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BIOLOGICAL CONTROL OF AQUATIC MACROPHYTES AND ECOLOGICAL IMPLICATION: A REVIEW

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ABSTRACT

The study reviews the biological control of aquatic macrophytes and its ecological implications to provide information on various future challenges in water quality management and aquaculture. Aquatic macrophytes cause various environmental (or ecological) and socio-economic impacts (which are in their majority negative), affecting floral and faunal diversity and ecosystem functioning and services. The aquatic macrophytes, many of which are invasive species and impact mechanisms differ between species which is largely based on differences in their growth form and the habitat that they have invaded. Invasive aquatic macrophytes threaten aquatic ecosystems and both the quantity and quality of potable water hence need for control. View the paucity of known ecological damage from biological control introduction agents, biological control method is generally safe with strict prevention of upset of ecosystem of the area by the population of the control agents to ensure bearable ecological implications. Successful biological control requires that the pest population is reduced to levels well below the economic threshold and maintained sufficiently to allow the survival of the agents. In management situations, integrated approaches involving multiple biological control agents or possible biological control and chemical methods be used with minimize potential negative environmental effects. Where possible use of native species is proper and if non-native species has to be used, it should be sterile to avoid spread via reproduction to new water bodies.

KEYWORDS: Macrophytes, Biological Control, Environmental Effect, Aquatic Organisms.

1.1 Macrophytes and its importance

Aquatic macrophytes are plants, growing in or near water that are emergent, submergent or floating. Aquatic macrophytes refers to all plants large enough to be visible to the naked eyes so long that parts of such plant involved in photosynthesis are submerged or float on the water surface either permanently or at least for several months yearly. These plants include not only flowering plants but also ferns, bryophytes and macrophytic algae (Crowder and Painter, 1991).

De Nie (1987) and (Thomaz *et al.*, 2006) used the following division for aquatic macrophytes, which expanded by the major tropical and subtropical plants.

A. Aquatic macrophytes rooting in sediment

I. Emergent aquatic macrophyte: Plants rooted in the sediment with foliage extending into air. These include Angiosperms; *Typha*, *Phragmites*, *Scirpus*, *Corex*, *Acorus*, *Butomus*, *Sagittaria*, *Pasalum*, *Echinochloa*, *Vassia*, etc.

II. Floating-leaved aquatic macrophyte: Plants rooted in the sediment with leaves floating on the water surface. These include; *Nymphaea*, *Nuphar*, *Nymphoides*, *Potamogeton*, *Polygonum*, *Hydrilla*, *Cyprus papyrus*, etc.

III. Submerged macrophyte: Plants that grow completely immersed and are rooted into sediment. These include the algae; *Chara* and *Nitella*, moss; *Fontinalis*, and angiosperms; *Myriophyllum*, *Elodea*, *Potamogetan* etc.

B. Freely floating macrophytes: Plants that float on or underwater surface. These include ferns; *Azolla* and *Salvinia*, angiosperm; *Lemna*, *Eichhorina*, *Pistia*, *Ceratophylum*, *Hydrocharis*, etc.

C. An additional two life forms have been proposed: Epiphytes – plants growing over other aquatic macrophytes (e.g. *Oxycarium cubense*); and Amphibious – plants that live most of their life in saturated soils, but not necessarily in water (e.g. *Polygonum* spp).

Macrophytes colonize almost all freshwater habitats, from the tiny “living ponds” supplied by Bromeliaceae (e.g. *Utricularia* spp), to thermal springs (e.g. *Najas tequefolia*) and waterfalls (e.g. members of the Podostemaceae colonize even the giant Iguaçu Falls, Brazil/Argentina). Most rivers, lakes, lagoons and reservoirs are colonized to differing degrees by macrophytes, whereas wetlands are categorized as areas where macrophytes dominate (Thomaz *et al*., 2006).

Aquatic macrophytes become a cause for concern when they form dense settlements, exceeding the environment's carrying capacity for their population and causing negative impacts to the multiple uses of water bodies. At high densities and high occupancy rates of the water body, the submersed macrophytes promote reduction of oxygen available in the water column, especially at night, with reflections on the local biological diversity, negatively affecting fish populations, and hindering fish catch, river transport, water sports and the generation of electricity (Borges & Pitelli, 2004; Mustafá, 2010; Souza, 2011).

Several species of freshwater aquatic plants, all notorious weeds in other parts of the world, have also become invasive in many of the rivers, man-made impoundments, lakes and wetlands of South Africa (Hill 2003). These are *Pistia stratiotes* L. (Araceae) (water lettuce); *Salvinia molesta* D.S. Mitch. (Salviniaceae) (salvinia); *Myriophyllum aquaticum* (Vell. Conc.) Verd. (parrot's feather); and *Azolla filiculoides* Lam. (Azollaceae) (red water fern) (Hill 2003), which along with water hyacinth comprise the 'Big Bad Five' (Henderson and Cilliers 2002). Recently, new invasive aquatic plant species have been recorded which are still at their early stages of invasion, including the submerged species, *Egeria densa* Planch. (Hydrocharitaceae) (Brazilian water weed) and *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae); the emergent species, *Sagittaria platyphylla* (Engelm.) J.G.Sm. and *S. latifolia* Willd. (Alismataceae); *Lythrum salicaria* L. (Lythraceae) (purple loosestrife), *Nasturtium officinale* W.T. Aiton. (Brassicaceae) (water cress); *Iris pseudacorus* L. (Iridaceae) (yellow flag); and *Hydrocleys nymphoides* (Humb. & Bonpl. ex Willd.) Buchenau (Alismataceae) (water poppy); and the new floating weeds, *Salvinia minima* Baker (Salviniaceae) and *Azolla cristata* Kaulf. (Azollaceae) (Mexican azolla); and the rooted floating *Nymphaea mexicana* Zucc. (Nymphaeceae) (Mexican water lily) (Coetzee *et al*. 2011; Coetzee, Bownes and Martin 2011). The mode of introduction of these species is mainly through the horticultural and aquarium trade (Martin and Coetzee 2011).

Two issues contribute to the invasiveness of these macrophytes following establishment: the lack of co-evolved natural enemies in their adventive range and disturbance, the presence of nitrate- and phosphate-enriched waters, associated with urban, agricultural and industrial pollution that promotes plant growth (Coetzee and Hill 2012).

Macrophytes affect aquatic ecosystems in a variety of ways, especially the shallower ones where they colonize large areas. These plants change the water and sediment physic-chemistry, influence nutrient cycling, may serve as food for aquatic invertebrates and vertebrates, both as leaves and dead biomass (detritus) and, in particular, change the spatial structure of the waterscape by increasing habitat complexity (Thomaz *et al*., 2004).

Aquatic invasive macrophytes are capable of causing extinction of native aquatic plants, reducing biodiversity, competing with native organisms for limited resources, and altering ecosystem processes (Peterson and Vieglais 2000).

In addition to aquatic organisms, there are several species of terrestrial animals such as birds and mammals, which use regularly macrophytes as food in the tropics. Good examples are manatee (*Trichechus inunguis*), deer (*Blastocerus dichoromus*) and capybara *(Hydrochoerus hydrochaeris*) in South America; hippopotamus (*Hippopotamus amphibious*) in Africa; and goose (*Anseranus semipalmata*) in Australia. Terrestrial invertebrates may feed heavily on macrophytes: the combined effects of the coleopteran (adults) *Neochetina bruchi* and *N. eichhorniae*, together with the larvae of the dipteran *Thrypticus* sp. may cause extensive damage to natural populations of water hyacinth in the Neotropics. These and other herbivorous insect species are regularly used in the biological control of water hyacinth, even in other continents (Scuthorpe, 1967; (Thomaz *et al*., 2006).

Invasive plants, however, are not native species and they are often destructive (Vtousek *et al*., 1996). Non-native plants and animals are responsible for economic losses and control costs estimated in one analysis at $137 billion per year in United State alone (Pimentel et al., 2000). Invasive aquatic plants are noted for their explosive growth potential (Barrett, 1989) and their ability to grow from a few plants to cover hundreds of acres in a few years (Groth *et al*., 1996).

Invasive aquatic plants have caused declines in native plant population throughout New England (Sheldon, 1994). In some water bodies, invasive plants have become so abundant that they have displaced native species (Langelnd, 1996). Many biologists feel invasive species are second only to habitat destruction as the most serious threat to endangered species globally (Wileove *et al*., 1998).

Because of their great growth potential, invasive aquatic plants can block navigation channels, irrigation, ditches and water intake pipes, and they can reduce aesthetic and recreational values of water bodies, affecting tourism and real estate values (Catling and Dobson, 1985). In some cases, the plants have been found to increase breeding habitat for mosquitoes (Eiswerth *et al*., 2000). An estimated 76% of the invasive aquatic plants in Southern New England were introduced as cultivated plants and later escaped (Les and Mehrhoff, 1985). It is thought that much of the subsequent spread of invasive plants from one lake to another is from recreational boating (Couch and Nelson, 1985).

Attempts to eradicate invasive aquatic plants once they become established often have failed (Anonymous, 1993; Groth *et al*., 1996; Simberloff, 1997). And management is expensive (Langeland, 1997; Center *et al*., 1997). Early identification of invasive plant populations, thus, is critically important (Simberioff, 1997; Wittenberg and Cook, 2001).

Non-native, invasive aquatic plants in the Delta block water conveyance for irrigation and urban use, impede navigation, and negatively influence critical aquatic habitat quality parameters. Chemical and mechanical control of floating water hyacinth (*Eichhornia crassipes*) and submersed Brazilian waterweed (*Egeria densa*) are hindered by lack of access to some invasive plant populations. The use of biological control, specifically insects from the native range that can survive only on the weed and that disperse to all weed populations, needs to be increased. Three insects were previously released for biocontrol of water hyacinth. In the present study, water hyacinth was surveyed monthly at 16 locations in the Delta and nearby. Only one weevil species, *Neochetina bruchi*, was present, averaging five adults and 14 larvae per plant in early summer and fall population peaks (Kolar and Lodge 2000).

Exotic species that become invasive have received a lot of attention since they are a growing threat to economies, biodiversity and ecosystem services worldwide (Mack *et al.* 2000). Progress in invasion biology has increased the understanding of the invasion process (Kolar and Lodge 2001; Peterson and Vieglais 2001) and the mechanisms through which invasive species influence the composition and structure of target communities (Mack *et al.* 2000). Despite this, biological invasions are so numerous and persistent today that it is likely that negative ecological effects of even infamous invasive species will not be quantified, unless they are conspicuous, in well-studied scientific or geographical areas, or of direct economic importance (Mack, *et al.* 2000).

Aquatic plant control typically involves a balance of multiple management objectives. Different water body users may have varying definitions of how much submerged aquatic vegetation is acceptable (Van Nes *et al*., 1998). This can be particularly important because some management objectives can be incompatible. For example, reducing macrophyte biomass can result in increased algal blooms and vice versa (Scheffer *et al.*, 1993; Scheffer, 1999). Success of many control methods could be improved by the timing of application to the nuisance species. For example, water hyacinth control agents should be applied when the plant carbohydrate stores are at their lowest which generally occurs in the spring. Eradication when plants are young and shoots and leaves are small may also increase rates of success (Madsen *et al*., 1993).

1.2 Biological Control Methods

Biological control (biocontrol for short) is the use of animals, fungi, or other microbes to feed upon, parasitize or otherwise interfere with a targeted pest species. Successful biocontrol programs usually significantly reduce the abundance of the pest, but in some cases, they simply prevent the damage caused by the pest (e.g. by preventing it from feeding on valued crops) without reducing pest abundance (Lockwood 2000; Strong and Pemberton 2000). Biocontrol is often viewed as a progressive and environmentally friendly way to control pest organisms because it leaves behind no chemical residues that might have harmful impacts on humans or other organisms, and when successful, it can provide essentially permanent, widespread control with a very favorable cost-benefit ratio. However, some biocontrol programs have resulted in significant, irreversible harm to untargeted (non-pest) organisms and to ecological processes. Of course, all pest control methods have the potential to harm non-target native species, and the pests themselves can cause harm to non-target species if they are left uncontrolled. Therefore, before releasing a biocontrol agent (or using other methods), it is important to balance its potential to benefit conservation targets and management goals against its potential to cause harm (Lockwood 2000; Strong and Pemberton 2000; Holmgren, 2002; Souza, 2011).

Organisms used to feed on, parasitize, or otherwise interfere with targeted pests are called biocontrol agents. There are several general approaches to using biocontrol agents:

1. ‘Classical’ biocontrol targets a non-native pest with one or more species of biocontrol agents from the pest’s native range.
2. New Association or Neoclassical approach targets *native* pests with non-native biological control agents.
3. Conservation, Augmentation and Inundation approaches maintain or increase the abundance and impact of biocontrol agents that are already present, and in many cases native to the area.

Classical biocontrol is by far the most common approach for plant pests. Conservation and augmentation approaches show great promise on their own and especially for enhancing the impacts of classical biocontrol and other weed control measures as researchers and managers focus on managing to maximize native biological diversity in invaded ecosystems (Newman *et al*., 1998; Lockwood 2000; Strong and Pemberton 2000; Holmgren, 2002).

As the direct and indirect effects of biocontrol agent attacks reduce the host invasive plant’s ability to compete within the plant community, invasive plant populations gradually decline, but are not eliminated. Biocontrol therefore has limited application for situations where rapid or complete invasive plant control is required. However, for widely established invasive plants, or for established plants with the potential to become widespread, biocontrol may be an appropriate strategy (Holmgren, 2002; Souza, 2011).

The effects and effectiveness of biocontrol for managing invasive plant populations in general is highly variable and depends on the unique interactions between biocontrol agents and host plants, as well as a number of other biological, environmental, and procedural factors (Holmgren, 2002; Souza, 2011.

Once released, biocontrol insect populations typically require two to three years to successfully establish, and 10 to 20 years before they significantly affect the invasive plant population. Overall, the cost of biocontrol is low relative to other approaches such as chemical and physical control, and expenses are incurred at the beginning of a program rather than on a continuing basis (not including the costs of long-term monitoring) (Lockwood 2000; Strong and Pemberton 2000; Stiling and Simberloff 2000; Donlan *et al*., 2002)).

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Bio-control involves using plant, animal or fungal species or components to reduce the survival, growth or reproduction of the nuisance species. This includes use of herbivores, such as grass carp or insects that consume parts or whole of the nuisance plant species. Bacterial and fungal pathogens are also used. These cause disease to the nuisance plant species, thereby reducing survival and recruitment. Additionally, biological materials, such as bacteria, enzymes, barley straw, organic matter amendment, may be added to the system to reduce growth of nuisance plants or algae, without preying on them or causing disease.

The proposed mechanisms for non-predatory bio-control methods include competition for resources and production of natural substances that inhibit the growth of the nuisance species. The development of bio-control agents has been limited due to production difficulties, unresolved regulatory question, virulence issues and lack of capital investment (Watson, 2003).

Biological control is often more successful when multiple methods are integrated. Plant weakened by insect damage or sublethal doses of chemicals are often more susceptible to pathogens. In water hyacinth management, for example, multiple insect species, insect combined with grass carp, or pathogens combined with chemical treatment are often more effective than individual treatment methods alone (Gopal, 1987).

1.3 Prospects and Consequences of Bio-control

Bio-control for reduction of nuisance plants in aquatic systems has both positive and negative attributes (Charudattan *et al*., 2002). A positive aspect of bio-control is that control agents are often host specific, so effects to non-target species may be reduced. Control agents can also reproduce in response to increases in nuisance species density often without reapplication of the agent. Development and registration (where necessary) of bio-control agents is generally less expensive than chemical agent. Additionally. The ecosystem impacts under bio-control can be more gradual, thereby allowing the system to adjust to loss of a species.

However, bio-control can have many potential disadvantages. An important risk is involved when new species are introduced as bio-control agents. To be considered successful, these species are expected to persist indefinitely in the environment where they are used, and may spread t. new locations. Therefore, there are many adverse effects resulting from the bio-control agent; these effects may be difficult or impossible to control. Adverse effects would include loss of habitat for some fauna, competition with native species, and production of toxic metabolites that are released to the environment. Others drawbacks include unpredictable success and rates of control that are lower than with chemical methods. Resistance in host species is unlikely to develop but can occur. Finally, agents that work in one area may not be suitable in all ecosystem. Climate, interference from herbicidal application, hydrological conditions and eutrophication of the system can influence the effectiveness of bio-control agents. The growth of nuisance weeds can be suppressed with the use of bio-control agents, but not fully eliminated (Hill and Olckers, 2001).

1.4 Commercially Available Bio-control Agents

Biological agents such as bacteria, viruses and enzyme solutions are commercially available to aid in the improvement of water quality. These agents are touted to increase water flow by reducing/eradicating algal and to some extent, macrophyte growth. Few field and lab. Experiments have been completed to test the efficacy of commercial microbial products. The products generally contain a mixture of bacteria and enzymes. The microbial products are typically applied to the system to augment the system’s bacterial populations. The theory is that increases bacterial concentrations will limit the availability of nutrients necessary for algal and macrophyte growth and reproduction. The bacteria, theoretically, utilize the same nutrients (nitrogen and phosphorus) as the photo synthesizers and therefore act as competitors for growth.

Bio-control agents are readily available as commercial formulations. Examples include Aqua5TM, 1998 LakePakTM, WSPR, Algae-TronTM and PK-70 all of which are relatively inexpensive to purchase. Nevertheless, the success of bio-control agents to reduce primary producer (Planktonic) populations is not well established. Few studies are available testing the effectiveness of these methods.

1.5 Plant Pathogens Currently in Development

Plant pathogens for the control of *Hydilla* and Eurasian watremifoil have shown progress over recent years but remain in the research phase. So far, only lab. Tests in aquariums and small ponds have been conducted and the methods are not available for widespread applications. The use of pathogen *Fusarium graminearum* in control of *Egeria* species is in the pre-commercial evaluation phase (Charudattan and Dinoor, 2000). The fungus *Alternaria eichhorniae* has shown some success in control of water hyacinth in Africa but rapid colonization by the fungus is necessary for long-term control (Reeder, 2003). Species of *Rhizoctonia* have the ability to kill plants but there is no host specificity and non-target plants can also be affected. Since 1980s, the corps of Engineers (USACE) has been researching plant pathogens to control *Hydrilla* in the South-eastern U.S. A fungal pathogen species from Texas (*Mycoleptodiscus terrestris*) holds promise for future control but is not yet commercially viable (Judy Shearer, pers. Comm.)

1.6 Organic Material Amendment

Organic materials such as peat and barley straw have been used for control of rooted aquatic plants and algae. Theoretically, control is achieved by reduction of nutrient availability to the nuisance species or release chemicals that impede growth. Organic material amendment results tend to be system specific, creating a need for small-scale pilots prior to widespread application in a specific water body (Strong and Pemberton 2000; Withers *et al.*, 2000).

Field studies have shown that sediment amendment with peat or barley straw may reduce *Hydrilla* production (Spencer *et al*., 1992). A number of lab. Studies have demonstrated that natural or human-altered increase in sediment organic matter content can reduce growth of Eurasian watermifoil (Barko *et al*., 1996; Gunnison and Barko, 1989). The chemistry of added organic materials can affect their ability to reduce aquatic plant growth; organic material may inhibit plant growth or stimulate plant growth depending on the nitrogen content of the added organic materials (Spencer *et al*., 1992). The use of organic additions, including barley straw, for control of *Hydrilla* has not been widespread. Barley straw has gained popularity in recent years for algae control via word-of-mouth success, but research indicates that it only works in certain management circumstances (Lembi, 2002). The activity of barley straw is usually described as preventing the new growth of algae, rather than killing algae already present. It is thought that fungi decompose the barley in water, which causes lignin- and tannin-derived polyphenolic compounds to be released, preventing the growth of algae. This method is most successful in well oxygenated water bodies where the decomposition of barley is not disrupted (Boylan and Morris, 2003).

1.7 Aim of the Dissertation

The aim of this write-up is to survey the relevant literature on the biological control of aquatic macrophytes as an entity and the control measures of various agents in order to evaluate the ecological implication of the control measures.

1.8 Triploid Grass Carp as Bio-control Agent

The grass carp, also known as the white amur (*Ctenopharyngodon idella*), feeds on aquatic plants and can therefore be used as a biological tool to control nuisance aquatic plants growth. To reduce the potential for unintended consequences, grass carp must be sterilized for use in waters of United State. Once grass carp are stocked in a water body, it may take several years for them to control the plant growth and reduce weeds to about 20% of the earlier plant cover)Washington State Department of Ecology, 2001). If practitioners stock enough fish to achieve control within the first few years, this can eventually result in detrimental effects to non-target plants, as the fish increase in size e.g. (Colle and Shireman,1994; Withers *et al*., 2000). If possible, it would be more cost-effective to stock a smaller number of fish and wait for them to grow sufficient size to control the plant problem (Stewart and Boyd, 1999).

A wide range of field application and scientific studies has demonstrated that grass carp can effectively reduce growth and biomass of undesirable vegetation (e.g. Leslie et al., 1994; Pauley *et al*., 1994; Santha *et al*., 1994; Van vierren *et al*., 2001).

However, success with grass carp may vary from site to site. Sometimes identical stocking rates result in no control, adequate control, or even complete elimination of all underwater plants. Therefore, before introducing grass carp to water body, it must be determined whether complete elimination of all submerged species could be tolerated. Many researchers and aquatic plant managers think that grass carp should only be stocked when complete elimination of all submerged plant species could be tolerated. As with any large-scale ecosystem manipulation, grass carp introduction may cause significant environmental impacts to a water body. Elimination of submerged plants by grass carp foraging could result in increased turbidity, water column nutrients, and phytoplankton production (Scheffer *et al*., 1993; Colle and Shireman, 1994; Scheffer, 1999). If all aquatic vegetation is removed, waterfowl, amphibians and aquatic mammals may also be adversely impacted (Brakhage, 1994). In light of the fact that grass carp, once introduced, are extremely difficult to remove from a water body, caution should be exercised when considering new waters for grass carp introduction (Colle and Shireman, 1994).

Case study results vary widely in overall impacts of grass carp introduction in native plant and animals communities. Overstocking can result in disturbance in the existing fish community, resulting from vegetation habitat removal. In two Florida lakes heavily stocked with grass carp, all submerged vegetation was wiped out, resulting in impaired water quality and declines in sensitive native fish species (Colle and Shireman, 1994). In contrast, when grass carp were carefully stocked in eight Oregonand Washington lakes, dissolved oxygen improved and other fish populations were affected (Pauley *et al*., 19940. By introducing dense monotypic vegetation and increasing underwater structural diversity, grass carp introduction may even increase abundance of other fish species (Killgore and Kirk, 1998; Killgore *et al*., 1998). California Department of fish and Game has implemented a number of restriction to reduce the probability of negative consequences of grass carp use. First of all grass carp may only be used in water bodies that are isolated from the 100-years floodplain of major California Rivers (Marty Muschinske, pers.comm.). Due to the risk of adverse impacts on adjacent water bodies, stocked water bodies should be isolated or have screened inlets and outlets (Washington State Department of Ecology, 2001).

Screens to inlets or outlets are generally only approved by CDFG where they do not interfere with anadromous fishes, e.g. Steelhead or Salmon runs. Additionally, grass carp must be sterilized, a process achieved by causing fertilized eggs to retain three sets of chromosomes (Triploid). The risk of inadvertent release of sterile grass carp according to Webb *et al*. (1994) is reduced by testing the blood of juvenile fish to confirm triploidy. In California waters, stocking casts include the purchase price of the fish (generally about $8-15/fish), purchase cost for the permit ($100 application fee), a one-time stocking fee of $15/fish paid to CDFG and an annual regulatory fee of $7.50/fish also paid to CDFG. Inquiries can be submitted to the local region office of CDFG or Marty Muschinske, of the Eastern Sierra/Inland Desert region, who currently is the most experience with the program (Marty Muschinske, pers.comm.). Applications are evaluated by the local region office. Stocking rates for Washington lakes generally range from 9 to 25 eight to elven inches fish per vegetated acre. This number will depend on the amount and types of plants as well as water temperatures (Washington State Department of Ecology, 2001). One-year-old fish (less than 225 grams body weight) have much lower plant feeding rate than larger fish (Pine et al., 1990). So if small fish are stocked, foraging rates may increase considerably with fish size.

For any given water body, it can be difficult to determine the optimal number of grass carp to stock. In the 1980s and 1990s, stocking rate varied widely among U.S water bodies (Stewart and Boyd, 1999). The optimal stocking rate is generally higher I Oregon and Washington than in south-eastern United States (Pauley *et al*., 19940, suggesting that cooler water bodies in northern California would require higher stocking rate than warmer southern California waters. Currently, a number of California practitioners often report simply stocking a fixed number of fish per year, based on the general observation of successful weed control (Paul Saunders, pers. Comm.; Ron Derma, Pers. Comm.).

Grass carp are more effective at removing some plant species than others highly preferred species include *Egeria densa*, *Hydrilla vorticillata*, common *Elodea* (*Elodea canadensis*) and duckweeds (*Lemna spp* and *Spirodela spp*). Non-preferred species include Coontail (*Ceratophyllum demersum* and milfoils (*Myriophylum spp*) (Stewart and Boyd, 1999). Success has been reported in controlling water hyacinth using a combination of grass carp and weevils (Gopal, 1987). Eurasian watermifoil is not a preferred food source and grass carp will consume most other aquatic species before eating it (Washington State Department of Ecology, 2001). Also, grass carp may consume submerged species before eating floating species in the same water body (Santha *et al*., 1994).

Grass carp have also been successfully employed in Arizona canals used for drinking water conveyance, where chemical pesticide application was discontinued. The Salt River Project (SRP) delivers a million acre-feet of water annually to 250,000 acres in central Arizona through approximately 130 miles of canals and 120 miles of laterals. Water usage in the SRP system has shifted from primary agricultural use to use as a drinking water source. As a result, environmental regulations prohibit the use of most chemical herbicides. Magnacide H (acrolein) and chelated elemental copper are currently the only used chemicals. SRP has used grass carp to control extensive aquatic weed growth in most of the canal systems for ten years and has found them to be “environmentally friendly and cost effective”. Weed growth and fish populations are monitored and fish are moved to maintain effective weed control throughout the system. Grass carp have been shown to adequately control aquatic weed growth in the SRP (Maldonado, 2001).

1.9 Fish Biomanipulation as Bio-control means

In addition to the use of herbivorous fish, water resources managers can also reduce aquatic plant growth by changing the abundance of fish higher in the food web. This method often refer to as biomanipulation, is typically used to control growth of nuisance planktonic alga blooms and had been most successful in small lakes when combined with nutrient input control (John Madsen, pers.comm). Fish manipulation may also be appropriate in water bodies characterized by large population of small fish that eat zooplankton. In these lakes, the heavy grazing by planktivorous fish can cause low zooplankton abundance and a consequent reduction in zooplankton grazing rates on algae. In these circumstances it may be possible to indirectly control algal production by manipulating the "top" of the food web. Specifically, managers reduce the population of smaller fish freed up from the predation pressure by the small fish, the zooplankton in the lake increase in size and foraging rate. This greater grazing by zooplankton consequently reduces the overall abundance of algae in the water body, improving water clarity (Carpenter et al., 1987; Carpenter and Kitchell, 1988). The water body manger can reduce the small fish population by directly removing the fish from the water body (Annadotter *et al*., 1999) or by adding a large population of predatory fish, which are expected to rage heavily on the smaller fish, thereby reducing their population (Kitchell, 1992). This is most successful when omnivorous, benthivorous fish are controlled at the same time (John Madsen, pers.comm). Fish biomanipulation a difficult management method to implement effectively. It typically requires good understanding of the community structure and chemistry of the water body. It is only successful in water bodies with certain community structure types. If predatory fish are added to the water body, severe fishing restrictions may be necessary to maintain the high populations (Kitchell, 19920. Additionally, many factors can influence algae growth, causing success to vary considerably from year to year (Carpenter *et al*., 1987). Nevertheless, biomanipulation has been reported to substantially improve lake water quality in lakes where other methods have failed (Annadotter *et al*., 1999).

1.10 Gastropod Molluscs as Bio-control agent

Introduction of snails or sea slugs is a bio-control option that has been researched for certain aquatic infestations. Cooke *et al*. (2001) reported that small research experiments indicate that snails grazing on biofilm algae may be useful for improving growth of desirable aquatic plants. Presumably, the use of these grazing snails would increase aquatic vascular plant biomass, thereby resulting in reduced nutrient availability for floating nuisance algae and ultimately improvement in water quality (Scheffer *et al*., 1993; Scheffer, 1999). Researchers are currently evaluating a number of sea slug species for potential bio-control of the marine invasive plants, *Caulerpa taxifolia*. Although the slug is very promising as a bio-control agent, there is considerable political ambivalence regarding the introduction of a non-native bio-control species in marine waters (Meinesz, 1999). Therefore, use of gastropods has not been developed for commercial bio-control application. Snails were extensively researched for bio-control of *Hydrilla*, but were found to be an ineffective control method and thus were not commercially developed (Bill Haller, Pers. Comm.). Interest in development of snails as a bio-control agent has been limited due to the environmental risk associated with purposeful introduction of prolific generalized herbivores. Additionally, there is concern that snails can serve as vectors for certain fish parasites (McCann *et al*., 1996). Thus, although gastropod molluscs may have potential for use in bio-control, there is yet to be an example of successful field-scale application.

1.11 Insects as Bio-control agents

Another alternative in biological control is the release of insects that specialize in feeding on particular nuisance plant species. In other State and Countries, insects have been developed for biological control of a number of aquatic and emergent plants that occur in California waters. These include *Hydrilla*, Eurasian watermifoil, water hyacinth, giant *Salvinia* and purple Loosestrife. In California, insects have been evaluated for biological control of *Hydrilla* and water hyacinth, but for Eurasian watemifoil or purple Loosestrife. Currently, the weevil, *Cyrtobagous salvinaie* is being evaluated for long-term control of giant *Salvinia* (*Salvinai molesta*) on the Colorado River and adjacent irrigation drains (Olson, 2003).

Biological control using insects has had limited field application in California waters, but has been reportedly successful for plant management in some other waters. In Florida and Louisiana, biological control of water hyacinth has been successful using two weevil species of the genus *Neochetina* and one moth of the genus *Sameodes*. However, large-scale reduction of water hyacinth (50-70% reduction in plant growth) often took years to occur (Bill Haller, Pers. Comm). Another concern is that even though plant height and flowering might be reduced, the expansion of the plant mat could still occur (John Madsen, Pers. Comm.).

In California, insects have been tested for control of water hyacinth and *Hydrilla*. In an effort to control water hyacinth in the Sacramento-San Joaquin Delta, three species of insects were released in 1982. Recent surveys have shown that one of species (*Neochetina bruch*-water hyacinth-eating weevil) has spread throughout the Delta, but the population are not of sufficient size to effectively control the hyacinth. Currently, research collaboration among CDBW, CDFA and the USDA is underway to understand the factors limiting the success of insect bio-control in the Delta (USDA and CDBW, 2003). Two insects species have been evaluated for control of *Hydrilla* in California, the *Hydrilla* tuber weevil (*Bagous affinis*) and Asian *Hydrilla* leaf mining fly (*Hydrelia pakistanae*). Laboratory and field studies have determined that both species feed on hydrilla tissue and have the potential to reduce Hydrilla densities (Godfrey and Anderson, 1994; Godfrey *et al*., 1994; Godfrey *et al*., 1995). The milfoil weevil (*Euhrychiopsis lecontei*) appears to be able to control Eurasian watermilfoil, causing significant biomass reduction in the laboratory (Creed and Sheldon, 1993) and in the field (Creed and Sheldon, 1993). This insect exposes vascular tissue of the stem when feeding on Eurasian watermilfoil and causes the collapse of the plant. Sheldon and O'bryan (1996)), have shown that the weevil preferred Eurasian watermilfoil. Their data from the six years following a Eurasian watermilfoil decline in a Vermont lake show that watermilfoil has not regained its dominance, while native plant density has increased. The increase in native plant density may result from poor egg hatching and recruitment on non-target plant species (Sheldon and Creed, 2003).

Biological control using insects or invertebrates does not appear to hold much promise for *Egeria densa*. Many organisms were tested to control *Egeria densa* (including snails), but generally showed little success (Bill Haller, pers. comm). Often times, insect population growth may not be sufficient to achieve biological control in weed-infested areas. Evaluation of feasibility is often required on a site specific basis. For example, the milfoil weevil appears to have such lower densities in waters with cooler temperatures and might not be suitable for regions with colder summer climates. Another important consideration is the potential for effects on non-target species or other unintended consequences of the insect introduction (Sheldon and Creed, 2003).

Shearer and Nelson (2002), found that application of a combination of M. terrestris and chemical herbicide endothal also reduced *Hydrilla* biomass in laboratory experiment. Shearer (2002), also noted that stressful conditions, such as herbicidal application in non-lethal doses, may weaken a plant and compromise a plant’s defenses, thereby making it more susceptible to infection by the fungus. Integrative control has been evaluated for water hyacinth using multiple insects on insects in combination with bacterial pathogens (Gopal, 1987)

Native biological control agents, when they can be found, offer potential advantages over classical biological control agents, they may have little impact on non-target native species that have coexisted with the control agent, and may save the time and expense of foreign research and quarantine procedures (Sheldon *et al*., 1995).

The introduction of *Neochetina eichhoriniae* and *Orthogalumna terbrantis* reduced plant density by 45%and petiole by 35% over a 50-week experimental period. Integrative control has been applied to water hyacinth management. The pathogen, *Cercospora rodmanii* and *Neochetina eichhoriniae* eliminated 99% of water hyacinth (Charundattan, 1984) as reviewed in Gopal, 1987).

Two nearly identical *Galerucella*, leaf beetles are responsible for most bio-control of purple loosestrife; in fact, these beetles have reduced purple loosestrife infestations by 90% in several state, especially Oregon and Washington. Larvae feeds on buds, leaves and stem of the plants and heavily defoliated plants are often killed by the feeding insects (James, 2009).

Two weevils- the root-attacking *Hylobius* and seed attacking *Nanophyes*- also contributes to the successful bio-control of purple loosestrife. Larvae of *Hylobius* feed and develop in the tap roots and pupation occurs in the upper part of the root. Larvae require 1 to 2 years to complete their development and adults can live for several years. Adults of *Nanophyes* feed on young leaves or flowers and lay their eggs in flower buds. Pupation occurs inside the bud and larvae consume the flower buds; buds then fail to open and drop prematurely from the plants. Although the entire life cycle is completed in about a month, there is only 1 generation per year. Leaf-eating *Galerucella* beetles, root-attacking *Hylobius* weevils and seed-attacking *Nanophyes* weevil have only recently been introduced as bio-control agents on purple loosestrife but appear to be very successful in reducing the growth, occurrence and competitiveness of this emergent weed (James, 2009).

The *Eurychiopsis* weevil is generally considered to be the most important bio-control agent of Eurasian watermilfoil from an operational perspective even though it is a native insect because this weevil prefers Eurasian watermilfoil over its native natural host. The life cycle of the weevil is completed in about 10 days; adults feed on leaves and stems, whereas larvae are stem borers that that consume apical meristems. Feeding damage causes the stem to break apart and heavy feeding by the insects prevents the formation of surface mats. High population of *Eurychiopsis* weevil have been associated with declines of populations of Eurasian watermilfoil in some northeastern and midwestern states but fish predation may prevent this weevil from reaching its full bio-control potential. The *Eurychiopsis* weevil is commercially available and can be purchased to augment existing weevil populations (James, 2009).

Two insects have been released as bio-control agents of water-lettuce but only the *Neohydronomus* weevil has been become established. Adults and larvae of the *Neohydronomus* weevil feed on the leaves, crown and newly emerging shoots of water-lettuce and the characteristic “shot hole” appearance of leaves indicates high weevil densities. Feeding by multiple larvae destroys the spongy of bases, which causes plants to lose buoyancy. The life cycle of the *Neohydronomus* weevil is completed in 3 to 4 weeks. The weevil has not contributed to long-term suppression of the plant in the US, but has provided successful bio-control of water-lettuce in other countries. It is thought that the *Neohydronomus* weevil is heavily preyed upon by imported fire ants in Florida; untrue, this provide an interesting example of an exotic invader controlling a valuable potential bio-control agent (James, 2009).

The *Cyrtobagous* weevil is the only insect that has been released as a bio-control agent of giant *Salvinia*. Adventive weevils that were discovered in Florida in1960 are used to control common *Salvinia* (*Salvinia minima*), whereas weevils released in 2001from a

Brazilian population are used as bio-control agents for giant *Salvinia*. The entire life cycle of the *Cyrtobagous* weevil takes about 46 days. Adult feed on leaf buds and leaves and larvae tunnel inside the plant, killing leaves and rhizomes. Attacked plants turn brown and eventually lose buoyancy (James, 2009).

The *Oxyops* weevil and the *Boreioglycapsis psyllid* were released in1997 and 2002 respectively, and are widely established on Melaleuca in south Florida. Damage to the tree is caused primarily by the immature stages of these insects. The slug-like weevil larvae feed on newly expanding leaves; *psyllid* nymphs attack older leaves and woody stems in addition to new leaves and the *psyllid* can kill newly emerged seedlings as well. These two insects complement each other well; the *psyllid* is able to complete its development entirely in the canopy under flooded conditions that prevent establishment of the weevil, which must pupate in the soil. Extensive leaf damage from both insects uses Melaleuca to divert resources to the production of new foliage instead of flowers. The life cycle of the weevil is completed in about 3 months, whereas a new *psyllid* generation is produced in 6 weeks. The *Oxyops* weevil and *Boreioglycapsis psyllid* have contributed to the substantial bio-control of Melaleuca (James, 2009).

1.12 Plant Competition as Bio-control agents

Nuisance aquatic plant impacts may be reduced by introduction or augmentation of other plant populations. The more desirable plants may compete with nuisance species, thereby impeding their growth and spread. Nevertheless, the addition of competing plants remains a highly experimental procedure with limited field application or assessments of effectiveness 9Holdren et al., 2001). The best results will be seen when the nuisance plant is controlled before the native plant is added in order to prolong the effectiveness of the initial control technique (John Madsen, Pers. comm).

In a Massachusetts lake native *Chara* species was experimentally planted in areas of invested for Eurasian watermilfoil. The researchers found that areas with transplanted *Chara* plants remained resistant to milfoil invasions over the plantation of the two-year study (Monnelly *et al*., 2003). For selected Qiscons in water bodies, the nature conservancy plants shoreline areas with wild rice, a native emergent plant. The replanting efforts are perceived as successful methods of re-establishing native vegetation (Hannah Spual, Pers. Comm.). Spikerush (*Eleocharis spp*.) has had some success in crowding out nuisance plant species in many aquatic system including irrigation drainage canals (Sytsma and Parker, 1999). Spikerush has a low growth habit and negligible effect on water flow, which are desirable characteristics. There is also some evidence that these plants secrete a growth inhibitor that is absorbed by surrounding plants. Slender spikerush (*Eleocharis acicularis)* may be more suited for California water bodies.

1.13 Other Herbivorous Fish that could be used as Bio-control agents

1.13.1 *Tilapia zilli*

When 5 to 8 cm long *Tilapia zilli* shifts from predominantly animal to predominantly herbivorous diet. In Africa, *T. zilli* is known to feed readily on *Hydrilla* (Pieterse, 1981). In Lake Naivasha, Kenya, Siddiqui (1977) reported that macrophytes represent 67.7% of its diet, but more recent information by Muchiri *et al*., (1995) for the same lake has shown that this species is herbivorous. They also compared the food web of *T. zilli* with that of another common lake Naivasha *Tillapia, Oreochromis leucostictus*.

The Volta Lake, Ghana, in *T. zilli* and *T. rendalli* higher plants (predominantly of terrestrial origin from flooded land, such as grass) formed 61.4% of the total food eaten (Petr, 1967). Preferential feeding of *T. zilli* was observed by Buddington (1979). He found it to prefer *Najas guadallupensis* to *Lemna, Myriophyllum* and *Potamogeton pectinatus*. Saeed and Ziebell (1986), found it to prefer *Chara*, followed by *Najas marina*, *Elodea densa* and *Myriophyllum xalbescens. T. zilli* avoided bushy twigs or bulky stems of such plants as *N. marina* and *E. densa* and fed leaves and soft slender stems which are easy to grasp and separate.

In the 1950s the cichlids, *Oreochromis leucostictus, Tilapia zilli* and *Oreochromis niloticus* were introduced in Lake Kyoga, Uganda. The Lake is situated a short distance down stream of Lake Victoria, receives the Victoria Nile. Both species were captured in traps and gill nets along the marginal papyrus mats or among aquatic macrophytes, while *O. niloticus* supports a very reactive fishery among floating island of papyrus (Twongo, 1995). *T. zilli* occurs mainly under the cover of submerged and floating macrophytes such as *Ceratophyllum, Myriophyllum, Potamogeton, Nymphaea* and *Pistia*, and in sheltered bays, often close to the papyrus fringe. The wide use of seine nets has led to the reduction in macrophyte cover and this has been suspected as being a factor which has contributed to the decline in stocks of *T. zilli*. Another factor could be the competition for nursery grounds with other *Tilapia*, that is *O. variabilis* and *O. niloticus* was introduced in USA for macrophyte control (Sheriman, 1984).

1.13.2 *Tilapia rendalli*

T. rendalli (formerly *T. melanopleura*) has demonstrated its potential in controlling aquatic macrophytes by removing them completely from some impoundment (Junor, 1969). However, in some situation the fish has had less impact, especially where the macrophytes are too dense. Higher aquatic macrophytes such as *Hydrilla, Chara, Sparganium, Potamogeton, Leersia, Lagarosiphon, Carex, Typha, Cyperus papyrus* and *Paspalum* have been found in the stomach of this species (De Bont *et al*., 1949).

Small fish feed on cladocerans and there is a shift to filamentous algae in fish larger than 50 mm (Munro, 1967). LexRoux (1956), observed a shift away from chironomid larvae at about 130 mm TL. In Malawi, the indigenous fish *T. rendalli* has been used to control aquatic plants in rain fed ponds. The analysis of stomach contents has shown that juvenile fish of less than 150 mm TL prefer to feed on filamentous algae, followed by submersed macrophytes such as *Myriophylum* and *Vallisneria* and on softer emergent vegetation (Brummett, 1995).

1.13.3 *Oreochromis mossambicus*

Lahser (1967) reported that leaves of aquatic plants are removed by *O. mossambicus* to obtain attached periphyton, and that the increase in turbidity used reduced macrophyte densities. Close observation of feeding fish indicated that the consumption of many aquatic macrophytes was incidental to the removal of periphyton using the plants as a substrate. Leaves, stems and roots were scraped or rasped to shreds; the plants were killed and consumed secondarily. But *Lemna* and *Azolla* were consumed in amounts equal to those of filamentous algae. *Cabomba, Myriophylum, Potamogeton, Vallisneria* and *Najas* were eaten extensively, *Eichhornia, Brasenia* and *Ludwigia* were killed through destruction of roots and stems but were not consumed in any appreciate amounts. Casual observations in the field showed that *O. mossambicus* would eliminate aquatic macrophytes (such as *Najas, Heteranthera, Chara)* and marginal vegetation (*Zizania, Setaria, Paspalum, Echonochloa, Cyperus, Polygonum*) from the bottom and margins of rearing ponds. This elimination is effected through grazing and through increasing the turbidity of the water during nest building.

1.13.4 *Oreochromis aureus*

Blue tilapia (*O. aureus*), stocked at 500 or 2500 adults ha $^{-1}$ in small ponds in Oklahoma (USA) successfully controlled submersed aquatic vegetation eliminated by *Najas* and *Chara* (Schwartz et al., 1986). The speed and degree of control were proportional to initial stocking density, with effective control observed in low density ponds and high density ponds within 120 and 90 days respectively. Blue tilapia uprooted and deleafed plants and there was an increase in turbidity, in water temperature and dissolved oxygen levels. The authors also reported a significantly lower stratification in the experimental ponds, perhaps a result of an increase in the wind force on the water surface without macrophytes and this resulted in a better mixing. Schuytema (1977) cautioned against the use of *O. aureus*, as this species has spread widely through western and central Florida, where it is competing with the native fish species and dominates the fauna in many eutrophic Florida Lakes. In the state Oklahoma, where Schwartz *et al*., (1986) carried out their experiments, this danger does not exist, as the fish generally could not survive the winter temperatures.

1.13.5 *Osphronemus gourami*

The *gourami* (*O. gourami)* has been considered useful in controlling some submersed macrophytes in Asian ponds and reservoirs. Edwards (1980), reported this species to feed mainly on plant leaves. It was introduced into irrigation wells in India from Java to control submersed macrophytes. In India giant gourami has also a large appetite for *Pistia stratiotes*, on which mosquitoes transmitting Filariasis breed. Full grown gourami consumes 300 g of *Pistia* day $^{-1}$ and can clear 1 $^{-ha}$ pond in a month (Anon, 1989).

1.13.6 *Trichogaster pectoralis*

This species does not feed directly on aquatic macrophytes, but the macrophytes represent an important link in its life cycle and indirect source of food. Mature fish build nests to spawn in the macrophytes. The fry, which hatches within 24 hours, after the absorption of yolk sac will feed on phytoplankton and zooplankton. The adult fish feed on periphyton and small invertebrates. In Thailand fish ponds aquatic weeds such as *Eleocharis equisetoides, Paspalum conjugatum* and *Hymenachne myurus* are cut and serve as fertilizer the presence of which results in zooplankton bloom in a short time (Boonsom, 1984).

1.13.7 Tor spp.

Pathani (1980) and Pathani and Joshi (1980) found that in India mahseer (*Tor tor* and *Tor putitora*) feed on and control the growth of submersed plants such as *Ceratophyllum demersum, Myriophyllum spp, Hydrilla verticillata* and *Vallisneria spiralis*. In the Narmada River, India, Desai (1970), found the food of *T. tor* dominated by macrophytes, feeding mainly on aquatic macrophytes and filamentous algae, but it also consumed molluscs and insects. Desai (1970), believes that mahseer could be a useful fish for controlling both aquatic macrophytes and with them associated molluscs, intermediate hosts of nematodes causing parasitic infection of fish. In Lake Govindgarh in Madhya Pradesh fingerling up to 160 mm were found to subsist mainly on macrophyres, while adult fish over 200 m preferred animal food such as insects, molluscs and fish (Pisolkar and Karamchandani, 1984). A study on the food and feeding habits of *Tor tor* in Meghalaya, northeastern India, where Dasgupta (1990) collected the fish from the Simsang River, has shown that while the larger fish feed predominantly on algae and macrovegetation, in its juvenile stage the consume more insects.

1.13.8 *Puntius* (Barbodes) spp.

The cyprinid *Puntius species* are generally omnivorous, with a tendency towards feeding on plants. Nandeesha *et al*., (1989), summarized the information available on the feeding habits of four species of *Puntius* in India. *P. pulchellus*, which reaches 8 kg weight in the Anjanapur reservoir in Kamataka and supports there a good fishery, was found to feed on *Cyperus, Hypha, Scirpus, Leersia, Pseodorphis, Hydrilla, Vallisneria, Lemna* and also on the roots of water hyacinth. According to Devaraj and

Manissery (1979), this species shows a great promise in controlling aquatic weeds in ponds. Fingerlings stocked in cisterns with *Lemna* and *Hydrilla* fed on them at a rate of more than 50% of their body weight per day. Nandeesha *et al*., 1989), found *P. dobsoni* and *P. sarana* to feed on *Chara, Hydrilla, Vallisneria,* diatoms and green algae. *P. kolus* prefers planktonic algae and plant matter, but also takes molluscs.

In Sri Lanka, the diets of *Putius amphibious* and *P. dorsalis* consist of 23 and 7 unidentifiable species, respectively, of higher plant leaves and animal matter (De Silva et al., 1980). In both species the major contribution comes from the plant material. In reservoir Parkrama Samudra in the littoral are with dense cover of *Ceratophyllum*, *P. filamentous* was the dominant species in fish hatches. This fish cuts the plant into pieces between 2 and 5 mm length, which however, are poorly assimilated as the digestive system of the fish is unable to attack crude fiber. Hofer and Schiemer (1983), have suggested that the fish probably obtains much of its nutrition from the animal, bacterial and algal periphyton. *Puntius sarana*, another important species of the reservoir fisheries in Sri Lanka, appears there to be rather omnivorous than herbivorous.

In Bangladesh, *P. javanicus* was effective in controlling aquatic vegetation under experimental conditions. In Indonesia and few other Asian countries it serves the dual purpose of fish production and weed control. *P. gonionotus*, a native of Thailand, Malaysia, Laos, Vietnam and Java (Indonesia) is now widely distributed throughout the Asian region, due to its use in aquaculture and introduction to establish commercial fisheries. It feeds on algae and aquatic macrophytes, it is used extensively for weed control in fish ponds (Jhingran and Pullin, 1985). Scattered references to its habits indicate that the species does not deviate from this essential vegetable matter diet. *P. gonionotus* controlled a dense cover of Ceroatophyllum in a 284 ha reservoir in vast java in Indonesia within 8 months of stocking (Schuster, 1952). In experiments carried out in Bangladesh on the diet and feeding ecology of the introduced *P. gonionotus* by Haroon (1998), macrophytes represented 89.2% of the gut content in small fish and 15.7% in large fish. Haroon classified this species as macrophytophagus column feeder, depending on aquatic macrophytes with increase in size and development of pharyngeal mill, and benthic foraging on tiny molluscs as the fish grow larger. This supports the findings by Ukkataweat (1979), who found this species feeding on macrophytes in Thailand at the size >12.5 cm.

To achieve fast results in submersed aquatic macrophyte control, *P. gonionotus* needs to be overstocked. Overstocking may also be required to prevent that not all this tasty fish end in the nets of commercial and subsistence fishermen prior to achieving the required results. The same concerns other aquatic weed-feeding fish, such as *T. rendalli* and *zilli.*

1.13.9 *Colossoma spp*

In the wild, Colossoma *macropomun* and *C. brachypomum* feed on plant seeds and fruits in inundated forests and with the retreat of water they will feed on zooplankton, fish, insect larvae (goulding and Carvalho, 1982). Colossoma can tolerate low concentration of dissolved oxygen for short periods of time and a flap on the lower lip, when extended, allows the fish to skim the surface layer of water for more oxygen when necessary (Ginnelly, 1990). This adaptation enables it to survive through the dry season in pools which become isolated from the river as flood waters recede. Goulding (1980), who studies the food of this species captured from the Rio Machado (Venezuela) flooded forests, found that rubber tree seeds (*Hevea spruceana*) and palm nuts (*Astrocaryum jauary*) were the dominant food consumed. Goulding notes that these may be selected because they are hard and most other fish species cannot exploit them. Other fruits/seeds are probably competed for by hundreds of other fish species. Large fat reserves are built up during the flood season, as the dry season is a time of poor feeding. In Varzea, juveniles of the characid, Colossoma *macropomun* have been found in the floating meadows to feed mainly on filamentous algae and wild rice seeds (Goulding and Carvalho, 1982).

Araujo-Lima et al., (1998), estimated the contribution of the flooded forest to Colossoma *macropomun* production and the economic value of this contribution to the economy of Manaus, the largest city in Central Amazon. Flooded forest seeds were responsible for more than 41% of the carbon assimilated in over 80% of the examined fish, while carbon from the sale of this fish in Manaus in 1993-1994 was estimated at US $13 million, US $8.2 million (65%) of which came from C. *macropomun* produced with flooded forest carbon. *C. bidens*, highly adapted to eating fruits and seeds in flooded forest, feeds during the water level decline on leaves and grass and hence it has much higher mean stomach fullness in dry season than *C. macropomum, Scardinius erythrophthalmus* (rudd) and *Rutilus rutilus* (roach).

The diet of rudd, one of the most common littoral fish in eutrophic European lakes, includes 65-90% submersed macrophyte tissue (Prejs, 1984). The contribution of submersed macrophytes to the food of rudd in three Polish lakes investigated by Prejs and Jackowska (1978), increased with the size of fish, attaining over 90% of the total food weight of fish longer than 16 cm.

According to Van Donk (1998), only larger rudd are herbivorous. In Polish lakes, Elodea Canadensis was found most frequently in the food of rudd and roach, although its biomass in lakes was lower than that of one or two or three of the dominant plant species. This represented some50% of the total weight of the macrophytes consumed. Second among the macrophytes consumed was *Ceratophylum demersum* and third Characeae and *Potamogeton pectinatus.*

1.13.10 *Cyprinus carpio* (Common carp)

The habits of feeding on bottom sediments, which uproots aquatic plants and stirs the sediment, which in turn leads to an increase in water turbidity, makes common carp an unwanted species in some water bodies, especially those which serve as a source of drinking water. At a density of 400 carp ha^{-1} in ponds the common carp activity controlled the submersed aquatic plant in Alabama. At a density of 488 kg ha^{-1} the carp destroyed submersed vegetation in enclosures place in a lake Erie marsh. Common carp is also very numerous in shallow bays of lake Ontario, where it causes resuspension of sediments and uprooting of aquatic macrophytes (Crowder and Painter, 1991).

1.14 Herbivorous Aquatic Vertebrates that could be use as Bio-control agents

1.14.1 Turtles

The herbivorous turtles *Kachuga tectum* and *Hardella thurgi* feed on aquatic plants in India and Bangladesh (Choker, 1967) with the first species found to feed in India on the following: *Lemna, Ceratophylum, Eichhornia, Hydrilla* and *Ipomea*. The species can be easily bred under controlled conditions and there is a good scope for their utilization in biological control of aquatic weeds (Nandeesha et al., 19890. In Florida, the turtle *Pseudoemys floridiana* is also herbivorous (Yount and Crossman, 1970).

1.14.2 Birds

Many ducks and geese domesticated or not, as well as swans and coots are consumers of aquatic plants. The smaller species of ducks are rather selective, giving preference to duck weeds and other small plants with soft tissues. Among aquatic birds, only geese and swans are strict herbivores, and apart from aquatic macrophytes both consume a certain amount of terrestrial plants. Other aquatic birds consume seeds and / or fruits of aquatic plants, thus reducing their reproduction (Van Zon, 1976). McAtee (1939), found that a number of waterfowl species feed on Potamogetonaceae, Cyperaceae and Polygonaceae, Potamogetonaceae being the preferred food source. Grazing affects both the biomass and the growth of submersed macrophytes significantly. In the colonization phase waterfowl may prevent growth of submersed macrophytes (Moss, 1990).

1.14.3 Manatee (*Trichechus spp*)

In Florida and Guyana, *T. manatus* is known to consume 36 genera of macrophytes, but not water hyacinth when other plants are available. It was reported that they efficiently clear canals when present in sufficient density. Various ponds and canals in Guyana have been kept clear of aquatic weeds by *T. inunguis* for many years (Anon, 1974). Their preference is for succulent aquatic macrophytes, but they will consume almost any aquatic plant (Ronald et al., 1978). They prefer submersed to floating, and floating to rooted-emergent plants.

1.14.4 Nutria (*Myocoster coypus*)

Schuytema (1977), reviewed the impact of Nutria on aquatic plants. This animal, often introduced for its pelt and meat, is able to control the emergent *Typha angustata* and *Phragmites australis* in ponds in Europe and Israel, and water grass (*Echinochloa*) in Africa (Cameroun). This it does quite efficiently, and where Nutria is present close to common carp ponds, it can significantly increase fish production by destroying the emergent vegetation. *M. coypus* are generally blamed for the disappearance of water-lillies (*Nymphaea caerulea*) from lake Naivasha, on which individuals were widely observed to be feeding. Water-lily shoots make up a major part of the *M. coypus*' diet (Gidson, 1973). Water-lilies began to disappear in the eastern part of the lake at around the same time that the crayfish, *Procambarus clarkii*. The crayfish had a substantial effect upon the submersed vegetation. It is likely that water-lilies disappeared under the combined grazing pressure of *M. coypus* and *P. clarkii* (Harper *et al*., 1990).

1.14.5 Muskrat (*Ondatra zibethicus*)

In the Czech Republic Muskrat consumed or used in lodge construction 9-14% of the annual biomass production of *Typha latifolia* (Pelikan *et al*., 1971), in a lake in northern Germany a population of Muskrats consumed or damaged 0.27 ha of *Typha*, 0.15 ha of *Phragmites australis*, 0.86 ha of *Glyceria* and 1.58 ha of *Scirpus*. The damaged area of *Scirpus* and *Phragmites* did not recover even when the Muskrats significantly decreased in number (Ukkermann, 1975). In the USA muskrat in the Atchafalaya Bay, Louisiana, graze on submersed swards for example *Eleocharis* (Fuller *et al*., 1984).

Brakhage (1994), suggests the involvement of wildlife as numerous birds, reptiles, amphibian and mammals in the bio-control of macrophytes since they rely on wetlands for their survival. Majority of these require aquatic macrophytes and the boundaries of their desirable habitat are generally delimited by the occurrence of aquatic macrophyte within a system.

DISCUSSION

Bio-control offers several potential advantages over conventional methods including reduced cost, long-term effectiveness and little or no negative impacts on other species or aquatic system if the planned are strictly followed (Sheldon and Greek, 1995).

Bio-control is the only techniques used alone or in combination that result in a timely, consistent and substantial reduction of target plant population to levels that alleviate an existing or potential impairment to the use or function of the water body (Brakhage, 1994).
However, if used improperly can present environmental risk to aquatic ecosystem. Introduction of new plant or animal species for use in bio-control can have unintended consequences on an aquatic ecosystem. Caution is particularly warranted with introduction of

non-native bio-control species, given the fact that introduced organisms (plants and animals) reproduce and spread to new water bodies, causing permanent ecological changes in the widespread areas. The use of triploid grass carp is a good example of a program with permanent regulatory mechanism in place to reduce the likelihood of widespread or adverse impacts (Madsen, 2004).

Elimination of submersed plants by grass carp foraging could result in increased turbidity, water column, nutrients and phytoplankton production (Scheffer *et al.*, 1993; Colle and Shireman, 1994; Scheffer, 1999). If all aquatic vegetation is removed; waterfowl and amphibians and aquatic mammals may also be adversely impacted (Brakhage, 1994).

Grass carp as bio-control agent, Schuytema 1997), pointed out a number of negative impacts to include uncertainty of the effect on natural fishes, possibility that removal of plants may eliminate endemic fish and other herbivorous food and cover, possibility of natural spawning place been affected, lack of knowledge of local plant preference and nutrient released into water by excretion can lead to increase in primary productivity.

Non-native insect species, once introduce to a new region could potentially spread rapidly and adversely affect local ecosystem. They could potentially impact non-target vegetation and cause loss of habitat for some fauna (Sheldon and Creek, 2003).

Use snails as bio-control agent has been limited due to environmental risk associated with purposeful introduce of prolific generation herbivores and concern that it can serve as vectors for certain fish parasite (McCann *et al.*, 1996).

Total elimination of aquatic macrophytes result in changes in water quality water shift from a plant based community to a system dominated by phytoplankton and microphytic algae open to wind and wave actions that stir up and suspend bare sediment (Schuytema, 1977).

The organism need not to stay in the habitat or region to which they are introduced, some bio-control agents have to move to other neighboring areas to cause ecological problems e.g. extinguish other population. For instance Cactus moth dispersed form its initial site of introduction where it is not known to have cause ecological damage to other island where it threatens at least one endemic species with extinction (Hopper *et al.*, 1993).

Equally problematic is the fact that living organism evolve; species evolve to acquire new host, to tolerate a greater range of physical factors and for pathogens to be more virulent or less vigilant. Any of these changes can turn innocuous species into harmful one (Ewald, 1983).

CONCLUSION

View the paucity of known ecological damage from bio-control introduction in compares to the numerous projects has proof that bio-control is generally safe. However care must be taken not to upset the ecosystem of the area by the population of control agents. Before embarking on the usage of a bio-control agent, there should be substantial effort expected on the experiments to ensure that it is without or bearable ecological implications.

Successful bio-control requires that the pest population is reduced to levels well below the economic threshold but maintained sufficiently to allow the survival of the agents.

The long-term management of alien aquatic vegetation relies on the correct implementation of biological control for those species already in the area and the prevention of other species entering the control area (Hill, M.P. and Julien 2017).

RECOMMENDATION

Based on the literature available to me, the following recommendation are made.

Standard experiments are carried out be used rather than any bio-control agents to be used in micro-habitats with same weather condition and other necessary parameters.

Preventive measures such as early detection, quarantine and regulation, education and outreach, Riparian buffer strips, wetland and watershed best management practices be used rather than the bio-control measures.

Possible means of agent’s escape such as the use of larval stage of insects in the bio-control since larvae do only trivial movement.

In management situations, integrated approaches involving multiple bio-control agents or possible bio-control and chemical method be used. However, care should be taken to minimize potential negative environmental effects.

Where possible use of native species is proper and if non-native species has to be used, it should be sterile to avoid spread via reproduction to new water bodies.

Promulgating appropriate legislation against a suite of new aquatic invaders could have in allowing their unmitigated establishment. In addition, Awareness and publicity programs on potential new threats could go a long way in preventing their introduction and trade, as well as improved phytosanitory efforts and border control. This legislation will provide much needed impetus to curb the spread and impacts of this suite of invaders anywhere in the world (Jaca and Mkhize 2015; Fraser *et al*., 2016).

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