International Plant Protection Convention

Protecting the world's plant resources from pests

ENG

Implementation Review and Support System

# AQUATIC PLANTS THEIR USES AND RISKS

*A review of the global status of aquatic plants*

# AQUATIC PLANTS
# THEIR USES AND RISKS

*A review of the*
*global status*
*of aquatic plants*

Ryan M. Wersal, Ph.D.
&
John D. Madsen, Ph.D.

## Contents

Acronyms and abbreviations 5
Glossary of terms 6

**Preface** 11

**Section I. Definition** 13

Species diversity of aquatic plants and algae 13
Ecology 14

**Section II. Uses and benefits of aquatic plants** 16

Ecosystem benefits 16
Use of aquatic plants as food 20
Other uses of aquatic plants 25
Economic benefits of aquatic plants 26

**Section III. Aquatic plants as pests or hosts of plant pests** 31

Important species that directly or indirectly, threaten commercially significant crop plants or wild flora 31
Commercially significant aquatic plant species, and the organisms that directly or indirectly impact their growth and production 48
Organisms that directly or indirectly impact aquatic plant growth 51
Indirect effects or impacts of aquatic weeds *54*

**Section IV. Conclusions and recommendations** 60

*Conclusions* *60*
*Recommendations* *61*

**Tables**

2.1 Annual net primary productivity of aquatic habitats compared to other ecosystems 16

**Figures**

*2.1* A diagrammatic representation of a freshwater littoral zone 17
2.2 A diagrammatic representation of marine zonation 17
2.3 A simplified representation of an aquatic food pyramid 18
2.4 The global harvest of marine and freshwater aquatic plants from 1950 to 2009 26
2.5 The global harvest of marine and freshwater aquatic plants by taxa group from 1950 to 2009 26 27
2.6 The global value of marine and freshwater aquatic plants from 1984 to 2009 28
2.7 The global value of marine and freshwater aquatic plants by taxa group from 1984 to 2009 29

## Photos


1 Invasive aquatic plants for sale at local hardware stores in the United States 31
2 Spartina alterniflora invading coastal mudflats in the state of Washington (USA 34
3 The dense growth of Spartina along the west coast of the United States 34
4 Water hyacinth clogging a hydroelectric dam on Lake Carraizo, San Jaun, Puerto Rico 35
5 Water hyacinth clogging the dam near Jinja, Uganda in 1996 36
6 Water hyacinth impeding navigation at the Port Bell ferry in Uganda, 1996 37
7 A bayou infested with giant salvinia in Mississippi, USA 37
8 A dense bed of giant salvinia covering golf course ponds at the Dorado Beach Golf Club, Dorado, Puerto Rico 38
9 Giant salvinia with stolon 39
10 Giant salvinia frond showing the dense pubescence 39
11 Water lettuce covering Lake Ocklawaha, Florida, USA 40
12 Water lettuce covering a large portion of a reservoir in the Laguna Cartageba Wildlife Refuge, Lajas, Puerto Rico 40
13 Water lettuce plant 41
14 Hydrilla infestation on Roman Reservoir in Florida, USA 42
15 Hydrilla leaf spines 42
16 Hydrilla turion (left) and subterranean tuber (right) 42
17 Hydrilla fouling a boat motor in Mississippi USA 43
18 Parrotfeather emergent shoots 44
19 Leaf form changes in parrotfeather from submersed to emergent as shoots reach the water surface 45
20 Parrotfeather in an irrigation canal in Idaho, USA 45
21 Parrotfeather takingover a river in Germany 46


## Annexes


1 Important aquatic plant species 66
2 Major nuisance aquatic plants worldwide 70
3 Commercially beneficial aquatic plants worldwide 71
4 Important pathogen, insect, and vertebrate plant pests 72

## Abbreviations and acronyms

| | |
|---|---|
| CBD | Convention on Biodiversity |
| COP | Conference of the Parties |
| CPM | Commission on Phytosanitary Measures |
| EPPO | European and Mediterranean Plant Protection Organization |
| FAO | Food and Agriculture Organization of the United Nations |
| ICCD | International Commission on Irrigation and Drainage |
| IPPC | International Plant Protection Convention |
| IRSS | Implementation Review and Support System (IRSS) |
| ISPM | International Standard for Phytosanitary Measures |
| ISSG | Invasive Species Specialist Group |
| ISSG | Invasive Species Specialist Group |
| IUCN | International Union for Conservation of Nature |
| NASS | National Agriculture Service Statistic |
| ppmw | parts per million per weight |
| ppt | part per thousands |
| SPTA | Strategic Planning and Technical Assistance |

## Glossary of terms

**Abiotic –** The non-living components, including chemical and physical factors, of the environment that affect ecosystem processes.

**Adaxial –** Refers to the side of the leaf that faces the stem.

**Agar –** A gelatinous carbohydrate obtained from seaweeds used as a culture medium for bacteria, a laxative, and a thickening agent in certain foods.

**Algae –** Unicellular to multicellular organisms that occur in fresh, salt water, or moist ground, and that have chlorophyll and other pigments but lack stems, roots and leaves.

**Alginate –** Alginic acid or algin is an anionic polysaccharide found in the cell walls of brown algae. This compound absorbs water quickly, which makes it useful as an additive in manufacturing, paper, textile, pharmaceutical and food industries.

**Amphipod –** Members of the invertebrate order Amphipoda which inhabit all parts of the sea, freshwater lakes, rivers and moist habitats. Freshwater species are known as scuds.

**Angiosperms –** The large group of flowering plants that develop seeds from ovules contained in ovaries. Seeds are enclosed by fruit, which develops from carpels.

**Antibiotic –** Any compound that slows or inhibits the growth of bacteria.

**Antiemetic –** Compounds or substances that suppress nausea or vomiting.

**Antifouling –** Paint or other coating that prevents the accumulation of barnacles, algae, or other organisms on underwater surfaces.

**Anti-inflammatory –** Medicine or other compounds that reduce inflammation, swelling, pain, or fever.

**Antimitotic –** A drug that inhibits or prevents mitosis typically used in chemotherapy treatments. Synonomous with mitotic inhibitor.

**Antiviral –** Any medicine or compound that inhibits the growth of viruses.

**Aquatic plant –** Any plant that grows partly or wholly in water, and can be rooted in sediment or free floating on the water surface.

**Aquatic macrophyte –** An aquatic plant that grows in or near water and is either emergent, submergent, or floating. In lakes macrophytes provide cover for fish and substrate for aquatic invertebrates, produce oxygen, and act as food for some fish and wildlife.

**Arable –** Land that can be tilled for crop production.

**Autotrophy –** The production of complex organic compounds (such as carbohydrates, fats, and proteins) from simple inorganic molecules using energy from light (photosynthesis) or inorganic chemical reactions (chemosynthesis).

**Axillary –** Growing in or relating to the axil.

**Biodiesel –** A fuel made primarily from plants with high oil content.

**Biomass –** The mass of organism per unit area or the volume of organisms per unit volume.

**Bioremediation –** The use of biological organisms, such as bacteria, fungi, or plants, to remove or neutralize contaminants in polluted soil or water.

**Biotype –** A group of genetically identical plants within a species.

**Bryophyte –** The group of nonvascular plants comprising the true mosses and liverworts. These species have stems and leaves but lack true vascular tissue, roots and reproduce by spores.

**Carotenoid –** Any group of red or yellow pigments, including carotenes, found in plants and certain animal tissues.

**Carrageenans –** Colloidal substances extracted from red seaweeds that are used as emulsifyers and stabilizers in foods, cosmetics and pharmaceuticals.

**Chloroplast –** A plastid in plants and algae that contain chlorophyll to carry out photosynthesis.

**Cyanobacteria –** Blue-green bacteria that are photosynthetically active and get there name from the blue pigment they contain.

**Cytoplasm –** The substance between the cell membrane and the nucleus, containing the cytosol, organelles, cytoskeleton and various particles.

**Cytotoxic –** A chemical that is toxic to living cells.

**Denizens –** A plant that is not native to a given location but has become naturalized in the environment.

**Detritus –** Organic debris formed by the decay of once living organisms.

**Detritivore –** An organism that consumes organic waste as a food source.

**Dicotyledon –** Flowering plants that have two seed leaves in the embryo of the seed.

**Diffusion –** The random movement and mixing of particles between two or more substances.**Dioecious –** Having male (staminate) and female (pistilate) reproductive organs in separate flowers on different plants.

**Diuretic –** A drug that increases the flow of urine.

**Electrophoresis –** A method used to sort proteins according to their responses to an electric field.

**Emollient –** A medicine or compound to smooth or soften, often in the form of lotions.

**Eradication –** To completely remove an organism from a given area.

**Eutrophic –** A lake that has an abundant accumulation of nutrients to support a dense growth of algae and other organisms; and frequent reductions of dissolved oxygen resulting from decaying organic matter.

**Filamentous –** The long slender chain of cells that are representative of some algae.

**Fodder -** Coarse food for livestock, composed of entire plants, including leaves and stalks.

**Forage –** Food for livestock. Or, to search for food.

**Fucoidan –** A sulfated polysaccharide found mainly in brown algae. Fucoidan is used as an ingredient in some dietary supplement products.

**Gall –** Abnormal growths on plants caused by insects, nematodes, fungi, bacteria, viruses, chemicals and mechanical injuries.

**Genotype –** The genetic makeup of an organism or group of organisms with reference to a single trait, set of traits, or an entire complex of traits.

**Hepatotoxin –** Chemicals and compounds toxic to the liver.

**Heterophyllous –** Having dissimilar leaf forms on the same plant.

**Heterotrophy –** Exhibiting two leaf forms on the same plant.

**Hybridization –** The production of offspring from parents of different stock.

**Hydrocolloids –** A colloid system where colloid particles are dispersed in water. A hydrocolloid has colloid particles throughout the water column and can be a gel or liquid.

**Invertebrate –** Any animal lacking a backbone.

**Lesions –** A localized, defined area of diseased tissue, as a spot, canker, blister, or scab.

**Littoral –** The shallow water area near the shoreline of a lake.

**Monoecious –** Having male (staminate) and female (pistilate) reproductive organs in separate flowers on the same plant.

**Neritic –** The region of shallow seas near the coastline, typically from the low tide mark out to 200 meters from the coastline.

**Neurotoxin –** Any substance that is toxic to nerves or the nervous system.

**Oligotrophic –** A lake characterized by a low accumulation of dissolved nutrients, supporting algae and macrophyte growth, and having a high oxygen content owing to the low organic matter content.

**Pastilles –** Tablets of aromatic substances that are burned to deodorize the air.

**Pathogen –** A micro-organism causing disease.

**Pectinate –** Closely parallel or comblike leaves.

**Perennation –** To survive or live through a number of seasons.

**Pistillate –** Having pistils, referring to the reproductive organ in flowers.

**Phytoplankton –** Free-floating algae, protists, and cyanobacteria that form the base for most aquatic food webs.

**Polysaccharides –** Carbohydrates containing more than three monosaccharide units per molecule, the units being attached to each other in the manner of acetals, and therefore capable of hydrolysis by acids or enzymes to monosaccharides.

**Prebiotics –** Natural substances in some foods that encourage the growth of healthy bacteria in the gut.

**Primary productivity –** A measure of the rate at which new organic matter is developed through photosynthesis and chemosynthesis in producer organisms based on the oxygen released and carbon taken in; the transformation of chemical or solar energy to biomass.

**Polyphenol –** Alcohols containing two or more benzene rings with at least one hydroxyl group attached.

**Pteridophyte –** Plants with vascular tissue and roots, stems and leaves.

**Pubescent –** Short hairs on the surfaces of some leaves.

**Rhizome –** A horizontal subterranean stem that typically produces roots below and sends up shoots from the upper surfaces of the stems.

**Rosette –** A circular cluster of leaves.

**Serrate –** Toothed margin.

**Sessile –** Attached from the base, having no projected support such as a petiole.

**Silting –** Fine sand or gravel carried by moving water and depostited as sediment in another area.

**Staminate –** Having stamens, referring to the reproductive organ in flowers.

**Stolon –** A horizontal stem just above the surface of the ground that produces new plants from buds at its tips or nodes.

**Stoloniferous –** Producing or bearing stolons.

**Subterranean –** Growing or living underground.

**Tannin –** Compounds found in many plants formed by gallic acid.

**Tiller –** A plant shoot that grows from the base of the original stem.

**Transpiration –** The movement of water through plants from the roots, through the vascular tissues into the atmosphere.

**Trematode –** A parasitic flatworm.

**Vascular plant –** Plants possessing xylem and phloem tissues including all seed-bearing plants.

**Zooplankton –** Plankton comprised of microscopic animals.

**Zoospore –** An asexual spore produced by certain algae and some fungi, capable of moving about by means of flagella.

## Preface

'Aquatic plants' are not specifically mentioned in the text of the International Plant Protection Convention (IPPC). Under the framework of the IPPC, however, 'aquatic plants' are mentioned for the first time in the International Standard for Phytosanitary Measures (ISPM) 1. 2006. *Phytosanitary principles for the protection of plants and the application of phytosanitary measures in international trade* when a reference to them is made in the scope of the ISPM to indicate that as plants, they are to be protected. This concept was introduced into the revision of ISPM 6:2006 in response to member's comments.

During the discussion of 'the strategic plan' in the Commission on Phytosanitary Measures-1 (CPM-1)(2006), it was noted that the Secretariat should liaise with other international organizations to clarify the mandate of the IPPC with respect to 'invasive aquatic plants' (CPM-1(2006) Report, Para 131).

The Business Plan 2007 – 2011, adopted in CPM-2 (2007), identified 'marine and other aquatic plants' as a new and emerging issue to be considered. In addition, it was stated that ISPMs should be developed/modified to take 'aquatic invasive plants' into account.

In addition, during the ninth session of the Conference of the Parties of the Convention of Biological Diversity (COP-9, 2008), the Conference of the Parties invited the International Plant Protection Convention to continue its efforts to expand, within its mandate, its actual coverage of invasive alien species impacting biodiversity, including aquatic environments (Paragraph 2 of decision IX/4).

At CPM-5 (2010) a presentation on aquatic plants was given during the scientific session. The speaker outlined the threats to and from aquatic plants. He also encouraged the IPPC and its contracting parties to address, in the phytosanitary framework, phytosanitary risks to aquatic plants and risks resulting from invasive aquatic plants.

At CPM-6 (2011), the Secretariat presented a paper introducing the concept of aquatic plants. The issue of aquatic plants within the IPPC had been discussed for a number of years within the IPPC and by the Convention on Biodiversity (CBD). The CPM agreed that the issue of aquatic plants within the IPPC should be further considered by the Bureau and Strategic Planning and Technical Assistance (SPTA) and the conclusions reported back to the CPM-7 (2012) (CPM-6(2011), Report, Para. 193).

The CPM Bureau, at its June 2011 meeting, agreed that a "Scoping study on aquatic plants and their significance to the IPPC", should be conducted under the framework of the Implementation Review and Support System (IRSS) (CPM Bureau June 2011 Report, Agenda 11.2) and John D. Madsen, Associate Professor, and Ryan M. Wersal, Postdoctoral Associate at Mississippi State University, were engaged to conduct this study.

A draft report was submitted to the Secretariat in January 2012, this draft was submitted for review by the members of the Expert Working Group on Capacity Development, the Secretariat, the Bureau and selected experts. The draft report was revised in response to these comments and a draft will be made available to CPM-7 (2012).

## SECTION I – DEFINITION

Defining an aquatic plant is more difficult than understanding what is meant by the term; because both terms ('aquatic' and 'plant') are used, which encompass a different set terminology than when each term is used alone. In this document we will use aquatic in the broader sense of environments defined by possessing seasonal or permanent standing water, both freshwater and marine.

The, environments discussed, therefore, will be lakes, rivers, ponds, estuaries and oceans. By plant, we will refer to microscopic and macroscopic photosynthetic organisms, both vascular and nonvascular. The term aquatic plant is used much like the term aquatic macrophyte – plants visible to the unaided eye. Therefore, this will include flowering plants, conifers, mosses, ferns and fern allies, charophytes, macro-algae of all descriptions, and any other plant found in standing or moving water. We will discuss plants that are completely submersed, rooted in the sediment with leaves floating on the surface, plants rooted in standing water with leaves emerging from the water, and plants that are free-floating in the water with leaves either submersed, or partly or fully emergent. Algal growth forms will include free-floating phytoplankton and algae that grow attached to a variety of substrates. The difficulty of defining 'aquatic plants' has been discussed more thoroughly by Sculthorpe (1967).

The purpose of this report is to discuss both potential hazards to the growing of plants that are beneficial to human uses, whether cultivated or uncultivated, or strictly for their ecosystem benefits, and aquatic plants that pose a potential to interfere with agriculture. The scope of habitats for this survey will include freshwater, brackish water and marine environments.

### *Species diversity of aquatic plants and algae*

The species diversity of aquatic plants is far more than most imagine. The taxonomy of the algae is confused, at best, ranging from cyanobacteria to giant kelp. The algae span anywhere from 12 to 14 major groups (Radmer, 1996; Lee, 1989; Bold and Wynne, 1985). Many algae are capable of sustaining themselves with a mixture of autotrophy (reducing carbon to make sugars from light or an alternate energy source) to heterotrophy (metabolizing sugars from other organisms). Algae are found in a wide-range of habitats, and produce a vast array of compounds. Many of these compounds are useful to humans, for which these algae are either harvested or cultivated. John (1994) estimated that the 36 000 known species comprised only 17 percent of the potential total number of algal species, making the total diversity of algae approximately 200 000 worldwide.

Algal growth varies from single-celled organisms, to small colonies of cells, to filamentous chains, two-dimensional sheets of cells, and other types of colonies. Cells may be motile, nonmotile, or attached. Macro-algae have a wide array of growth forms; some having complex structures.

The diversity of vascular plants is somewhat more limited than that of algae. One flora for eastern North America covers almost 1 200 taxa from 109 families, spanning pteridophytes to angiosperms (Crow and Hellquist, 2000). Aquatic vascular plants are found in only 33 families, and many of these have relatively few taxa (Sculthorpe, 1967). While there are a number of dicotyledon families with aquatic denizens, there are no dictoyledon families with marine inhabitants.

### *Ecology*

Aquatic plants grow partially or completely in water. As with other plants, they require light and carbon dioxide (or other inorganic carbon source) for photosynthesis, oxygen for respiration, water, and nutrients such as nitrogen, phosphorus and others. Plants that grow with emergent or floating leaves form some of the most productive communities in the world, because they are rarely limited by water availability. With leaves exposed to the air, they have a ready source of light, carbon dioxide and oxygen.

As a rule, submersed plants, however, are much less productive. Light energy is rapidly attenuated as it penetrates the water, so light becomes a limiting resource for submersed plant growth. Carbon dioxide and oxygen must be acquired from the water, or stored in the plant stem, with the consequence that it is much more limiting to submersed plants than to emergent species. Diffusion is slow through water, further reducing plant growth rates. Plants rooted in the bottom typically have a ready source of nutrients such as nitrogen and phosphorus. Algae and free-floating plants, however, must acquire nutrients from the water column, which can likewise limit their growth.

The depth limitation of aquatic plants is controlled by light penetration through the water column. While plants may grow only 3 m deep in productive, eutrophic waters, in oligotrophic waters they may grow to depths of 10 m or more, with bryophytes found at a depth of over 60 m in Crater Lake, the United States (Madsen, 2009). The strong gradient of light energy also creates a natural zonation of aquatic plants in lakes, with communities stratified by depth. This natural 'depth zonation' is a common feature of aquatic plant communities worldwide (Sculthorpe, 1967).

Marine plants and macro-algae are also depth-limited by light availability, but the depth range for these habitats is even greater. Marine algae have been found at depths of 200 m (Bold and Wynne, 1985).

Both freshwater and marine macrophytes (plants and algae) form a critical habitat for other aquatic organisms; a substrate for attached plants and animals, spawning areas for animals, nursery areas for young fish and other biota and habitat for adult life stages. In addition, they form the base of the food chain as either a direct food source, or as detrital matter after plant death.

## SECTION II – USES AND BENEFITS OF AQUATIC PLANTS

### *Ecosystem benefits*

Aquatic plants provide many ecological benefits and are essential in promoting the diversity and function of aquatic systems (Carpenter and Lodge, 1986). Aquatic habitats, both freshwater and marine, are some of the most productive areas worldwide (Table 2.1).

Table 2.1 – Annual net primary productivity of aquatic habitats compared to other ecosystems. Data reprinted from Wetzel, 2001

| **Ecosystem** | **Approximate organic (dry) production (tonnes ha$^{-1}$ yr$^{-1}$)[a]** | **Range (tonnes ha$^{-1}$ yr$^{-1}$)** |
|---|---|---|
| Marine phytoplankton | 2 | 1 - 4.5 |
| Lake phytoplankton | 2 | 1 - 9 |
| Freshwater submersed macrophytes | | |
| Temperate | 6 | 5 - 10 |
| Tropical | 17 | 12 - 20 |
| Marine submersed macrophytes | | |
| Temperate | 29 | 25 - 35 |
| Tropical | 35 | 30 - 60 |
| Marine emergent macrophytes (salt marsh) | 30 | 25 - 85 |
| Freshwater emergent macrophytes | | |
| Temperate | 38 | 30 - 70 |
| Tropical | 75 | 60 - 90 |
| Arid desert | 1 | 0 - 2 |
| Temperate forest | | |
| Deciduous | 12 | 9 - 15 |
| Coniferous | 28 | 21 - 35 |
| Temperate herbs | 20 | 15 - 25 |
| Temperate annuals | 22 | 19 - 25 |
| Tropical annuals | 30 | 24 - 36 |
| Rain forest | 50 | 40 - 60 |

[a]t =tonnes. Values X 100 = g m$^{-2}$ yr$^{-1}$ and X 50 = g C m$^{-2}$ yr$^{-1}$

Much of the primary production in aquatic systems occurs in neritic (marine) or littoral (freshwater) areas as a function of both macrophytes and algae (Figure 2.1).

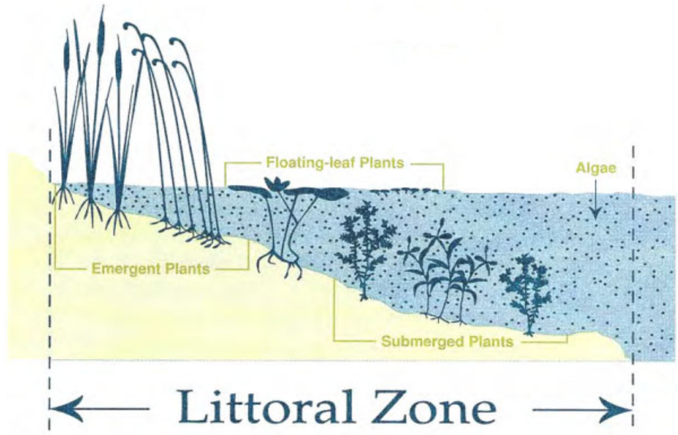
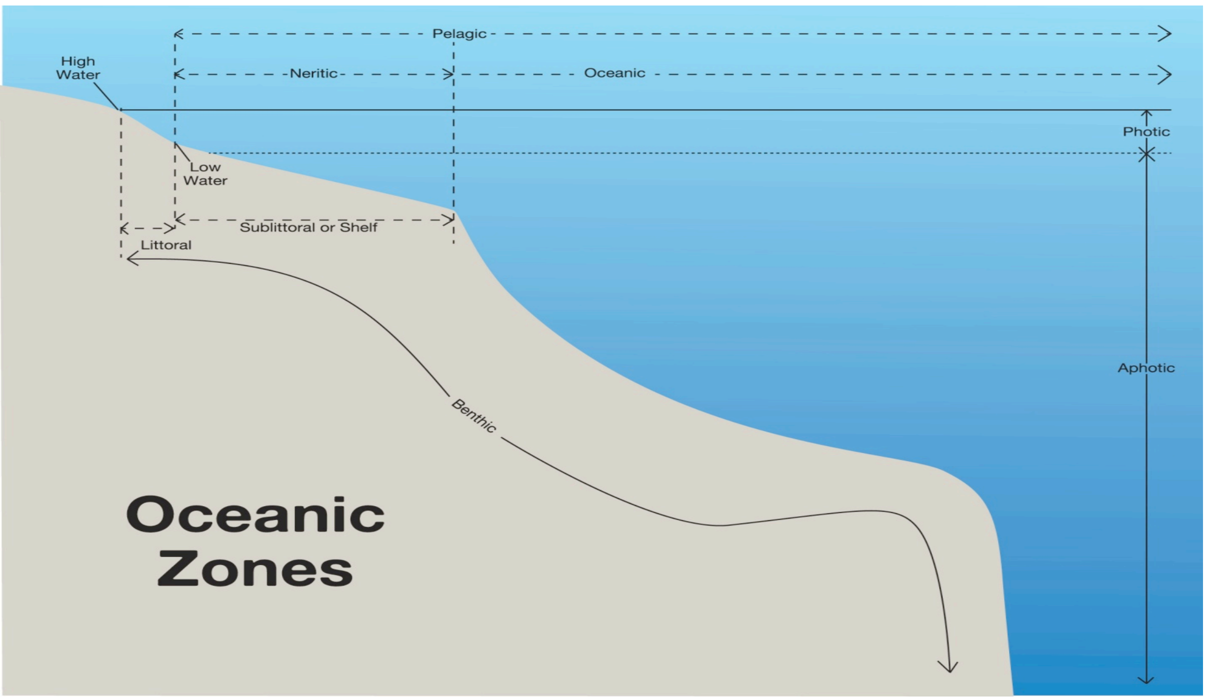



*Figure 2.1. A diagrammatic representation of a freshwater littoral zone, Minnesota Department of Natural Resources.*

These productive areas are characteristically shallow, have relatively stable water chemistry, and enough light reaches bottom substrates to support the growth of aquatic organisms (Dodds, 2002). For most submersed freshwater plant species, growth can occur at water depths where approximately 21 percent of light reaches bottom substrates (Chambers and Kalff, 1985). Because of the greater availability of light and warmer water temperatures, phytoplankton, zooplankton, and other aquatic organisms thrive in these areas; and concerning marine habitats, support some of the world's best fisheries.

*Figure 2.2 – A diagrammatic representation of marine zonation. Diagram developed by Bethany Stroud, High Performance Computing Collabratorium, Mississippi State University.*




Within aquatic ecosystems, algae form the base of aquatic food chains. As primary producers, algae are responsible for producing more than 70 percent of the world's oxygen (Smith, 2011). Algae can have many different growth forms and can exist as either single cells or complex multi-cellular forms such as filamentous, sheets, or cylindrical forms (Smith, 2011). In general, small, single-celled algae are often called phytoplankton, while larger multicellular species are described as macrophytes, if growing in freshwater or seaweeds (macro-algae) if growing in marine environments (Smith, 2011).

***Marine habitats –*** Macro-algae serve many functions within the marine environment including serving as the base of the food chain for both humans and animals. Important algae genera include *Laminaria*, *Macrocysis*, *Nereocystis*, *Palmaria*, *Ulva*, *Undaria*, *Fucus*, *Porphyra*, and *Saccharina*. Macro-algae beds are important refuges for small zooplankton and other animals, and serve as a direct food source for a number of larger animals including marine amphipods (Cruz-Rivera and Hay, 2000). Furthermore, as macro-algae become dislodged they form large floating wracks that continue to serve ecological functions. These large wracks are important sources of recycled nutrients in near shore seagrass meadows and reefs, and the detritus produced as a result of these wracks forms the basis of the food chain (Robertson and Hansen, 1982; Kirkman and Kendrick, 1997).

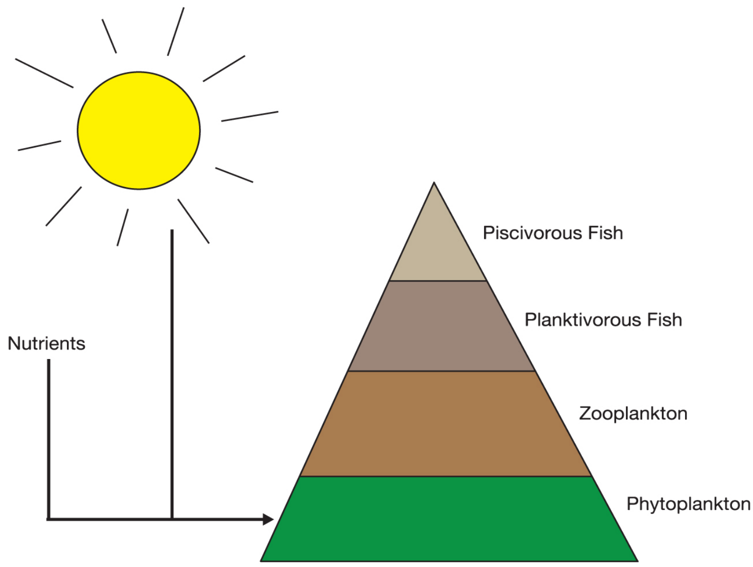



*Figure 2.3 – A simplified representation of an aquatic food pyramid. Adapted from Madsen (2009).*

In Australia, surf zone accumulation of nutrients in the presence of detached vegetation was high ($NO_3$ 2.0-8.0 μmol $L^{-1}$; $PO_4$ 1.0-7.0 μmol $L^{-1}$) compared to coastal areas were no plants were present ($NO_3$ 0.9-2.0 μmol $L^{-1}$; $PO_4$ 0.2-0.3 μmol $L^{-1}$) (Hansen, 1984). Decomposition of algae in these coastal areas are likely a vital source of nutrients for subtidal communities (Robertson and Hansen, 1982; Walker *et al.*, 1988). Surf-zone and beach-cast algae wracks are also sources of particulate carbon that supports the near shore detrital-based food webs, which include suspension feeders (Duggins *et al.*, 1989), near shore fishes (Lenanton *et al.*, 1982), and beach waders (Bradley and Bradley, 1993). In California (United States), black and ruddy turnstone populations increase with increasing amounts of kelp wrack that wash ashore on beaches (Bradley and Bradley, 1993). Bird species feed on wrack-inhabiting organisms such as crustaceans, mollusks, insects, and polychaetes that also use algae wracks (Kirkman and Kendrick, 1997).

***Freshwater habitats –*** The importance of plants in the littoral zone are far reaching as they contribute to the structure, function, and diversity of aquatic ecosystems, aid in nutrient cycling, produce food for aquatic organisms, and provide habitat for invertebrates and fish (Carpenter and Lodge, 1986; Ozimek *et al*., 1990; Madsen *et al*., 2001). Aquatic plants help anchor soft sediments, stabilize underwater slopes, remove suspended particles, and remove nutrients from overlying waters (Barko *et al*., 1986; Doyle, 2000; Madsen *et al*., 2001). The lack of submersed plants results in frequent resuspension of bottom sediments and low light environments both of which negatively affects the growth of submersed plants (Chambers and Kalff, 1985; Barko *et al*., 1986; Scheffer, 1998). Pursuant to this, the spatial distributions of submersed plants often are regulated by the availability of light, which is influenced to a large extent by suspended materials (Chambers and Kalff, 1985; Congdon and McComb, 1979; Barko *et al*., 1986; Madsen *et al*., 2006).

In most freshwater systems aquatic plants are important components of food web dynamics. In most cases, some algae are present, both as phytoplankton and epiphytic, but much of the food is derived from plants (Madsen, 2009). The majority of aquatic plants are consumed only after they have died and partially decomposed into detritus. Detritus is eaten primarily by aquatic insects, invertebrates and larger crustaceans (Madsen, 2009). These detritivores, which live on or near the lake bottom, are in turn consumed by the dominant littoral forage fish such as bluegill sunfish. Lastly, forage fish are consumed by the top predator such as largemouth bass (Madsen, 2009).

Fish, both juvenile and adult fish of many species, rely on aquatic plants at some point during their lives and often move to different habitats based on their growth stage (Dibble, 2009). Several of these fish species prefer habitats with aquatic vegetation; over 120 different species, representing 19 fish families, have been collected in aquatic plant beds (Dibble, 2009). In general, sites with vegetation have higher numbers of fish compared to non-vegetated areas. Young fish use the cover provided by aquatic vegetation to hide from predators and their diets may be dependent on algae and the microfauna (e.g. zooplankton, insects and larvae) that live on aquatic plants (Dibble, 2009). Overall, nesting, growth and foraging success of several fish species are influenced by plant composition and density (Dibble, 2009).

Aquatic habitats are also crucial in providing preferred food and necessary habitat for feeding, nesting, and migrating waterfowl (Havera, 1999). Diving species of waterfowl require emergent aquatic plants for nesting habitat (Wersal and Getsinger, 2009). Canvasbacks (*Aythya* *valisineria*) and redheads (*Aythya americana*) nest almost exclusively above the water in specific types of vegetation. Hardstem bulrush (*Scirpus acutus*), cattails (*Typha* spp.), bur-reed (*Sparganium* spp.) and sedges that extend up to 1 m above the water surface are the preferred habitat for nesting (Baldassare and Bolen, 1994). These plant species generally have more succulent and flexible stems that waterfowl can manipulate for nest construction. Waterfowl also consume a wide variety of vegetation of which submersed plants comprise a large fraction of the total food items consumed (Martin and Uhler, 1939; Havera, 1999).

Submersed plant communities are a direct source of waterfowl food and indirectly serve as an environment for aquatic macro-invertebrates, which are also major sources of protein for migrating and breeding waterfowl (Baldassarre and Bolen, 1994). For example, curlyleaf pondweed (*Potamogeton crispus*) on average yields 140 kg/ha of seed per growing season, or enough to sustain 2 470 Mallards (*Anas platyrhynchos*) per hectare per day (Hunt and Lutz, 1959). Furthermore, as a group the pondweeds (*Potamogeton* and *Stuckenia* spp.) are the most important aquatic plants regarding waterfowl as they ranked first, by volume, as food consumed by 18 species of waterfowl (Martin and Uhler, 1939; Wersal, 2005).

Of the pondweeds, sago pondweed *Stuckenia pectinata* is said to be one of the most sought after food plants by waterfowl (Kantrud, 1990). Sago pondweed is probably the most important single waterfowl food plant on the continent and is responsible for about half, or more, of the total food percentage credited to the genus *Potamogeton* (*Stuckenia*) (Martin and Uhler, 1939). As a food item, sago pondweed can form a significant portion of foods found in gizzards of fall staging populations, pre-molting birds, flightless molting ducks, and ducklings (Chura, 1961, Hay, 1974; Keith and Stanislawski, 1960; Wersal, 2005). Waterfowl continue to be an important food source for humans worldwide, largely because of available habitat.

### *Use of aquatic plants as food*

***Marine plants –*** One of the primary and oldest uses of marine macro-algae has been for human consumption. Species of algae are consumed by people throughout the world, with Eastern Asian countries consuming more than any other country worldwide. In Asia, macro-algae has served as a vegetable since ancient times (Burtin, 2003). In Japan, people consume on average 1.4 kg of macro-algae per person every year (Burtin, 2003). France has recently authorized the use of 12 macro-algae for human consumption including six brown algae, 5 red algae, 2 green algae, and 2 microalgae (Burtin, 2003). One of the most notable of the algae uses is dried *Porphyra*, often called Nori, Zicai, and Gim in Japan, China, and Korea respectively, which is used extensively throughout the world to make sushi. *Porphyra* has been collected since the year 530, has been cultivated since 1640, and today forms a US$1 billion industry in Asia (Pulz and Gross, 2004).

Macro-algae are a good source of dietary fiber (25-75 percent dry weight), of which water-soluble fibre constitutes 50-85 percent (Jimenez-Escrig *et al.*, 2000). *Fucus vesiculosus* is registered by the European pharmaceutical industry as a natural source of iodine to treat thyroid conditions (Burtin, 2003). *Laminaria* spp. contain 1 500 – 8 000 ppmw of iodine with *Fucus* spp. containing 500-1000 ppmw of iodine (Burtin, 2003). Macro-algae are a vegetable source of calcium with calcium content of some species being as high as 7 percent dry weight (Burtin 2003). Furthermore, algae are a good source of vitamin B12 (Watanabe *et al.*, 1999), vitamin C (Qasim et Barkati, 1985), vitamin E (Solibami and Kamat, 1985), polyphenols (Nakamura *et al.*, 1996), and carotenoids (Yan *et al.*, 1999). For example, the daily ingestion of 1 gram of *Spirulin* spp. would meet the daily requirements for vitamin B12 (Watanabe *et al.*, 1999).

Besides nutritional benefits, macro-algae are used for their antibiotic, antiviral, antifouling, anti-inflamatory, cytotoxic, and antimitotic activities; some of which have been pursued in pharmaceutical industries (Chen and Jiang, 2001). In the Mediterranean, extracts from several algal species are being used for antibacterial and antifungal uses (Ballesteros *et al.*, 1992; Salvador *et al.*, 2007). Emerging research has identified the potential use of seaweed-derived polysaccharides for use as prebiotics and other human and animal health applications; though to date there have been no studies concerning prebiotics conducted on humans (O'Sullivan et al. 2010). Extracts from the red algae *Corallina elongate* have been identified as being important for immunodiagnostic therapy and cosmetics (Rossano *et al.*, 2003). As for cosmetics, fucoidans (aqueous extracts from marine algae) are listed and available for use in cosmetic products (Fitton *et al.*, 2007). Fucoidan extracts from *Laminaria japonica*, *Ascophyllum nodosum*, *Undaria pinnatifida*, and *Durivillea antarctica* serve as skin protectors; extracts from *Fucus vesiculosus* serve as skin smoothers, smoothing emollient, and skin conditioners; and extracts from *Macroystis pyrifera* serve as viscosity controlling agents (Fitton *et al.*, 2007).

The primary commercial uses of macro-algae continue to be the production of the three hydrocolloids: agar, alginates, and carrageenans (Bixler and Porse, 2011). In a review conducted by Bixler and Porse (2011) the authors reported that the processed food industry is the primary market for seaweed hydrocolloids where they serve as texturing agents and stabilizers. Agar is also used extensively in microbiological and electrophoresis applications. Alginates are used in textile, printing, paper coating, other industrial applications, and use in restructured meat products for humans and animals (Bixler and Porse, 2011). Carrageenan is used in personal care items such as toothpaste, and has started to be used in cosmetics and pharmaceuticals (Bixler and Porse, 2011).

***Freshwater plants –*** Similar to marine plants, freshwater plants have been used by people worldwide for centuries. Important plant species include algae, wild rice (*Zizania* spp.), water caltrop (*Trapa natans*), Chinese water chestnut (*Eleocharis dulcis*), Indian lotus (*Nelumbo nucifera*), water spinach (*Ipomoea aquatica*), watercress (*Rorippa nasturtium-aquaticum*), water mimosa (*Neptunia oleracea*), wild taro (*Colocasia esculenta*), and cattails (*Typha* spp.). Plants specie have been harvested as wild stock, or cultivated in flooded paddies for food, aquaculture and livestock fodder. All parts of plants (stems, roots, rhizomes, tubers, seeds, etc.) have been used for food, medicine, mulch, compost, and building materials. Some species, such as Indian lotus, also have religious significance.

Blue-green algae have historically been used as food. *Spirulina* spp. is a blue green-algae that is 60-70 percent protein and rich in vitamins such as B12 (Edwards, 1980). In Africa, *S. platensis* is harvested from Lake Chad, dried, and cut into blocks, which is cooked and eaten as a vegetable (Ruskin, 1975). *Nostochopsis* spp. another blue green-algae, is eaten in Thailand as an ingredient in fish soup or boiled with syrup and eaten as a dessert (Edwards, 1980). *Spirogyra* spp. a green alga, is eaten as a fresh vegetable or used in soups in northern Thailand (Lewmanomont, 1978). Some species of green algae, such as *Dunaliella salina*, have high concentrations of carotenoids, and extraction of β-carotene is being conducted on a large scale (Borowitzka, 1998). Worldwide production rates for algae are approximately 7 000 tonnes year, with the majority being comprised of *Spirulina*, *Chlorella*, and *Dunaliella* spp. (Pulz and Gross, 2004). The predominate uses (75 percent of production) for *Spirulina* and *Chlorella* have been in the health food market as powders, capsules, tablets, or pastilles (Pulz and Gross, 2004).

Although there are numerous benefits in using algae-derived compounds, some groups such as cyanobacteria can be harmful to humans and wildlife. Cyanobacteria are known for producing hepatotoxins or neurotoxins that cause serious human health issues when blooms occur in lakes, rivers, or drinking water reservoirs (Pulz and Gross, 2004). Though some bioactive compounds produced by cyanobacteria are being screened for potential medicinal properties (Sirenko *et al.*, 1999; Muller-Fuega *et al.*, 2003).

***Water garden and aquarium industries* –** Water gardening and aquaria keeping has become very popular in several countries over the past decade, and is one of the fastest growing segments of garden hobbyists (Maki and Galatowitsch, 2004). It is estimated that over 400 species of aquatic plants have been traded in Australia alone over the past 30 years (Petroeschevsky and Champion, 2008: cited in Champion *et al*., 2010). Approximately 16 million American households have a water garden (Crosson, 2010); which requires the importation and purchase of billions of aquatic plants. In Europe, the top ten countries that imported aquatic plants in 2006 and 2007 were the Netherlands, France, Czech Republic, Germany, Hungary, Switzerland, Austria, Turkey, Latvia, and Estonia (Brunel, 2009). In total, it was estimated that these 10 countries imported over 6.5 million aquatic plants for ornamental use, of which the Netherlands comprised 73 percent of the total (Brunel, 2009). Plants were imported primarily for aquarium use (Brunel, 2009). The most imported species (1 878 098) was the submersed plant *Egeria densa* (Brunel, 2009). Other popular ornamental species included (in order of magnitude) *Cabomba caroliniana*, *Hygrophila polysperma*, *Vallisneria spiralis*, *Echinodorus bleheri*, *Vallisneria americana*, *Najas marina*, and *Hygrophila difformis* (Brunel, 2009).

Of 240 plant species for which an origin could be determined, only 7 percent of plants originated in Europe; indicating a strong preference for non-native plants (Brunel, 2009). In fact, it was estimated that Singapore exported 1 550 800 aquatic plants in a given year followed by Indonesia, Thailand, Guinea, Morocco, Madagascar and Israel; highlighting the fact that many aquatic plants utilized for ornamental purposes are not native in the country where it is planted (Brunel, 2009). The water garden and aquarium industries have become major pathways for the introduction of problematic plants, plant pests and animals globally (Champion *et al*., 2010). For example, *Caulerpa taxiflolia* is a marine macro-algae that is widely available through the aquarium trade and was unintentionally introduced into the Mediterranean in 1984 (Galil, 2011). In less than 15 years the algae has spread to Spain, France, Italy, Croatia, and Tunisia overtaking native algal and seagrass species (Galil, 2011). Maki and Galatowitsch (2004) reported that 93 percent of 40 aquatic plant orders from commercial sources contained other plants, animals, fungi, or algae as contaminants. The sale of ornamental waterlilies (*Nymphae* spp.) is a major pathway for the spread of hydrilla, as hydrilla tubers are often contaminants in the sediment where waterlilies are harvested. It is estimated that over 206 species of aquatic plants have been imported into Europe that are not known to be from the region (Brunel, 2009), further demonstrating the volume of plant material being moved globally.

***Biomass feedstock and biofuel generation –*** The photosynthetic efficiency of aquatic plant biomass is much higher than the average photosynthetic efficiency of terrestrial biomass (Aresta *et al*., 2005). The resource potential for macro-algae as an energy source is considered to exceed terrestrial biomass by approximately threefold (Chynoweth *et al*., 2001). Over the last decade a considerable amount of research has been directed towards the development of biofuels (Bastianoni and Marchettini, 1996). Although biofuels have gained attention, and their benefits well documented (Subramanian and Singal, 2005), terrestrial applications are limited to small-scale production and use because of an excessive need for land to grow crops (Bastianoni *et al*., 2008). Recently, attention has been focused on the use of macro-algae to produce biodiesel due to their high oil yield (Han *et al*., 2006; Xiaoling and Qingyu 2006; Yusuf 2007). Bastianoni *et al*., (2008) concluded that the system used in their research to process sunflower oil had a higher environmental efficiency, with respect to the macro-algae system, because of higher inputs of non-renewable resources to produce algae-derived oil. The authors also concluded that macro-algae oil extraction would not be profitable on the basis of the actual oil yield extraction. However, Maceiras *et al*. (2011) considered macro-algae biodiesel stocks to be a potentially attractive investment. The authors concluded that biodiesel production from oil extracted from algae was feasible.

After reviewing several methods to convert algae biomass to liquid fuel, Roesijadi *et al*. (2010) concluded that even at the low end of estimated seaweed production costs, improvements in processing throughout the supply chain would be needed to make fuel production viable. In the United States, questions still remain of where and how macro-algae based fuels can be produced, and the economic feasibility of production and conversion of biomass to liquid fuel (Roesijadi *et al*., 2010). The use of algae to produce biofuels has shown promise, though there still appears to be logistical and economical obstacles to its widespread adoption.

Although research has demonstrated that biofuels can be produced using oil extracted from macro-algae, the feasibility of cultivating the necessary volumes of algae at the scale required for biofuel markets is unknown (Roesijadi *et al*., 2010). Recent work has utilized freshwater algae species for biofuel generation and there was interest in using freshwater plants, such as water hyacinth and giant salvinia, as a source of biomass to generate biofuels. However, weed management scientists caution the use of such species based on their potential to impact the environment and ecology (DiTomaso *et al*., 2007).

### *Other uses of aquatic plants*

Aquatic plants, both marine and freshwater, are used extensively worldwide as livestock fodder, fertilizer, compost, mulch and bioremediation. These uses have received considerable attention prior to this report and therefore little additional information will be presented here. In a review by Little (1979) on the utilization of aquatic plants, it was reported that many aquatic plants contain as much or more crude protein, crude fat and mineral matter as many conventional forage crops on a dry weight basis. Although, fibre values were usually lower in aquatic plants than for forages. Aquatic plants tended to have increased tannin content, which may decrease the digestibility of protein. It was concluded that using aquatic plants as fodder would help pay for harvesting, which is the best way to remove nutrients from lakes suffering from artificial enrichment. Harvesting should be done when protein content of the plants is highest for their maximum usefulness as fodder.

Further, Hasan and Chakrabarti (2009) offer a global review of the uses of aquatic plants as feed in aquaculture production. The authors concluded that under current conditions algae may not be a viable choice as a feed for aquaculture production, though a cost-benefit analysis would be needed before drawing any definite conclusions for its use as fish feed. Pursuant to this, the authors suggested that the use of algae as an additive to fish feed may be limited to the commercial production of high-value fish.

*Azolla* spp. showed promise as fish feed, however additional research is needed in its use patterns, mixes, and the appropriate system for use. Duckweed species (*Lemna*, *Wolffia*, *Spirodela*, and *Landoltia*) was found to provide a complete feed package for carp/tilapia polyculture, though the year round availability of duckweed in some countries may be problematic for widespread adoption. For additional information on duckweed see Leng (1999). The use of water hyacinth (*Eichhornia crassipes*) did not show promise unless plants were composted or fermented and included as one ingredient in fish feed for small-scale aquaculture.

The use of submersed plants would depend largely on the species of fish in culture and the environmental conditions in different parts of the world. Grass carp (*Ctenopharyngodon idella*), for example, prefer soft submersed vegetation. In controlled feeding grass carp preferred aquatic plants in the following order: American pondweed (*Potamogeton nodusus*) > dioecious hydrilla (*Hydrilla verticillata*) > elodea (*Elodea nuttallii*) > egeria (*Egeria densa*) > curlyleaf pondweed (*Potamogeton crispus*) > waterprimrose (*Ludwigia peploides*) > sago pondweed (*Stuckenia pectinata*) > chara (*Chara flexilis*) > spike rush (*Elocharis acicularis*) > parrotfeather

(*Myriophyllum aquaticum*) > Eurasian watermilfoil (*Myriophyllum spicatum*) > water hyacinth (*Eichhornia crassipes*) > and coontail (*Ceratophyllum demersum*) (Pine and Anderson, 1991). Coontail was uprooted but never eaten by grass carp (Pine and Anderson, 1991)

## *Economic benefits of aquatic plants*

The demand for aquatic plants, primarily marine macro-algae has increased exponentially over the past few decades. Global harvests of aquatic plants in 2009 were roughly 17 million tonnes with marine algae comprising > 85 percent of this total (Figure 2.4).

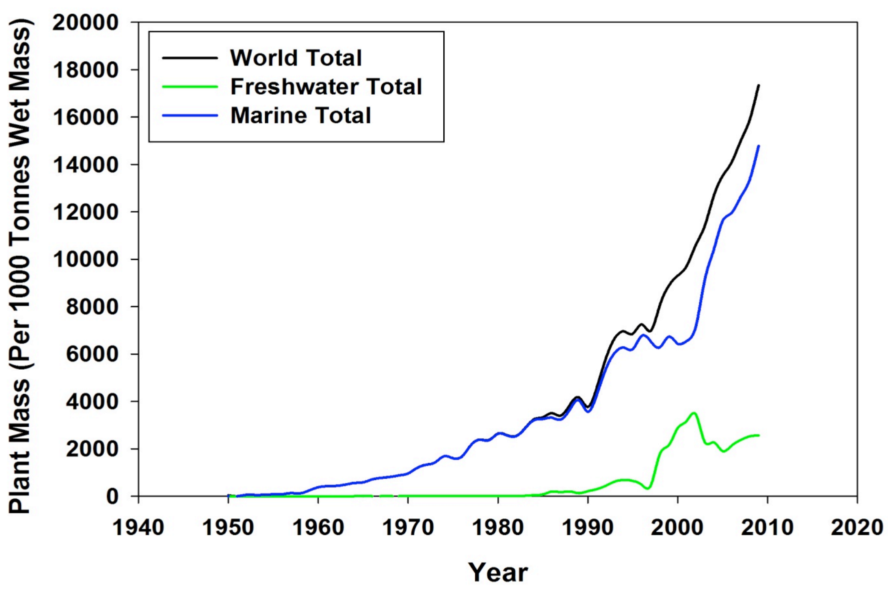
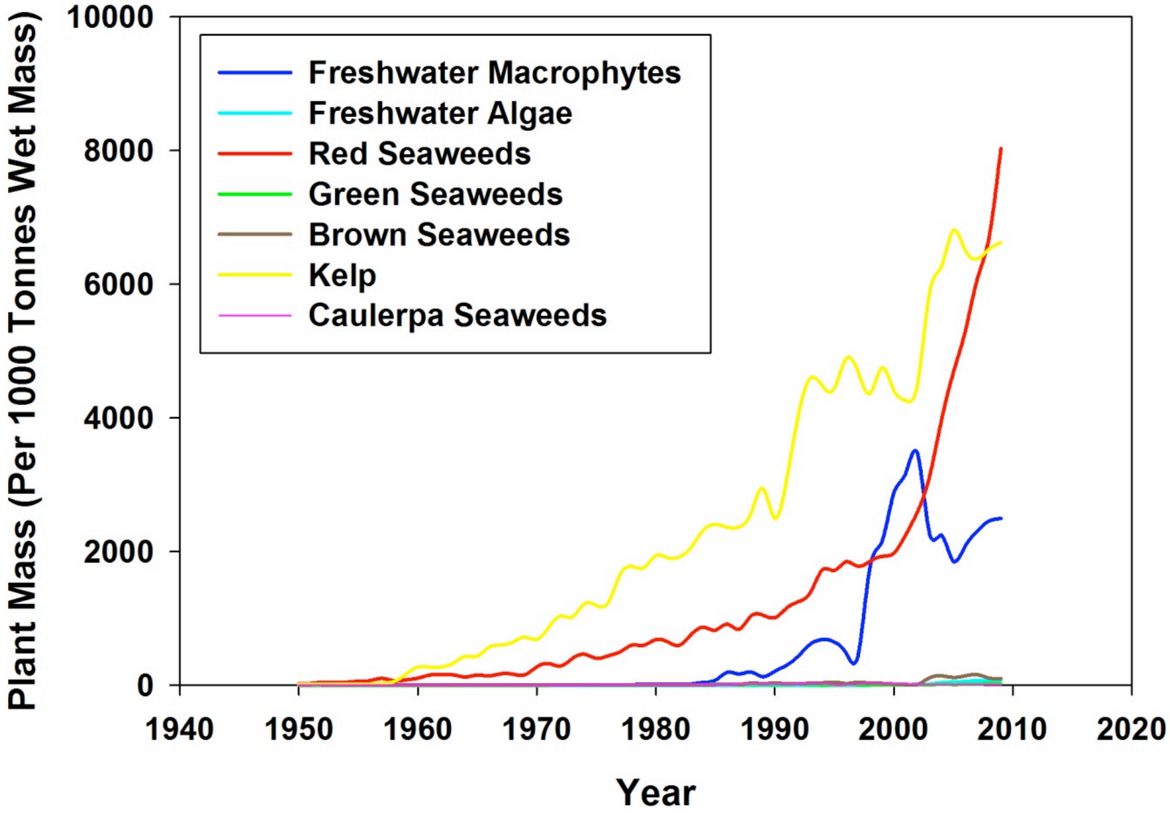



*Figure 2.4 – The global harvest of marine and freshwater aquatic plants from 1950 to 2009. Data were downloaded from the Food and Agriculture Organization, Fisheries and Aquaculture Department, Fisheries Statistics Collection available at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.*

Kelp has historically been the class of marine algae harvested in the greatest volume with peak harvests occurring from 2004 to 2009 at > 6 million tonnes (Figure 2.5). However in 2009, the harvest of red algae surpassed kelp by approximately 2 million tonnes (Figure 2.5).

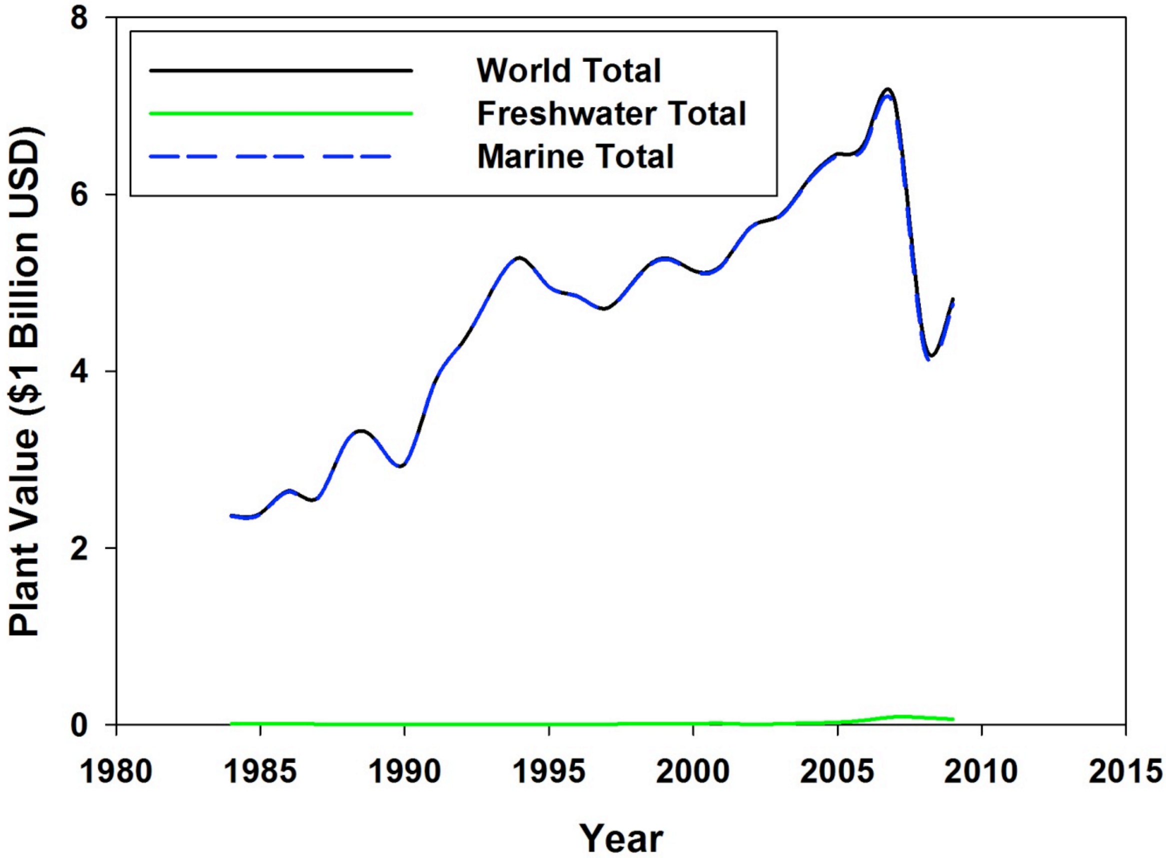
*Figure 2.5 – The global harvest of marine and freshwater aquatic plants by taxa group from 1950 to 2009. Data were downloaded from the Food and Agriculture Organization, Fisheries and Aquaculture Department, Fisheries Statistics Collection available at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.*




Countries contributing the majority of wild harvested macro-algae include China, Chile, Norway, Japan, and Russia (FAO, 2010). Macro-algae production as a result of aquaculture is greatest in China followed by Indonesia, thePhilippines, Korea, Japan, Malaysia and Viet Nam (FAO, 2010).

The harvest of freshwater plants has been relatively minimal ranging from no reported harvest from 1950 to 1966, to a harvest of over 2 million tonnes per year in the last decade (Figure 2.4 and 2.5). The sharp increase in marine aquatic plant harvests probably is the result of increased demand from the food, pharmaceutical, and biomass feedstock; whereas the increase in freshwater plant harvests is possibly driven by increased popularity of water gardening and aquarium plantings. Many of the most popular water garden species are imported from tropical and subtropical regions. Since 1990, the global value of aquatic plants has been between US $4 8 billion, with a peak in 2007 at > US$7 billion (Figure 2.6).

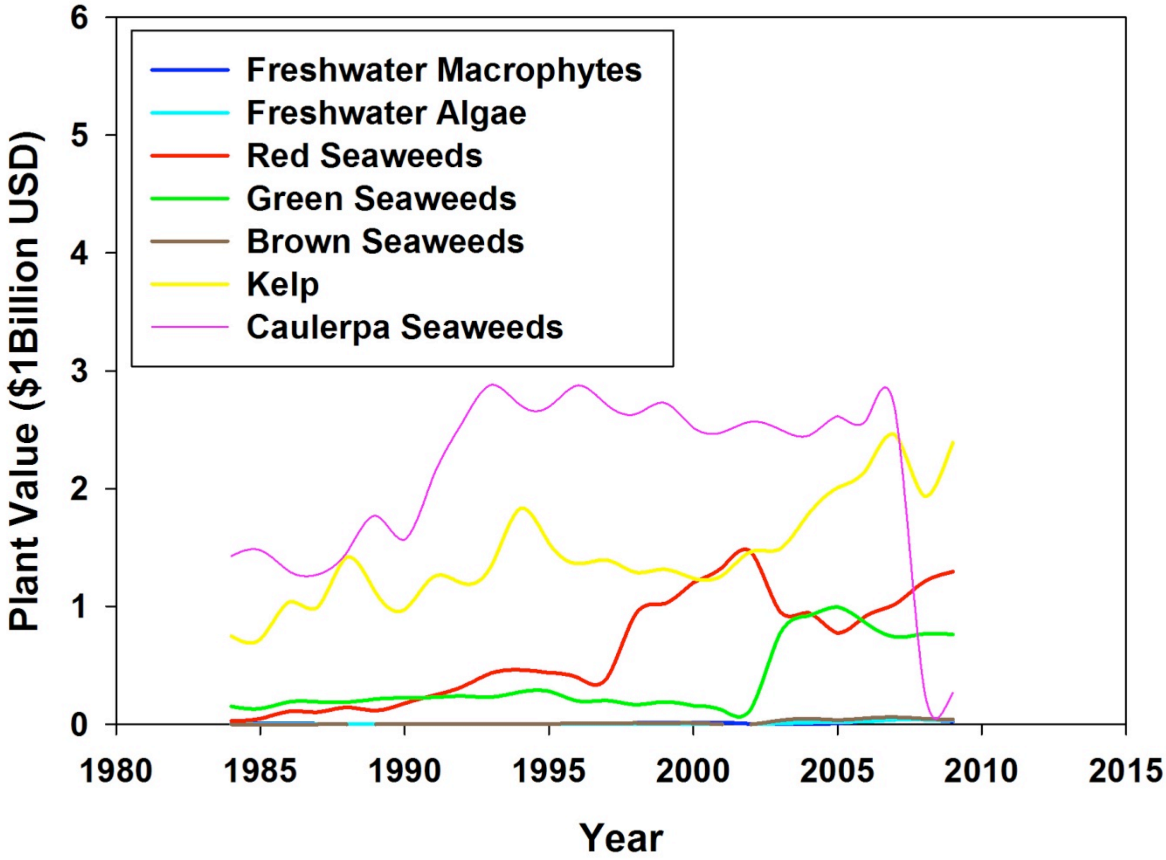
*Figure 2.6 – The global value of marine and freshwater aquatic plants from 1984 to 2009. Data were downloaded from the Food and Agriculture Organization, Fisheries and Aquaculture Department, Fisheries Statistics Collection available at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.*




Similar to harvest statistics, marine macro-algae are having the greatest influence in the value of aquatic plants worldwide. From a global perspective, freshwater aquatic plants comprise a small amount of the total value; however in the United States, water gardening is a > US$1 billion industry as determined by retail sales (Crosson, 2010). Sales volumes of aquatic plants in Europe were approximately 7 million plants in 2006 and 2007, with over 2 million plants being sold by one Danish company and an additional 2.1 million plants coming from the Near East and Asia (Brunel, 2009). With the increasing globalization of commerce as a result of the internet and improved shipping methods, a growing number of sales are made with species transported greater distances at increased rates.

Unlike harvest statistics, where kelp and red seaweeds comprised the greatest volume, *Caulerpa* seaweeds have historically been a higher-value plant species (Figure 2.7). The value of *Caulerpa* seaweeds remained between US$2 and 3 billion from the early 1990s until 2007 when a sharp decline was observed (Figure 2.7).

*Figure 2.7 – The global value of marine and freshwater aquatic plants by taxa group from 1984 to 2009. Data were downloaded from the Food and Agriculture Organization, Fisheries and Aquaculture Department, Fisheries Statistics Collection available at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.*




The high-value of *Caulerpa* seaweed is a result of its popularity in the aquarium industry. The decline in value after 2007 is probably attributed to *Caulerpa taxifolia* being placed on the list of 100 of the World's Worst Invasive Alien Species published by the Invasive Species Specialist Group (ISSG). Sales of *Caulerpa* varieties have likely been banned in a number of countries and thus the global value has decreased.

Generally, however, human consumption of macro-algae (Nori, aonori, kombu, wakame, etc.) remains the primary use with an estimated global value in 2003 of US$5 billion (McHugh, 2003). After human food uses, macro-algae hydrocolloids comprise the next largest segment of the aquatic plant industry. In 2009, the hydrocolloid industry was estimated at US$1.02 billion with carrageenans comprising US$527 million followed by alginates US$318 million, and agar US$173 million (Bixler and Porse, 2011). Other major macro-algae uses include fertilizers and conditioners US$5 million; and animal feed US$5 million (McHugh 2003).

The benefits of aquatic plants to people are far reaching with many new uses yet to be discovered. Currently, however, both marine and freshwater habitats are being threatened by the introduction of aquatic plant species that become problematic under certain conditions. These plant species are often introduced from other parts of the world for beneficial or horticultural uses, and then escape cultivation to form natural populations. Aquatic habitats are often vulnerable to colonization by problematic plant species because of repeated disturbance that favours the growth of these species (Shea and Chesson, 2002). When problematic plants colonize an area, changes in biotic and abiotic interactions often occur (Madsen, 1998). The growth of problem species often results in reductions in more desirable plant species, decreased fish production (Savino and Stein, 1989), and increased sediment resuspension, turbidity and algal production; the latter further exacerbates submersed plant loss in freshwater systems (Madsen *et al*., 1996; Doyle 2000; Case and Madsen 2004; Wersal *et al*., 2006).

## SECTION III – AQUATIC PLANTS AS PESTS OR HOSTS OF PLANT PESTS

### *Important species that directly or indirectly, threaten commercially significant crop plants or wild flora*


*Photo 1 – Invasive aquatic plants for sale at local hardware stores in the United States. The centre shelf has containers of both water hyacinth and water lettuce for sale, and the bottom shelf has containers of parrotfeather for sale. Photo by Tom Woolf.*

Globally, there are aquatic plant problems in every country. Most aquatic plant problems are regional, but some plant species have caused significant agricultural, economic, and human health impacts worldwide. The following is not meant to be an exhaustive list of problematic aquatic plant species, but a description of those species that have routinely been named in literature as causing serious global problems for agriculture, aquaculture, natural areas, people and economic security. Some of these species can also be found in the Global Invasive Species Database, and are listed by the International Union for Conservation of Nature (IUCN) and Invasive Species Specialist Group (ISSG). Other species occur on individual country's noxious weed lists.

**Killer alga (*Caulerpa taxifolia*) –** is a green macroaglae that is native to tropical waters worldwide, but has been introduced into the Mediterranean Sea, Australia, and the west coast of North America (Smith, 2011). The first known infestation was observed in the mid-1980s in the Mediterranean Sea off the coast of Monaco (Meinesz and Hesse, 1991 cited in Jousson *et al*., 1998). Molecular evidence has identified that the species growing in the Mediterranean is genetically identical to a strain cultivated in the Western European aquaria trade (Jousson *et al.*, 1998). This initial infestation spread from approximately 1 $m^2$ in 1984 to more than 131 $km^2$ along 191 km of coastline by 2000 (Meinesz *et al.*, 1995; Meinesz *et al.*, 2001). The rapid spread of *Caulerpa taxifolia* is fuelled by its explosive rate, and ability to form dense meadows of up to 14 000 blades $m^{-2}$ on bottom substrates (Galil, 2011).

Upon introduction, it rapidly colonizes bottom substrates and out-competes native species and impacts fisheries and tourism of coastal communities (Meinesz and Hesse, 1991; Bartoli and Boudouresque, 1997; Relini *et al.*, 2000; Meinesz *et al.*, 2001). In a review of the impacts of *C. taxifolia*, Galil (2011) stated that the removal of structural complexity of the invaded area, in combination with the replacement of native biota with a species-poor community; results in a reduction in the overall richness and diversity of littoral ecosystems, which threatens coastal biodiversity.

Once *C. taxifolia* is established in a given area, removal of the species is very difficult, labour intensive and expensive. Ruesink and Callado-Vides (2006) concluded from their models, based on the invasion dynamics of *C. taxifolia*, it will increase rapidly in the absence of control techniques. Pursuant to this, the most effective time to implement control is before summer by removing patches, and after summer by removing the remaining fragments (Ruesink and Callado-Vides, 2006). Their models, however, indicated that only by combining 99 percent removal of all fragments and 99 percent annual removal of established patches, was complete elimination of *C. taxifolia* was possible (Ruesink and Callado-Vides, 2006). Though, manual removal at that level would only be possible early in the invasion process (Ruesink and Callado-Vides, 2006). Eradication is possible as *Caulerpa taxifolia* was eradicated from coastal waters of the western United States; although it required US$7 million and 6 years to achieve control (Anderson, 2011).

**Wakame seaweed, Japanese kelp (*Undaria pinnatifida*) –** is a brown kelp species native to Asia where it is primarily cultivated in Japan for human consumption (Akiyama and Kurogi, 1982; Valentine and Johnson, 2003; Smith, 2011). It has since been introduced into Europe, the Mediterranean, Australia, New Zealand, the west coast of North and South America (Valentine and Johnson, 2003; Silva *et al.*, 2002; Martin and Cuevas, 2006; Casas *et al.*, 2004; Smith, 2011). *Undaria pinnatifida* has invaded the coast of Tasmania where it is overgrowing and out-competing native algal species (Valentine and Johnson, 2003; Low 2011). The species was intentionally introduced to the Atlantic coast of Europe in 1983 (Floc'h *et al.*, 1991), though other introductions elsewhere in the world are thought to be accidental as a result of shipping activity (Perez *et al*., 1981; Hay 1990; Silva *et al*., 2002; Casas *et al*., 2004).

*Undaria pinnatifida* can rapidly overtake bottom substrates, crowd native flora, and out-compete desirable species for light and nutrients. Mature fronds in nature typically reach 1.5 m with lengths in cultivated stocks reaching 3 m (Perez *et al*., 1984). Previous reports indicate that *U. pinnatifida* prefers a firm substrate for growth (Hay and Luckens, 1987; Hay, 1990; Piriz and Casas, 1994: Silva *et al*., 2002); protected areas (Hay and Luckens, 1987; Silva *et al*., 2002); growth is not impacted by organic pollution (Castric-Fey *et al*., 1999; Cecere *et al*., 2000); and has a wide tolerance to environmental conditions (Hay, 1990; Hay and Villouta, 1993; Castric-Fey *et al*., 1999). Heavy infestations in Australia saw densities of 150 plants $m^{-2}$ (Campbell and Burridge, 1998). In laboratory tests, zoospore release was reported to be up to 100 000 zoospores $mL^{-1}$ (Campbell and Burridge, 1998), further illustrating the reproductive capacity of this species.

In Argentina, *U. pinnatifida* was shown to directly reduce native seaweed diversity (Casas *et al*., 2004). When *U. pinnatifida* was removed from experimental plots native seaweed species quickly re-vegetated the area (Casas *et al*., 2004). Although, the effects on native communities are still under investigation in many locations, *U. pinnatifida* has the potential to be an ecosystem transformer like *C. taxifolia* through alterations in community structure (Smith, 2011).

A major source of *U. pinnatifida* is for food and, as such, could have implications for its management or regulation of its global use because of its economic value. In 1998, a total of 2 839 tonnes of *U. pinnatifida* was harvested from natural populations in Japan for an estimated US$8 million, while cultivated harvests reached 70 670 tonnes for an estimated US $132.5 million (H. Ohba: cited in Silva *et al*., 2002). In 2009, an estimated 1 694 540 tonnes of *U. pinnatifida* was harvested globally value at US$2.38 billion (FAO, 2011). Again, the global value placed on *U. pinnatifida* will likely cause problems regarding regulating its distribution, sale and spread.

**Cord-grass (*Spartina anglica* and *Spartina alterniflora*) –** is descriptive of a group of salt marsh grasses comprised of species in the *Spartina* genus. The *Spartina* genus is comprised of roughly 17 species, a number of variations and hybrids (Mabberley, 1997). One notable hybrid is *Spartina anglica*, which is a cross between *S. alterniflora* (native to the Atlantic coast of North America) and *S. maritime* (native to Europe) (Hedge *et al*., 2003; Schierenbeck, 2011). *Spartina* *alterniflora* was moved incidentally to the Pacific northwest of the United States possibly in packing material for oysters in the 1800s (Sayce, 1988; Kriwoken and Hedge, 2000; Bartley, 2011). Hybridization came about as *S. alterniflora* was moved to Europe (likely in ballast) and reproduced with *S. maritime*. The resulting *S. anglica* now grows in a broader range of habitats than either parental species (Kriwoken and Hedge, 2000; Hedge *et al.*, 2003; Schierenbeck, 2011).

P*hoto 2 – Spartina alterniflora invading coastal mudflats in the state of Washington (USA). Photo by Kim Patten.*

*Spartina anglica* has been introduced into Denmark, Germany, Ireland, the United Kingdom, North and South America, South Africa, Australia, New Zealand, China, and has also been recorded in France and The Netherlands (Gray and Raybould, 1997). The current range of *S. anglica* is from 48 °N to 57.5 °N in Europe, from 21 °N to 41 °N in China and from 35 °S to 46 °S in Australia and New Zealand (Gray and Raybould, 1997: accessed from the Global Invasive Species Database, available at: www.issg.org/database/species/ecology.asp?si=76).

*Photo 3 – The dense growth of Spartina along the west coast of the United States. Photo by Kim Patten.*

*Spartina anglica* and *S. alterniflora* growth includes dense stiff stems, rapid vegetative production via runners, and the ability to emerge from under deposited sediments (Ehrenfeld, 2011). *Spartina anglica* spreads through seed production, rhizomes, tillering and rhizome fragments (Nehring and Hesse, 2008). Annual aboveground biomass was reported in a Dutch saltmarsh to be between 1 162 and 1 649 g $m^{-2}$ (Groenendijk, 1984). The rapid vegetative growth allows *Spartina* spp. to trap additional sediments in the area and act as ecosystem engineers (Nehring and Hesse, 2008; Ehrenfeld, 2011). The trapping of sediments results in the construction of tall continuous dunes in areas where only small, patchy dunes once existed (Ehrenfeld, 2011). The trapping of sediments by *Spartina alterniflora* and *anglica* alter hyrdrologic regimes, water chemistry, soils, nutrient cycling, and shifts in food web dynamics for a number of species (Goss-Custard and Moser, 1988; Gray *et al*., 1991; Ehrenfeld, 2011). Seedling densities on bare mudflats can reach as high as 10 000 seedlings $m^{-2}$ (Nehring and Hesse, 2008). The dense growth of cord-grass on mudflats results in a complete shift in ecosystem function concerning plant and animal communities, as well as ecosystem function (Ehrenfeld, 2011).

*Spartina anglica* has been used throughout Europe to stabilize coastal habitat (Nehring and Hesse, 2008). Widdows *et al*. (2008) however, concluded that *S. anglica* should not be regarded as an ecosystem stabilizer; rather the presence of this species increased the potential for erosion of muddy sediments, which would further degrade salt marsh habitat. *Spartina* species, primarily *S. anglica* and *S. alterniflora*, have become severe threats to salt marshes worldwide, particularly concerning spread in the Pacific northwestern United States, East Asia, New Zealand, Australia, and the United Kingdom (Gray *et al*., 1991; Kriwoken and Hedge, 2000; Hedge *et al*., 2003; Nehring and Hesse, 2008). If left unmanaged, *Spartina* will continue to threaten and negatively impact coastal diversity, fisheries, aquaculture and recreation in coastal estuaries (Gray *et al*., 1991; Kriwoken and Hedge 2000; Hedge *et al*., 2003).

**Water hyacinth (*Eichhornia crassipes*) –** is an invasive free-floating aquatic plant from the tropical and subtropical regions of South America (Holm *et al*., 1991). Water hyacinth has been spread primarily by people throughout the world since the early 1800s. By 1884 it had spread to most of South America, the Caribbean Islands and into the United States (Hill *et al*., 2011). By the end of the nineteenth century, water hyacinth had spread to Egypt, India, Australia, and Java (Hill *et al*., 2011). In Africa, along with giant salvinia and water lettuce, water hyacinth continues to be a major problem throughout the continent (Labrada and Fornasari, 2002).

*Photo 4 – Water hyacinth clogging a hydroelectric dam on Lake Carraizo, San Jaun, Puerto Rico. Photo by Victor Gonzalez.*

Water hyacinth is a free-floating perennial aquatic plant that is considered the world's worst aquatic weed. It can reproduce by both sexual and asexual means, though asexual (vegetative) propagation has been largely attributed to its widespread distribution. Water hyacinth effectively doubles the number of plants within 12.5 days (Penfound and Earle 1948), increases dry biomass at a rate of 1.2 percent $day^{-1}$, and peak biomass can reach a maximum of 2.5 kg

$m^{-2}$ under optimal conditions (Center and Spencer, 1981). Water hyacinth growth is limited primarily by available phosphorus in the water column (Kobayashi *et al*., 2008). Plants respond to flooding in large riverine systems where, during flood cycles, water moves out onto adjacent land and upon receding brings with it increased nutrients to support water hyacinth growth (Kobayashi *et al*., 2008).

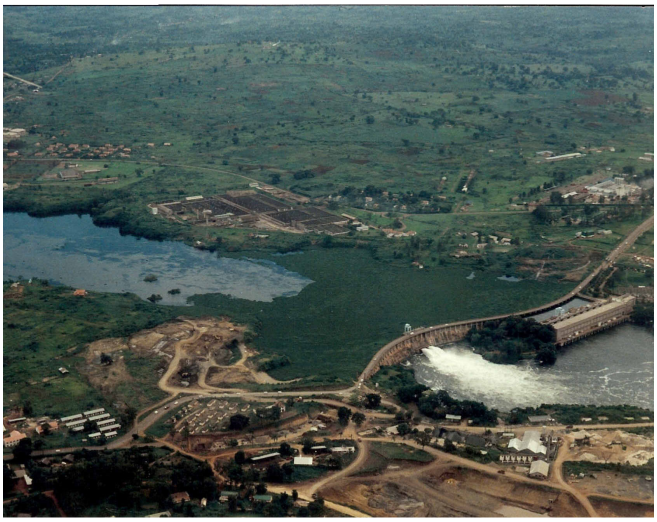


*Photo 5 – Water hyacinth clogging the dam near Jinja, Uganda in 1996. Photo by Tom McNabb.*

Water hyacinth impedes the recreational use of rivers and lakes (fishing, swimming and boat traffic) and the generation of hydroelectric power. Furthermore, water hyacinth increases the potential for flooding, reduces primary productivity (e.g. phytoplankton) and alters ecosystem properties (McVea and Boyd, 1975; Honnell *et al*., 1993; Toft *et al*., 2003).

*Photo 6 – Water hyacinth impeding navigation at the Port Bell ferry in Uganda, 1996. Photo by Tom McNabb.*

With respect to altering phytoplankton assemblages, water hyacinth can impact important fisheries by facilitating changes in phytoplankton, zooplankton, and bait fish assemblages thus resulting in species shifts (Hill *et al*., 2011). Socio-economic impacts can include reduced quantity and quality of drinking water and increased incidence of water-borne and water-related diseases (e.g. malaria, encephalitis, and filariasis) (Hill *et al*., 2011).

Being the world's worst aquatic weed, great attention has been focused on controlling water hyacinth where it occurs. As part of this, research has sought to use water hyacinth for beneficial purposes. Uses include biofuel generation, livestock fodder, fertilizer, mulch, utilization of plant pulp for paper production and furniture and bioremediation (Hill *et al*., 2011). However, water hyacinth is 95 percent water, which makes most utilization projects commercially impracticable and, no matter what the use would be, it could not reduce biomass to acceptable levels (Hill *et al.*, 2011). Moreover, relying on water hyacinth for biomass feedstocks would likely lead to increased propagation and spread, thereby negating any benefits derived from using water hyacinth biomass (DiTomaso *et al.*, 2007). Rreliance on water hyacinth biomass would also create conflicts between user groups who want to propagate and use biomass, and groups who want to control the plant species (Hill *et al.*, 2011). To date, the aquarium/water garden industry continues to be the primary means of transport and spread of water hyacinth worldwide.

**Giant salvinia (*Salvinia molesta*) –** also known as African pyle and Kariba weed, is an aquatic fern native to southeastern Brazil (Forno and Harley, 1979) that has spread to more than 20 countries (Oliver, 1993). Giant salvinia commonly occurs in warm climates where winter frost is slight or absent (Mitchell, 1979). It inhabits the calm waters of lakes, ponds, wetlands and rivers. Giant salvinia could become the world's worst aquatic weed, as it is capable of out-growing and possibly even out-competing water hyacinth in certain environments (Abbasi and Nipaney, 1986).

*Photo 7 – A bayou infested with giant salvinia in Mississippi, USA. Photo by Wilfredo Robles.*

Typically, in new infestations, the colonizing stage of giant salvinia has thin stems and fragments easily, which results in rapid dispersal and accumulation of new biomass (Oliver, 1993). Biomass has been shown to double in 3.4 days in sterile culture and 8.1 days in Lake Kariba (Gaudet, 1973; Mitchell, 1979). In greenhouse studies, however, leaf doubling times have been as low as 2.2 days (Barrett, 1989; Cary and Weerts, 1983; Harley and Mitchell, 1981).

*Photo 8 – A dense bed of giant salvinia covering golf course ponds at the Dorado Beach Golf Club, Dorado, Puerto Rico. Photo by Wilfredo Robles.*

The rapid doubling times of leaves would allow giant salvinia, growing in good conditions to produce 45.6-110 dry tonnes ha/year and, it is speculated, that under more favourable conditions, such as those in warm climates, production could far exceed those estimates (Mitchell and Tur, 1975; Rani and Bhambie, 1983).

Giant salvinia growth is affected by available water column nutrients (Madsen and Wersal, 2008). Particularly, growth is limited under low nutrient availability. Giant salvinia growth is affected by water column pH during the early stages of growth; however, pH did not affect plant growth as plants matured (Madsen and Wersal, 2008). While pH may not be a long-term factor in controlling giant salvinia growth it would be beneficial, from a management perspective, to identify and deploy management techniques during the early growth stages when pH is an important factor before this species becomes problematic (Madsen and Wersal, 2008).

Giant salvinia has caused public health concerns by serving as a breeding habitat for species of mosquitoes that transmit encephalitis, dengue fever and malaria (Creagh, 1991/1992). In Zambia and Rhodesia, giant salvinia growth resulted in the buildup and spread of the snail (*Biomaphalaria boissyi*), which is the intermediate vector of schistosomiasis (Bennett, 1975). Giant salvinia populations have also been responsible for choking out waterways leading to reduced tourism, hunting, and fish industries in Sri Lanka, India and Borneo (Oliver, 1993; Thomas and Room 1986). In Papau New Guinea, entire villages dependent on aquatic navigation have been abandoned as a result of giant salvinia; these populations prevented villagers access to health care, food, markets and schools (Mitchell *et al.*, 1980; Thomas and Room, 1986). Furthermore, floating islands of giant salvinia have caused livestock deaths because animals sink or break through the mats and drown in deep water (Harper, 1986 cited in McFarland *et al.*, 2004).

*Photo 9 – Giant salvinia with stolon. Photo by Ryan Wersal.*

Giant salvinia can pose other negative threats to aquatic ecosystems by restricting light penetration and the exchange of gases between the water and atmosphere (McFarland *et al*., 2004). Giant salvinia can shade native submersed or floating macrophytes from light; as a result, declines in native plant communities may be observed (Barko and Smart, 1981; Barko *et al*., 1986). Water quality beneath dense mats is often degraded by decreased dissolved oxygen and pH and increased $CO_2$ and $H_2S$ concentrations (Mitchell, 1969). These factors contribute to reduced diversity and densities of benthic fauna (Coates, 1982). Likewise, this altered environment could impact fish stocks negatively by preventing breeding of fish in shallow waters and causing organic build up and oxygen depletion as a result of decomposing biomass (Oliver, 1993).

*Photo 10 – Giant salvinia frond showing the dense pubescence. Photo by Ryan Wersal.*

Although the negative impacts on ecological systems and humans are numerous, some attention has been focused on finding uses for large amounts of giant salvinia biomass (McFarland *et al*., 2004). Giant salvinia has been used as compost and mulch and as a supplement for livestock feed in Asia (Oliver, 1993). Studies have examined its effectiveness in treating sewage (Abbasi and Nipaney, 1986; Finlayson *et al*., 1982), paper-making and biogas production (Thomas and Room, 1986). However, none of the proposed uses of giant salvinia have proven economically feasible nor practical (McFarland *et al*., 2004) and, as a result, research has focused on the control of giant salvinia rather than its uses.

**Water lettuce (*Pistia stratiotes*) –** is a free-floating aquatic plant in the Araceae family and is native to South America. A brief but thorough review of water lettuce was given by Langeland *et al*. (2008) and is summarized here. Water lettuce may have been introduced to North

America by humans or natural means (Stoddard, 1989), and is currently one of the most widely distributed hydrophytes in the tropics (Holm *et al*., 1991). Water lettuce is considered a serious weed in Ceylon, Ghana, Indonesia, and Thailand and at least present as a weed in 40 other countries (Holm *et al*., 1991). Water lettuce has become extremely problematic all over the continent of Africa where it directly impacts people's livelihoods (Labrada and Fornasari, 2002).


*Photo 11 – Water lettuce covering Lake Ocklawaha, Florida, USA. Photo by William Haller.*

Water lettuce grows in rosettes with grey-green leaves, rosettes occur singly or connected to others by short stolons. Plants have numerous, feathery, roots. Leaves are often spongy near the base, densely soft pubescent with obvious parallel veins, slightly broader than long (Langeland *et al*., 2008). Flowers are inconspicuous, clustered on small, fleshy stalks nearly hidden in leaf axils, with single female flowers below and a whorl of male flowers above. Fruit grows from female flowers as a many-seeded green berry (Langeland *et al*., 2008). Water lettuce reproduces rapidly by vegetative offshoots formed on short, brittle stolons. Growth varies seasonally in density of rosettes, from less than 100 to over 1 000 per $m^2$ in south Florida (Dewald and Lounibos, 1990).

*Photo 12 – Water lettuce covering a large portion of a reservoir in the Laguna Cartageba Wildlife Refuge, Lajas, Puerto Rico. Photo by Wilfredo Robles.*

Seed production, once thought not to occur in North America, now is considered an important means of reproduction and dispersal (Dray and Center, 1989). Water lettuce is not cold tolerant (Holm *et al*., 1991). It can survive for extended periods of time on moist muck, sandbars and banks (Holm *et al*., 1991).

The floating growth habit and rapid reproduction allows water lettuce to cover large expanses of water in short periods of time.

Dense infestations reduce access and use of waterways, navigation, hydroelectric generation, and recreation (Holm *et al.*, 1991).

*Photo 13 – Water lettuce plant. Photo by John Madsen.*

Ecologically, dense infestations of water lettuce can cause reduced dissolved oxygen, which may lead to fish mortality; these infestations can also shade native submersed aquatic plants reducing the spatial heterogeneity and habitat for aquatic invertebrates (Attionu, 1976; Brunner, 1982; Sharma, 1984; Holm *et al.*, 1991). Water lettuce also serves as host to at least two genera of mosquitoes, which may lead to increased insect-borne diseases (Holm *et al.*, 1991).

**Hydrilla (*Hydrilla verticillata*) –** is a very prolific, submersed aquatic plant in the family Hydrocharatacea. It is native to Asia and Australia (Cook and Lüönd, 1982), but has been spread to every continent except Antarctica, causing significant impacts to aquatic ecosystems where it has been introduced. Hydrilla was introduced into the United States in the 1960s as a contaminant in commercially available waterlilies (Langeland, 1996). Langeland (1996) named hydrilla "the perfect aquatic weed" based upon its reproductive, morphological plasticity, and physiological adaptations that allow this species to reproduce, spread, colonize, infest, and ultimately persist in a wide-range of aquatic habitats in many different environmental conditions. Hydrilla posses an extraordinary capacity to adapt to different environmental conditions and has a high ecological amplitude (Sousa 2011). Generally, hydrilla has long circular stems that can grow up into the water column or be stoloniferous; growing horizontally over the sediment surface. Leaves are in whorls of 3-8 around the stem, are sessile and elongate with smaller ovate leaves on the lower portions of the stems. Leaves have serrate margins and spines along the midrib on the adaxial side of the leaf. The spines along the midrib are a distinguishing characteristic of this species from other closely-related species.


*Photo 14 – Hydrilla infestation on Roman Reservoir in Florida, USA. Photo by William Haller.*

Hydrilla can reproduce both sexually and asexually with two biotypes being common. Hydrilla is sexually classified as being either monoecious (bearing both staminate and pistillate flowers on the same plant) or dioecious (bearing either staminate or pistillate flowers on separate plants) (Sousa, 2011).

*Photo 15 – Hydrilla leaf spines. Photo by Wilfredo Robles.*

Both biotypes are common in the United States and have invaded a variety of habitats. Interestingly, the dioecious biotype is almost exclusively present in the southeastern United States while the monoecious biotype is more common in northern states. Hydrilla produces both axillary and subterranean turions, which aid in its persistence in aquatic habitats (Netherland, 1997; Madsen and Smith, 1999). Dioecious hydrilla produces fewer larger tubers than monoecious hydrilla (Van, 1989).

*Photo 16 – Hydrilla turion (left) and subterranean tuber (right). Photo by Wilfredo Robles.*

Tubers can remain viable in sediments for at least 4 years (Van and Steward, 1990). Fragmentation of stems, however, is probably its primary mechanism for dispersal and colonization. Habitats most at risk of infestation include clear, slow-moving water, a stable water regime, shallow lakes and reservoirs, and littoral areas of larger water bodies (Sousa, 2011). Propagules are easily spread as they can be attached to boats, fishing gear and waterfowl (Madeira *et al*., 2000).

Hydrilla produces a dense surface canopy by allocation of as much as 50 percent of its biomass in the upper 0.5 m of the water column (Haller and Sutton, 1975). Pursuant to this, plants have been observed growing at depths of up to 15 m (Langeland, 1996). The dense surface canopy (composed of up to 1 200-1 900 g/m$^2$ dry mass of hydrilla) allows plants to maximize light acquisition at the water surface. The surface canopy also limits light penetration into the water column thereby reducing light availability to other submersed plants (Haller and Sutton, 1975). Invertebrate assemblages can be impacted as a result of reduced dissolved oxygen content in the water column below the surface canopy (Colon-Gaud *et al*., 2004).

*Photo 17 – Hydrilla fouling a boat motor in Mississippi USA. Photo by Wilfredo Robles.*

Hydrilla can reduce water flow, increase sedimentation rates, increase flood duration and intensity; it interferes with navigation, fisheries and recreation activities (Langeland, 1996). Hydrilla affects important human activities that rely on water resources such as, agriculture, irrigation, fishing and hydropower generation (Sousa, 2011).

If left unmanaged, non-native aquatic plants, such as hydrilla, can be beneficial to fish species over the short term, such as largemouth bass (*Micropterus salmoides*), and juvenile survival (Moxley and Langford, 1982; Tate *et al*., 2003). However, long-term evidence suggests that dense populations can have significant deleterious effects on other fish species such as black crappies (*Pomoxis nigromaculatus*) and sunfish species (*Lepomis* spp.) (Bonvechio and Bonvechio, 2006), that are important prey species for largemouth bass. Furthermore, long-term evidence in Lake Tohopekaliga, Florida, in the United States, found that as hydrilla infestations increased, the growth of largemouth bass less than age 5 declined (Bonvechio and Bonvechio, 2006), suggesting that recruitment is being affected by dense plant growth, which will ultimately affect the fishery in the lake. Dense growth can affect littoral zone plant communities and macro-invertebreate assemblages that are also important for fish species (Krull, 1970; Theel *et al*., 2008).

Hydrilla is a serious weed problem worldwide, which continues to persist regardless of management activities. The economic impacts of water uses on real estate value, tourism, and user groups can be staggering (Langeland, 1996). For example, Florida state agencies have spent nearly US$250 million to manage hydrilla in Florida waters over the past 30 years; if one accounts for local government and local water management districts, this total for managements costs associated with hydrilla alone approaches US$750 million. Extrapolated globally, dollar amounts are staggering concerning economic losses and management costs if this species is permitted to spread.

**Parrotfeather (*Myriophyllum aquaticum*) –** belongs to the Haloragaceae family and is native to South America (Aiken, 1981). Parrotfeather has been introduced into Southeast Asia, Australia, New Zealand, Japan, South Africa and North America. Parrotfeather was introduced into southern Africa around 1918 or 1919 near Paarl, Western Cape Province (Guillarmod, 1977). It has since become one the five most widespread and influential plant aquatic plant species along with water hyacinth, giant salvinia, water lettuce and red water fern (*Azolla filiculoides*) (Richardson *et al*., 2011). The European and Mediterranean Plant Protection Organization (EPPO) has rated parrotfeather as a 'high risk' species (Brunel, 2009).

*Photo 18 – Parrotfeather emergent shoots. Photo by Ryan Wersal.*

Parrotfeather is an evergreen stoloniferous plant. Parrotfeather is heterophyllous, meaning it has both an emergent and submersed leaf form. Emergent leaves are whorled, stiff, and usually have 20 or more linear divisions on each leaf (Godfrey and Wooten, 1981). The leaves appear feather-like and greyish green. Submersed shoots are composed of whorls of four to six filamentous, pectinate leaves arising from each node (Mason, 1957). Submersed leaves are reddish orange in appearance. When the submersed shoots reach the water surface, plant growth changes and begins to creep along the water surface with extensive branching from nodes followed by vertical growth of the stem (Moreira *et al*., 1999).

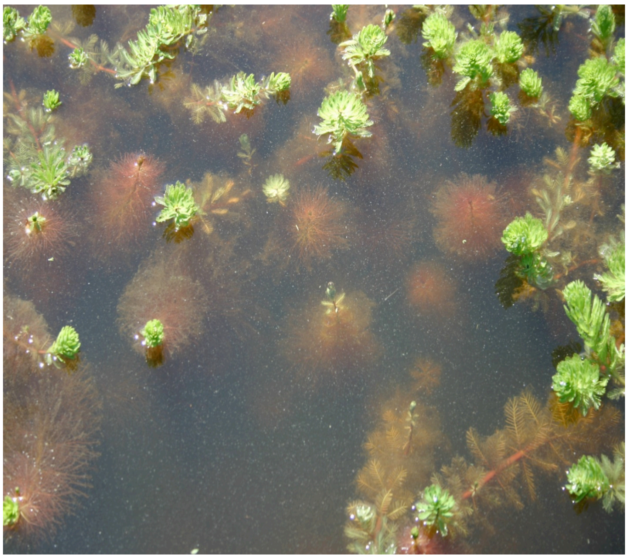


*Photo 19 – Leaf form changes in parrotfeather from submersed to emergent as shoots reach the water surface. Photo by Ryan Wersal.*

Flowering occurs in the leaf axils on the emergent shoots. Parrotfeather is a dioecious species; however only pistillate plants are found outside of South America. Staminate plants are rare, even in native populations of South America (Orchard, 1981). For this reason, seed production is not known to occur (Aiken, 1981) and reproduction is exclusively vegetative (Orchard, 1981). Parrotfeather lacks structures for carbohydrate storage (Wersal *et al*., 2011), dispersal, and perennation (e.g. tubers, turions and winter buds) and therefore stolons serve all these functions (Sytsma and Anderson, 1993; Wersal *et al*., 2011). Vegetative reproduction occurs solely by fragmentation of emergent and/or submersed shoots. Once fragmentation occurs, adventitious roots are rapidly grown for rooting and likely for nutrient uptake (Wersal and Madsen, 2011).

*Photo 20 – Parrotfeather in an irrigation canal in Idaho, USA. Photo by Tom Woolf.*

Parrotfeather grows well in shallow wetlands, slow-moving streams, irrigation reservoirs or canals, edges of lakes, ponds, sloughs, or backwaters (Sutton, 1985). Parrotfeather can grow in moist soil and has been documented at depths of up to 2 m. (Sutton, 1985; Sytsma and Anderson, 1993). Parrotfeather requires rooting in bottom sediments, so habitats where light can penetrate to the bottom favour growth and colonization. Parrotfeather is not seriously affected by frost (Moreira *et al*., 1999), however a hard frost may kill emergent shoots in northern latitudes. Parrotfeather can survive winters as the submersed form and begin growth when water temperatures reach 7 °C (Moreira *et al*., 1999). Parrotfeather can survive frequent inundation of salt water as long as concentrations remain below 4 ppt (Sutton, 1985).

*Photo 21 – Parrotfeather takingover a river in Germany. Photo by Andreas Hussner.*

The ranges of habitats and climates that can support parrotfeather growth make it very attractive as an ornamental pond plant. Parrotfeather is a very popular and common component of water garden landscaping and is being sold as an 'oxygenating' plant worldwide. The ease of cultivation and attractiveness as a pond plant is likely the most common means of spread and has aided in the escape and subsequent colonization of natural areas by this plant. Parrotfeather spread can be almost exclusively attributed to humans.

> "As portions of these plants are easily entangled in propellers, or fishing gear, and as it is a favoured ornamental, it seems man alone can be held responsible for its distribution."
>
> Jacot Guillarmod 1977

Little information exists on the direct impact that parrotfeather has on fish and wildlife. Dense beds of parrotfeather have resulted in reduced dissolved oxygen in the water column, which may be detrimental to fish (Fonesca: cited in Moreira *et al*., 1999). Parrotfeather growth can inhibit the growth of more desirable plant species such as pondweeds and coontail (Ferreira and Moreira, 1994), which are readily used by waterfowl as food (Wersal *et al*., 2005). A strong correlation has been determined between the density of parrotfeather growth and the presence of mosquito eggs and larvae (Orr and Resh, 1989), which may lead to increased mosquito born diseases that could infect wildlife and people. In developing countries, parrotfeather infests major river systems and tributaries and poses a direct threat to potable water supplies (Guillarmod, 1977)

Parrotfeather is not generally a strong competitor, especially as species richness at given site increases, therefore, it is often overlooked in areas where it occurs until it becomes firmly established. Once established, however, parrotfeather has shown great resiliency to many of the current management techniques. Parrotfeather is not currently regulated in most countries; and therefore, buying, selling, and transporting this species is not restricted. Parrotfeather is widely sold in the water garden industry and is one of the most popular plants sold for this purpose. The buying and selling of this species is aiding in its spread and will further exacerbate nuisance problems.

**Didymo (*Didymosphenia geminata*) –** is a freshwater diatom that most likely comes from Scotland, Sweden, and Finland. A good review of Didymo is presented by Spaulding and Elwell (2007) and portions of their work are summarized here. Didymo is considered a unique diatom, as it has developed the capacity to expand its range from historically cold, nutrient rich waters of northern hemisphere rivers, to nutrient rich rivers and streams, and to rivers in New Zealand (Bothwell *et al.*, 2009; Smith, 2011). Globally, this species could invade aquatic habitats on every continent except Antarctica. It is considered one of the worst freshwater introduced algal species (Bothwell *et al.*, 2009; Smith, 2011).

Didymo is capable of producing large amounts of 'stalk' (extracellular mucopolysaccarides) that can cover stream beds resulting in changes in the density of phytoplankton, zooplankton, invertebrate and fish (Kilroy *et al.*, 2006; Larned *et al.*, 2006; Larson and Carreiro, 2008). When conditions are favourable (high nutrient availability), colony expansion allows this stalk material to form thick, gelatinous masses that smother the bottom of rivers (Bowman 2008; Bothwell *et al.*, 2009). Stalks can remain for up to 2 months following a didymo bloom where they trap fine sediment and change the nature of the stream substrate, which influences stream community compositions. Didymo infestations could cause long lasting impacts to all aspects of stream ecology (Larned *et al.*, 2006). It is believed that Didymo is spread primarily by human activity when algal cells hitchhike on footwear or fishing gear (Bothwell *et al.*, 2009; Smith, 2011).

In the western United States, Didymo has impacted water flow and use of canal systems in many states (Spaulding and Elwell, 2007). Water from these canals are used for irrigation, hydropower, and human consumption (Pryfogle *et al.*, 1997). Didymo has impacted tourism and outdoor recreation, especially fishing. In New Zealand, the presence of Didymo has profoundly impacted the country's economy, and it has only been present since 2004 (Kilroy, 2004). The presence of Didymo directly threatens tourism, commercial eel fisheries, water supplies, and biodiversity. Economic losses are projected to be from NZ$57 to 285 million (NZ dollar 1= US$0.82; 03/2012) over the next eight years (Branson, 2006). The speed at which Didymo is spreading in New Zealand also suggests human mediated transport (Kilroy, 2008).

Didymo is a diatom that is becoming a growing problem in New Zealand, North America, and Europe; and has the capacity to impact stream ecosystems on a global scale (Spaulding and

Elwell, 2007). Spaulding and Elwell (2007) indicate that a global community of scientists, land managers, and anglers are in agreement regarding the threats of Didymo, and conclude that Didymo:

- is the only freshwater diatom to exhibit large-scale invasive behaviour, and a persistent phenomenon on a global scale;
- is a species having the biological capacity to produce inordinate amounts of stalk material with unique properties;
- has, and will continue to have, a significant impact on stream ecosystem functions, with the ability to alter food web dynamics;
- has expanded its ecological range and tolerances;
- exhibits a pattern of growth with potential impact on fisheries;
- has already become a significant strain on regional and national economies impacting tourism, fisheries and hydropower.

### *Commercially significant aquatic plant species, and the organisms that directly or indirectly impact their growth and production*

Aquatic plants are used worldwide for food, fibre and feedstock. Many plant species are used regionally or within a specific country and are locally important to local populations. The following is a broad overview of several species that comprise a significant component of human lives over larger geographic areas, or are commercially farmed and harvested for sale.

**Nori, Zicai, and Gim (*Porphyra* spp.) –** are edible seaweeds, largely from the genus *Porphyra* spp., that are known as *nori* in Japan, *gim* in Korea, and *zicai* in China (Rao *et al*., 2007). Fresh seaweeds have been used as a food source in Asia for centuries, but only recently have been introduced throughout the world. *Porphyra* is an excellent source of fibre, protein, vitamins and minerals (particularly iodine) for the human diet. The algal aquaculture industry worldwide is estimated to be worth US$5-6 billion, with the bulk of this oriented towards *Porphyra* (Wikfors and Ohno, 2001). Besides aquaculture, some natural harvest occurs. Porphyra was traditionally cultivated by drying 'ripe' conchospores on land, then reimmersing them in seawater. However, an agronomic approach to this process was not developed commercially until the 1930s. Aquaculture of Porphyra may be used to control excess nutrient production by finfish and shellfish aquaculture programmes, bringing a secondary benefit of nutrient control (Carmona *et al*., 2006). Porphyra is commonly used as fresh or dried food for humans and animals, and processed as a food supplement (Fleurence, 1999).

**Wild rice (*Zizania palustris*) –** in North America, there are three species, *Z. aquatica*, *Z. palustris*, and *Z. texana*, and associated varieties that are referred to as wild rice (Aiken *et al.*, 1988; Oelke, 1993; Duvall, 1995). Wild rice is an aquatic grass that inhabits shallow portions of lakes and slow-moving rivers in north central and northeastern North America (Aiken *et al.*, 1988). Wild rice is the only cereal grain indigenous to North America (Counts and Lee, 1987), has been cultivated and harvested by Native Americans for over three centuries as an important food source (Vennum, 1999), and was important to early European settlers of the Great Lakes region of North America (Chamblis, 1940). Ecologically, wild rice provides food and shelter for fish and wildlife, most notably, migratory waterfowl (Baldasserre and Bolen, 1994). Today, wild rice is exploited both as a subsistence food and as a cash crop (Counts and Lee, 1987; Aiken 1988; Oelke, 1993).

**Water caltrop (*Trapa natans*) –** has been used as a food crop in China, India, and European countries (Swapna *et al.*, 2011). The large seeds of this plant are typically roasted, boiled, or consumed raw (Swapna *et al.*, 2011). Recent evidence suggests that prehistoric civilizations relied on the seeds of water caltrop especially in times of cultivated crop failure (Karg, 2006). Currently, however, water caltrop populations in Europe are becoming rare (Karg, 2006). Although this species was/is enjoyed in many countries worldwide, it is considered a noxious weed in Australia and in some states of the United States.

**Chinese water chestnut (*Eleocharis dulcis*) –** is widespread from Madagascar to India, southeast Asia, Melanesia and Fiji, but is rarely cultivated outside of China (Edwards, 1980; Swapna *et al.*, 2011). In China, water chestnuts are grown in paddies as a rotational crop with other aquatic plant species such as rice (*Oryza* spp.), lotus (*Nelumbo* spp.) and arrowhead (*Sagittaria* spp.) (Edwards, 1980). The highly sought after corms are produced on underground rhizomes. Corms are high in carbohydrates, though low in protein (Hodge, 1956; Ruskin and Shipley, 1976; Swapna *et al.*, 2011).

**Indian lotus (*Nelumbo nucifera*) –** is the sacred flower of the Hindus (Cook *et al.*, 1974) and the flower is also of religious significance to Buddhists (Edwards 1980). It is native to China, Japan, and probably India (Rai *et al.*, 2005). Indian lotus has been cultivated in China since at least 12 BC (Herklots, 1972). Most Indian lotus plants can be eaten as a vegetable or used in a variety of dishes (Rai *et al.*, 2005, Swapna *et al.*, 2011). The seeds are widely sold in Indian markets. Seeds are used to treat tissue inflammation, cancer, are antiemetic, and are used as a diuretic (Liu *et al.*, 2004; Swapna *et al.*, 2011). The antioxidant properties of Indian lotus have also been well established in the leaves (Wu *et al*., 2003), stamens (Jung *et al*., 2003), rhizomes (Hu and Skibsted, 2002, Cho *et al*., 2003) and seeds (Rai, 2005).

**Water spinach (*Ipomoea aquatic*) –** .is a floating plant that can root in moist soil and is native to India, southeast Asia, and southern China (Edwards, 1980; Swapna *et al*., 2011). The young leaves of water spinach are boiled or fried in oil and eaten as a vegetable (Ruskin and Shipley, 1976; Swapna *et al*., 2011). The crude protein content of water spinach ranges from 18 to 34 percent dry weight (Göhl, 1975). Production of water spinach largely occurs in Hong Kong on small farms (0.08 to 0.32 ha), though these small farms produce 3-5 million kg of plant material per year and supplies 15 percent of the local vegetables under peak growth (Edie and Ho, 1969; Edwards, 1980).

**Watercress (*Rorippa nasturtium*) –** is an emergent plant native to Europe and northern Asia, but has also been cultivated in temperate and subtropical areas (Cook *et al*., 1974; Ruskin and Shipley, 1976). Watercress is a source of iron, iodine, vitamin A, B, and C; and is eaten as a fresh salad or cooked as a green vegetable (Cook *et al*., 1974). In Hong Kong, it is typically grown during the cool season in the same fields where water spinach was grown during warmer months (Edie and Ho, 1969). Watercress is also eaten in many regions of the Iberian Peninsula (Tardío *et al*., 2005).

**Water mimosa (*Neptunia oleracea*) –** is a legume that can grow as a floating plant in open water or root in moist soil as water depths decrease. Young plants are cooked and eaten as a green vegetable that is likely high in protein (Ruskin and Shipley, 1976). This species is largely cultivated in Thailand along the banks of rivers and in borrow pits, but is generally not as popular as water spinach (Edwards, 1980).

**Taro (*Colocasia esculenta*) –** is an emergent plant its rhizomes have a high starch content that are eaten by humans (Cook, 1974; Swapna *et al*., 2011). Taro also produces a large corm that can be consumed as well. It is cultivated in Egypt, the Phillipines, Hawaii, and other Pacific and Caribbean islands, and India (Swapna *et al*., 2011). Taro rhizomes are a good source of calcium, phosphorus, and vitamins A and B (Edwards, 1980). The leaves and petioles are good sources of protein, calcium, iron, potassium, and vitamins A, B, and C; it can be cooked and eaten as a vegetable (Edwards, 1980).

### *Organisms that directly or indirectly impact aquatic plant growth*

The IPPC defines a pest as any species, strain, or biotype of plant, animal, or pathogenic agent that is injurious to plants or plant products. The following is a description of important organisms (other than plants) including pathogens, insects, and vertebrates that are pests to aquatic plants. These organisms have intentionally been introduced as biological control agents to manage a plant population or are naturally occurring and have impacted plant growth.

**Marine plant pests –** wasting disease has been a significant contributor to the decline of seagrass populations and has been linked to marine pathogen in the genus *Labyrinthula* (Garcias-Bonet *et al*., 2011). *Labyrinthula* spp. produce lesions on the leaves of seagrasses through the degradation of the cell wall and destruction of chloroplasts and cytoplasm (Muehlstein, 1992). This destruction of cell function also allows for the spreading of the disease inside the leaves and into the vascular tissues of the plant (Muehlstein, 1992). *Labyrinthula* spp. decreases photosynthesis in the lesions and surrounding leaf tissues, which can lead to reduced plant productivity and possible plant mortality (Ralph and Short, 2002).

Phytomyxids are a relatively understudied group of parasites that infect brown algae, seagrasses, and marine diatoms (Neuhauser *et al*., 2011). The class of organisms Phytomyxea comprises: Plasmodiophorida, parasites of green plants; and Phagomyxida, parasites of brown algae and diatoms (Neuhauser *et al*., 2011). Brown algae parasites include *Maullinia ectocarpii*, and *Phagomyxa algarum,* which can cause reduced reproduction (Maier *et al*., 2000). Seagrass parasites include *Plasmodiophora maritime*, *P. halophilae*, *P. diplantherae*, and *P. bicaudata*, where they cause gall formation in plant shoots, dwarfing of infected plants, and reduced root growth and root numbers (Walker and Campbell, 2009). Decreased root production has resulted in the increase of uprooting in seagrass species (Walker and Campbell, 2009).

*Phagomyxa bellerochaea* and *P. odontellae* are parasites of marine diatoms (Schnepf *et al*., 2000), where the parasites digest the host's cytoplasm and chloroplasts for nutritive gain (Neuhauser *et al*., 2011). In addition to the direct effects, phytomyxids can also be vectors of viral diseases (Rochon *et al*., 2004). In terrestrial systems, at least 20 viruses have been identified that were transmitted by phytomxids that cause diseases in flowering plants important to agriculture (Rochon *et al*., 2004). To date, there have been no virus transmissions or virus particles detected in zoospores of marine phytomyxids (Neuhauser *et al*., 2011).

**Freshwater plant pests –** like marine plants, freshwater aquatic plants also have organisms that impact their growth. Freshwater plant pests are commonly pathogens (fungi and bacteria), arthropods (insects and mites) and fish (grass carp) (Cuda *et al*., 2008). Pathogens commonly associated with aquatic plants include species from the generas *Botryosporium*, *Cercosporidium*, *Chaetophoma*, *Diplodia*, *Pyrenochaeta*, *Rhizoctonia*, *Alternaria*, *Helminthosporium*, *Phyllosticta*, *Fusarium, Pythium*, *Plectosporium*, *Sclerotium*, and *Cercospora;* for a more comprehensive handling of pathogens regarding aquatic plants see Barreto *et al*. (2000) and Shearer (2010). Since 1980, over 61 pathogens have been identified on water hyacinth alone (Shearer, 2010). Shabana and Charudattan (1996) isolated 458 different microorganisms (211 bacteria, 202 fungi, 44 actinomycetes, and 1 cyanobacterium) from only 48 aquatic plant samples taken from small ponds. Reports from Australia indicate that the fungal pathogen *Plectosporium alismatis* infects plants of the Alismataceae family and has caused localized declines of starfruit (*Damasonium minus*) populations, the latter is a major weed in Australian rice production (Pitt *et al*., 2004; Jahromi, 2007). A major concern regarding plant pathogens, is the concentration and dissemination of pathogens in the irrigation water of commercially significant crops (Ghimire *et al*., 2011).

Most research directed towards isolating plant pathogens has been focused on developing bioherbicides as biological control agents for aquatic plant management (Barreto *et al*., 2000; Shearer, 2010). *Mycoleptodiscus terrestris* is a fungus that has been shown to affect the submersed plants hydrilla and Eurasian watermilfoil (*Myriophyllum spicatum*), was one of the first fungal pathogens to undergo a large-scale formulation process as a mycoherbicide (Shearer, 1999). Later research documented that the integration of the fungus with low concentrations of herbicides resulted in enhanced control of problem aquatic plants (Nelson and Shearer, 2002; Nelson and Shearer, 2005; Nelson and Shearer, 2008). Also, water hyacinth has been successfully managed in Mexico by integrating insects and the fungi *Cercospora piaropi* and *Acremonium zonatum* (Jiménez and Gómez Balandra, 2007). Currently, however, there are no commercially available pathogens for aquatic plant control (Cuda *et al*., 2008). Though, progress has been made in the fermentation and formulation technologies that could enhance pathogen performance, make the development (mass rearing) of pathogens more economical, and make the deployment of pathogens more efficient (Shearer, 2010).

Herbivory by insects on aquatic plants is also an important factor that can influence plant growth and production. Harms and Grodowitz (2009) present a comprehensive listing of insect herbivores that have been documented on aquatic and wetland plants. The list was compiled for the United States, however, many of the plants species have a cosmopolitan distribution, which could have implications for insect rearing or spread. The list represents 761 plant-herbivore interactions, comprising 313 insects and 167 plant species (Harms and Grodowitz, 2009). Insects from the orders Coleoptera, Diptera, Lepidoptera, Trichoptera, Orhoptera, and Homoptera have been associated with herbivory on aquatic plants. Much of the impetus behind quantifying insect/plant interactions has been for the development of biological control agents for the management of problematic plants (Culliney, 2005; Cuda *et al*., 2008).

Some of the more notable insects include the weevils (*Neochetina bruchi*, *Neochetina eichhorniae*), the water hyacinth moth (*Niphograpta albiguttalis*), and *Megamelus scutellaris* a small plant hopper that feeds on water hyacinth. The salvinia weevil (*Cyrtobagous salviniae*), which has been released in large-scale management programmes and has seen some localized success in managing giant salvinia populations (Stone, 2011). Insects that impact hydrilla include *Bagous affinis* (hydrilla tuber weevil), *Bagous hydrillae* (a stem feeding weevil), *Hydrellia pakistanae* and *H. balciunasi* (leaf-mining fly), and *Cricotopus lebetis* (shoot tip mining midge). The weevil *Neohydronomus affinis* has been released to manage water lettuce in many countries. The alligatorweed flea beetle *Agasicles hygrophila* has also been released in many countries and there has been some success in reducing alligatorweed (*Alternanthera philoxeroides*) populations. The majority of these insects are from tropical and subtropical areas of South America, which implies they can be used throughout the world as biological agents. Abiotic factors such as climate, weather, and habitat conditions will impact insect colonization and growth; as well as biotic factors such as host quality, genotypes, energy reserves, and insect densities (Cuda *et al*., 2008).

Vertebrate animals also use aquatic plants for many purposes; though the grass carp (*Ctenopharyngodon idella*) is one of the most controversial animal pests affecting aquatic plants (Cuda *et al*. 2008; Dibble and Kovalenko, 2009). Grass carp have been released extensively for the management of hydrilla with some success. However, the ecological consequences of grass carp use are not well documented (Dibble and Kovalenko, 2009). Some evidence suggests that grass carp are 'selective generalists' and will feed on aquatic plants in order of palatability (Leslie *et al*., 1987; Pine and Anderson, 1991). Research has also reported shifts in plant community compositions to less palatable, grazing resistant plant species after grass carp have been introduced (Pipalova, 2006). Other studies have shown grass carp eliminate native plant species and leave non-native vegetation intact (Van Dyke, 1994; McKnight and Hepp, 1995). Grass carp can also impact water quality, fish assemblages, macro-invertebrate assemblages, trophic dynamics, and the overall community structure of an aquatic ecosystem. (For a more in depth review of ecological impacts of grass carp see Dibble and Kovalenko, 2009).

### *Indirect effects or impacts of aquatic weeds*

*Indirect effects include interactions of weeds in irrigation canals, thus interfering with agricultural crop production*

Irrigation and drainage canals are a necessity in several areas around the world. Of the world's total geographical land area of 13 045 million ha,1 450.8 million ha of arable land area is under permanent crops (FAO, 2000 cited in: ICID-CIID, 2002). The world's total irrigated area was 249.5 million ha in 1997 (FAO, 2000 cited in: ICID-CIID 2002), which is 17.2 percent of total arable land. These numbers have continued to increase in the twenty-first century with the world's irrigated area now over 306.2 million ha, which comprises 20.1 percent of total arable land (data derived from FAO, 2010). In supporting the movement of such large volumes of water, structures are often created to hold and divert water to other portions of the landscape. Water is often diverted or pumped through hundreds of kilometers of constructed or natural canal systems. This water is used primarily for irrigation or agriculture, aquaculture, and livestock; or water is diverted to keep commercially valuable areas from becoming inundated.

Often, however, these constructed canal systems become optimal habitats for the growth of aquatic plants, which can become problematic with respect to water availability. Aquatic plants decrease the velocity of water and cause water loss through transpiration, silting, and seepage; all of which reduces the amount of water available for agriculture (Coates and Redding-Coates ,1981; Fall *et al*., 2004). Furthermore, aquatic plants growing in canals serve as breeding areas for mosquitoes (*Anopheles* spp.) and gastropod snails (*Bulinus* spp.), which are intermediate hosts for parasitic trematodes *Schistosoma mansoni* and *S. haematobium* (Coates and Redding-Coates 1981; Fall *et al*., 2004). These trematodes cause the crippling disease Schistosomiasis.

Irrigation is used on 3.32 million ha of agricultural land in Thailand, with more than 332 000 ha infested with aquatic plants (Thamasara, 1989). Problematic plant species in irrigation and river canals include water hyacinth, hydrilla, *Potamogeton malainus*, Chinese water chestnut, and *Najas graminea* (Thamasara, 1989). Other species that cause problems in lakes and holding reservoirs include *Mimosa pigra*, *Coix aquatica*, *Salvinia cucullata*, Taro, and cattails (*Typha* spp.) (Thamasara, 1989). These species directly impact the water available for rice farming.

In the Senegal river basin in Africa, more than 70 percent of the population engages in some sort of agricultural practice (Fall *et al*., 2004). Because of the high variation in flows of the

Senegal river irrigation systems are needed to supply water for agriculture production (Fall *et al*., 2004). Major aquatic plant species that routinely cause problems in this area include the emergent plants *Oriza garthii*, *Typha domingensis*, *Cyperus articulates*, and *Phragmites australis*. Submersed species include *Potamogeton* spp. and *Najas* spp. Floating species that cause problems with irrigation in the Senegal river basin include *Azolla africana*, *Nymphae lotus* and giant salvinia (Fall *et al*., 2004).

In the Sudan, roughly 4.2 million ha of land suitable for irrigation lies near the Nile river and its tributaries (Coates and Redding-Coates, 1981). The largest gravity flow irrigation system in the region is composed of the Gezira scheme and Managil extension scheme, which comprises more than 89 000 km of canals (Coates and Redding-Coates, 1981). In a survey, conducted by Beshir (1978), problematic species were identified on the banks of canals and plants rooted or floating in the canals. Bank species included *Panicum repens*, *Cyperus rotundus*, and *Ipomoea repens*. Aquatic plants found in the canals included *Potamogeton* spp., *Najas* spp., *Chara globulins*, and *Ottelia* spp.

The rooted, submersed aquatic plant elodea has significantly impacted irrigation systems in southeast Australia over the past several decades (Bowmer *et al*., 1979). Other problematic submersed aquatic plants species include *Potamogeton* spp., coontail, *Vallisneria spirallis*, and *Myriophyllum* spp. (ICID-CIID, 2002). Emergent species include cattails, phragmites, *Sagittaria graminea* and *Juncus* spp. (ICID-CIID, 2002).

In the United States, sago pondweed has been a major problem in western irrigation canals, and water storage reservoirs for more than 35 years (Anderson, 1990; Sisneros *et al*., 1998). Interestingly though, when sago pondweed is effectively controlled in many irrigation canals, horned pondweed (*Zannichellia pulustris*) becomes problematic. In southern Idaho, parrotfeather has infested several main irrigation canals. Parrotfeather is also a concern in Portugal where it infests irrigation and drainage canals, as well as rice fields (Moreria *et al.,* 1999). Further, in southern Florida thousands of kilometers of flood canals divert water from the interior of the state to lakes and oceans thus preventing the inundation of residential and commercial property. Hygrophila (*Hygrophila polysperma*) has become one of the most serious plant problems in south Florida canals (Vandiver, 1980) and, in south Florida, may be more problematic than hydrilla. For a more comprehensive handling of aquatic plant problems in several countries please see *Aquatic weeds & their management*, a report of the International Commission on Irrigation and Drainage available at http://www.icid.org/weed_report.pdf.

### *Unintended effects on agricultural crop production*

Rice (*Oryza sativa*) is one of the most important cereal grains produced worldwide. In 2009, there were 161 420 743 ha of rice planted worldwide and 678 688 289 tonnes of rice were harvested (data derived from FAO statistics). China, India, and Indonesia were the three leading rice producing countries. Rice paddies are typically shallow (<15 cm) and have high levels of both nitrogen and phosphorus (Spencer *et al*., 2006). Rice paddies are ideal habits for growing algae, some species of vascular aquatic plants and rice (Chapman *et al*., 1972).

Algae became problematic when mat-forming species, such as green algae *Rhizoclonium* and *Hydrodictyon*, and cyanobacteria *Nostoc spongiaeforme,* become abundant (Spencer *et al*., 2006). Large mats of algae interfere with seedling growth by entangling young plants and uprooting them when mats dislodge from the sediment (Spencer *et al*., 2006). Moreover, planktonic green algae and cyanobacteria (blue-green algae) can shade or cling to rice seedlings during large blooms (Spencer *et al*., 2006). Therefore, algae could potentially reduce rice yield by damaging seedling plants or outcompeting rice seedlings for available light. The critical period regarding algae effects on rice is during the 30-day period following initiation, after which, the shading by algae may benefit more mature rice plants by shading non-desirable aquatic plants (Spencer *et al*., 2006; Spencer and Lembi, 2007; Spencer *et al*., 2011).

In many rice growing countries, rice production typically uses a continuous flooding system where water is maintained on the field for all or most of the growing season. The presence of water and high nutrients not only support algae growth, but can support nuisance growth of aquatic vascular plants as well. Early watergrass (*Echinochloa oryzoides*) and late watergrass (*Echinochloa phyllopogon*) are considered serious weeds affecting water-seeded rice in many European countries (Carretero, 1981 cited in: Damalas *et al*., 2008) and the United States (Hill *et al*., 1985).

Both plant species are almost exclusively restricted to rice fields and have morphological and physiological characteristics to outcompete rice (Gibson and Fischer, 2001; Gibson *et al*., 2004). If left alone, these plant species could cause more than 50 percent yield loss of rice (Hill *et al*., 1985). Creeping rivergrass (*Echinochloa polystachya*) is a problem for rice production in Argentina, Mexico, India, the United States and Africa (Holm *et al*., 1991). This species could cause extensive yield loss as well as damage tillage or harvest equipment (Griffin *et al*., 2008).

Additionally, one of the most common areas invaded by giant salvinia are rice paddies because of the continued supply of both water and nutrients (Barrett, 1989). In the United States, the increased occurrence of giant salvinia in and around rice fields is of great concern for southern rice-producing states; as the rice acreage in Arkansas, Louisiana, and Mississippi alone accounted for approximately 78 percent of the total area in the United States from 1999 to 2003 (NASS, reported in the Pest Management Strategic Plant for MidSouth Rice, 2004). The estimated value of the rice area from just these three states averaged US$738 million per year from 1999 to 2003 and forms a large portion of those states' economic base (National Agriculture Service Statistic, NASS, No date). The presence of giant salvinia in and around crop production can greatly reduce crop yield and access to water for irrigation and rice field flooding (Mitchell, 1979). Furthermore, giant salvinia could shade seedling rice plants thereby reducing rice growth or even causing rice plant mortality.

### *Non-agricultural impacts caused by aquatic plants*

Aquatic plants can affect aesthetics, drainage, fishing, water quality, fish and wildlife habitat, flood control, human and animal health, hydropower generation, irrigation, navigation, recreation and, ultimately, land values (Pimental *et al*., 2000; Rockwell, 2003). Consequently, the fraction of harmful invasive plants does not have to be large to inflict significant damage to an ecosystem (Pimental *et al*., 2000). Globally, the economic impact of invasive aquatic plants with respect to agricultural losses, damage, human health, and management is likely to be in the hundreds of billions of dollars. The annual economic impact of weeds, both terrestrial and aquatic (including losses, damage and control costs) is estimated to be US$39 billion in India, US$34 billion in the United States, US$17 billion in Brazil, US$1.4 billion in the United Kingdom (Pimentel *et al*., 2001), US$12 billion in South Africa (van Wilgen *et al*., 2001), US$3 billion in Australia (Sinden *et al*., 2004), and US$1 billion in New Zealand (Williams and Timmins, 2002).

The floating aquatic plant *Azolla filiculoides* has cost South Africa approximately US$58 million through the loss of water resources (water availability, water pump damage, irrigation system maintenance and management costs) and livestock losses (van Wilgen *et al*., 2001). In southern Benin it was estimated that water hyacinth infestation reduced the annual income of the population (200 000 people) by US$84 million (De Groote *et al*., 2003). Income was mainly lost because of lower fish yields and trade (De Groote *et al*., 2003). Transportation was perceived to be the most important impact of water hyacinth on daily lives, followed by impacts to fishing, human health (increases in itching, malaria, and aches and pains), and water quality (De Groote *et al*., 2003).

In China, direct economic losses to fisheries, transportation, storage, water conservation, and public facilities represent 3, 4, 0.4, 0.4, and 14 percent of total economic losses (Xu *et al*., 2006). Road and water transportation losses were US$92.2 million followed by fisheries losses (US$73.9 million) and water conservancy and environment losses (US$10.4 million) (Xu *et al*., 2006). Road and water transportation losses were related to costs associated with prevention, management, and oil consumption of machinery as a result of water hyacinth infestations (Xu *et al*., 2006). Fisheries losses were because of reduced yields associated with infestations of smooth cordgrass and common cordgrass (Xu *et al*., 2006).

In the United States, reports have been given of what might be termed ‘nontraditional’ costs of invasive species. For example, economic analyses of home values has shown a negative trend when invasive species are present both for terrestrial and aquatic species. Data provided by Taylor and Irwin (2004) suggest that the impacts of these invasive species on real estate values could be expected to have substantial cumulative impacts in the United States over the long term.

Other impacts of aquatic plants that are much more difficult to quantify include the intrinsic benefits of aquatic habitats and the ecosystem services these habitats provide (Charles and Dukes, 2007). Ecosystem services provide an important portion of the total contribution to human health and welfare on this planet (Costanza *et al.*, 1997). For example, indirect costs associated with wetland services in China were estimated to be US$8.3 billion (Xu *et al.*, 2006). Globally, it is estimated that ecosystems provide on average US$33 trillion worth of services annually (Costanza *et al.*, 1997). Marine systems comprise approximately US$21 trillion of the global estimate, followed by wetlands at US$4.9 trillion (Costanza *et al.*, 1997). These estimates highlight the importance of conserving these ecosystems and the services they provide to global human welfare (Costanza *et al.*, 1997).

## SECTION IV – CONCLUSIONS AND RECOMMENDATIONS

### *Conclusions*

- Aquatic plants, both marine and freshwater, are used globally for food and fibre, as well as for biofuel and chemical precursors; whether in cultivated or aquaculture settings, or through collection of naturally-occurring populations. With the need to develop sustainable food and fibre systems, aquatic plants are an underutilized resource and their use should be considered for other systems around the world.

- While many aquatic plant species have proven to be beneficial, a small percentage of species often cause problems as a pest when introduced to new environments. Species such as waterhyacinth, waterlettuce, giant salvinia, hydrilla, and several others are generally recognized to be pest species worldwide.

- Aquatic plants are also widely used in the ornamental trade, including both aquarium plants and the water garden trade. The traits that allow these plants to do well in cultivation are often the same characteristics that enable the plant to develop as a pest.

- As a group, aquatic plants seem somewhat less afflicted with pests that impact their growth and survival than their terrestrial counterparts. That being said, a number of pests to cultivated and natural aquatic plant populations have been described.

- Natural populations of freshwater and marine plants in their native habitats provide substantial ecosystem functions and services, such as nutrient cycling, flood reduction, habitat for fish and shellfish, protection of juvenile fish from predators, food for waterfowl, fish, and mammals, absorb wave energy, produce oxygen, and improve water clarity by stabilizing bottom sediments. Indirectly aquatic plants provide economic benefits such as sustaining fisheries, water supply, and recreation. The economic importance of sustainable natural populations alone warrants their protection and enhancement.

*Recommendations*

- While the use of aquatic plant systems, such as aquaculture of macroalgae or sequential cultivation of rice and water spinach in rice paddies, may provide more food and fibre production than currently in use, caution must be exercised so as not to introduce a non-native pest into a new environment. An appropriate risk analysis of the introduction of new species should be performed by the national plant protection organization of each country before introducing a new species into an aquaculture, cultivation, or multiculture programme.

- A small percentage of aquatic plant and macroalgae species are recognized as pests in areas where they have been introduced. These 'world class weeds' should be handled with care: See Annex 2: Major nuisance aquatic plants worldwide.
  - Before introducing them, or any other vigorously-growing aquatic species, into a new area, an appropriate risk analysis should be performed to assess the potential pest risk for this species. While most national plant protection organizations have their own risk analysis procedure, New Zealand and Australia are recognized as having astringent protocols for risk analysis.
  - National plant protection organizations should regulate those species that are not already in their area of responsibility, if possible to prevent their introduction, based on an appropriate risk analysis.
  - National plant protection organizations that detect an outbreak of a regulated plant pest should, to the best of their abilities, make an effort to eradicate it.
  - National plant protection organizations that have areas of widespread occurrences of regulated pests should be encouraged or assisted in developing an integrated pest-management plan for those species.
  - With the advent of the internet, educational and outreach materials are widely available on pest species. A database of these resources could be developed by the IPPC allowing for best management practices to be disseminated.

- The use of aquatic plants in the ornamental trade is likely to increase, as the level of economic development in the world increases. While the economic and environmental benefits of water gardens and aquaria are well known and appreciated, some phytosanitary measures should be implemented by national plant protection organizations to contain the spread of some known regulated pests in the ornamental trade.

    - The use and distribution of aquatic plant species in the ornamental trade should be evaluated by national plant protection organizations to determine if regulation is appropriate.

- Organisms that could potentially be pests of economically-important aquatic plants, for aquaculture or cultivation for food, fibre, biofuel feed stock, and chemical precursors, should be evaluated by national plant protection organizations using risk analysis techniques.
    - If an organism is determined to be a quarantine pest, then the national plant protection organization should consider implementing phytosanitary measures.
    - If a pest is already present in a country, the national plant protection organization might consider regulating it; including implementing an integrated pest management plan to target the species and minimize damage to desirable aquatic plant species.

- Protection of natural populations of freshwater and marine plants will ensure their continued ecosystem functions and services and sustain natural ecosystem benefits.
    - On the one hand, the introduction of regulated plants can dramatically impact natural aquatic plant communities and degrade their ability to provide ecosystem functions and services such as nutrient cycling, flood reduction, wildlife food and habitat, oxygen production, and fisheries, water supply and recreation for humans. The best practices for dealing with aquatic non-native pest plants are detailed in Recommendation 2.
    - On the other hand, a recently introduced pest to the dominant aquatic plant in an environment can also dramatically alter natural ecosystem functions. These pests could include a vertebrate herbivore (e.g. fish or rodent), a pathogen, or other type of pest species. Some of the pests have the potential to move from natural communities to cultivated communities. A prudent national plant protection organization will investigate possible pests of aquatic plant species.
    - The third major cause of injury to natural plant communities is environmental degradation from pollution. While governments and NGOs should be concerned to rectify and prevent this issue, pollution and environmental degradation per se are outside the purview of the IPPC.

## Resources for aquatic plant topics

The following resources include websites on aquatic plant biology, ecology, and management. They provide information on regional and global aquatic plant issues including invasive species monitoring and management. Other resources listed include regional and global databases that contain geographic locations of important aquatic plants.

**Aquatic Ecosystem Restoration Foundation**

http://www.aquatics.org/index.html

**Aquatic Plant Control Research Program**

http://el.erdc.usace.army.mil/aqua/

**CABI**

http://www.cabi.org/Default.aspx?site=170&page=999

**Convention on Biological Diversity**

http://www.cbd.int/

**Ecoport**

http://ecoport.org/

**Exotic Aquatics on the Move**

http://ag.ancs.purdue.edu/EXOTICS/related_links.htm

**Food and Agriculture Organization of the United Nations**

http://www.fao.org/

**International Union for Conservation of Nature**

http://www.iucn.org/

**Invasive Species Specialist Group**

http://www.issg.org/

**National Invasive Species Council**

http://www.invasivespecies.gov

**National Invasive Species Information Center**

http://www.invasivespeciesinfo.gov/

**Global Ballast Management Programme**

http://globallast.imo.org/

**Global Biodiversity Information Facility**

http://www.gbif.org/

**Global Invasive Species Program**

http://www.gisp.org/about/index.asp

**Global Invasive Species Information Network**

http://www.gisin.org/DH.php?WC=/WS/GISIN/home.html&WebSiteID=4

**Integrated Systems for Invasive Species. Ecological Forecasting and Risk Analysis for Nonindigenous Species.**

http://www.math.ualberta.ca/~mathbio/ISIS/index.html

**International Portal on Food Safety, Animal and Plant Health**

http://www.ipfsaph.org/En/default.jsp

**International Union for Conservation of Nature**

http://www.iucn.org/

**International Weed Science Society**

http://www.iwss.info/

**National Aquatic Nuisance Species (ANS) Task Force**

http://www.anstaskforce.gov/index.htm#64

**National Aquatic Nuisance Species Clearinghouse. New York Sea Grant**

http://www.aquaticinvaders.org/nan_ld.cfm

**National Sea Grant**

http://www.nsgo.seagrant.org

**National Sea Grant Nonindigenous Species Site (SGNIS)**

http://www.sgnis.org/

**Smithsonian Environmental Research Center. Marine Invasions Research Lab**

http://www.serc.si.edu/labs/marine_invasions/

**US Geological Survey. Nonindigenous Aquatic Species Information Resource**

http://nas.er.usgs.gov/

# ANNEXES

1. A list of important aquatic plant species expanded from Charudattan 2001 and Swapna *et al*. 2011. Plants are representative of freshwater, wetland, moist soil, and marine environments.

| Botanical name | Common name | Growth habit | Economic or human usefulness[1] |
|---|---|---|---|
| **Freshwater plants** | | | |
| *Acorus calamus* | Sweet flag | Emergent/Wetland | X |
| *Aeschynomene aspera* | Pith plant | Emergent, Mat forming | X |
| *Alternanthera philoxeroides* | Alligatorweed | Emergent, Mat forming | |
| *Alternanthera sessilis* | Sessile joyweed | Emergent, Mat forming | |
| *Ammannia auriculata* | | Emergent/Wetland | X |
| *Ammannia baccifera* | | Emergent/Wetland | X |
| *Aniseia martinicensis* | | Emergent/Wetland | X |
| *Arundo donax* | Giant reed | Riparian, emergent, grass | |
| *Azolla caroliniana* | Mosquito fern | Floating | |
| *Azolla pinnata* | Mosquito fern | Floating | |
| *Bacopa monnieri* | Bacopa | Emergent/Wetland | X |
| *Butomus umbellatus* | Flowering rush | Emergent | |
| *Caesulia axillaris* | | Rooted, floating | X |
| *Centella asiatica* | Indian pennywort | Rooted, floating | X |
| *Centipeda minima* | Sneezweed | Emergent/Submersed | X |
| *Ceratophyllum demersum* | Coontail | Submersed | |
| *Coix aquatic* | | Rooted, floating | X |
| *Coix lachryma* | Poochakkal | Emergent/Wetland | X |
| *Coldenia procumbens* | | Emergent/Wetland | X |
| *Colocasia esculenta* | Taro | Emergent | X |
| *Crassula helmsii* | Australian swamp stonecrop | Submersed | |
| *Cryptocoryne retrospiralis* | Water trumpet | Emergent | X |
| *Cyanotis axillaris* | | Emergent/Wetland | X |
| *Cyathocline purpurea* | | Emergent/Wetland | X |
| *Dentella repens* | | Emergent/Wetland | X |
| *Eichhornia azurea* | Anchored waterhyacinth | Emergent, mat forming | |
| *Eichhornia crassipes* | Water hyacinth | Floating | |
| *Egeria densa* | Egeria | Submersed | |
| *Eleocharis dulcis* | Chinese water chestnut | Rooted, Floating | X |
| *Elodea canadensis* | Canadian waterweed | Submersed | |

| Botanical name | Common name | Growth habit | Economic or human usefulness[1] |
|---|---|---|---|
| *Epaltes divaricata* | | Emergent | X |
| *Glinus appositifoilus* | Bitter cumin | Emergent | X |
| *Grangea maderaspatana* | | Emergent | X |
| *Hydrilla verticillata* | Hydrilla | Submersed | |
| *Hydrocotyl* spp. | Water pennywort | Emergent, mat forming | |
| *Hydrolea zeylanica* | | Emergent | X |
| *Hygrophila polysperma* | Miramar weed | Emergent, mat forming | |
| *Hygrophila schulli* | | Emergent | X |
| *Hygroryza aristata* | | Floating grass | X |
| *Ipomoea aquatica* | Water spinach | Emergent, mat forming | X |
| *Ischaemum rugosum* | | Wetland Grass | X |
| *Lagarosiphon major* | Oxygen weed | Submersed | |
| *Lagenandra ovate* | | Emergent/Wetland | X |
| *Landoltia punctata* | Dotted duckweed | Floating | |
| *Leersia hexandra* | Swamp rice grass | Emergent grass | |
| *Lemna minor* | Common duckweed | Floating | X |
| *Limnobium laevigatum* | West Indian spongeplant | Floating | |
| *Limnophila indica* | | Amphibious, mat forming | X |
| *Limnophila sessiliflora* | Asian marshweed | Amphibious, mat forming | |
| *Lindernia* spp. | | Emergent | X |
| *Ludwigia* spp. | Water primrose | Rooted, mat forming | |
| *Lythrum salicaria* | Purple loosestrife | Emergent, Wetland | |
| *Marsilea minuta* | | Emergent | X |
| *Melaleuca quinquenervia* | Melaleuca | Wetland tree | |
| *Monochoria* spp. | Falsepickerelweed | Emergent | X |
| *Murdannia nudiflora* | | Emergent | X |
| *Myriophyllum aquaticum* | Parrotfeather | Emergent, mat forming | |
| *Myriophyllum spicatum* | Eurasian watermilfoil | Submersed | |
| *Nelumbo nucifera* | Indian lotus | Rooted, floating | X |
| *Neptunia oleracea* | Water mimosa | Rooted, floating | X |
| *Nuphar luteum* | Yellow pondlily | Rooted, floating | |
| *Nymphaea* spp. | Waterlilies | Rooted, floating | X |
| *Nymphoides hydrophylla* | | Rooted, floating | X |
| *Nymphoides indica* | | Rooted, floating | X |
| *Nymphoides peltata* | Yellow floating heart | Rooted, floating | |
| *Otellia alismoides* | Duck lettuce | Submersed | X |
| *Panicum repens* | Torpedo grass | Emergent, grass | |
| *Paspalum repens* | Water paspalum | Emergent, grass | |
| *Phragmites australis* | Common reed | Emergent, grass | |
| *Phyla nodiflora* | | Emergent | X |

| Botanical name | Common name | Growth habit | Economic or human usefulness[1] |
|---|---|---|---|
| *Pistia stratioides* | Water lettuce | Floating | |
| *Polygonum* spp. | Smartweeds, knotweeds | Emergent, mat forming | |
| *Potamogeton crispus* | Curlyleaf pondweed | Submersed | |
| *Potamogeton* spp. | Pondweeds | Submersed | |
| *Rorippa nasturtium* | Watercress | Emergent | X |
| *Rotala rotundifolia* | Round leaf toothcup | Emergent | X |
| *Rotala indica* | | Emergent/Wetland | X |
| *Rotula aquatic* | | Emergent | X |
| *Sagittaria* spp. | Arrowhead | Emergent | |
| *Salvinia auriculata* | Eared watermoss | Floating | |
| *Salvinia biloba* | Giant salvinia | Floating | |
| *Salvinia herzogii* | Giant salvinia | Floating | |
| *Salvinia minima* | Water sprangles | Floating | |
| *Salvinia molesta* | Giant salvinia, Kariba weed | Floating | |
| *Scirpus* spp. | Bulrush | Emergent | |
| *Schoenoplectus* spp. | Bulrush | Emergent | |
| *Spartina anglica* | Common cord-grass | Emergent | |
| *Spartina alterniflora* | Cord grass | Emergent | |
| *Sphaeranthus indicus* | Indian globe flower | Emergent | X |
| *Sphenoclea zeylancia* | | Emergent | X |
| *Spilanthes calva* | | Emergent/Wetland | X |
| *Spirodela polyrhiza* | Giant duckweed | Floating | |
| *Stuckenia* spp. | Pondweeds | Submersed | |
| *Trapa natans* | Water chestnut | Rooted, floating | X |
| *Typha* spp. | Cattail | Emergent | X |
| *Utricularia* spp. | Bladderwort | Submersed | |
| *Vallisneria* spp. | Eelgrass | Submersed | X |
| *Vetiveria zizanoides* | | Wetland Grass | X |
| *Wedelia chinensis* | | Emergent/Wetland | X |
| *Xyris indica* | | Emergent/Wetland | X |
| *Zizania palustris* | Wild rice | Emergent, Grass | X |
| **Macro-algae** | | | |
| *Chara* spp. | Muskgrass | Submersed | |
| *Nitella* spp. | Stonewort | Submersed | |
| *Nitellopsis obtusa* | Starry stonewort | Submersed | |
| **Freshwater algae** | | | |
| *Didymosphenia geminata* | Didymo | Mat forming algae | |
| *Nostoc* spp. | | | |
| **Marine** | | | |
| *Ascophyllum nodosum* | | | |

| Botanical name | Common name | Growth habit | Economic or human usefulness[1] |
|---|---|---|---|
| *Caulerpa taxifolia* | Caulerpa seaweed | Macro-algae | X |
| *Chlorella* spp | | Algae | X |
| *Codium fragile* | Oyster thief | Macro-algae | |
| *Chondrus crispus* | Irish moss | Macro-algae | X |
| *Hypnea musciformis* | Red algae | Macro-algae | X |
| *Laminaria spp.* | Kelp | Macro-algae | X |
| *Membranipora membranacea* | | Macro-algae | |
| *Macrocystis pyrifera* | Giant kelp | Macro-algae | X |
| *Nereocystis luetkeana* | Bull-head kelp | Macro-algae | X |
| *Palmaria palmate* | Dulse | Macro-algae | X |
| *Porphyra* spp. | Nori, Gim | Macro-algae | X |
| *Sargassum* spp. | | Macro-algae | X |
| *Spirulina* spp. | | Algae | X |
| *Undaria pinnatifida* | Wakame seaweed | Macro-algae | |
| *Ulva* spp. | Sea lettuce | Macro-algae | X |
| | | | |

[1]*It is worth noting that even 'economical useful' species can cause severe problems when conditions are favourable. For example, sago pondweed is considered a 'beneficial' native plant in freshwater lakes and ponds, however, it is a severe problematic weed in irrigation canals worldwide. Water caltrop (water chestnut) is used as a food crop in Asia and some European countries, but is a severe weed problem in other parts of the world.*

2. Major nuisance aquatic plants worldwide

| Botanical name | Common name | Growth habit | Habitat |
|---|---|---|---|
| *Alternanthera philoxeroides* | Alligatorweed | Emergent | Freshwater |
| *Caulerpa taxifolia* | Caulerpa seaweed | Macro-algae | Marine |
| *Ceratophyllum demersum** | Coontail | Submersed | Freshwater |
| *Didymosphenia geminata* | Didymo | Algae | Freshwater |
| *Eichhornia crassipes** | Water hyacinth | Floating | Freshwater |
| *Hydrilla verticillata* | Hydrilla | Submersed | Freshwater |
| *Leersia hexandra** | Rice grass | Emergent | Freshwater |
| *Myriophyllum aquaticum* | Parrotfeather | Submersed/Emergent | Freshwater |
| *Myriophyllum spicatum* | Eurasian watermilfoil | Submersed | Freshwater |
| *Phragmites australis** | Common reed | Emergent | Freshwater |
| *Pistia stratiodes** | Water lettuce | Floating | Freshwater |
| *Salvinia auriculata** | Salvinia | Floating | Freshwater |
| *Salvinia molesta* | Giant salvinia | Floating | Freshwater |
| *Spartinia anglica* | Cord-grass | Emergent | Brackish |
| *Undaria pinnatifida* | Wakeme seaweed | Macro-algae | Marine |

**denotes species identified in The worlds worst weeds: distribution and biology (Holm, 1991)*

3. Commercially beneficial aquatic plants worldwide

| Botanical name | Common name | Growth habit | Habitat |
|---|---|---|---|
| *Chlorella spp.* | Chlorella | Algae | Marine |
| *Chondrus crispus* | Irish moss | Macro-algae | Marine |
| *Colocasia esculenta* | Taro | Emergent | Freshwater |
| *Eleocharis dulcis* | Chinese water chestnut | Rooted floating | Freshwater |
| *Ipomoea aquatic* | Water spinach | Floating | Freshwater |
| *Laminaria spp.* | Kelp | Macro-algae | Marine |
| *Nelumbo nucifera* | Indian lotus | Rooted floating | Freshwater |
| *Neptunia oleracea* | Water mimosa | Rooted floating | Freshwater |
| *Palmaria palmate* | Dulse | Macro-algae | Marine |
| *Porphyra spp.* | Nori, Zicai, Gim | Macro-algae | Marine |
| *Rorippa nasturtium* | Watercress | Emergent | Freshwater |
| *Sargassum spp.* | | Macro-algae | Marine |
| *Spirulina spp.* | Spirulina | Algae | Marine |
| *Trapa natans* | Water caltrop | Rooted floating | Freshwater |
| *Ulva spp.* | Sea lettuce | Macro-algae | Marine |
| *Zizania palustris* | Wild rice | Emergent | Freshwater |

4. Important pathogen, insect, and vertebrate plant pests

| Pest species | Pest type | Host or target |
|---|---|---|
| *Acremonium curvulum* | Pathogen | Eurasian watermilfoil |
| *Acremonium zonatum* | Pathogen | Water hyacinth |
| *Agasicles hygrophila* | Insect | Alligatorweed |
| *Alternaria eichhorniae* | Pathogen | Water lettuce/Water hyacinth |
| *Argyrotaenia ivana* | Insect | Parrotfeather |
| *Articulospora tetracladia* | Pathogen | Water lettuce |
| *Bagous affinis* | Insect | Hydrilla |
| *Bagous hydrillae* | Insect | Hydrilla |
| *Botrytis* sp. | Pathogen | Water lettuce |
| *Cephalosporium eichhorniae* | Pathogen | Freshwater plants |
| *Cercospora piaropi* | Pathogen | Water hyacinth |
| Choristoneura parallela | Insect | Parrotfeather |
| *Cricotopus lebetis* | Insect | Hydrilla |
| *Ctenopharyngodon idella* | Fish | Submersed freshwater plants |
| *Curvularia clavata* | Pathogen | Freshwater plants |
| *Cyrtobagous salviniae* | Insect | Giant salvinia |
| *Dactylella microaquatica* | Pathogen | Water lettuce |
| *Doassansia eichhorniae* | Pathogen | Freshwater plants |
| *Flagellaspora stricta* | Pathogen | Water lettuce |
| *Fusarium acuminatum* | Pathogen | Emergent/Floating freshwater plants |
| *Fusarium poae* | Pathogen | Emergent/Floating freshwater plants |
| *Fusarium roseum* | Pathogen | Emergent/Floating freshwater plants |
| *Fusarium sporotrichioides* | Pathogen | Emergent/Floating freshwater plants |
| *Fusarium tricinctum* | Pathogen | Emergent/Floating freshwater plants |
| *Helminthosporium bicolor* | Pathogen | Freshwater plants |
| *Hydrellia balciunasi* | Insect | Hydrilla |
| *Hydrellia pakistanae* | Insect | Hydrilla |
| *Hypochnus sasakii* | Pathogen | Water hyacinth |
| *Labyrinthula* spp | Pathogen | Seagrass |
| *Listronotus marginicollis* | Insect | Parrotfeather |
| *Lysathia flavipes* | Insect | Parrotfeather |
| *Lysathia ludoviciana* | Insect | Parrotfeather |
| *Maullinia ectocarpii* | Pathogen | Marine brown algae |

| Pest species | Pest type | Host or target |
|---|---|---|
| *Megamelus scutellaris* | Insect | Water hyacinth |
| *Mycelia sterilia* | Pathogen | Water lettuce |
| *Mycoleptodiscus terrestris* | Pathogen | Eurasian watermilfoil |
| *Myrothecium roridum* | Pathogen | Eurasian watermilfoil |
| *Myrothecium roridum* var. *eichhorniae* | Pathogen | Freshwater plants |
| *Neochetina bruchi* | Insect | Water hyacinth |
| *Neochetina eichhorniae* | Insect | Water hyacinth |
| *Neohydronomus affinis* | Insect | Water lettuce |
| *Niphograpta albiguttalis* | Insect | Water hyacinth |
| *Parapoynx allionealis* | Insect | Parrotfeather |
| *Phagomyxa algarum* | Pathogen | Marine brown algae |
| *Phagomyxa bellerochaea* | Pathogen | Marine diatoms |
| *Phagomyxa odontellae* | Pathogen | Marine diatoms |
| *Phyllosticta stratiotes* | Pathogen | Water hyacinth |
| *Plasmodiophora bicaudata* | Pathogen | Seagrass |
| *Plasmodiophora diplantherae* | Pathogen | Seagrass |
| *Plasmodiophora halophilae* | Pathogen | Seagrass |
| *Plasmodiophora maritime* | Pathogen | Seagrass |
| *Plectosporium alismatis* | Pathogen | Emergent freshwater plants |
| *Pythium* spp. | Pathogen | Freshwater plants |
| *Pythium carolinianum* | Pathogen | Parrotfeather |
| *Rhizoctonia solani* | Pathogen | Freshwater plants |
| *Sclerotium rolfsii* | Pathogen | Water hyacinth |
| *Sclerotium hydrophilum* | Pathogen | Eurasian watermilfoil |
| *Spicariopsis* spp. | Pathogen | Giant salvinia |
| *Stemphylium* sp. | Pathogen | Eurasian watermilfoil |
| *Uredo eichhorniae* | Pathogen | Freshwater plants |

## References

**Abbasi, S.A. & Nipaney, P.C**. 1986. Infestation by aquatic weeds of the fern genus *Salvinia*: Its status and control. *Environmental Conservation* 13:235-241.

**Akiyama, K. & Kurogi, M**. 1982. *Cultivation of* Undaria pinnatifida *(Harvey) Suringar: the decrease in crops from natural plants following crop increase from cultivation*. Bulletin of the Tohoku Regional Fisheries Research Laboratories 44, 91–100.

**Aiken, S.G.** 1981. A conspectus of *Myriophyllum* (Haloragaceae) in North America. *Brittonia* 33: 57-69.

**Aiken, S.G., Lee, P.F., Punter, D. & Stewart, J.M**. 1988. *Wild rice in Canada*. Toronto, Ontario, NC Press Limited. 130 pp.

**Anderson, L.W.J**. 1990. Aquatic weed problems and management in the western United States and Canada, pp. 371-391. In: *Aquatic Weeds: The ecology and management of nuisance aquatic vegetation* (Pieterse and Murphy, eds.). New York, Oxford University Press. 593 p.

**Anderson, L.W.J**. 2011. Freshwater Plants and Seaweeds, pp. 248-258. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Aresta, M., Dibenedetto, A., Carone, M., Colonna, T. & Fragale, C**. 2005. Production of biodiesel from macro-algae by supercritical $CO_2$ extraction and thermochemical liquefaction. *Environmental Chemistry Letters* 3:136-139.

**Attionu, R.H**. 1976. Some effects of water lettuce (*Pistia stratiotes* L.) on its habitat. *Hydrobiologia* 50:245-254.

**Baldassarre, G.A. & Bolen, E.G**. 1994. *Waterfowl ecology and management*. New York, John Wiley and Sons. 609 p.

**Ballesteros, E., Martín, D. & Uriz, M.J**. 1992. Biological activity of extracts from some Mediterranean macrophytes. *Botanica Marina* 35:481-485.

**Barko, J.W. & Smart, R.M**. 1981. Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. *Ecological Monographs* 51:219-235.

**Barko, J.W., Adams, M.S. & Clesceri, N.S**. 1986. Environmental factors and their consideration in the management of submersed aquatic vegetation: A review. *Journal of Aquatic Plant Management* 24:1-10.

**Barreto, R., Charudattan, R., Pomella, A. & Hanada, R**. 2000. Biological control of neotropical aquatic weeds with fungi. *Crop Protection* 19:697-703.

**Barrett, S.C.H**. 1989. Waterweed invasions. *Science American* 261:90-97.

**Bartley, D.M**. 2011. Aquaculture, pp. 27-32. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Bartoli, P. & Boudouresque, C.F**. 1997. Transmission failure of parasites (Digenea) in sites colonized by the recently introduced invasive alga *Caulerpa taxifolia*. *Marine Ecology Progress Series* 154:253-260.

**Bastianoni, S. & Marchettini, N**. 1996. Ethanol production from biomass: Analysis of process efficiency and sustainability. *Biomass & Bioenergy* 11:411-418.

**Bastianoni, S., F. Coppola, E. Tiezzi, A. Colacevich, F. Borghini, and S. Focardi**. 2008. Biofuel potential production from the Orbetello lagoon macro-algae: A comparison with sunflower feedstock. *Biomass and Energy* 32:619-628.

**Bennet, F.D**. 1975. Insects and plant pathogens for the control of *Salvinia* and *Pistia*, pp. 28-35. In: *Proceedings of the biological control for water quality enhancement workshop* (Brezonik, P.L. and J.L. Fox, eds.). Gainseville, USA, University of Florida.

**Beshir, M.E**. 1978. Gravity flow irrigation and the spread of aquatic weeds in Sudan. *Environmental Conservation* 5:143-146.

**Bixler, J.H. & Porse, H**. 2011. A decade of change in the seaweed hydrocolloids industry. *Journal of Applied Phycology* 23:321-335.

**Bold, H.C. & Wynne, M.J**. 1985. *Introduction to the algae*. Englewood (NJ), USA, Prentice-Hall.

**Bonvechio, K.I. & Bonvenchio, T.F**. 2006. Relationship between habitat and sport fish populations over a 20-year period at west Lake Tohopekaliga, Florida. *North American Journal of Fisheries Management* 26:124-133.

**Borowitzka, M.A**. 1998. Company news. *Journal of Applied Phycology* 10:417.

**Bothwell, M.L., Lynch, D.R., Wright, H. & Deniseger, J**. 2009. On the boots of fisherman: the history of Didymo blooms on Vancouver Island, British Columbia. *Fisheries* 34:382-388.

**Bowman, M.F**. 2008. Increased *Didymosphenia geminata* biomass in response to low-level phosphorus enrichment of oligotrophic rivers, pp. 30-31. In: *Proceedings of the 2007 International Workshop on* Didymosphenia geminata*,*(Bothwell, M.L. and S.A. Spaulding eds.). Montreal, Quebec, Canadian Technical Report of Fisheries and Aquatic Sciences 2795. 58p.

**Bowmer, K.H., Sainty, G.R., Smith, G. & Shaw, K**. 1979. Management of elodea in Australian irrigation systems. *Journal of Aquatic Plant Management* 17:4-12.

**Bradley, R.A. & Bradley, D.W**. 1993. Wintering shorebirds increase after kelp (*Macrosystis*) recovery. *The Condor* 95:372-376.

**Branson, J**. 2006. *Didymosphenia geminata* economic impact assessment. New Zealand Institute
of Economic Research Report.

**Brunel, S**. 2009. *Pathway analysis: aquatic plants imported in 10 EPPO countries*. Bulletin OEPP/EPPO Bulletin 39:201-213.

**Brunner, M.C.** 1982. Water-lettuce, *Pistia stratiotes* L. *Aquatics* 4:4-14.

**Burtin, P**. 2003. Nutritional value of seaweeds. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 2:498-503.

**Cambell, S.J. & Burridge, T.R.** 1998. Occurrence of *Undaria pinnatifida* (Phaeophyta:Laminariales) in Port Phillip Bay, Victoria, Australia. *Marine and Freshwater Research* 49:379-381.

**Carmona, R., Kraemer, G.P. & Yarish, C**. 2006. Exploring Northeast American and Asian species of Porphyra for use in an integrated finfish-algal aquaculture system. *Aquaculture* 252:54-65.

**Carpenter, S.R. & Lodge, D.M**. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26:341-370.

**Cary, P.R. & Weerts, P.G.J**. 1983. Growth of *Salvinia molesta* as affected by water temperature and nutrition. I. Effects of nitrogen level and nitrogen compounds. *Aquatic Botany* 17:163-172.

**Casas, G., Scrosati, R. & Piriz, M.L**. 2004. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions* 6:411-416.

**Case, M.L. & Madsen, J.D**. 2004. Factors limiting the growth of *Stuckenia pectinata*
(Sago Pondweed) in Heron Lake, Minnesota. *Journal of Freshwater Ecology* 19:17-23.

**Castric-Fey, A., Beaupoil, C., Bouchain, J., Pradier, E. & L'Hardy-Halos, M.T**. 1999. The introduced alga *Undaria pinnatifida* (Laminariales, Alariaceae) in the rocky shore ecosystem of the St Malo area: growth rate and longevity of the sporophyte. *Botanica Marina* 42:83-96.

**Carretero, J.L**. 1981. El género *Echinochloa* Beauv. En el suroeste de Europa. *Anales del Jardín Botánico de Madrid* 38:91-108.

**Cecere, E., Petrocelli, A. & Saracino, O.D**. 2000. *Undaria pinnatifida* (Fucophyceae, Laminariales) spread in the central Mediterranean: its occurrence in the Mar Piccolo of Taranto (Ionian Sea, southern Italy). *Cryptogamie Algologie* 21:305-309.

**Center, T. D. &Spencer, N.R**. 1981. The phenology and growth of water hyacinth in a eutrophic north-central Florida lake. *Aquatic Botany* 10: 1-32.

**Chambers, P.A. & Kalff, J**. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. *Canadian Journal of Fisheries and Aquatic Sciences* 42:701-709.

**Chamblis, C.E**. 1940. The botany and history of *Zizania aquatica* L. ("Wild rice"). *Journal of the Washington Academy of Sciences* 30:185-205.

**Champion, P.D., Clayton, J.S. & Hofstra, D.E.** 2010. Nipping aquatic plant invasions in the bud: weed risk assessment and the trade. *Hydrobiologia* 656:167-172.

**Chapman, R.L., Bayer, D.E. & Lang, N.J**. 1972 Observations on the dominant alga in experimental California rice fields. *Phykos* 8:17.

**Charles, H. & Dukes, J.S**. 2007. Impacts of invasive species on ecosystem services. *Biological Invasions* 193:217-237.

**Charudattan, R**. 2001. *Are we on top of aquatic weeds? Weed problems, control options, and challenges*. Paper presented at an international symposium on the World's Worst Weeds, British Crop Protection Council, Brighton, UK.

**Chen, F. & Jiang, Y**. 2001. Algae and their Biotechnological Potential. *Springer*. 316 p.

**Cho, E.J., Yokozawa, T., Rhyu, D.Y., Gim, S.C., Shibahara, N. & Park, J.C**. 2003. Study on the inhibitory effects of Korean medicinal plants and their main compounds on the 1,1-diphenyl-2-picrylhydrazyl radical. *Phytomedicine* 10544-551.

**Chura, N.J**. 1961. Food availability and preferences of juvenile mallards. *Transactions of the North American Wildlife and Natural Resources Conference* 26: 121-134.

**Chynoweth, D.P., Owens, J.M. & Legrand, R**. 2001. Renewable methane from anaerobic digestion of biomass. *Renewable Energy* 22:1-8.

**Coates, D**. 1982. *Salvinia*-possible biological effects on fish in Papua New Guinea? *Aquatics* 4:2.

**Coates, D. & Redding-Coates, T.A**. 1981. Ecological problems associated with irrigation canals in the Sudan with particular reference to the spread of Bilharziasis, Malaria, and aquatic weeds and the ameliorative role of fishes. *International Journal of Environmental Studies* 16:207-212.

**Colon-Gaud, J.C., Kelso, W.E. & Rutherford, D.A**. 2004. Spatial distribution of macroinvertebrates inhabiting hydrilla and coontail beds in the Atchafalaya Basin, Louisiana. *Journal of Aquatic Plant Management* 42:85-91.

**Congdon, R.A. & McComb, A.J**. 1979. Productivity of *Ruppia*: seasonal changes and dependence on light in an Australian estuary. *Aquatic Botany* 6: 121-132.

**Cook, C.D.K., Gut, B.J., Rix, E.M., Schneller, J. & Seitz, M**. 1974. *Water plants of the world. A manual for the identification of the genera of freshwater Macrophytes*. The Hague, Dr W. Junk B.V. Publishers. 561 p.

**Cook, C.D.K. & Lüönd, R**. 1982. A revision of the genus *Hydrilla* (Hydrocharitaceae). *Aquatic Botany* 13:485-504.

**Costanza, R., d'Arge, R., de Groote, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & van den Belt, M**. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

**Counts, R.L. & Lee, P. F.** 1987. Patterns of variation in Ontario wild rice (*Zizania aquatica* L.). I. The influence of some climatic factors on the differentiation of populations. *Aquatic Botany* 28:373-392.

**Creagh, C**. 1991/1992. A marauding weed in check. *Ecos* 70:26-29.

**Crosson, H**. 2010. *Keeping aquatic plants in their place: Common sense tips to protect lakes and rivers*. Landscape Online available at: http://www.landscapeonline.com/research/article5226. Accessed 8 December 2011. 5 p.

**Crow, G. E. & Hellquist, C. B**. 2000. *Aquatic and wetland plants of northeastern North America. Volume 1. Pteridophytes, Gymnosperms, and Angiosperms: Dicotyledons*. Madison, UK, University of Wisconsin Press. 480 p.

**Cruz-Rivera, E. & Hay, M.E**. 2000. The effects of diet mixing on consumer fitness: macro-algae, epiphytes, and animal matter as food for marine amphipods. *Oecologia* 123:252-264.

**Cuda, J.P., Charudattan, R., Grodowitz, M.J., Newman, R.M., Shearer, J.F., Tomayo, M.L. & Villegas, B**. 2008. Recent advances in biological control of submersed aquatic weeds. *Journal of Aquatic Plant Management* 46:15-32.

**Culliney, T.W**. 2005. Benefits of classical biological control for managing invasive plants. *Critical Reviews in Plant Sciences* 24:131-150.

**Damalas, C.A., Dhima, K.V. & Eleftherohorinos, I.G**. 2008. Bispyribac-sodium efficacy on early watergrass (*Echinochloa oryzoides*) and late watergrass (*Echinochloa phyllopogon*) as affected by coapplication of selected rice herbicides and insecticides. *Weed Technology* 22:622-627.

**De Groote, H., Ajuonu, O., Attignon, S., Djessou, R. & Neuenschwander, P**. 2003. Economic impact of biological control of water hyacinth in Southern Benin. *Ecological Economics* 45:105-117.

**Dewald, L.B. & Lounibos, L.P**. 1990. Seasonal growth of *Pistia stratiotes* L. in south Florida. *Aquatic Botany* 36:263-275.

**Dibble, E.D**. 2009. Chapter 2: Impacts of invasive aquatic plants on fish, pp. 9-18. In: *Biology and control of aquatic plants: a best management practices handbook* (Gettys L.A., W.T. Haller, and M. Bellaud, eds.). Marietta GA, USA, Aquatic Ecosystem Restoration Foundation. 210 p.

**Dibble, E.D. & Kovalenko, K**. 2009. Ecological impact of grass carp: a review of the available data. *Journal of Aquatic Plant Management* 47:1-15.

**DiTomaso, J., Holt, J. & Jackson, N**. 2007. *Biofuels and invasive plant species*. Weed Science Society of America White Paper, 1 p. (Available at: http://wssa.net/Weeds/Invasive/Reports/BIOFUEL_AND_INVASIVES_white_paper.pdf#search=%22biofuels%22. Accessed 7 December 2011).

**Dodds, W.K**. 2002. *Freshwater ecology: concepts and environmental applications*. San Diego, CA, USA, Academic Press. 569 p.

**Doyle, R.D**. 2000. *Effects of navigation on aquatic plants: effects of sediment resuspension and deposition on plant growth and reproduction. Upper Mississippi River – Illinois Waterway System Navigation Study, ENV Rep. 28*. US Army Corps of Engineers, Rock Island District, St. Louis District, St. Paul District. 64 p.

**Dray, F.A. & Center, T.D**. 1989. Seed production by *Pistia stratiotes* L. (waterlettuce) in the United States. *Aquatic Botany* 33:155-160.

**Duggins, D.O., Simenstad, C.A. & Estes, J.A**. 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. *Science* 245:170-173.

**Duvall, M.R**. 1995. Wild rice (*Zizania palustris*), pp. 261-271. In: *Cereals and pseudo cereals* (Williams, J.T. ed.). London, Chapman & Hall.

**Edie, H. & Ho, B**. 1969. *Ipomoea aquatica* as a vegetable crop in Hong Kong. *Economic Botany* 23:32-36.

**Edwards, P**. 1980. *Food potential of aquatic macrophytes*. Manila, The Philippines, International Center for Living Aquatic Resources Management.

**Ehrenfeld, J.G.** 2011. Transformers, pp. 667-670. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765p.

**Fall, O., Fall, I. & Hori, N**. 2004. Assessment of the abundance and distribution of the aquatic plants and their impacts in the Senegal River Delta: The case of Khouma and Djoudj streams. *Weed Technology* 18:1203-1209.

**FAO**. 2010. *2008 Fishery and Aquaculture Statistics*. Rome, FAO. 72 p.

**Ferreira, H.T. & Moreira, I**. 1994. *The seasonal evolution of river plants*. EWRS Ninth International Symposium on Aquatic Weeds. Abstracts.

**Finlayson, C.M., Farrell, T.P. & Griffiths, D.J**. 1982. *Treatment of sewage effluent using the water fern* Salvinia. *Report No. 57*. Water Research Foundation of Australia.

**Fitton, H.J**. 2007. Macroalgal fucoidan extracts: A new opportunity for marine cosmetics. *Cosmetics & Toiletries magazine* 122:55-64.

**Fleurence, J**. 1999. Seaweed proteins: Biochemical, nutritional aspects and potential uses. *Trends in Food Science and Technology* 10:25-28.

**Floc'h, J.Y., Pajot, R. & Wallentinus, I**. 1991. The Japanese brown alga *Undaria pinnatifida* on the coast of France and its possible establishment in European waters. *Journal du Conseil International pour l'Exploration de la Mer* 47:379-390.

**Fonseca, P.C**. 1981. Estudo ecologico de valas da Leziria Grande de Vila Franca de Xira. Rei. Estagio Fac. Oeneos Lisboa. pp. 9.

**Forno, I.W. & Harley, K.L.S**. 1979. The occurrence of *Salvinia molesta* in Brazil. *Aquatic Botany* 6:185-187.

**Galil, B.S**. 2011. Mediterranean Sea: Invasions, pp. 452-458. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Garcias-Bonet, N., Sherman, T.D., Duarte, C.M. & Marbá, N**. 2011. Distribution and pathogenicity of the protest *Labyrinthula* sp. in western Mediterranean seagrass meadow. *Estuaries and Coasts* 34:1161-1168.

**Gaudet, J.J**. 1973. Growth of a floating aquatic weed, *Salvinia*, under standard conditions. *Hydrobiologia*. 41:77-106.

**Ghimire, S.R., Richardson, P.A., Kong, P., Hu, J., Lea-Cox, J.D., Ross, D.S., Moorman, G.W. & Hong, C**. 2011. Distribution and diversity of *Phytophthora* species in nursery irrigation reservoir adopting water recycling system during winter months. *Journal of Phytopathology* 159713:719.

**Gibson, K.D. & Fischer, A.J**. 2001. Relative growth and photosynthetic response of water-seeded rice and *Echinochloa oryzoides* (Ard.) Fritsch to shade. *International Journal of Pest Management* 47:305-309.

**Gibson, K.D., Fischer, A.J. & Foin, T.C**. 2004. Compensatory responses of late watergrass (*Echinochloa phyllopogon*) and rice to resource limitation. *Weed Science* 52:271-280.

**Godfrey, R.K & Wooten, J.W**. 1981. *Aquatic and Wetland Plants of Southeastern United States: Dicotyledons*. Athens, GA, USA, University of Georgia Press. 933p.

**Göhl, B**. 1975. *Tropical feeds*. Rome, FAO. 661p.

**Goss-Custard, J.D. & Moser, M.E**. 1988. Rates of change in the numbers of Dunlin, *Calidris alpina*, wintering in British estauries in relation to the spread of *Spartina anglica*. *Journal of Applied Ecology* 25:95-109.

**Gray, A.J., Marshall, D.F. & Raybould, A.F**. 1991. A century of evolution in *Spartina anglica*. *Advances in Ecological Research* 21:1-62.

**Gray, A.J. & Raybould, A.F**. 1997. The biology and natural history of spartina, pp. 12-16. In: *Proceedings of the Second International Spartina Conference* (Patten, K. ed.), Olympia, Washington, USA, Washington State University. 90p.

**Griffin, R.M., Webster, E.P., Zhang, W. & Blouin, D.C**. 2008. Biology and control of creeping rivergrass (*Echinochloa polystachya*) in rice. *Weed Technology* 22:1-7.

**Groenendijk, A.M**. 1984. Primary production in four dominant angiosperms in the SW Netherlands. *Vegetatio* 57:143-152.

**Guillarmod, A.J**. 1977. *Myriophyllum*, an increasing water weed menace for South Africa. *South African Journal of Science* 73:89-90.

**Haller, W.T. & Sutton, D.L**. 1975. Community structure and competition between hydrilla and vallisneria. *Hyacinth Control Journal* 13:48-50.

**Han, X., Xiaoling, M. & Qingyu, W**. 2006. High quality biodiesel production from a macroalga *Chlorella protothecoides* by heterotrophic growth in fermenters. *Journal of Biotechnology* 126:499-507.

**Hansen, G**. 1984. *Accumulations of macrophyte wrack along sandy beaches in western Australia: biomass, decomposition rate and significance in supporting nearshore production*. University of Western Australia, 93 pp. (Ph.D. Thesis)

**Harley, K.L.S. & Mitchell, D.S.** 1981. The biology of Australian weeds. 6. *Salvinia molesta* D.S. Mitchell) *Journal of the Australian Institute of Agricultural Science* 47:67-76.

**Harms, N.E. & Grodowitz, M.J**. 2009. Insect herbivores of aquatic and wetland plants in the United States: a checklist from literature. *Journal of Aquatic Plant Management* 47:73-96.

**Harper, L.M.** 1986. Management plan: *Salvinia molesta* Mitchell. Unpublished report. Hamilton, New Zealand, Advisory Services Division, Ministry of Agriculture and Fisheries.

**Hasan, M.R. & Chakrabarti, R**. 2009. *Use of algae and aquatic macrophytes as feed in small-scale aquaculture: A review*. Fisheries and Aquaculture Technical Paper 531, Rome, FAO. 123 p.

**Havera, S.P**. 1999. *Waterfowl of Illinois: status and management*. Illinois Natural

History Survey Special Publication 21, Illinois. xliii + 628 p.

**Hay, C.H**. 1990. The dispersal of sporophytes of *Undaria pinnatifida* by coastal shipping in New Zealand, and implications for further dispersal of *Undaria* in France. *British Phycological Journal* 25:301-313.

**Hay, C.H. & Luckens, P.A**. 1987. The Asian kelp *Undaria pinnatifida* (Phaeophyta : Laminariales) found in a New Zealand harbor. *New Zealand Journal of Botany* 25:329-332.

**Hay, C.H. & Villouta, E**. 1993. Seasonality of eh adventive Asian kelp *Undaria pinnatifida* in New Zealand. *Botanica Marina* 36:461-476.

**Hay, R.L**. 1974. *Molting biology of male gadwalls at Delta, Manitoba*. Madison, Wisconsin, USA,

University Wisconsin. 20 p. (M.S. Thesis)

**Hedge, P., Kriwoken, L.E. & Patten, K**. 2003. A review of spartina management in Washington State, US. *Journal of Aquatic Plant Management* 41:82-90.

**Herklots, G.A.C**. 1972. *Vegetables of Southeast Asia*. New York, Hafner Press. 522 p.

**Hill, J.E., Le Strange, M.S., Bayer, D.E. & Williams, J.F**. 1985. Integrated weed management in California. *Proceedings of the Western Weed Science Society*, 38:100.

**Hill, M., Coetzee, J., Julien, M. & Center, T**. 2011. Water Hyacinth, pp. 689-692. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Hodge, W.H**. 1956. Chinese water chestnut or matai-a paddy crop of China. *Economic Botany* 10:49-65.

**Holm, L.G., Plucknett, D.L., Pancho, J.V. & Herberger, J.P**. 1991. *The world's worst weeds; Distribution and biology*. Malabar, FL, USA, Krieger Publishing Company. 609 pp.

**Honnell, D.R., Madsen, J.D. & Smart, R.M**. 1993. *Effects of selected exotic and native aquatic plant communities on water temperature and dissolved oxygen*. Vicksburg, MS, USA, US Army Corps of Engineers, Environmental Laboratory. Information Bulletin A-93-2. December 1993. 8 pp.

**Hu, M. & Skibsted, L.H**. 2002. Antioxidative capacity of rhizome extract and rhizome knot extract of edible lotus (*Nelumbo nucifera*). *Food Chemistry* 76:327-333.

**Hunt, G.S., & Lutz, R.W**. 1959. Seed production by curly-leaved pondweed and its significance to waterfowl. *Journal of Wildlife Management* 23: 405-408.

**ICID-CIID**. 2002. *Aquatic weeds and their management*. Report from the International Commission on Irrigation and Drainage. 65 p.

(Available at: http://www.icid.org/weed_report.pdf).

**Jahromi, F.G**. 2007. Effect of environmental factors on disease development caused by the fungal pathogen *Plectosporium alismatis* on the floating-leaf stage of starfruit (*Damasonium minus*), a weed of rice. *Biocontrol Science and Technology* 17:871-877.

**Jiménez, M.M. & Gómez Balandra, M.A**. 2007. Integrated control of Eichhornia crassipes by using insects and plant pathogens in Mexico. *Crop Protection* 26:1234-1238.

**Jimenez-Escrig, A. & Sanchez-Muniz, F.J**. 2000. Dietary fiber from edible seaweeds: chemical structure, physicochemical properties and effects on cholesterol metabolism. *Nutrition Research* 20:585-598.

**John, D.M**. 1994. Biodiversity and conservation: an algal perspective. *The Phycologist* 38: 3-15.

**Jousson, O., Pawlowski, J., Zaninetti, L., Meinesz, A. & Boudouresque, C.F**. 1998. Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. *Marine Ecology Progress Series* 172:275-280.

**Jung, H.A., Gim, J.E. Chung, H.Y. & Choi, J.S**. 2003.Antioxidant principles of *Nelumbo nucifera* stamens. *Archives of Pharmacal Research* 26:279-285.

**Kantrud, H.A**. 1990. Sago pondweed (*Potamogeton pectinatus* L.) A literature review. US Fish and Wildlife Service Resource Publication 176. 89 p.

**Karg, S**. 2006. The water chestnut (*Trapa natans* L.) as a food resource during the fourth to first millennia BC at Lake Federsee, Bad Bucha (southern Germany). *Environmental Archaeology 11:125-130.*

**Keith, L.B. & Stanislawski, R.P**. 1960. Stomach contents and weights of some flightless adult pintails. *Journal of Wildlife Management* 24:95-96.

**Kobayashi, J.T., Thomaz, S.M. & Pelicie, F.M**. 2008. Phosphorus as a limiting factor for *Eichhornia crassipes* growth in the upper Paraná River floodplain. *Wetlands* 28:905-913.

**Kilroy, C**. 2004. *A new alien diatom* Didymosphenia *geminate (Lyngbye) Schmidt: its biology, distribution, effects and potential risks for New Zealand fresh waters*. Christchurch, New Zealand, National Institute of Water and Atmospheric Research Client Report: CHC2004-128.

**Kilroy, C., Lagerstedt, A., Davey, A. & Robinson, K**. 2006. *Studies on the survivability of the exotic, invasive diatom* Didymosphenia geminata *under a range of environmental and chemical conditions*. National Institute of Water and Atmospheric Research Client Report: CHC2006-116. Christchurch, New Zealand.

**Kilroy, C**. 2008. *Didymosphenia geminata* in New Zealand: Distribution, dispersion and ecology of a non-indigenous invasive species, pp. 15-20. In: *Proceedings of the 2007 International Workshop on* Didymosphenia geminata,(Bothwell, M.L. and S.A. Spaulding eds.). Montreal, Quebec, Canadian Technical Report of Fisheries and Aquatic Sciences 2795. 58p.

**Kirkman, H. & Kendrick, G.A**. 1997. Ecological significance and commercial harvesting of drifting and beach-cast macro-algae and seagrasses in Australia: a review. *Journal of Applied Phycology* 9:311-326.

**Kriwoken, L.K. & Hedge, P**. 2000. Exotic species and estuaries: managing *Spartina anglica* in Tasmania, Australia. *Ocean & Coastal Management* 43:573-584.

**Krull, J.N**. 1970. Aquatic plant-invertebrate associations and waterfowl. *Journal of Wildlife Management* 34:707-718.

**Labrada, R. & Fornasari, L**. 2002. *Management of problematic aquatic weeds in Africa. FAO efforts and achievements during the period 1991-2001*. Rome, FAO. 28 p.

**Langeland, K.A**. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". *Castanea* 61:293-304.

**Langeland, K.A., Cherry, H.M., McCormick, C.M. & Craddock Burks, K.A**. 2008. *Identification & Biology of Non-Native Plants in Florida's Natural Areas, Second Edition*. University of Florida, Institute of Food and Agricultural Sciences. 210 p.

**Larned, S., Biggs, B., Blair, N., Burns, C., Jarvie, B., Jellyman, D., Kilroy, C., Leathwick, J., Lister, K., Nagels, J., Schallenberg, M., Sutherland, S., Sykes, J., Thompson, W., Vopel, K. & Wilcock, B**. 2006. Ecology of *Didymosphenia geminata* in New Zealand: habitat and ecosystem effects – Phase 2. NIWA Client Report CHC2006-086, NIWA Project MAF06507.

**Larson, A.M. & Carriero, J**. 2008. Relationship between nuisance blooms of *Didymosphenia geminata* and measures of aquatic community composition in Rapid Creek, South Dakota, pp. 45-49. In: *Proceedings of the 2007 International Workshop on* Didymosphenia geminata,(Bothwell, M.L. and S.A. Spaulding eds.). Montreal, Quebec, Canadian Technical Report of Fisheries and Aquatic Sciences 2795. 58 p.

**Lee, R.E**. 1989. *Phycology*. Cambridge (UK), Cambridge University Press.

**Lenanton, R.C.J., Robertson, A.I. & Hansen, J.A**. 1982. Nearshore accumulations of detached macrophytes as nursery areas for fish. *Marine Ecology Progress-Series* 9:51-57.

**Leng, R.A**. 1999. *Duckweed: A tiny aquatic plant with enormous potential for agriculture and environment*. (Available at: http://www.fao.org/ag/againfo/resources/documents/DW/Dw2.htm. Accessed December 8, 2011). 108 p.

**Leslie, A.J. Jr., Van Dyke, J.M., Hestland III, R.S. & Thompson, B.Z**. 1987. Management of aquatic plants in multi-use lakes with grass carp (*Ctenopharyngodon idella*), pp. 266-276. In: G. Redfield (ed). *Lake and reservoir management, Volume III*. Washington, DC. North American Lake Management Society.

**Lewmanomont, K.** 1978. *Some edible algae of Thailand*. Paper presented at the Sixteenth National Conference on Agriculture and Biological Sciences, Kasetsart University, Bangkok. 22 p.

**Low, T**. 2011. *Australia: Invasions*, pp. 36-42. In: Encyclopedia of Biological Invasions (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Little, E.C.S**. 1979. *Handbook of utilization of aquatic plants*. A review of world literature. Fisheries Technical Paper 187. Rome, FAO. 176 p.

**Liu, C.P., Tsai, W.J., Lin, Y.L., Liao, J.F., Chen, C.F. & Kuo, Y.C**. 2004. The extracts from *Nelumbo nucifera* suppress cell cycle progression, cytokine genes expression, and cell proliferation in human peripheral blood mononuclear cells. *Life Science* 75:699-716.

**Mabberley, D.J**. 1997. *The plant book*. Second edition. Cambridge, UK, Cambridge University Press,. 858 p.

**Maceiras, R., Rodríguez, M., Cancela, A., Urréjola, S. & Sánchez, A**. 2011. Macro-algae: Raw material for biodiesel production. *Applied Energy* 88:3318-3323.

**Madeira, P.T., Jacono, C.C. & Van, T.K**. 2000. Monitoring hydrilla using two RAPD procedures and the non-indigenous aquatic species database. *Journal of Aquatic Plant Management* 38:33-40.

**Madsen, J.D**. 1998. Predicting invasion success of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 36:28-32.

**Madsen, J.D**. 2009. Chapter 1: Impact of invasive aquatic plants on aquatic biology, pp. 1-8. In: *Biology and control of aquatic plants: a best management practices handbook* (Gettys L.A., W.T. Haller, and M. Bellaud, eds.). Marietta GA, USA, Aquatic Ecosystem Restoration Foundation. 210p.

**Madsen, J.D., Bloomfield, J.A., Sutherland, J.W., Eichler, L.W. & Boylen, C.W**. 1996. The aquatic macrophyte community of Onondaga Lake: Field survey and plant growth bioassays of lake sediments. *Lake and Reservoir Management* 12:73-79.

**Madsen, J.D. & Smith, D.H**. 1999. Vegetative spread of dioecious *Hydrilla* colonies in experimental ponds. *Journal of Aquatic Plant Management* 37:25-29.

**Madsen, J.D., Chambers, P.A., James, W.F., Koch, E.W. & Westlake, D.F**. 2001. The interactions between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444:71-84.

**Madsen, J.D., Wersal, R.M., Tyler, M. & Gerard, P.D.** 2006. The distribution and abundance of aquatic macrophytes in Swan Lake and Middle Lake, Minnesota. *Journal of Freshwater Ecology* 21:421-429.

**Madsen, J.D. & Wersal, R.M**. 2008. Growth regulation of *Salvinia molesta* by pH and available water column nutrients. *Journal of Freshwater Ecology* 23:305-313.

**Maki, K. & Galatowitsch, S**. 2004. Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade. *Biological Conservation* 118:389-396.

**Maier, I., Parodi, E., Westermeier, R. & Müller, D.G**. 2000. *Maullinia ectocarpii* gen. et sp. nov. (Plasmodiophorea), an intracellular parasite in *Ectocarpus siliculosus* (Ectocarpales, Phaeophyceae) and other filamentous brown algae. *Protist* 151:225-238.

**Martin, A.C. & Uhler, F.M**. 1939. *Food of game ducks in the United States and Canada*. US Department of Agriculture Technical Bulletin 634. 156 p.

**Martin, J.P. & Cuevas, J.M**. 2006. First record of *Undaria pinnatifida* (Laminariales, Phaeophyta) in southern Patagonia, Argentina. *Biological Invasions* 8:1399-1402.

**Mason, H.L**. 1957. *A flora of the marshes of California*. Berkeley, CA, USA, University of California Press.

**McFarland, D.G., Nelson, L.S., Grodowitz, M.J., Smart, R.M. &Owens, C.S**. 2004. *Salvinia molesta* D.S. Mitchell (giant salvinia) in the United States: A review of species ecology and approaches to management. Special Report, SR-04-2. Vicksburg, MS, USA, Army Engineer Research and Development Center.

**McHugh, D.J**. 2003. *A guide to the seaweed industry*, Fisheries Technical Paper 441, Rome, FAO. 105 p.

**McKnight, S.K. & Hepp, G.R**. 1995. Potential effect of grass carp herbivory on waterfowl foods. *Journal of Wildlife Management* 59:720-727.

**McVea, C., & Boyd, C.E**. 1975. Effects of waterhyacinth cover on water chemistry, phytoplankton, and fish in ponds. *Journal of Environmental Quality* 4:375-378.

**Meinesz, A. & Hesse, B**. 1991. Introduction et invasion de l'algue tropicale *Caulerpa taxifolia* en Méditerranée Occidentale. *Oceanologica Acta* 14:415-426.

**Meinesz, A., Benichou, L., Blachier, J., Komatsu, T., Lemée, R., Molenaar, H. & Mari, X**. 1995. Variations in the structure, morphology and biomass of Caulerpa taxifolia in the Mediterranean Sea. *Botanica Marina* 38:499-508.

**Meinesz, A., Belsher, T., Thibaut, T., Antolic, B., Mustapha, K.B., Boudouresque, C.F., Chiaverini, D., Cinelli, F., Cottalorda, J.M., Djellouli, A., Abed, A., Orestano, C., Grau, A.M., Ivesa, L., Jaklin, A., Langar, H., Massuti-Pascual, E., Peirano, A., Tunesi, L., de Vaugelas, J., Zavodnik, N. & Zuljevic, A**. 2001. The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. *Biological Invasions* 3:201-210.

**Mitchell, D.S**. 1969. The ecology of vascular hydrophytes on Lake Kariba. *Hydrobiologia* 34:448-464.

**Mitchell, D.S**. 1979. *The incidence and management of* Salvinia molesta *in Papua New Guinea*. Draft Report, Office of Environmental Conservation, Papua New Guinea.

**Mitchell, D.S. & Tur, N.M**. 1975. The rate of growth of *Salvina molesta* (*S. auriculata* auct.) in laboratory and natural conditions. *Journal of Applied Ecology* 12:213-225.

**Mitchell, D.S., Petr, T. & Viner, A.B**. 1980. The water fern *Salvinia molesta* in the Sepik River, Papua New Guinea. *Environmental Conservation* 7:115-122.

**Moreira, I., Monteira, A. & Ferreira, T**. 1999. Biology and control of parrotfeather (*Myriophyllum aquaticum*) in Portugal. *Ecology, Environment and Conservation* 5:171-179.

**Moxley, D.J. & Langford, F.H**. 1982. Beneficial effects of hydrilla on two eutrophic lakes in central Florida. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 36:280-286.

**Muehlstein, L.K**. 1992. The host-pathogen interaction in the wasting disease of eelgrass, *Zostera marina*. *Canadian Journal of Botany* 70:2081-2088.

**Muller-Fuega, A., Moal, J. & Kaas, R**. 2003. The microalgae for aquaculture. In: Stottrup, J.G., L.A. McEvovy (eds) *Life feeds in marine aquaculture*. Oxford, UK, Blackwell. 318 p.

**Nakamura, T., Nagayama, K., Uchida, K. & Tanaka, R**. 1996. Antioxidant activity of phlorotannins isolated from the brown alga *Eisenia bicyclis*. *Fisheries Science* 62:923-926.

**Nehring, S. & Hesse, K.J**. 2008. Invasive alien plants in marine protected areas: the *Spartina anglica* affair in European Wadden Sea. *Biological Invasions* 10:937-950.

**Nelson, L.S. & Shearer, J.F**. 2002. *Response of Eurasian watermilfoil to integrated fluridone-fungal pathogen treatment*. Vicksburg, MS: US Army Engineer and Development Center, Aquatic Plant Control Research Program, Technical Notes Collection, ERDC/TX APCRP-IC-03.

**Nelson, L.S. & Shearer, J.F.** 2005. 2,4-D and *Mycoleptodiscus terrestris* for control of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 43:29-34.

**Nelson, L.S. & Shearer, J.F**. 2008. Evaluation of triclopyr and *Mycoleptodiscus terrestris* for control of Eurasian watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science and Management* 1:337-342.

**Netherland, M.D**. 1997. Turion ecology of *Hydrilla*. *Journal of Aquatic Plant Management* 35:1-10.

**Neuhauser, S., Kirchmair, M. & Gleason, F.H**. 2011. Ecological roles of the parasitic phytomyxids (plasmodiophorids) in marine ecosystems – a review. *Marine and Freshwater Research* 62:365-371.

**Oelke, E.A**. 1993. Wild rice: Domestication of a native North American genus, pp. 235-243. In: *New crops* (Janick, J. and J. E. Simon, eds.). New York, John Wiley and Sons.

**Oliver, J.D**. 1993. A review of the biology of giant slavinia (*Salvinia molesta* Mitchell).
*Journal of Aquatic Plant Management* 31:227-231.

**Orchard, A.E**. 1981. A revision of South American *Myriophyllum* (Haloragaceae), and its repercussions on some Australian and North American species. *Brunonia* 4:27-65.

**Orr, B.K. & Resh, V.H**. 1989. Experimental test of the influence of aquatic macrophyte cover on the survival of Anopheles larvae. *Journal of the American Mosquito Control Association* 5:579-585.

**O'Sullivan, L., Murphy, B., McLoughlin, P., Duggan, P., Lawlor, P.G., Hughes, H. & Gardiner, G.E**. 2010. Prebiotics from marine macro-algae for human and animal health applicatons. *Marine Drugs* 8:2038-2064.

**Ozimek, T., Gulati, R.D. & van Donk, E**. 1990. Can macrophytes be useful in biomanipulation of lakes? The Lake Zwemlust example. *Hydrobiologia* 200/201:399-407.

**Penfound, W.T. & Earle, T.T**. 1948. The biology of the water hyacinth. *Ecological Monographs* 18:447-472.

**Perez, R., Lee, J.Y. & Juge, C**. 1981. *Undaria pinnatifida* on the French coast. Cultivation method. Biochemical composition of sporophyte and gametophyte. pp. 315-327. In: Stadler, T. (Ed.) *Algal Biotechnology, France*.

**Perez, R., Kaas, R. & Barbaroux, O**. 1984. Culture experimental de l'algue japonaise Unnidaria *pinnatifida* sur les Cotes de France. *Science et Peche* 343:1-15.

**Pest Management Strategic Plan for Midsouth Rice**. 2004.
Available at: http://www.ipmcenters.org/pmsp/pdf/SouthRice.pdf, Accessed January 20, 2012.

**Petroeschevsky, A. & Champion, P.D**. 2008. *Preventing further introduction and spread of aquatic weeds through the ornamental plant trade*. Sixteenth Australian Weed Conference, Cairns. pp. 200-302.

**Pimentel, D., Lack, L., Zuniga, R. & Morrison, D**. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience* 50:53-65.

**Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T. & Tsomondo, T**. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment* 84:1-20.

**Pine, R.T. & Anderson, L.W.J**. 1991. Plant preferences of triploid grass carp. *Journal of Aquatic Plant Management* 29:80-82.

**Pipalova, I.** 2006. A review of grass carp use for aquatic weed control and its impact on water bodies. *Journal of Aquatic Plant Management* 44:1-12.

**Piriz, M.L. & Casas, G**.1994. Occurrence of *Undaria pinnatifida* in Golfo Nuevo, Argentina. *Applied Phycology Forum* 10:4.

**Pitt, W.M., Cother, E.J., Cother, N.J. & Ash, G.J**. 2004. Infection process of *Plectosporium alismatis* on host and non-host species in Alismataceae. *Mycology Research* 108:837-845.

**Pryfogle, P.A., Rinehart, B.N. & Ghio, E.G**. 1997. *Aquatic plant control research*. Idaho National Engineering Laboratory, DE-AC07-94ID13223.

**Pulz, O. & Gross, W**. 2004. Valuable products from biotechnology of microalgae. *Applied Microbiology and Biotechnology* 65:635-648.

**Qasim, R. & Barkati, S**. 1985. Ascorbic acid and dehydroascorbic acid contents of marine algal species from Karachi Pakistan. *Journal of Scientific and Industrial Research* 28:129-133.

**Radmer, R.J**. 1996. Algal diversity and commercial algal products. *BioScience* 46:263-270.

**Rai, S., Mukherjee, A.K., Saha, B.P. & Mukherjee, P.K**. 2005. Antioxidant activity of *Nelumbo nucifera* (sacred lotus) seeds. *Journal of Ethnopharmacology* 104:322-327.

**Ralph, P.J. & Short, F.T**. 2002. Impact of the wastin disease pathogen, *Labyrinthula zosterae*, on the photobiology of eelgrass *Zostera marina*. *Marine Ecology Progress Series* 226:265-271.

**Rani, V.U. & Bhambie, S**. 1983. A study on the growth of *Salvinia molesta* Mitchell in relation to light and temperature. *Aquatic Botany* 17:119-124.

**Rao, P.V.S., Mantri, V.A. & Ganesan, K**. 2007. Mineral composition of edible seaweed *Porphyra vietnamensis*. *Food Chemistry* 102:215-218.

**Relini G., Relini, M. & Torchia, G**. 2000. The role of fishing gear in the spreading of allochthonous species: the case of *Caulerpa taxifolia* in the Ligurian Sea. *ICES Journal of Marine Science* 57:1421–1427.

**Richardson, D.M., Wilson, J.R., Weyl, O.L.F. & Griffiths, C.L**. 2011. South Africa: Invasions, pp. 643-651. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). University of California Press, Los Angeles, CA. 765p.

**Robertson, A.I. & Hansen, J.A**. 1982. *Decomposing seaweeds: A nuisance or a vital link in coastal food chains?* CSIRO Marine Laboratories Research Report, 75-83.

**Rochon, D., Reade, R., Kakani, K. & Robbins, M**. 2004. Molecular aspects of plant virus transmission by *Olpidium* and plasmodiophorid vectors. *Annual Review of Phytopathology* 42:211-241.

**Rockwell, W.H**. 2003. *Summary of a survey of the literature on the economic impact of aquatic weeds*. Report to the Aquatic Ecosystem Restoration Foundation. (Available at: http://www.aquatics.org/pubs/economic_impact.pdf). 18 p.

**Roesijadi, G., Jones, S.B., Snowden-Swan, L.J. & Zhu, Y**. 2010. *Macro-algae as a biomass feedstock: A preliminary analysis*. Report PNNL-19944 prepared for the US Department of Energy, Pacific Northwest National Laboratory, Richland, Washington. 41 p.

**Rossano, R., Ungaro, N., D'Ambrosio, A., Liuzzi, G.M. & Riccio, P**. 2003. Extracting and purifying R-phycoerythrin from Mediterranean red algae *Corallina elongata* Ellis & Solander. *Journal of Biotechnology* 101:289-293.

**Ruesink, J.L. & Collado-Vides, L**. 2006. Modeling the increase and control of *Caulerpa taxifolia*, and invasive marine macroalga. *Biological Invasions* 8:309-325.

**Ruskin, F.R**. 1975. *Underexploited tropical plants with promising economic value*. Report of an Ad Hoc Panel of the Advisory Committee on Technology Innovation Board on Science and Technology for International Development, Commission on International Relations. Washington, DC, National Academy of Sciences. 200 p.

**Ruskin, F.R. & Shipley, D.W**. 1976. *Making aquatic weeds useful: some perspectives for developing countries*. Ad Hoc Panel of the Advisory Committee on Technology Innovation Board on Science and Technology for International Development, Commission on International Relations. Washington, DC. National Academy of Sciences. 194 p.

**Salvador, N., Garreta, A.G., Lavelli, L. & Ribera, M.A**. 2007. Antimicrobial activity of an Iberian macro-algae. *Scientia Marina* 71:101-113.

**Savino, J.F. & Stein, R.A**. 1989. Behavior of fish predators and their prey: habitat choice between open water and dense vegetation. *Environmental Biology of Fishes* 24:287-293.

**Sayce, K**. 1988. *Introduced cordgrass (Spartina alterniflora Loisel.) in saltmarshes and tidelands of Willapa Bay, Washington*. Ilwaco, Washington State, USA, Scientific Report 87053, US Fish and Wildlife Service Research Report, Willapa National Wildlife Refuge. 70 p.

**Scheffer, M**. 1998. *Ecology of shallow lakes*. London, Chapman and Hall. 357p.

**Schierenbeck, K.A**. 2011. Hybridization and Introgression, pp. 342-346. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765p.

**Schnepf, E., Kühn, S.F. & Bulman, S**. 2000. *Phagomyxa bellerocheae* sp. nov. and *Phagomyxa odontellae* sp. nov., Plasmodiophoromycetes feeding on marine diatoms. *Helgoland Marine Research* 54:237-241.

**Sculthorpe, C.D**. 1967. *The biology of aquatic vascular plants*. London, Edward Arnold. 610 p.

**Shabana, Y.M. & Charudattan, R**. 1996. Microorganisms associated with hydrilla in ponds and lakes in North Florida. *Journal of Aquatic Plant Management* 34:60-68.

**Sharma, B.M**. 1984. Ecophysiological studies on water lettuce in a polluted lake. Journal of *Aquatic Plant Management* 22:17-21.

**Shea, K. & Chesson, P**. 2002. Community ecology theory as a framework for biological invasions. *Trends in Ecology and Evolution* 17:170-176.

**Shearer, J.F**. 2010. A historical perspective of pathogen biological control of aquatic plants. *Weed Technology* 24:202-207.

**Silva, P.C., Woodfield, R.A., Cohen, A.N., Harris, L.H. & Goddard, J.H.R**. 2002. First report of the Asian kelp *Undaria pinnatifida* in the northeastern Pacific Ocean. *Biological Invasions* 4:333-338.

**Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., James, R. & Cacho, O**. 2004. The economic impact of weeds in Australia. *Weed Management Technical Series* 8:1-55.

**Sirenko, L.A., Kirpenko, Y.A. & Kirpenko, N.I**. 1999. Influence of metabolites of certain algae on human and animal cell cultures. *International Journal on Algae* 1:122-126.

**Sisneros, D., Lichtwardt, M. & Greene, T**. 1998. Low-dose metering of endothall for aquatic plant control in flowing water. *Journal of Aquatic Plant Management* 36:69-72.

**Smith, J.E**. 2011. Algae, pp. 11-15. In: *Encyclopedia of biological invasions* (Simberloff, D. and Rejmánek, M., eds.). Los Angeles, CA, USA, University of California Press. 765 p.

**Solibami, V.J. & Kamat, S.Y**. 1985. Distribution of tocopheral (vitamin E) in marine algae from Goa, West Coast of India. Indian *Journal of Marine Sciences* 14:228-229.

**Sousa, W.T.Z**. 2011. *Hydrilla verticillata* (Hydrocharitaceae), a recent invader threatening Brazil's freshwater environments: a review of the extent of the problem. *Hydrobiologia* 669:1-20.

**Spaulding, S. & Elwell, L**. 2007. *Increase in nuisance blooms and geographic expansion of the freshwater diatom* Didymosphenia geminate*: Recommendations for response*. White Paper. United States Environmental Protection Agency, 33 p.

**Spencer, D., Lembi, C. & Blank, R**. 2006. Spatial and temporal variation in the composition and biomass of algae present in selected California rice fields. *Journal of Freshwater Ecology* 21:649-656.

**Spencer, D. & Lembi, C**. 2007. Evaluation of barley straw as an alternative algal control method in California rice fields. *Journal of Aquatic Plant Management* 45:84-90.

**Spencer, D.F., Liow, P.S. & Lembi, C.A.** 2011. Growth response to temperature and light in *Nostoc spongiaeforme* (Cyanobacteria). *Journal of Freshwater Ecology* 26:357-363.

**Stoddard, A.A. III**. 1989. The phytogeography and paleofloristics of *Pistia statiotes* L. *Aquatics* 11:21-23.

**Stone, L**. 2011. Waltz of the weevil. *Nature* 470:47-49.

**Subramanian, K.A. & Singal, S.K**. 2005. Utilization of liquid biofuels in automotive diesel engines: An Indian perspective. *Biomass & Bioenergy* 29:65-72.

**Sutton, D.L**. 1985. Biology and ecology of *Myriophyllum aquaticum*. Proceedings*, First* International Symposium on watermilfoil (*Myriophyllum spicatum*) and Related Haloragaceae Species. 23-24 July 1985. Vancouver, BC, Canada. pp. 59-71.

**Swapna, M.M., Prakashkumar, R., Anoop, K.P., Manju, C.N. & Rajith, N.P**. 2011. A review on the medicinal and edible aspects of aquatic and wetland plants of India. *Journal of Medicinal Plants Research* 5:7163-7176.

**Sytsma, M.D. & Anderson, L.W.J**. 1993. Biomass, nitrogen, and phosphorus allocation in parrotfeather (*Myriophyllum aquaticum*). *Journal of Aquatic Plant Management* 31:244-248.

**Tate, W.B., Allen, M.S., Myers, R.A., Nagid, E.J. & Estes, J.R**. 2003. Relation of age-0 largemouth bass abundance to hydrilla coverage and water level at Lochloosa and Orange Lakes, Florida. *Journal of Fisheries Management* 23:251-257.

**Tardío, J., Pascual, H. & Morales, R**. 2005. Wild food plants traditionally used in the Province of Madrid, central Spain. *Economic Botany* 59:122-136.

**Taylor, B.W. & Irwin, R.E**. 2004. Linking economic activities to the distribution of exotic plants. *Proceedings of the National Academy of Science* 101: 17725–17730.

**Thamasara, S**. 1989. Problems and control of aquatic weeds in the irrigation systems of Thailand. *Journal of Aquatic Plant Management* 27:37-40.

**Theel, H.J., Dibble, E.D. & Madsen, J.D**. 2008. Differential influence of a monotypic and diverse native aquatic plant bed on a macroinvertebrate assemblage; an experimental implication of exotic plant induced habitat. *Hydrobiologia* 600:77-87

**Thomas, P.A. & Room, P.M**. 1986. Taxonomy and control of *Salvinia molesta*. *Nature* 320:581-584.

**Toft, J.D., Simenstad, C.A., Cordell, J.R. & Grimaldo, L.F**. 2003. The effects of introduced water hyacinth on habitat structure, invertebrate assemblages, and fish diets. *Estuaries* 26:746-758.

**Valentine, J.P. & Johnson, C.R**. 2003. Establishment of the introduced kelp Undaria pinnatifida in Tasmania depends on disturbance to native algal assemblages. *Journal of Experimental Marine Biology and Ecology* 295:63-90.

**Van, T.K.** 1989. Differential responses in monoecious and dioecious *Hydrilla verticillata*. *Weed Science* 37:552-556.

**Van, T.K. & Steward, K.K**. 1990. Longevity of monoecious hydrilla propagules. *Journal of aquatic plant management* 28:74-76.

**Vandiver, V.V., Jr**. 1980. Hygrophila. *Aquatics* 2:4-11.

**Van Dyke, J.M.** 1994. Long-term use of grass carp for aquatic plant control in Deer Point lake, Bay County, Florida, pp. 146-150. In: *Proceedings of the Grass Carp Symposium*. Vicksburg, MS, USA, US Army Corps. Engineers.

**van Wilgen, B.W, Richardson, D.M., Le Maitre, D.C., Marais, C. & Magadlela, D**. 2001. The economic consequences of alien plant invasions: examples of impacts and approaches to sustainable management in South Africa. *Environmental, Development and Sustainability* 3:145-168.

**Vennum, T.** 1999. Traditional and social context of ricing, pp. 1-7. In: *Proceedings of the Wild Rice Research & Management Conference* (Williamson, L.S., L.A. Dlutkowski, and A.P. McCammon Soltis, eds.). Odanah, WI, USA, Great Lakes Indian Fish and Wildlife Commission. 238 p.

**Walker, A.K. & Cambell, J**. 2009. First records of the seagrass parasite *Plasmodiophora diplantherae* from the northcentral Gulf of Mexico. *Gulf and Caribbean Research* 21:63-65.

**Walker, D.I., Masini, R.J. & Paling, E.I**. 1988. Comparison of annual production and nutrient status of the primary producers in a shallow limestone reef system (Rottnest Island), Western Australia. Proceedings of Australian Marine Sciences Association Silver Jubilee Conference: 1–5.

**Watanebe, F., Takenaka, S., Katsura, H., Zakir Hussain Masumder, S.A.M., Abe, K., Tamura, Y. & Nakano, Y**. 1999. Dried green and purple lavers (Nori) contain substantial amounts of biologically active vitamin B12 but less of dietary iodine relative to other edible seaweeds. *Journal of Agricultural and Food Chemistry* 47:2341-2343.

**Wersal, R.M., McMillan, B.R. & Madsen, J.D**. 2005. Food habits of dabbling ducks during fall migration in a prairie pothole systems, Heron Lake, Minnesota. *Canadian Field Naturalist* 119:546-550.

**Wersal, R.M., Madsen, J.D., McMillan, B.R. & Gerard, P.D**. 2006. Environmental factors affecting biomass and distribution of *Stuckenia pectinata* in the Heron Lake System, Minnesota, USA. *Wetlands* 26:313-321.

**Wersal, R.M. & Getsinger, K.D**. 2009. Chapter 3: Impacts of invasive aquatic plants on waterfowl, pp. 19-24. In: Biology and control of aquatic plants: a best management practices handbook (Gettys L.A., W.T. Haller, and M. Bellaud, eds.). Marietta GA, USA, Aquatic Ecosystem Restoration Foundation. 210 p.

**Wersal, R.M., Cheshier, J.C., Madsen, J.D. & Gerard, P.D**. 2011. Phenology, starch allocation, and environmental effects on *Myriophyllum aquaticum*. *Aquatic Botany* 95:194-199.

**Wersal, R.M. & Madsen**, **J.D.** 2011. Influences of water column nutrient loading on growth characteristics of the invasive aquatic macrophyte *Myriophyllum aquaticum* (Vell.) Verdc. *Hydrobiologia* 665:93-105.

**Wetzel, R.G.** 2001. Limnology: lake and river ecosystems, third edition. San Diego, CA, USA, Academic Press. 1006 p.

**Widdows, J., Pope, N.D. & Brinsley, M.D**. 2008. Effect of Spartina anglica stems on near-bed hydrodynamics, sediment erodibility and morphological changes on an intertidal mudflat. *Marine Ecology Progress Series* 362:45-57.

**Wikfors, G. H. & Ohno, M**. 2001. Impact of algal research in aquaculture. *Journal of Phycology*37:968-974.

**Williams, P.A. & Timmins, S.** 2002. Economic impacts of weeds in New Zealand, pp. 175-184. In: Pimentel, D., (ed.) *Biological Invasions: economic and environmental costs of alien plant, animal, and microbe species*. Boca Raton, FL, USA, CRC Press.

**Wu, M.J., Wang, L., Weng, C.Y. & Yen, J.H**. 2003. Antioxidant activity of methanol extract of the lotus leaf (*Nelumbo nucifera* Gaertn.). *The American Journal of Chinese Medicine* 31:687-698.

**Xiaoling, M. & W. Qingyu**. 2006. Biodiesel production from heterotrophic microalgal oil. Bioresource Technology 97:841-846.

**Xu, H., Ding, H., Li, M., Qiang, S., Guo, J., Han, Z., Huang, Z., Sun, H., He, S., Wu, H. & Wan, F**. 2006. The distribution and economic losses of alien species invasions to China. *Biological Invasions* 8:1495-1500.

**Yan, X., Chuda, Y., Suzuki, M. & Nagata, T**. 1999. Fucoxanthin as a major antioxidant in *Hijikia fusiformis*, a common edible seaweed. *Bioscience Biotechnology and Biochemistry* 63:605-607.

**Yusuf, C.** 2007. Biodiesel from microalgae. *Biotechnology Advances* 25:294-306.