi Wharf community as mentioned by the respondents could help the community to derive some benefits. This in one way helps to manage the impact of the weeds on the Tano lagoon. Annang 2009, in EPA's integrated management of invasive aquatic weed project stated the use of harvested *E. crassipes* in composting and which goes to confirm 30% of the respondents view. King *et al.*, (2004) had also stated that aquatic weeds such as *Salvinia sp* could be used as a supplementary feed for the Nile tilapia, *Oreochromis niloticus*. However, Moozhiyil and Pallauf (1986) stated that the plant is not suitable as a sole source of fodder because high content of crude ash, lignin and tannins reduce digestibility. This finding may affect pig production when *S. molesta* is used.

Table (e): Some uses of the weeds at Jewi Wharf

Uses	No. of respondents	Percent of respondent (%)
Compost	15	30
Mulch	17	34
Feed for Pigs	9	18
Fish breeds under them	6	12
No idea of weed use	3	6
Total	50	100

In contrast to Jewi Wharf where as part of the weed management strategy, *E. crassipes* is used for compost and feed for farm animals, Big Ada on the other hand, had no known use of *S. nymphellula*. However, 1 respondent stated that *S. nymphellula* serves as a breeding place for fish. Infering from the data, it may be that much has not been done on the possible beneficial uses of *S. nymphellula*. This could be attributed to the low level of infestation of the plant on the lower Volta which had not created much interest in research on the possible uses of the plant.

4.4.8 OCCUPATION OF RESPONDENTS

Another factor captured in this study was to examine respondents occupation. Results show that majority of the respondents in Jewi Wharf were Fishermen and Boat Coxswains (58%) whiles others forms a total of 42% (Table f). In the same way, Big Ada recorded a total of 62% for Fishermen and Boat Coxswains, whiles others recorded a total of 38% (Table g).

The occupation was determined to know the percentage of respondents who are linked directly or indirectly in the use of water and its resources. For example, Fishermen and Boat Coxswains are the group of workers whose activities are directly link to the Tano lagoon and the Lower Volta. It is a fact that this group directly encounters the problems caused by these weeds as they navigate on the water body and can therefore provide valuable information with regards to the weed infestations. As a result, most Fishermen and Boat Coxswains were interviewed. Some group of people popularly known as Zoom Crocodile who were employed by EPA-Ghana to be removing the water hyacinth manually were also interviewed based on their availability at the time of data collection. In all, about 6 respondents from this group were interviewed as they could provide useful information on the problems they encounter and their involvement in the removal of the weeds in the Jewi Wharf community.

Table (f): Occupation of respondents at Jewi Wharf

Occupation of respondents	No. of respondents	Percent of respondents (%)
Fisherman	17	34.0
Boat Coxswain	12	24.0
Cart Pusher	2	4.0
Student	1	2.0
Farmer	2	4.0
Custom Officer	1	2.0
Internal Revenue	1	2.0
Immigration Officer	1	2.0
Ministry of Trade & Industry	1	2.0
Driver	1	2.0
PPRSD Officer	1	2.0
Caterer	1	2.0
Carpenter	3	6.0
Zoom Crocodile	6	12.0
Total	50	100.0

Table (g): Occupation of respondents at Big Ada

Occupation of respondents	No. of respondents	Percent of respondents (%)
Fishermen	26	52.0
Boat Coxswain	5	10.0
Truck Pusher	2	4.0
Trader	8	16.0
Student	6	12.0
Driver	2	4.0
Retired worker	1	2.0
Total	50	100.0

4.4.9 IDENTIFICATION AND NAMING OF WEEDS

Perceptions and awareness of the weeds was determined based on the respondents ability to identify the weeds in Jewi Wharf. In all, 98% of respondents were able to identify the weeds and 2% could not. After identification, 20% were able to name weed 1 as Water hyacinth and 58% used a local name called Alowa, 22% could not provide any name to weed 1 (Table h).

Table (h): Responses to Water hyacinth- weed 1 at Jewi Wharf

Name of weed	No. of respondents	Percent of respondents (%)
Water Hyacinth	10	20.0
Alowa	29	58.0
No idea of name of weed	11	22.0
Total	50	100.0

On the other hand, 10% were able to name weed 2 as *Salvinia* and 22% also used a local name called Alowa, 68% could not provide any name to weed 2 (Table i). Some explained that both Water hyacinth and *Salvinia* are named Alowa in the community. Most people (68%) expressed no knowledge of weed 2 (*Salvinia*) with the reason that it is not much of a problem in the Tano lagoon unlike Water hyacinth.

Table (i): Responses to *Salvinia molesta*- weed 2 at Jewi Wharf

Name of weed	No. of respondents	Percent of respondents (%)
Alowa	11	22.0
Salvinia	5	10.0
No idea of name of weed	34	68.0
Total	50	100.0

The high percentages of the use of the local names (Alowa) for water hyacinth (58%) and *Salvinia* (22%) show that the people actually know the weed but were unable to provide the Scientific or English names probably because of the lack of continual education of the indigenous people on the weeds.

However, in Big Ada, 76% were able to identify *Salvinia nymphellula* and 24% were not. Though majority were able to identify the weed as prevalent on the lower Volta, they were not able to provide the name (Local, Scientific or English) except 2% (1 respondent) who were able to name the weed as *Salvinia*, and 98% (49 respondents) could not provide names. The inexistence of a local name for *Salvinia nymphellula* as found in this study, does not agree with the fact that the plant is native to Ghana as stated by deGraft-Johnson (pers. com, 2010) and Hall *et al.* (1975). That is, a native species should definitely have a native name. However, it may also be possible that a native name exists for *S. nymphellula* but the respondents did not know. Surprisingly, Water hyacinth which is exotic species was even named locally as Alowa in Jewi Wharf. With regards to the naming and identification of the weeds, it was realized that majority of the people in Jewi Wharf and Big Ada were able to identify the weeds but they were however having a problem with their naming.

4.4.10 PERIOD OF LIVING IN COMMUNITY

Another factor that was studied was the period of living in the community. Results show that majority of the respondents lived in the Jewi Wharf community above 5 years (80%) and 20% lived below 5 years (Fig 4.7).

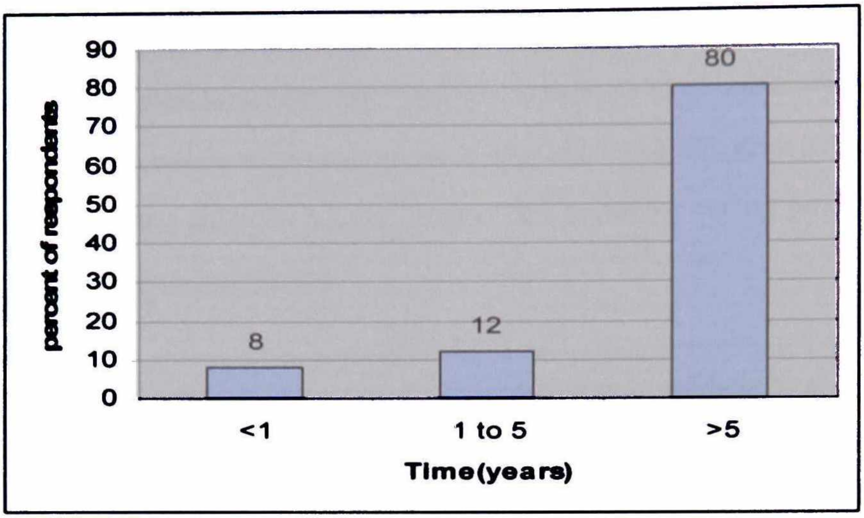

Fig. 4.7: Respondents period of living in Jewi Wharf community.

However, in Big Ada, those who lived above 5 years were 88%, whiles those between 1 to 5 years were 12%. No respondent lived below 1 year (Table j). Results here depict that majority of the respondents in both locations lived above 5 years and are likely to provide valuable information on the weeds than those who lived less than a year.

Table (j): Respondents period of living at the lower Volta, Big Ada

Period in community	No. of respondents	Percent of respondents (%)
< 1 year	0	0
1 – 5 years	6	12.0
Above 5 years	44	88.0
Total	50	100.0

4.4.11 RELATING RESPONDENTS PERIOD OF LIVING IN COMMUNITY WITH PERIOD OF KNOWING WEEDS

It can be realized that the longer the respondents lived in the Jewi Wharf community, the more they stood the chance of knowing the weed. This manifested with those living 5 years and above (80%) and below 5 years a total of 20% correlating with the period of knowing the weeds (Figure 4.7 & 4.8).

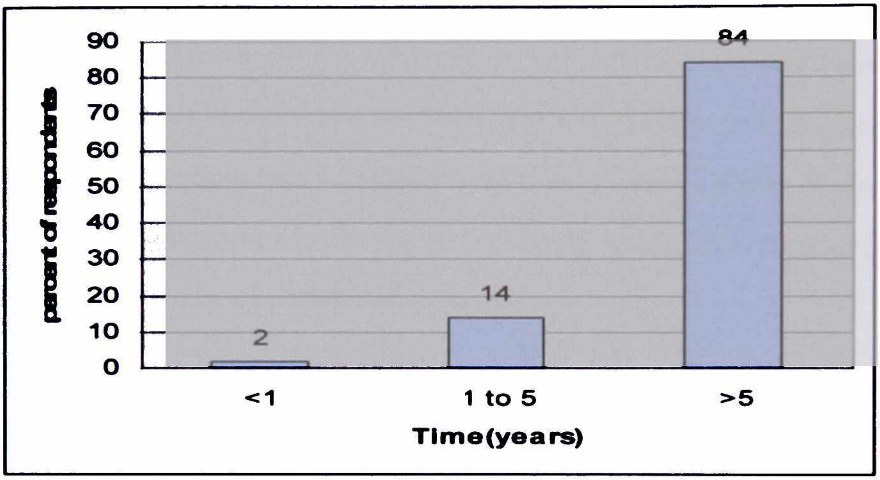

Fig. 4.8: Period respondents have known weeds at Jewi Wharf.

In Big Ada, respondents who lived above 5 years recorded 88% and 5 years and below 12%, this also correlated with the period of knowing the weeds (Table j & k).

Table k: Period respondents have known weeds at the lower Volta, Big Ada

Period of knowing weeds	No. of respondents	Percent of respondents (%)
Less than 1 Year	4	8.0
1 - 5 Years	4	8.0
Above 5 Years	42	84.0
Total	50	100.0

4.4.12 RESPONDENTS INFORMATION ON WEED INFESTATION IN OTHER WATER BODIES

Responses from respondents in Jewi Wharf show that Water hyacinth and *Salvinia* have invaded a number of water bodies in Ghana and Cote D'Ivoire waters. But from the graph, a total of 44 respondents expressed having first seen the weeds in the Tano and Juen Lagoons which all forms part of the Tano/Nveye/Ehye lagoon complex between Ghana and Cote D'Ivoire, whiles Volta Lake and Cote D'Ivoire waters had 1 respondent each. Ankobra and Bia rivers also had 2 each (Fig 4.9). The data shows that apart from the Tano lagoon, respondents were able to identify the weeds in a number of other water bodies. This again supports the fact that the respondents actually know the plant but only have problem with their Scientific or English names.

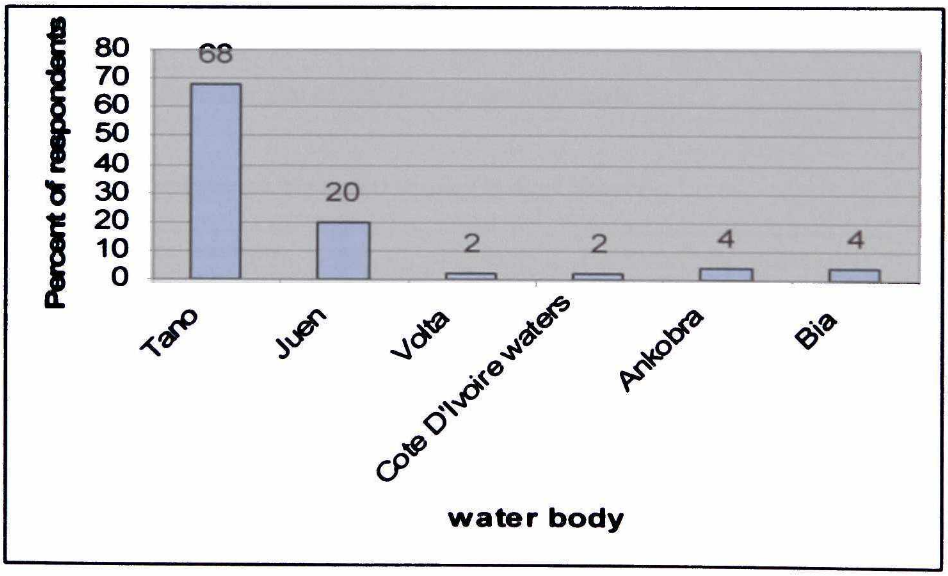

Fig. 4.9: Water bodies in which the respondents saw the weeds.

In Big Ada however, 50 respondents constituting 100% expressed having first seen *Salvinia nymphellula* in the lower Volta. Respondents did not mention any other water body apart from the lower Volta as being infested by *S. nymphellula*.

4.4.13 PERCEPTIONS ON WEED MANAGEMENT

4.4.13.1 Biological control

The perceptions of respondents with regards to the various methods of control of the weeds were taken. Out of a total of 50 respondents, a total of 32% of them were of the view that biological control provides a slower but longterm means of control unlike 28% of the respondents who were of the view that the method is not effective. Twenty-two percent however, stated that the method was not good enough, whiles 16% did not have idea about biological control of the weeds. Details of the perceptions on biological control of weeds are shown in Table (l). In Big Ada on the other hand, 50 respondents (100%) did not have any idea of biological control of weeds.

Table (l): Perceptions on biological control at Jewi Wharf

Perceptions of respondents	No. of respondents	Percent of respondents (%)
Controls, but slow	15	30.0
Not good enough	11	22.0
Effective	1	2.0
Long term control	1	2.0
Not Effective	14	28.0
No idea of biological control	8	16.0
Total	50	100.0

4.4.13.2 Chemical control

With regards to chemical control of the weeds, majority, constituting 62% out of 50 respondents stated that the use of herbicides on the weeds can be effective but will have negative ecological and economic consequences by contaminating the Tano lagoon. Four percent and 6% stated that the method is effective and not good enough, respectively. Two percent expressed that the method provides short term control and 8% mentioned its ineffectiveness. The remainder of 18% respondents expressed no knowledge of the chemical control method (Table m).

Table (m): Perceptions on chemical control at Jewi Wharf

Perceptions of respondents	No. of respondents	Percent of respondents (%)
Effective, but will contaminate water	31	62.0
Effective	2	4.0
Not good enough	3	6.0
Short Term control	1	2.0
Not Effective	4	8.0
No idea on chemical control	9	18.0
Total	50	100.0

In Big Ada on the other hand, a majority of 38 respondents (76%) stated that they have no idea on the use of herbicides in the control of the weeds followed by 24% who explained that herbicides can be effective but will contaminate the lower Volta.

The use of herbicides in the control of the weeds, apart from the contamination of the water, results in the damage of large biomass of the weeds which affects life in the water body (Brooker and Edwards, 1975; Culpepper and Decell, 1978; Madsen, 1997). This may cause the death of large biomass at a time thereby increasing the Biochemical Oxygen Demand (BOD) which makes the water uninhabitable to aquatic organisms. This could result in major fish kills and interruption of the food chain, due to the depletion of oxygen. The method, though effective as voiced by 4% of the respondents in Jewi Wharf, and could provide a short term means of control which everybody could desire, but others stated that it is not good enough (6%). This could be due to the high cost of herbicides coupled with its negative effects on life (AfDB, ECOWAS/ IAS Project, 2003).

4.4.13.3 Physical control

In this study, majority, constituting more than half of the respondents in Jewi Wharf (60%) expressed their opinion that physical control is effective, followed by 18% who stated that the method is effective only if machines such as dredgers are used. Again, 6% explained that the physical control has the capability but it is slow in achieving control, whiles 4% gave the assertion that the method is effective but dangerous. Four percent and 2% stated that it is effective but difficult and effective when people are many, respectively. Details are shown in Table (n).

Table (n): Perceptions on physical control at Jewi Wharf

Perceptions of respondents	No. of respondents	Percent of respondents (%)
Controls, but slow	3	6.0
Effective	30	60.0
Effective, but dangerous	2	4.0
Effective, when machines are used	9	18.0
Medium Term control	1	2.0
Effective, but difficult	2	4.0
Effective, if people are many	1	2.0
Not Effective	2	4.0
Total	50	100.0

At Big Ada on the other hand, a majority of 42% out of a total of 50 respondents had no idea about physical control followed by 28% who stated that the method is effective. Details are shown in Table (o).

Table (o): Perceptions on physical control at Big Ada

Perceptions of respondents	No. of respondents	Percent of respondents (%)
Effective, when machines are used	1	2.0
Effective	14	28.0
Long term control	7	14.0
Short Term control	6	12.0
Effective, but difficult	1	2.0
No idea on physical control	21	42.0
Total	50	100.0

Respondents perception on Physical control was in line with the fact that it was very effective in small areas of infestation but proved to be difficult and expensive in large areas (AfDB, ECOWAS/ IAS Project, 2003). This was based on the number of people to be engaged in weed removal and provision of logistics to facilitate removal such as boats and protective clothing. With mechanical application, another problem usually encountered in developing countries was the expenses involved in the purchase and maintenance of machines (AfDB, ECOWAS/ IAS Project, 2003). The method has also proven to be dangerous among weed removers as most of them are exposed to dangerous reptiles such as snakes and crocodiles found among weeds. Physical control, in combination with biological control is the recommended means of control since physical is used to achieve short term control in small infested areas whiles biological control provides long term control through the impact of bio-agents ((AfDB, ECOWAS/ IAS Project, 2003).

4.4.14 SOURCES OF THE IDEA OF BIOLOGICAL CONTROL IN THE JEWI WHARF COMMUNITY

The data showed that 76% of respondents at Jewi Wharf had heard of biological control whiles 24% had not heard. On the other hand, all the respondents at Big Ada (100%) had no knowledge of biological control of aquatic weeds. The idea of biological control according to the respondents in Jewi Wharf was obtained mostly from Environmental Protection Agency (EPA) (48%) and Plant Protection and Regulatory Services Division (PPRSD) (24%) out of a total of 50 respondents. Two percent each, however, obtained the idea from a student of the University of Ghana and Water Research Institute of the Council for Scientific and Industrial Research (WRI/CSIR) (Table p).

The high number of respondents for EPA shows that their activities in the community with regards to invasive weeds control is imparting the concept of biological control of weeds to the people. PPRSD officials whose over-sight responsibility is to regulate the entry of some plants and food crops from Cote D'Ivoire also help immensely in imparting the idea of biological control to the community.

Table (p): Sources of the idea of biological control at Jewi Wharf

Sources of the idea of biological control	No. of respondents	Percent of respondents (%)
EPA	24	48.0
PPRSD	12	24.0
Student from the University of Ghana	1	2.0
WRI/CSIR	1	2.0
Have not heard from any source	12	24.0
Total	50	100.0

4.4.15 IDENTIFICATION AND NAMING OF BIO-AGENTS

There was a high number of respondents (68%) who claimed that they could identify the bio-agents, *C. salviniae* and *Neochetina* sp. These bio-agents were shown to them in pictures. Thirty-two percent also stated they could not identify them. When the names of the bio-agents were asked, very few respondents (8%) attempted to provide their names, 4% mentioned maize weevil, and 2% each mentioned *Neochetina sp* and *Cyrtobagous sp.* Details are shown in Table (q). With regards to responses on *Neochetina* sp, 4% of respondents each mentioned maize weevil, *Neochetina* and *eichhorniae*. Details in Table (r).

Table (q): Responses on *Cyrtobagous* species at Jewi Wharf

Name	No. of respondents	Percent of respondents (%)
Maize Weevil	2	4.0
Neochetina	1	2.0
Cyrtobagous sp	1	2.0
No idea of name	46	92.0
Total	50	100.0

Table (r): Responses on *Neochetina* species at Jewi Wharf

Name	No. respondents	Percent of respondents (%)
Maize Weevil	2	4.0
Neochetina	2	4.0
Eichhorniae	2	4.0
No idea of name	44	88.0
Total	50	100.0

The response to the names of the bio-agents shows that very few have an idea about their names. This implies that majority of the people in the community though may know the bio-agents but could not mention their names. Since there was no use of local names for the bio-agents, it may also imply local names of the insects may not exist because they were introduced. The inabilities to mention their names give a clue that majority of the respondents who were mostly Fishermen, Boat Coxswains and water hyacinth removers (Zoom Crocodile) are unaware of the bio-agents and their activities on the Tano lagoon. It can also be deduced that majority though understood biocontrol of the weeds but could not identify the insects which are used for this purpose. This implies more needs to be done in creating awareness of biocontrol and its application.

4.4.15.1 Importance of the bio-agents

The importance of the bio-agents, *Cyrtobagous salviniae* and *Neochetina* species were ascertained. Out of the total of 50 respondents in Jewi Wharf, only 10% were able to mention the importance of the bio-agents as organisms which feed on the invasive weed thereby controlling them. The rest of the respondents had no idea on the activities of the organisms (Table s).

Table (s): Importance of the bio-agents at Jewi Wharf

Importance of the bio-agents	No. of respondents	Percent of respondents (%)
Control the weeds by feeding on them	3	6.0
Help control the weeds	1	2.0
Controls weeds by creating holes in them	1	2.0
No idea bio-agents	45	90.0
Total	50	100.0

4.4.15.2 Rearing facilities of bio-agents at Jewi Wharf

To ascertain whether there are any nearby rearing facilities, 10% respondents mentioned some rearing stations in Jewi Wharf and some surrounding communities. The others constituting 90% did not know of any rearing facility. In all, 6% of respondents mentioned the Jewi Wharf rearing facility and 2% each mentioned Nyamebekyire and Esukro rearing facilities, all near Half Assini (Table t).

Table (t): Locations of the rearing facilities at Jewi Wharf

Locations of rearing facility	No. of respondents	Percent of respondents (%)
Nyamebekyire	1	2.0
Esukro	1	2.0
Jewi Wharf	3	6.0
No idea of rearing facilities	45	90.0
Total	50	100.0

Eight percent of the respondents stated that the facilities are meant for the rearing of the bio-agents, whiles 2% mentioned that they were established for research purposes by students (Table u). The rest however, had no idea about the rearing facilities.

Table u: Purpose of the rearing facilities at Jewi Wharf

Purpose of rearing facilities	No. of respondents	Percent of respondents (%)
To rear the bio-agents	4	8.0
For research purposes by students	1	2.0
No idea of rearing facilities	45	90.0
Total	50	100.0

Though biological control is on-going on the Tano lagoon for the management of *E. crassipes* and *S. molesta*, little is being understood of the activities of bio-agents at the Jewi Wharf community. Majority (90%) of the respondents did not really know these bio-agents, their rearing facilities and their importance. (Tables, s, t & u).

4.4.16 TRAINING IN WEED CONTROL AT JEWI WHARF

To ascertain whether some community members have been trained in the management of weeds in Jewi Wharf, 48% of the respondents stated as being trained by EPA in the manual removal of the weeds and 52% were not. On the other hand, the data shows that all the 50 respondents in Big Ada were not trained by EPA. This could be attributed to the fact that *S. nymphellula* is not of much problem on the lower Volta as compared to the problems *E. crassipes* pose on the Tano lagoon at Jewi Wharf. From the data shown above, it can be deduced that manual removal of weeds is used as a complement to biological control by EPA in the Jewi Wharf community.

4.4.17 GOVERNMENT'S SUPPORT TO FIGHT THE WEEDS

The government of Ghana initiated steps by assisting the Jewi Wharf community to participate in the control of the weeds. In all, the number of respondents who were aware of the support and the kinds of support constituted a total of 98% (49 respondents). Two percent (1 respondent) however, was not aware of any government support. The support given according to 47 respondents (95.9%) was payment of allowances to a group of weed removers popularly known as Zoom Crocodile and provision of boats and other equipment such as Wellington boots. Two respondents (4.1%) explained that research institutions such as EPA and CSIR also had access to carry out research on effective method(s) of control of the weeds. Upon the recommendation of Volta Basin Research Project (VBRP), some other means of physical control have been explored to convert harvested weeds to compost to be used on farmlands (Annang, 2009). The approach is to reduce water weed levels and get some benefits out of them.

4.4.18 SUGGESTIONS TO FIGHT THE SPREAD OF THE WEEDS

In order to mitigate the spread of the weeds, respondents stated various means by which government could assist to facilitate the control of the weeds. These were provision of dredging machines and trucks to facilitate the physical removal of the weeds. Other approaches suggested were, provision of anti-snake venoms at the hospitals to be able to treat snake bites which might result from weed removal. Additionally, respondents stated that the EPA should employ more hands in Zoom Crocodile and improve and pay their allowances promptly. Some also suggested provision of protective clothing and intensification of education on the weeds so as to arouse the interest of the community in the weeds control. About 10.8% responses also suggested the repair of the Wharf for use as landing site for the harvested weeds. Almost fifth-teen percent of respondents also suggested that government should encourage the use of the weeds in mulching and composting. Detailed of suggestions by respondents are shown in Appendix Tables v & w.

CHAPTER FIVE

5.0 DISCUSSION

5.1 *SALVINIA MOLESTA*

5.1.1 Baseline studies and release of *Cyrtobagous salviniae* on *Salvinia molesta*

Baseline studies on *S. molesta* at the Insectary, Legon, and at Jewi Wharf, appeared to have no damage to the plant. Initial sampling using the 6.25×10^{-2} m^2 quadrat estimated 77 and 32 individuals of *C. salviniae* populations at Legon and Jewi Wharf, respectively. A total of 10 individuals of *C. salviniae* adults were released from the rearing pool immediately after conducting the baseline studies, 5 in each tank. This then augmented the baseline figures totaling 82 and 37 individuals of *C. salviniae* adults at Legon and Jewi Wharf, respectively.

5.1.2 Production of *Cyrtobagous salviniae* on *Salvinia molesta*

Population estimation using a quadrat yielded up to about 525 individuals of *C. salviniae* adults in the tank at Legon within two months, giving an estimated 6.4 fold increase in population. By the third month, the population reduced to 147 adult weevils with a 100% colour change of *S. molesta* from green to yellow or brown. On the other hand, in Jewi Wharf, population estimation using the quadrat yielded 608 individuals of *C. salviniae* adults in the tank by the third month giving an estimated 16.4 fold increase in population. The increase in insect recovery within the period was as expected. By the sixth month, the population reduced to 77 adult weevils. The above figures indicate that *C. salviniae* was able to survive and reproduce on *S. molesta*. The differences in the numbers of *C. salviniae* individuals on the third and sixth month at Legon and Jewi Wharf could be attributed to the fact that at Legon, there was no host nearby the tank. As a result the *C. salviniae* adults had no where to fly to and feed after the damage of *S. molesta* in the tank, so their numbers were higher than that of Jewi Wharf which had a nearby host. The *C. salviniae* numbers on the sixth month at Jewi Wharf could be due to the nearby host on the Tano lagoon which is about 150 m away from the tanks. This probably made some of the salvinia weevils to fly of to feed on *S. molesta* in the lagoon when those in the tanks were damaged. The rise and the decline in the *C. salviniae* populations could be explained with a predator-prey relationship where the availability of a resource (*S. molesta*) increases the fitness of the prey (*C. salviniae*) and vice versa. That is, where the target weed is most dense, it is also likely to suffer the highest levels of damage as the bio-agent number increases (Root, 1973). Therefore, the decrease in *S. molesta* population due to damage over the period starved some of the weevils to death. According to Forno *et al.* 1983, the *C. salviniae* is so host-specific that when *S. molesta* population is reduced, the weevil will often starve to death instead of switching host plants and this has been evident in all cases of introduction of the weevil with the exception of one case where feeding occurred on *Pistia stratiotes*.

Considering the baseline figures conducted as stated earlier in this discussion, the number of individuals of *C. salviniae* obtained in Legon was a little more than twice that of Jewi Wharf. This goes to explain why 100% colour change of *S. molesta* was recorded earlier in 3 months in Legon unlike Jewi Wharf which took 5 months. The impact of 82 individuals of *C. salviniae* therefore proved to be greater than 37 of them. This therefore gives an insight that when the population density of *C. salviniae* is increased, one could achieve effective control in a relatively short time. In a mesocosm study conducted in the year 2003, 120 individuals of *C. salviniae* adults released cumulatively for 7 weeks on uninfested *S. molesta* covering a plastic pool of area 7.31m^2 resulted in the control of the plant within the ninth week. Within this period, the population of *C. salviniae* adults recovered was 648 giving a 5.4 fold increase in population with a population density of 88.6 individuals of *C. salviniae* adults per m^2 (Awuni, 2003). This was less than the densities recorded in Legon (131 adults per m^2) and Jewi Wharf (152 adults per m^2) which recorded relatively higher population densities. The differences could be attributed to the fact that releases of *C. salviniae* was conducted on uninfested *S. molesta* in 2003, so it had to take sometime for the establishment of the weevils and their reproduction unlike this study where *S. molesta* was already infested with the weevils, hence they already established from the Tano lagoon. Mitchell (1979) also indicated that 250 adult weevils were released at one site in Botswana's Okavango swamps but none were seen but feeding damage characteristics of this insect was observed four months after it was released. Consequently, it was considered that the biological control agents were not making much impression on the weed but had probably successfully established and could make a contribution to control when their population densities increased.

Mitchell (1979) findings may be due to the fact that the population of the bio-agents released was small in comparison to the field where the weeds population may be greater and it has to take time for the population densities of the agents to increase. The wetland of Okavango covers an area of 14,000 km^2 including areas infested with *S. molesta* (Smith, 1976; Smith, 1989). Comparing the field with 250 weevils to the simulated experiment in the tanks, definitely the impact in the tanks will be greater. Also, the timing of the period within which release was done may be another factor since *C. salviniae* reproduction and activity is greatly impeded by extreme cold and hot weather conditions (Forno *et al.*, 1983) and this might have delayed their establishment and efficiency in reducing *S. molesta* populations.

Another possible factor was that the whole of Okavango ecosystem was low in nutrients (such as nitrogen and phosphorus) and productivity (Thompson, 1974). As stated by Julien and Bourne (1986), that the establishment of *C. salviniae* is highly dependent on the nitrogen content of the plants, it is again possible the low nutrients levels of the swamp at the time was what accounted for the delayed establishment of the 250 weevils released by Mitchell.

The ability of *C. salviniae* to reproduce with 6.4 (density 131 adults per m^2) and 16.4 (density 152 adults per m^2) fold increase in populations in Legon and Jewi Wharf respectively, could be attributed to a suitable environmental condition such as temperature and nutrients which enabled *C. salviniae* to mature within their stipulated maturity period of 17-28 days (Room, 1990). According to Room (1988), the density of 300 adults per m^2 is estimated as necessary for the control of *S. molesta*. The increase in population density of *C. salviniae* in this research though did not attain Room's (1990) findings of 300 *C. salviniae* adults per m^2, but were able to effect control in a few months at Legon and Jewi Wharf. This presupposes that the number of *C. salviniae* adults though may not reach 300 adults per m^2, but are capable of multiplying and facilitating control once environmental conditions are suitable for their development. This research was done without replacement of the *S. molesta* in the tanks. Replacement of the weeds by introducing fresh plants could have increased the fitness of the *C. salviniae* further. This could have further increased their population densities to attain Room's findings as stated above.

According to Tipping as cited in ARS news (2001), *C. salviniae* are capable of producing a new generation in about a month during the warmer parts of summer and adults stop laying their eggs in the cooler temperatures of spring and fall. This implies that temperature greatly affects their population densities by inhibiting or promoting reproduction. The ability of *C. salviniae* to effect control may be due to a temperature range typical of tropical and subtropical climates (Forno *et al.*, 1983; Sands *et al.*, 1983) prevailing on the University of Ghana Campus, Legon and Jewi Wharf, which may be the ideal conditions for the insects activities. This coupled with nutrients such as nitrogen and other suitable physicochemical properties such as very low salinity and suitable PH may also aid the fitness of the weevils and their establishment.

5.1.3 Area and percentage damages to *Salvinia molesta* by *Cyrtobagous salviniae*

Within a period of one month, damage started manifesting in both tanks by the presence of feeding punctures on the leaves and buds which were small irregularly shaped holes as reported by Sands and Schotz (1984). As the feeding progressed, the leaves changed from green to yellow or brown within 3 and 5 months at Legon and Jewi Wharf, respectively. Severely damaged plants had predominantly dark brown leaves with very few green buds; moderately damaged plants had an integrated mixture of brown and green leaves; and healthy plants appeared green, but had a few brown leaves within the canopy.

In this study, damage was assessed based on the colour change of *S. molesta* in the tanks from green to yellow or brown. Yellow or brown colour change indicates damage. The damage which manifested with a progressive increase in percentage damage uptill the third and sixth month resulted in 95% of colour change of *S. molesta* at Legon and Jewi Wharf, respectively. This point was approximated at 100% colour change of *S. molesta*. The remaining 5% were newly formed buds from damaged plants. Thus in weed biological control, there is no complete eradication as a result of new buds formation from damaged plants (Julien & Bourne, 1986). The damage also manifested in an increase in area damaged of the plants uptill the third and sixth month when there was 100% area damage achieved at Legon and Jewi Wharf, respectively (Fig 3.4, 3.5 & Appendix Tables, 3 & 4).

The levels of the first damage recorded after one month in the tanks in Legon and Jewi Wharf was 30.0% and 16.7%, respectively. These figures increased to 100% damage within a period of about 3 months in Legon and 5 months in Jewi Wharf showing the establishment and impact of *C. salviniae*. This goes further to confirm the fact that the feeding action of both the *C. salviniae* adult and larvae can be devastating which can be observed in months instead of years as reported by Sands and Schotz (1984).

Percentage damaged of *S. molesta* in the tank at Legon correlated with the percentage damaged of *S. molesta* in the tank at Jewi Wharf. (Correlation coefficient = 0.99).

Table (i): Correlation of Percentages damaged on *S. molesta* at Legon and Jewi Wharf

Percentage damaged at Legon (%)	Percentage damaged at Jewi Wharf (%)
0	3.3
30	16.7
100	70
	90
	100
Correlation Coefficient	0.994431146

On the other hand, area damaged at Jewi Wharf increased from 0.1 m^2 to 3.9 m^2 with a corresponding increase in area damaged at Legon from 0 m^2 to 4 m^2. (Correlation coefficient = 0.99). The trend shows a progression in area and percentage damaged on *S. molesta* by *C. salviniae* within 5 months.

Table (ii): Correlation of Areas damaged on *S. molesta* at Legon and Jewi Wharf

Area damaged in Legon (m^2)	Area damaged in Jewi Wharf (m^2)
0	0.1
1.2	0.7
4	2.8
	3.6
	3.9
Correlation Coefficient	0.996522387

Inferring from the data, it is very obvious that the activities of the *C. salviniae* held the *S. molesta* population in check with subsequent reduction in the area coverage of the weeds. As *S. molesta* in the tanks damaged, they lost their water-repelling properties which makes them buoyant, so they begun to sink to the bottom as reported by Forno *et al.* (1983). The sinking therefore reduced the area coverage of the plants on the water surface thereby exposing the water for sunlight penetration and oxygenation as necessary for aquatic life development (Thomas and Room, 1986b). When the *S. molesta* damaged, some of the leaves easily fell off on handling. This may be due to the weakening of the petiole of the leaves which helps to conduct water and nutrients to the leaves. Also, the surface area of the leaves which intercept sunlight for photosynthesis was reduced due to the feeding punctures. These factors presumably initiated the browning of the leaves which appeared as small patches initially, which coalesced and the entire mat appeared brown and damaged.

Establishment of *C. salviniae* is highly dependent on the nitrogen content of the plants (Julien and Bourne, 1986). It has also been reported by USDA (2001) that the effectiveness of *C. salviniae* was dependent upon climatic conditions such as temperature, plant nutritional status and other biotic and abiotic conditions. It also stated that *C. salviniae* adults and young feed on the weed's nitrogen rich buds (Room & Thomas, 1986). This then implies that nitrogen application either directly or indirectly to the plants will significantly increase the chance for the establishment and initial population build-up of *C. salviniae*. This could explain the reason why nitrogen is usually the limiting nutrient that affects the growth rate of *S. molesta* (Room 1990). In this research, about 20 g of unhydrated NPK was used to fertilize each tank and plastic pool, as a source of nutrients and nitrogen which is very important for the establishment of *C. salviniae*. This might have accounted for the success of *C. salviniae* in their establishment, population build-up and damage on *S. molesta*.

5.2 *SALVINIA MOLESTA* COMPARED TO *SALVINIA NYMPHELLULA*

5.2.1 Damage and host-specificity

The damage inflicted on *S. molesta* in Legon and Jewi Wharf shows that the insect is host-specific to the weed unlike *S. nymphellula* where no damage or feeding was recorded in 3 months after the release of 60 individuals of *C. salviniae* adults in the plastic pool at the insectary in Legon, followed by the release of 180 individuals of the insect within a period of 5 months in the lower Volta. Since there was no feeding both in the lower Volta and at Legon, it was therefore clear that the insect is host-specific to *S.molesta* though they belong to the same genus but different species. According to Room *et al*, (1981), *Cyrtobagous salviniae* is a biological control agent that is host-specific to *Salvinia* species but was not the case in this research with *S. nymphellula* since the insect couldn't feed on it. Just as *S. molesta* is foreign to Ghana's waters, *S. nymphellula* is native and this might explain why *C. salviniae* was obtained from its native range in south-eastern Brazil in South America, thus its host-specificity to *S. molesta*. Since *S. nymphellula* is native to Ghana, the potential for any biocontrol measure could be explored within its native range and other parts of West Africa where the weed is prevalent. Though it has been established that *S. nymphellula* is equally invasive and believed to have caused the death of Aku lagoon upstream the Lower Volta (between Akuse and Amedeka) (de-Graft Johnson pers.com, 2010), it has not proven to be much of a problem in the community where the research was carried out probably because of high tide from the sea which adds some salinity into the lower Volta at Big Ada. This could impair the growth of *S. nymphellula* just as *S. molesta* growth is impaired at different degrees by sea water (Room and Julien, 1995). It is possible upstream the lower Volta, very low salinity and other favourable conditions such as high nutrient levels could favour a robust growth of *S. nymphellula*.

Data collected on the 2 sites on the lower Volta showed no damage and *C. salviniae* recovery within the 5 months period. This shows that because *C. salviniae* is host-specific to *S. molesta* and could not feed on *S. nymphellula*, the insects starved and died (Forno *et al.* 1983).

5.3 PERCEPTIONS OF THE COMMUNITIES ON INVASIVE AQUATIC WEEDS

The perceptions conducted on the weeds (*E. crassipes* and *S. molesta*) in Jewi Wharf produced 127 responses from 50 respondents. The 127 responses were as a result of each of the respondents providing one or more of the effects they usually experience from the weeds. These perceptions were based on socioeconomic factors. The problems encountered in the Jewi Wharf community were very evident in Mitchell's (1979) findings that invasive water weeds causes serious environmental, economic and health-related effects through the use of water and its resources. This is because mats of the weeds are capable of blanketing water bodies thereby affecting boat transport, blocking channels and pumps in irrigation, reduction in fish catch and increased costs including health-related problems such as water-borne vector-disease e.g. malaria, encephalitis and filariasis. Among the responses given was that the weeds habours snakes which pose another serious health risk. This perception agreed with AfDB, ECOWAS/IAS project 2003 report that dangerous reptiles such as snakes associated with the weeds poses serious health risk especially when manual removal of weeds are employed. As a result, these weeds affect the socioeconomic development of many national economies (Cilliers, 2003).

Salvinia nymphellula did not seem to pose problems on the Lower Volta. A few respondents (16%) identified some problems which were not profound as compared to Jewi Wharf. A high number of 84% respondents could not identify any socioeconomic problems associated with *S. nymphellula*.

The study shows that the perceptions of the Jewi Wharf community on the weeds were right and that the weeds are actually posing serious problems to the community and other communities where the weeds are prevalent.

5.4 LEVEL OF AWARENESS OF BIOLOGICAL CONTROL OF WEEDS

The study again shows that Jewi Wharf was much aware of biological control (34% of respondents) whiles Big Ada was not (Table l). In Big Ada on the other hand, none of the 50 respondents had an idea of biological control of *S. nymphellula*. This may be due to the prevalence of only *S. nymphellula* which uptill date has no known report on a bio-agent as stated earlier in the first part of this research where *C. salviniae* known to be host-specific to *Salvinia* species failed to feed and cause damage to *S. nymphellula* in the large out-door plastic pool at Legon and at Big Ada on the lower Volta. The results to the best of my knowledge may be the first to be conducted to investigate host-specificity of *C. salviniae* on *S. nymphellula*. The plant, though equally invasive, did not prove to be as troublesome like *E. crassipes* and *S. molesta.*

Biological control is actually known to provide slow but long term measure of control of the weeds and has its advantages and disadvantages, but its advantages was known to outweigh its disadvantages (McLaren and Amor, 1979). The main advantages were its environmentally friendliness, its cost-effectiveness, its ability to spread to inaccessible places on water bodies and the way it tends to be self regulatory as bio-agents are able to multiply through reproduction (AfDB, ECOWAS/IAS, 2003). One major problem biological control agents face is climatic conditions which may provide adverse effects in their establishment, reproduction and control of the weeds (Forno *et al.*, 1983; Sands *et al.*, 1983). However, when conditions are right, the method has proven in several countries that it is effective in the long term (Julien and Griffith, 1998).

5.5 COMMUNITY PARTICIPATION IN WEED CONTROL

The involvement in weed control at Jewi Wharf was both at the community and individual levels. However, at the lower Volta, the control was only at the individual level probably because of low infestation of the weed. It was also realized that manual removal of the weeds was the main method employed. This manifested in very high response for physical control at Jewi Wharf and the lower Volta. At the individual level, patronage of biological control was very low whiles at the community level it was relatively high. It has also been found that manual removal is very effective and environmentally friendly considering the high number of responses for why the method was being used.

The high patronage of manual control by respondents (Fig. 4.3 and 4.4) in the communities could be attributed to the perceptions the people have on the other means of control. For instance, the Jewi Wharf community have the perception that herbicides application will negatively impact on the environment (Table m) and that biological control is slow in achieving effective control (Table l). The manual removal of the weeds by Zoom crocodile group employed by EPA is much evident in this case.

Another possible reason why manual control is high is that when the weeds are removed, they may be put into other beneficial uses such as compost, mulch and pig feed (Table e). It is also perceived in the communities that physical control is effective and environmentally-friendly in the management of the weeds as well (fig 4.5 and 4.6).

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The results obtained indicate that the study is very useful in establishing the importance of biological control agents and their host specificity. The importance of *Cyrtobagous salviniae* as a biocontrol agent of *Salvinia molesta* was established with an increase in percentage damage from 0% to 100% both in Legon and Jewi Wharf (Correlation Coefficient = 0.99). As a result, the leaves started appearing brown and some started sinking and this resulted in a reduction in the area coverage of the plant at the study sites with time (i.e. area damaged increased at both locations) (Correlation coefficient= 0.99). The density of insect recovery per quadrat and the estimated number of *C. salviniae* in the tanks shows that there was an increase in the population of *C. salviniae* which made control effective.

It was also established that *C. salviniae* is host-specific to *S. molesta* and as a result could not cause any damage characteristic of the insect on *S. nymphellula* in Legon and in the lower Volta, after the release of 60 and 180 individuals of *C. salviniae* respectively. *Cyrtobagous salviniae* could not establish and reproduce on *S. nymphellula* due to the fact that there was no insect recovery throughout the sampling period. Since there was no recovery, it was presumed that the insects starved and died (Forno *et al.* 1983).

The community approach in the control of weeds shows that the people prefer physical control (54.4% of 90 responses) followed by biological (34.4% of 90 responses) since they believed the methods will yield short term results to mitigate the spread of the weeds. Though there were mixed perceptions of biological control in Jewi Wharf, the people were much aware of the method than at Big Ada. It was also established that physical and biological control was the most prefered methods of control of the invasive water weeds (AfDB, ECOWAS/IAS, 2003).

The results for herbicides use in the control of the weeds show the fear of water contamination which could endanger the environment and life. The results again indicate that the perception of the communities on the weeds were mainly based on the socioeconomic effects the people encounter due to the invasion of the weeds and in the utilization of the water and its resources.

6.2 RECOMMENDATIONS

1. Since the impact of *Cyrtobagous salviniae* and their production on *Salvinia molesta* was very obvious in the tanks at Legon and Jewi Wharf, I will recommend the use of the bio-agent as part of the overall management strategies of *S. molesta* control, especially on the Tano lagoon where it had already been recorded and other inland water bodies such as the Volta Lake. This will help curb the high expenditure through physical and chemical means of control and the environmental and health effects that accompany the use of chemicals (AfDB, ECOWAS/ IAS Project, 2003). The economic and ecological nuisance caused by this weed will also be minimized.

2. Since increase in the population density of the *C. salviniae* effects control in a relatively short time, I will recommend that in order to achieve a satisfactory control of *S. molesta* in the field where area coverage may be greater, the weevils be released proportionately to the size of the field covered. This will ensure that the population densities of *C. salvinae* be increased at a faster rate and then facilitate control, if not small numbers may delay control and may create doubt on the effectiveness of *C. salviniae*.

3. As it had been established in this research that *C. salviniae* did not attack *S. nymphellula*, I will recommend that the search for any biocontrol agents for *S. nymphellula* be done in its native range of Ghana and other parts of West Africa where the weed may be found. This had always been the case which led to the search for *C. salviniae* in the native range of *S. molesta* in the southeastern Brazil and upon several host-specificity testing, it was realized that the weevil was the biological control agent for the control of *S. molesta* (Mitchell, 1979).

4. Because some responses indicate that the weeds can cause skin diseases, I will recommend that research be carried out on the effect of manual removal of the weeds on the skin.

5. Once manual control is embraced in the communities, protective clothing should be provided to weed removers to protect them from possible snake bites and other risk involved in the work.

6. More education has to be conducted by EPA on the weeds and their biological control agents as well as their rearing facilities.

7. Other uses of the weeds in the area of energy production such as biogas generation must be tested and if possible encouraged. This will in a way help in the management of weeds to acceptable levels.

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APPENDICES

BIOLOGICAL CONTROL OF *SALVINIA*

Table 1: **Changes in estimated *C. salviniae* population in Legon and Jewi Wharf.**

Month	Estimated No. of Insects in tank (Legon)	Estimated No. of Insects in Tank (Jewi Wharf)
1	82	37
2	525	320
3	147	608
4		416
5		211
6		77

Table 2: **Changes in estimated *C. salviniae* population in the rearing pool at the University of Ghana, Legon**

Date/Week	Estimated No. of *C. salvinae* in pool
20/6/09 (1)	50
4/7/09 (3)	69
18/7/09 (5)	129
01/08/09(7)	298
15/08/09 (9)	436
29/08/09(11)	496

Table 3: **Progression of area damaged and undamaged on *S. molesta* by *C. salviniae* over a period of three months in the release tank at the University of Ghana, Legon**

Date/ Month	Area undamaged (m^2)	Area damaged (m^2)
23/10/09(1)	4	0
20/11/09(2)	2.8	1.2
18/12/09(3)	0	4

Table 4: **Progression of area damaged and undamaged on *S. molesta* by *C. salviniae* over a period of five months in the release tank at the Jewi Wharf.**

Date/Month	Area undamaged (m^2)	Area damaged (m^2)
16/08/09(1)	3.9	0.1
13/09/09(2)	3.3	0.7
17/10/09(3)	1.2	2.8
21/11/09(4)	0.4	3.6
20/12/09(5)	0	3.9

Table 5: **Progression in percentage damage by *C. salviniae* in the release tank at the University of Ghana, Legon**

Date/ Week	Percentage damage per quadrat (%)
23/10/09(1)	0
20/11/09(2)	30
18/12/09(3)	100

Table 6: **Progression in percentage damage by *C. salviniae* in the release tank at Jewi Wharf**

Date/ Month	Percentage damage per quadrat (%)
16/08/09(1)	3.3
13/09/09(2)	16.7
17/10/09(3)	70
21/11/09(4)	90
20/12/09(5)	100

Table 7: **Progression in percentage damage on *S. molesta* by *C. salviniae* in Legon compared to Jewi Wharf**

Month	Percentage damage in tank (Legon) (%)	Percentage damage in tank (Jewi Wharf) (%)
1	0	3.3
2	30	16.7
3	100	70
4		90
5		100

Table 8: ***Salvinia molesta* control, University of Ghana, Legon**

Date/Month	Area undamaged(m^2)	Area damaged(m^2)	Mean No. of *C. salviniae* recovered per qdt	Mean proportion damaged per qdt
23/10/09(1)	4	0	1.2+ 5 released	0
20/11/09(2)	2.8	1.2	8.2	3/10
18/12/09(3)	0	4.0	2.3	1

Table 9: *Salvinia molesta* control at Jewi Wharf.

Date/Month	Area undamaged (m^2)	Area damaged (m^2)	Mean No. of *C. salviniae* recovered per qdt	Mean proportion damaged per qdt
16/08/09(1)	3.9	0.1	0.5+ 5 released	1/30
13/09/09(2)	3.3	0.7	5.0	1/6
17/10/09(3)	1.2	2.8	9.5	7/10
21/11/09(4)	0.4	3.6	6.5	9/10
20/12/09(5)	0	3.9	3.3	1

Table 10: *Salvinia nymphellula* control, University of Ghana, Legon.

Date/ Month	Area undamaged (m^2)	Area damaged (m^2)	No. of *C. salviniae* released	No. of *C. salviniae* recovered per qdt	Proportion damaged per qdt
6/11/09(1)	6.2	0	20	-	0
4/12/09(2)	6.2	0	14	0	0
3/01/10(3)	6.2	0	26	0	0
2/02/10(4)	6.2	0	-	0	0
4/03/10(5)	6.2	0	-	0	0

Table 11: *Salvinia nymphellula* control at the lower Volta (Site 1)

Date/ Month	Area undamaged (m^2)	Area damaged (m^2)	No. of *C. salviniae* released	No. of *C. salviniae* recovered per qdt	Proportion damaged per qdt
4/01/10(1)	12.0	0	60	-	0
3/02/10(2)	12.0	0	40	0	0
5/03/10(3)	12.0	0	-	0	0
4/04/10(4)	12.0	0	-	0	0
4/05/10(5)	12.0	0	-	0	0

Table 12: ***Salvinia nymphellula* control at the lower Volta (Site 2)**

Date/ Month	Area undamaged (m^2)	Area damaged (m^2)	Number of *C. salviniae* released	Number of *C. salviniae* recovered per qdt	Proportion damaged per qdt
4/01/10(1)	8.0	0	60	-	0
3/02/10(2)	8.0	0	20	0	0
5/03/10(3)	8.0	0	-	0	0
4/04/10(4)	8.0	0	-	0	0
4/05/10(5)	8.0	0	-	0	0

Calculation of Area of Tanks, Pool, Quadrats and Field

Dimension of Tank (Legon) = 2 m × 2 m = Area = 4 m^2

Dimension of Tank (Jewi Wharf) = 2 m × 2 m = Area = 4 m^2

Height of Tanks = 1.30 m

Depth of water in Tanks = 1.0 m

Volume of water in tanks = Area of tank × Depth of water = 4 m^2 × 1 m^2 = 4 m^3

Height of plastic pools = 0.76 m

Depth of water in plastic pool = 0.60 m

Diameter of plastic pool = 2.80 m

Area of pool = Area covered by weed = $\pi d^2/4$ = 6.2 m^2

Volume of water in pool =Area of pool×Depth of water in pool = 6.2m^2×0.60m = 3.72 m^3

Area of quadrat (for tanks & pool) = $L^2 = (0.25\ m)^2 = 6.25 \times 10^{-2}\ m^2$

Area of quadrat (for field) = $L^2 = (0.50\ m)^2 = 2.5 \times 10^{-1}\ m^2$

Area covered by weed in tanks = Area of tanks

Area of Field (site 1) lower Volta = 6 m × 2 m = 12 m^2

Area of Field (site 2) lower Volta = 4 m × 2 m = 8 m^2

Total Area of Field (site 1 & 2) lower Volta = 20 m^2

Area covered by weed in pool = Area of pool

Estimation of insect population in tanks was by proportion

i.e 6.25×10^{-2} m^2 ≅ No. of insects in quadrat

∴ 4 m^2 ≅ No. of insects in tank

Estimation of insect population in plastic pool was by proportion

i.e 6.25×10^{-2} m^2 ≅ No. of insects in quadrat

∴ 6.2 m^2 ≅ No. of insects in plastic pool

Area of weed damaged in tank = mean proportion (percentage) damaged × Area of tank

Area of weed damaged in pool = mean proportion (percentage) damaged × Area of pool

Percentage damaged = mean proportion damaged × 100%

Qdt = quadrat

QUESTIONNAIRE 1

Water hyacinth & *Salvinia molesta*

I am a student from the Faculty of Science, University of Ghana pursuing M.Phl, Environmental Science and conducting a research on 'An Environmentally friendly and Participatory Approach to the Management of an Invasive Aquatic Weed' in the lower Volta and on the Tano lagoon. The community participation approach requires that I administer questionnaires in the surrounding communities in Jeway Wharf. I would like to invite you to participate in the study. It is highly confidential

Date of Interview [ ] Questionnaire No [ ]

Please Tick [√] Appropriately

SECTION I: INFORMATION ON RESPONDENTS

1. Age: (a) 18 – 30 [ ] (b) 31 – 50 [ ]
   (c) above 50 years [ ]

2. Gender: (a) Male [ ] (b) Female [ ]

3. Occupation: ....

4. Name of the community..

5. Period of living within the community:
   (a) Less than 1 year [ ] (b) 1 – 5yrs [ ]
   (c) Above 5 years [ ]

6. Have you seen these weeds in the pictures below in your water bodies?
   (a) Yes [ ] (b) No [ ]

   If yes, what are the names of the weeds?

(a)................................ (b)...

7. For how long have you known these weeds?
   (a) Less than 1 year [ ] (b) 1 – 5yrs [ ]
   (c) Above 5 years [ ]

8. In which water bodies did you first see the weeds? ....

9. Do you or your community have some important uses of the weeds?
   (a) Yes [ ] (b) No [ ]

   If Yes, What are some of their uses?...

10. Do you know of any socioeconomic effects posed by the weeds?
    (a) Yes [ ] (b) No [ ]

    If yes, what effects do you experience? ....

11. How do you manage to control the weeds?...

12. Do your community have any management measures in controlling the weeds?
    (a) Yes [ ] (b) No [ ]

    If Yes, What measures?..
    (a) Physical removal [ ] (b) chemical control [ ]
    (c) Biological control [ ]
    (d) Others specify...

13. Why do you use the above selected method?
    (a) Effective [ ] (b) cheaper [ ]
    (c) environmentally-friendly [ ] (d) cost-effective [ ]
    (e) Expensive [ ] (f) other reasons specify.........

14. What do you think of the other control methods?

(a) Biological...

(b) Chemical..

(c) Physical...

15. Have you heard of biological control?
(a) Yes [ ] (b) No [ ]

16. How did you hear of biological control?..

17. What does biological control mean to you?..

18. Can you identify the organisms shown in the pictures below?

(a) Yes [ ] (b) No [ ]

If yes, what are their names?

(a) ....

(b) ....

19. What are the importance of the organisms shown above?..

20. Have your community or any organization established a rearing station for the organisms shown above?
(a) Yes [ ] (b) No [ ]

If Yes, where is the location of the rearing station?...

21. What is the purpose of the rearing station?...

22. Have you received any training by any agency as to how to control the weeds?
(a) Yes [ ] (b) No [ ]

If Yes, What is the name of the agency?..

23. How were you trained?...

24. Do you receive any support from government to participate in the control of the weeds?
(a) Yes [ ] (b) No [ ]
(c) Not aware [ ]

If Yes, What support were you given?..

25. Is the government putting some measures in place to fight the spread of weeds?
(a) Yes [ ] (b) No [ ]
(c) Not aware [ ]

If Yes, what measures have been put in place?..

26. What measures would you like the government take to mitigate the spread of weeds?...

THANK YOU

QUESTIONNAIRE 2

Salvinia nymphellula

I am a student from the Faculty of Science, University of Ghana pursuing M.Phl, Environmental Science and conducting a research on 'An Environmentally friendly and Participatory Approach to the Management of an Invasive Aquatic Weed' in the lower Volta and on the Tano lagoon. The community participation approach requires that I administer questionnaires in the surrounding communities in Big Ada. I would like to invite you to participate in the study. It is highly confidential.

Date of Interview [ ] Questionnaire No [ ]

Please Tick [√] Appropriately

SECTION I: INFORMATION ON RESPONDENTS

1. Age: (a) 18 – 30 [ ] (b) 31 – 50 [ ]
   (c) above 50 years [ ]

2. Gender: (a) Male [ ] (b) Female [ ]

3. Occupation: ....

4. Name of the community..

5. Period of living within the community:
   (a) Less than 1 year [ ] (b) 1 – 5yrs [ ]
   (c) Above 5 years [ ]

6. Have you seen these weed shown to you in your water body?
   (a) Yes [ ] (b) No [ ]

   If yes, what is the name of the weed?...

7. For how long have you known these weeds?
   (a) Less than 1 year [ ] (b) 1 – 5yrs [ ]
   (c) Above 5 years [ ]

8. In which water body did you first see the weed?......................................

9. Do you or your community have some important uses of the weed?
   (a) Yes [ ] (b) No [ ]
   If Yes, What are some of their uses?...

10. Do you know of any socioeconomic effects posed by the weed?
(a) Yes [ ] (b) No [ ]

If yes, what effects do you experience? ....

11. How do you manage to control the weed?..

12. Do your community have any management measures in controlling the weed?
(a) Yes [ ] (b) No [ ]

If Yes, What measures?..
(a) Physical removal [ ] (b) chemical control [ ]
(c) Biological control [ ]
(d) Others specify..

13. Why do you use the above selected method?
(a) Effective [ ] (b) cheaper [ ]
(c) environmentally-friendly [ ] (d) cost-effective [ ]
(e) Expensive [ ]
(f) other reasons specify..

14. What do you think of the other control methods?

(a) Biological...

(b) Chemical...

(c) Physical...

15. Have you heard of biological control?
(a) Yes [ ] (b) No [ ]

16. How did you hear of biological control?...

17. What does biological control mean to you?...

19. What are the importance of the organisms shown above?.......................................

20. Have you received any training by any agency as to how to control the weeds?
(a) Yes [ ] (b) No [ ]

If Yes, What is the name of the agency?...

21. How were you trained?...

22. **Do you receive any support from government to participate in the control of the weed? (a) Yes [ ] (b) No [ ] (c) Not aware [ ]**

If Yes, What support were you given?...

25. **Is the government putting some measures in place to fight the spread of weed?**
(a) Yes [ ] (b) No [ ]
(c) Not aware [ ]

If Yes, what measures have been put in place?..

26. **What measures would you like the government take to mitigate the spread of weed?...**

THANK YOU

TABLES ON PARTICIPATORY APPROACH TO WEED CONTROL (COMMUNITY PARTICIPATION)

Table (v): Suggestions to fight the spread of the weeds at Jewi Wharf

Suggestions	No. of responses	Percent of responses (%)
Provide machines to dredge the weeds	29	39.2
Encourage the use of the weeds in composting and mulching	11	14.9
Provide trucks to speed up removal	3	4.1
Provide anti-Snake venoms	2	2.7
Improve allowances of weed removers	4	5.4
Employ more people	4	5.4
Provide protective clothing	8	10.8
Intensify Education	1	1.4
Prompt payment of allowances	4	5.4
Repair wharf for use as landing site for weeds	8	10.8
Total	74	100.0

The number of responses exceeded the 50 respondents because some of the respondents provided more than one suggestions.

Table (w): Suggestions to fight the spread of the weeds at Big Ada

Measures	No. responses	Percent of responses (%)
Provide equipment to remove the weeds	8	57.1
Provide effective means to remove the weeds	1	7.1
Employ people	2	14.3
Intensify Education	3	21.4
Total	14	100.0

The number of responses was less than the 50 respondents because some of the respondents could not provide suggestions.