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Protecting the world's plant resources from pests

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Aquatic plants their uses and risks

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Contents

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 m 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 was 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

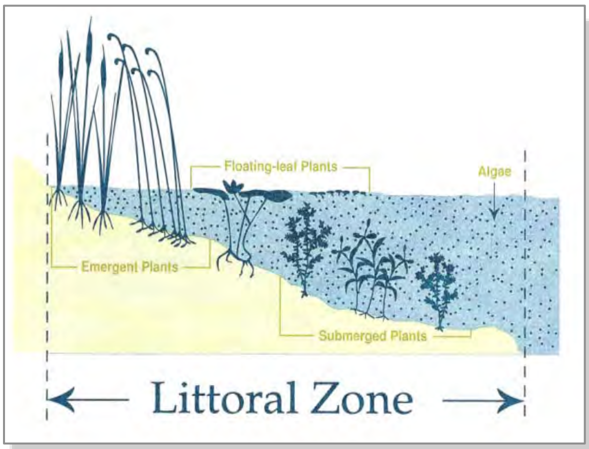


Figure 2.1. A diagrammatic representation of a freshwater littoral zone, Minnesota Department of Natural Resources.

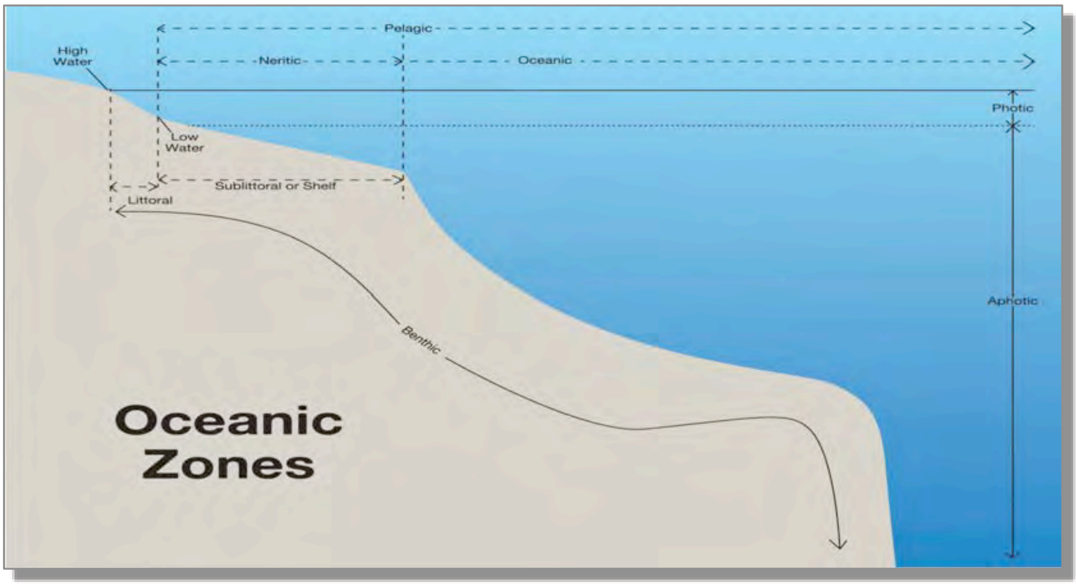
Much of the primary production in aquatic systems occurs in neritic (marine) or littoral (freshwater) areas as a function of both macrophytes and algae (Figure 2.1 and 2.3).

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.

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, Macrocystis, Nereocystis, Palmaria, Ulva, Undaria, Fucus, Porphyra, and Saccharina

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



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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).

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 largely by suspended materials (Chambers and Kalff, 1985; Congdon and McComb, 1979; Barko *et al.*, 1986; Madsen *et al.*, 2006).

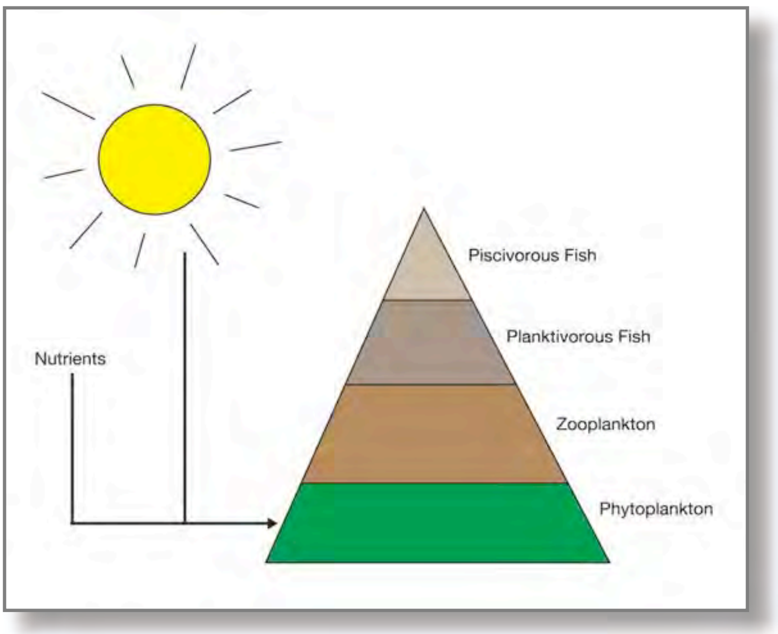


Figure 2.3 – A simplified representation of an aquatic food pyramid. Adapted from Madsen (2009).

In most freshwater systems aquatic plants are important components of food-web dynamics (Figure 2.3). 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 been 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, five red algae, two green algae, and two 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 fibre (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 and 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 g 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 used 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.). Plant species 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 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 per year, with the majority being comprised of Spirulina, Chlorella, and *Dunaliella* spp. (Pulz and Gross, 2004). The predominate uses (75 percent of production) of 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, the Czech Republic, Germany, Hungary, Switzerland, Austria, Turkey, Latvia, and Estonia (Brunel, 2009). In total, it was estimated that these ten 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 used for ornamental purposes are not native to the country where they are 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 spread to Spain, France, Italy, Croatia, and Tunisia overtaking native algal and seagrass species (Galil, 2011). Furthermore, 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 water lilies (*Nymphae* spp.) is a major pathway for the spread of hydrilla, as hydrilla tubers are often contaminants in the sediment where water lilies 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 as a result of 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 environments they invade (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 use 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).

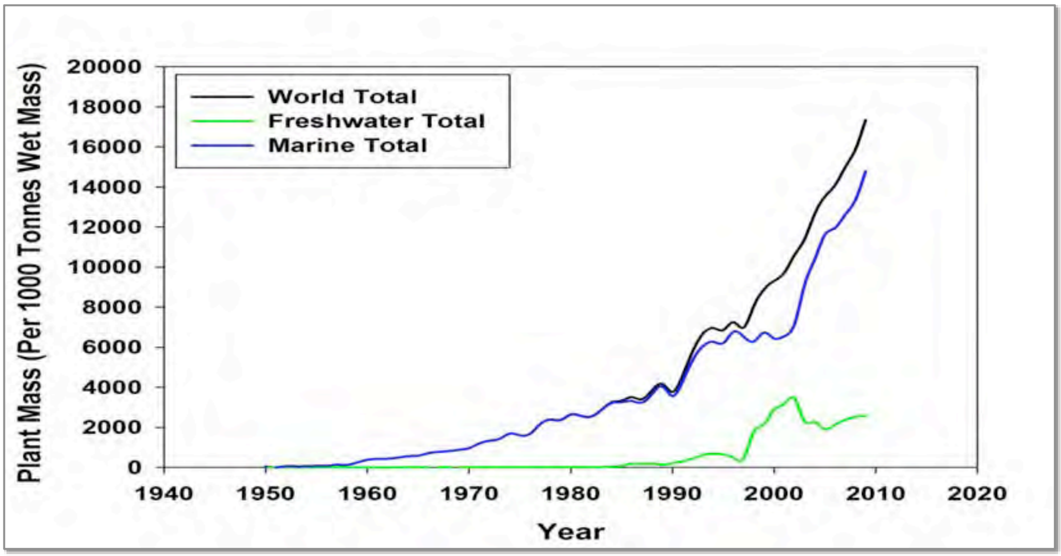
Economic benefits of aquatic plants

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). 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). Countries contributing to 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, the Philippines, 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 and 8 billion, with a peak in 2007 of > US$7 billion (Figure 2.6). 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).

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.



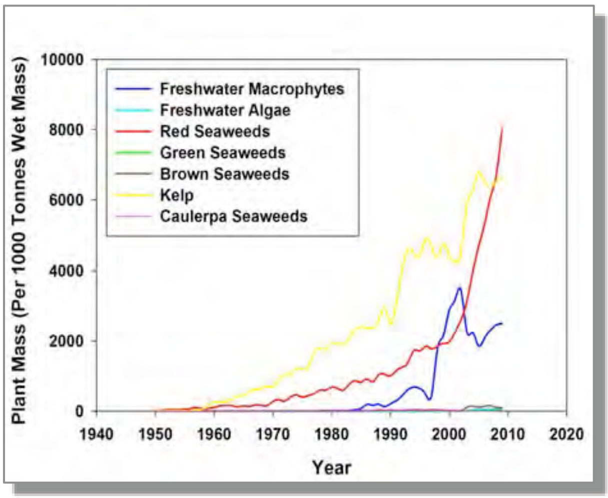


Figure 2.5 – The global harvest of marine and freshwater aquatic plants by taxa group from 1950 to 2009.

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.

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). 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.

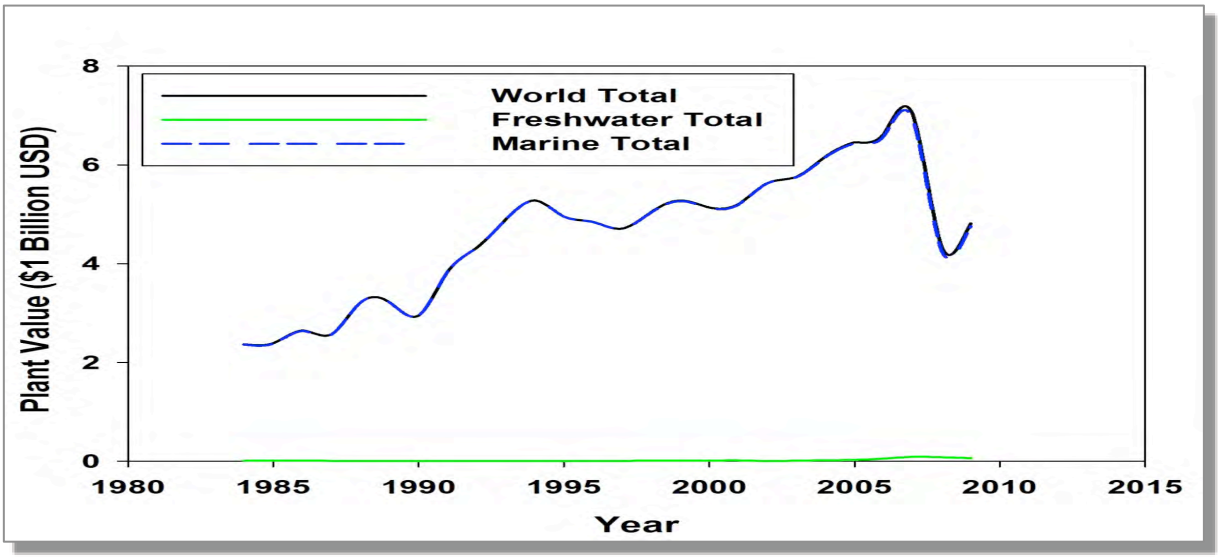


Figure 2.6 – The global value of marine and freshwater aquatic plants from 1984 to 2009.

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

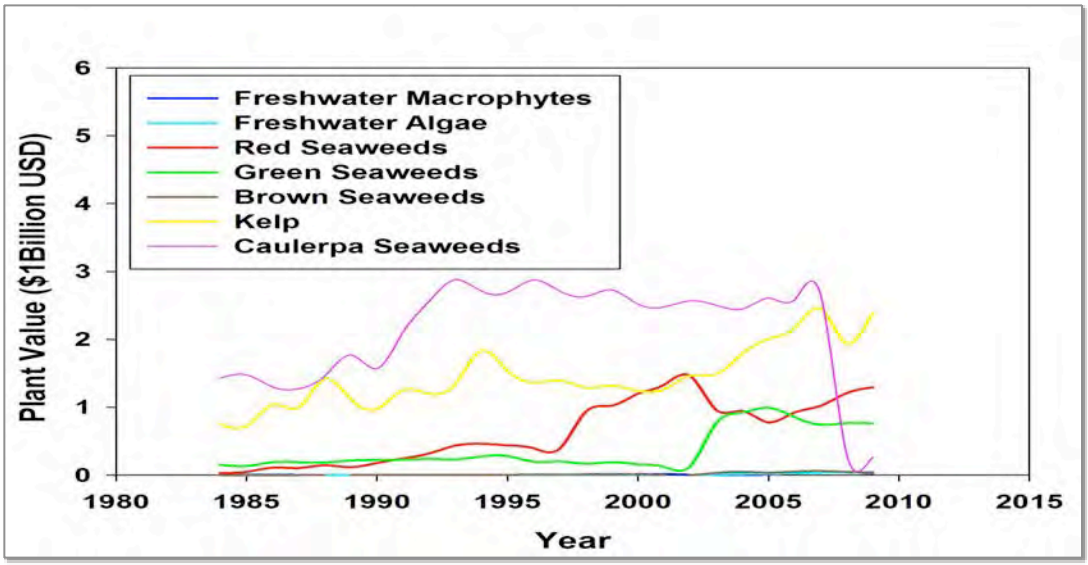


Figure 2.7 – The global value of marine and freshwater aquatic plants by taxa group from 1984 to 2009. Data were downloaded from the Food and Agriculture Organization, Fisheries and Aquaculture Department, Fisheries Statistics Collection available at: http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en.

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. Photo by Tom Woolf.

The centre shelf has containers of both water hyacinth and water lettuce for sale, and the bottom shelf containers of parrotfeather for sale.

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 growth 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 it possible to completely eliminate *C. taxifolia* (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 the 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).

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

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, and valued 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.

Cordgrass (*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).

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).

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

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

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 cordgrass on mudflats results in a complete shift 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). Since the 1800s water hyacinth has been spread primarily by people throughout the world. 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

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

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).

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).

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).

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

Reliance 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.

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

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 twenty 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).

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).

The rapid doubling times of leaves would allow giant salvinia, growing in good conditions to produce 45.6 to 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 Zimbabwe, 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 8 – A dense bed of giant salvinia covering golf course ponds at the Dorado Beach Golf Club, Dorado, Puerto Rico. Photo by Wilfredo Robles.

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).

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

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).

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).

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

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.

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

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).

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).

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).

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

Ecologically, dense infestations of 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.

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.

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

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).

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).

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.

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

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). 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).

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

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*), including 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) 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 (Schardt pers. comm.). 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).

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

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).

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).

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).

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).

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

Parrotfeather can survive frequent inundation of salt water as long as concentrations remain below 4 ppt (Sutton, 1985). 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.

There is little information about the direct impact 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-borne 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 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.

Photo 20 – Parrotfeather in an irrigation canal in Idaho (USA). Photo by Tom Woolf.

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

Parrotfeather is not generally a strong competitor, especially as species richness at a 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.

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 streambeds 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 to 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, which 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 has implications as to where 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 and 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, there are reports of what might be termed 'nontraditional' costs of invasive species. For example, economic analysis 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 Annex 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	
Epaltes divaricata		Emergent	X

Annex 1 continued

Botanical name	Common name	Growth habit	Economic or human usefulness[1]
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	

Annex 1 continued

Botanical name	Common name	Growth habit	Economic or human usefulness[1]
Phragmites australis	Common reed	Emergent, grass	
Phyla nodiflora		Emergent	X
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 cordgrass	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	

Annex 1 continued

Botanical name	Common name	Growth habit	Economic or human usefulness1
Freshwater algae			
Didymosphenia geminata	Didymo	Mat forming algae	
Nostoc spp.			
Marine			
Ascophyllum nodosum			
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	Cordgrass	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

Annex 4 continued

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

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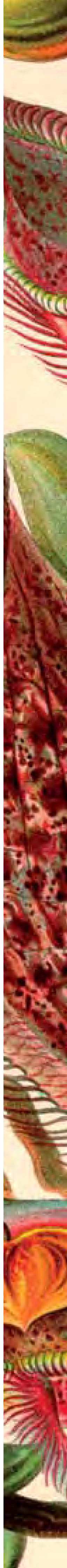
IPPC

The International Plant Protection Convention (IPPC) is an international plant health agreement that aims to protect cultivated and wild plants by preventing the introduction and spread of pests. International travel and trade are greater than ever before. As people and commodities move around the world, organisms that present risks to plants travel with them.

Organization

- The number of contracting party signatories to the Convention exceeds 177.
- Each contracting party has a National Plant Protection Organization (NPPO) and an Official IPPC contact point.
- Regional Plant Protection Organizations (RPPOs) have been established to coordinate NPPOs in various regions of the world.
- IPPC liaises with relevant international organizations to help build regional and national capacities.
- Secretariat is provided by the Food and Agriculture Organization of the United Nations (FAO-UN).



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