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INVASIVE AQUATIC PLANTS AND THE AQUARIUM AND ORNAMENTAL POND INDUSTRIES

by

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A thesis

presented to Ryerson University

in partial fulfilment of the

requirements for the degree of

Master of Applied Science

in the Program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2011

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ABSTRACT

INVASIVE AQUATIC PLANTS AND THE AQUARIUM AND ORNAMENTAL POND INDUSTRIES

Master of Applied Science 2011

Shakira Stephanie Elaine Azan

Environmental Applied Science and Management

Ryerson University

The purpose of the research was to clarify the common traits of a successful aquatic invasive plant. The biological traits of aquatic plants sold by aquarium and ornamental pond stores in the Greater Toronto Area, Ontario were analysed using logistic regression analyses (LRM). The multinomial LRM successfully predicts group identity 63% of the time, clearly differentiating native invasive and native non invasive from alien invasive (AI), but not alien non invasive (ANI) from AI. In contrast, the binomial LRM effectively discriminates ANI from AI taxa 77% of the time. The variables that best discriminated between AI and ANI are type of propagation strategies, number of propagation strategies used, number of dispersal mechanisms used, minimum temperature, and sales volume of aquatic plants as a proxy for introduction. Recognizing the common traits of successful invaders allows for the identification of ANI taxa that have the potential to become invaders, prior to introduction, thus preventing future invasions.

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"A gem cannot be polished without friction, nor a man perfected without trials"

Chinese proverb

When I decided to embark on the journey of pursuing another Masters, I had no expectations, but had an open mind for anything that could happen. I did not foresee that this journey would have been filled with so many unforgettable experiences that have helped to shape me into the gem that I have become. To all who contributed to these experiences, I would like to say a big thank you. The completion of this thesis would not have been possible without the assistance of a number of persons; to them I would like to express my deepest appreciation.

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LIST OF ABBREVIATIONS

AI	Alien and invasive
ANI	Alien and non-invasive
APHIS	Animal and Plant Health Inspection Service
BLRM	Binomial logistic regression model
CFIA	Canadian Food Inspection Agency
CI	Confidence interval
GTA	Greater Toronto Area
IAS	Invasive alien species
IPNI	International Plant Nomenclature Index
IPPC	International Plant Protection Convention
ISPM	International Sanitary and Phytosanitary Measures
ITIS	Integrated Taxonomic Information System
LRM	Logistic regression model
MVP	Minimum viable population
NI	Native and invasive
NNI	Native and non-invasive
PHRA	Plant Health Risk Assessment Unit
PPA	Plant Protection Act
PPR	Plant Protection Regulations
PRA	Pest risk analysis
RMD	Risk management document
OFAH	Ontario Federation of Anglers and Hunters
USA	United States of America
USDA	United States Department of Agriculture
WSO	Weed Seeds Order

1.0 INTRODUCTION

1.1 *Invasive alien species*

As trade and shipments between and within countries increase, the inclusion of potentially invasive alien species is of increasing concern. Invasive alien species (IAS) are species that are introduced, or distributed outside of their native geographical range (historical and present) and as a result, threaten biological diversity (CBD, 2010). Consequently, IAS have been recognised as the second greatest threat to biological diversity globally after habitat loss (Genovesi, 2009; UNEP, 2010).

IAS are mainly introduced into environments through direct and/or indirect human activity. Raaymakers (2002) noted that humans aided the process of species dispersal based on their movements from place to place as well as traversing the seas, creating pathways for the introduction of IAS. These pathways include, but are not limited to: floating marine debris; recreational and commercial vessels; hitch-hiking on humans, their equipment, and ships; research and education; household goods, packaging material and containers; waste materials; biological control agents; agriculture and horticulture; marine biofouling (hull fouling) and ballast water; and trade in plant seeds, pets, aquaculture, mariculture, and aquarium species (Carlton, 2001; McNeeley *et al.*, 2001; Wittenberg and Cock, 2001; Nentwig *et al.*, 2007).

IAS have become established in almost every ecosystem on earth (CBD, 2010). The success of these invasions has been attributed to common traits exhibited by the species, that is: they are tolerant to a variety of habitat conditions; grow and reproduce rapidly; have high dispersal and survival rates; lack natural predators or pests within the new environment; exhibit phenotypic plasticity; are able to survive on a wide range of food types; have single parent reproduction (asexual or vegetative reproduction); compete aggressively for food, water and space; and are usually associated with humans (Williams and Meffe, 1998; Raaymakers, 2002; Sutherland, 2004; Thiébaud, 2007; CBD, 2010).

Even though these traits are considered common amongst successful invaders, Williams and Meffe (1998, p. 119) notes that the traits were “mere generalizations and did not guarantee that an invader would be highly successful and absence of most of the characteristics did not preclude the invasion of a species in a given circumstance.” Other issues associated with using only these traits to determine future invaders is the fact that all species do not behave in a like manner (Williams and Meffe, 1998) and even if these species possessed the traits that favour invasion, they may not become established in the new environment and/or become naturalized species (Mack, 1996; Williams and Meffe, 1998).

There is also the discrepancy of how many attributes actually make for a successful invader since some species show most if not all traits, while some show only few (Mack, 1996). In addition, the invasive potential of a species may not be attributable to the traits possessed, but actually to the state of the environment (e.g. disturbed sites) in which it was introduced (Mack, 1996). Owing to the continued debate about the traits of a successful invader, one precautionary approach that has been recommended is that a good predictor of invasiveness is whether or not the species had successfully or unsuccessfully invaded somewhere else (CBD, 2010). For example, although mosquito fern (*Azolla pinnata*) has not been recorded for Canada, and more specifically, Southern Ontario, this aquatic plant is invasive in New Zealand and has replaced a native species of the same genus (GISD, n.d.a).

Since there appears to be some inconclusiveness in using the traits of successful invaders on their own, this research seeks to determine if there is a relationship between the presence of biological traits of successful invaders and likelihood of introduction. There is a possibility that the biological traits of successful invaders are co-dependent on their opportunities for introduction to determine likelihood of invasion success. For example, if a particular plant has traits that make it a successful invader but has a low chance of introduction in the natural environment, then this plant would be considered low risk in comparison to a plant with less favourable traits but has a greater chance for introduction.

Nevertheless, the presence of IAS results in extensive, and in some instances, irreversible impacts to the environment, public health and the economic sector. When present, IAS may alter the natural habitat and its ecological processes, displace native species, introduce pathogens to the ecosystem as well as the public sector, and reduce economic outputs in agriculture, industry, commercial and recreational activities (Raaymakers, 2002; Genovesi, 2009). For example, the presence of water hyacinth (*Eichhornia crassipes*) in basins and streams of countries such as tropical Africa and Australia has impeded the navigation of local communities on water as well as access to potable water and fish (Genovesi, 2009).

1.1.1 The Problems with prevention, control and mitigation of IAS

The prevention, control and mitigation of IAS are not without problems. Generally, in nature, species distribution is influenced by factors such as evolved dispersal mechanisms, distance from colonizing sources, geographic barriers (e.g. landmasses, water bodies), chance, and geological structures (e.g. mountains and oceans), which have fostered the evolution of distinctive regional biotas (MacIsaac *et al.*, 2001). However, events such as climate change, natural disasters, and human activities have been found to facilitate dispersal of species to suitable habitats that were, until that time, beyond the species' natural dispersal capabilities (MacIsaac *et al.*, 2001). Additionally, Genovesi (2009, p. 3) notes that the "increasing rate of invasions is largely a consequence of the continuing globalisation of economies and the subsequent increase in trade, travel and tourism, which result in IAS moving into new environments faster." Owing to the presence of these pathways, introductions of plants and other species into aquatic environments, for example, will likely increase, and as such, will prove difficult to prevent, control, and/or mitigate.

As human activities increase in areas such as trade, travel, and tourism, so do the number of invasion pathways attributed to humans. In instances where these pathways are unknown, undocumented or unresearched, the ability to prevent and control IAS becomes extremely difficult. The importance in knowing the pathways of IAS invasions has been described by Leung *et al.* (2006, p. 241), who indicate that "it is critical to forecast where

invasions will take place and to identify areas that act as major sources for further invasions in order to focus management efforts and to reduce the probability of invasion or the rate of spread.” Leung *et al.* (2006, pp. 241-242) also note that while analysis of specific single species is important and necessary (e.g. biology and behaviour), “analyses of pathways allow the prediction of the spread of multiple species and facilitates the forecasting of potential spread before the IAS actually arrive.”

Other problems associated with the prevention and control of IAS have been adequately summarised by Mack *et al.* (2000, p. 1) who report that

identifying future invaders and taking effective steps to prevent their dispersal and establishment is a major challenge to ecology, agriculture, aquaculture, horticulture and pet trades, conservation, and international commerce as the identification of the general attributes of future invaders has proven difficult; prediction of susceptible locales for future invasions is even more problematic given the large differences in trade among various regions and in the rate of arrival of potential invaders; eradication of established invaders was rare and control efforts varied enormously in their efficacy; and prevention of invasions is much less costly than post-entry control.

It is important to note that Mack *et al.* (2000) highlighted the fact that identification of future invaders has proven difficult despite earlier research studies (e.g. Baker, 1974; Bazzaz, 1986; Newsome and Noble, 1986; Ehrlich, 1989; Sutherland, 2004) that have tried to ascertain the attributes of future and successful invaders. Accordingly, this research is important as it strives to understand how the biological traits that are favourable for invasion interacts with opportunities of introduction by considering a potentially important pathway for invasion of IAS aquatic plants (e.g. aquarium and ornamental pond industries¹).

1.2 Aquatic plant species

Aquatic plants are one group of organisms where the prevention and control of IAS continues to be a problem. MacIsaac *et al.* (2001, p. 406) notes that “the frequency of species invasion problems in aquatic ecosystems, in general, will likely continue to grow

¹ The ornamental pond industry is synonymous with the water garden industry.

commensurate with enhanced global commerce and human exploitation of these communities, which may be exacerbated by natural changes to species range owing to global climate change.” In terms of aquatic plants, and alien plants in general, human movement through the centuries have contributed to their establishment in new environments.

Aquatic plants were chosen as the focus of this research as some of the most problematic aquatic invaders known are aquatic plants (e.g. water hyacinth) (Lowe *et al.*, 2004). Moreover, the presence of invasive aquatic plants has resulted in large sums of money being expended by countries in order to manage their impacts. These costs not only include activities such as prevention, control and mitigation, but also indirect costs that result from impacts on ecological services and commerce. Furthermore, these costs may represent an underestimation of the true costs of IAS since they have the potential to disrupt ecosystem functions that are damaging but are not easily monetized. Trade in aquatic and ornamental plants, for example, has resulted in the United States of America (USA) investing a total of US\$110 million annually (~\$10 million in loss and damages, and \$100 million in control costs) in order to control the invasive aquatic plants, Hydrilla (*Hydrilla verticillata*), water hyacinth, and water lettuce (*Pistia stratiotes*) (Pimentel *et al.*, 2000). In addition, the USA exceeds US\$800 million per year in economic costs associated with the annual damage and/or control of three additional invasive aquatic plants, purple loosestrife (*Lythrum salicaria*), Eurasian watermilfoil (*Myriophyllum spicatum*), and water chestnut (*Trapa natans*) (Pimentel, 2005).

In order to illustrate the financial cost associated with a single aquatic plant species, purple loosestrife was selected. Purple loosestrife is an introduced aquatic plant that has resulted in the degradation of wetland habitats within the USA and Canada by the production of large monotypic vegetative stands. These stands in turn reduce biological diversity by replacing native plant species, thereby eliminating food and cover for wildlife (Malecki *et al.*, 1993; Liu *et al.*, 2008), and affect decomposition rates and nutrient recycling within wetlands (Liu *et al.*, 2008). Purple loosestrife has resulted in a loss of US\$45M in annual management costs and lost forage value, since the plant is currently found in 42 states of

the USA (US ANS Task Force, 2009). Comparatively, the Canadian provinces of Alberta, Saskatchewan, and Ontario expend cumulatively about CDN\$210,000 per annum for the eradication and control of purple loosestrife (Colautti *et al.*, 2006). Although purple loosestrife is also found in Manitoba, there have not been any projected economic costs (Lindgren, 2006).

Aquatic plants are also introduced into new environments via similar pathways of IAS; these include: movement of boating equipment (e.g. boats, anchors, trailers) between waterways, and dumping of live organisms into waterways (Minnesota Sea Grant Program, 1995); ships' ballast water and hull fouling from ships; canals; and releases from fishery, cultivation and aquaria (Mills *et al.*, 1993). In general, aquatic plants perform many functions including providing shelter for fish, birds, and other wildlife, protecting shorelines from erosion, serving medicinal purposes (e.g. water lettuce), providing fuel (e.g. water hyacinth), mosquito control (e.g. *Azolla*) and mulching and weed control (e.g. water hyacinth) (Little, 1979). When aquatic plants become invasive, however, their existence can result in negative impacts to one or more ecosystem functions (Raaymakers, 2002) as is true of IAS more generally.

Aquatic plants have been the subject of research studies to determine the traits that have made them successful invaders (e.g. Ashton and Mitchell, 1989; Thiébaud, 2007). Sutherland (2004) reported that knowing the traits of a successful invader was important as the knowledge provided greater understanding of the traits that could determine which species would be invasive, how invasive the species may become, the habitats that may be invaded by the species, and how could the species be controlled. In the case of aquatic plants, Breen *et al.* (1987) indicated that the success of aquatic plants as invaders in any habitat reflected the plant's ability to adapt its morphological, reproductive, and physiological strategies to avoid or overcome competition for the acquisition of resources.

On the other hand, there is uncertainty as to whether non-invading aquatic plants utilise the same strategies as aquatic invaders in the new environment; for example, a non-invading aquatic plant may possess similar traits of a successful invader but is not an

invader itself. Accordingly, this uncertainty has initiated a need to better understand the hierarchy of traits that will best predict the invasive success of aquatic plants including aspects such as opportunity for introduction. The ability to discern which traits are important in determining whether a plant will become invasive or not, if given the opportunity for introduction, is another knowledge gap that this research aims to fill.

1.2.1 Aquatic plants and the aquarium and ornamental pond industries

Since the biological traits that increase the likely success of invasive aquatic plants may be different in dissimilar environments (e.g. temperate versus tropical)², in order to focus the research paper, the province of Ontario, Canada was selected. Ontario has the highest numbers of invasive alien plant species in Canada (441), followed by Quebec (395) and British Columbia (368) (CFIA, 2008). In contrast, OIPC (2009) reported that Southern Ontario alone has approximately 440 invasive alien plants. Even though there is a discrepancy as to the exact number of invasive alien plants in Ontario, the CFIA (2008, p. 22) approximated that “0.58 new invasive alien plant species has been established in Canada every year during the last century.”

In terms of aquatic plants, 23 alien aquatic plants have been found in Lake Ontario (Mills *et al.*, 1993) while 56 aquatic plants in total had been introduced to the Great Lakes region and inland waters of Ontario as of 1993 (Mills *et al.*, 1993). Moreover, Liu *et al.* (2008) and the CBCN (2009) recorded an additional 10 aquatic plant species in Ontario waters that were not previously recorded by Mills *et al.* (1993). Examples of invasive aquatic plants found in Ontario waterways include, but are not limited to, the flowering rush (*Butomus umbellatus*), fanwort or Cabomba (*Cabomba caroliniana*), Eurasian watermilfoil, and European frog-bit (*Hydrocharis morsus-ranae*) (Liu *et al.*, 2008).

In Ontario, eight pathways were identified by Kerr *et al.* (2005) for the introduction of aquatic species: fish stocking programmes, private aquaculture, bait industry, aquarium

² One example of an aquatic plant that behaves differently in dissimilar environments is giant Salvinia (*Salvinia molesta*). In tropical environments, giant *Salvinia* doubles in population within two to four days whereas in temperate environments, the population doubles in 40–160 days (Ramakrishnan, 1991).

and ornamental pond industries, live food industry, recreational boating, canals and diversions, and commercial shipping. Of the eight pathways, the aquarium and ornamental pond industries and recreational boating were identified as sources for the introduction of aquatic plants. Kerr *et al.* (2005) further concluded that owing to gaps observed in Ontario's policies and legislations (e.g. a relative lack of regulatory control and import restrictions) one of the pathways of greatest potential for future introduction and spread of invasive aquatic species was the aquarium and ornamental pond industries; as such, the aquarium and ornamental pond industries was selected as the pathway for this research.

Kerr *et al.* (2005) reported that about 12 exotic plants and animals have been introduced in the Great Lakes Basin from aquarium releases; however, there were no records indicating the total number of introductions that have resulted from the aquarium and ornamental pond industries combined. The only other data presented were the number of aquatic plants that has been introduced into the Great Lakes (Table 1). Of note, the proportion of aquatic plants introduced was 42% of the total, while the second most introduced taxa, fish, amounted to 18% (Table 1).

Table 1: Number of aquatic species introduced into Ontario (Mills *et al.*, 1993)

Species	Number of species introduced
Aquatic plants	59
Fish	25
Algae	24
Molluscs	14
Crustaceans	6
Miscellaneous invertebrates	5
Oligochaetes	3
Diseases/pathogens	3
TOTAL	139

Funnell *et al.* (2009) in commentary on the number of alien aquatic plants recorded in the Great Lakes by Mills *et al.* (1993) emphasized the fact that the aquarium and ornamental pond industries may not have introduced these plants; however, given the fact that these plants are widely available through both industries, trade in these plants increased the risk of new introductions and spread. In the broader sense, Funnell *et al.* (2009, p. 105) indicates that “there is a relative lack of information regarding trends in the aquarium and water garden industry in Canada.” Provincially, Ontario has minimal statistics available on the aquarium and ornamental pond industries; however, the impression is that the sector is rapidly growing (Kerr *et al.*, 2005).

Despite the lack of statistics pertaining to the aquarium and ornamental pond industries, these industries have resulted in the introduction of aquatic plants such as *Cabomba*, Eurasian watermilfoil, water chestnut, and European frog-bit (Mills *et al.*, 1993). The presence of the aforementioned aquatic invasive species has resulted in costs of approximately CDN\$500 million per year in their control within the Great Lakes (CESD, 2001). Kerr *et al.* (2005), quoting MacIsaac (2003), also reported that approximately CDN\$750 million is expended annually to rectify damages to aquatic ecosystems caused by the presence of aquatic invaders in Canada. It is important to note that no information has been found regarding the economic costs of aquatic plants introduced specifically by the aquarium and ornamental pond industries. There are several stakeholders associated with the aquarium and ornamental pond industries who are involved in the dissemination of information regarding the trade within Ontario. These stakeholders are the Canadian Association of Aquarium Clubs (CAOAC), the Pet Industry Joint Advisory Council of Canada (PIJAC), Ontario Federation of Anglers and Hunters (OFAH), and Ontario Streams.

1.3 Rationale for study

Owing to the increasing success of aquatic plant IAS, one of the questions that arise is: What makes one aquatic plant a more successful invader than another? More specifically, what vital biological traits when combined with opportunities for introduction best distinguish successful invaders from unsuccessful invaders? The answer to this question is

important given the fact that several attempts have been made to prepare lists of common traits for successful invaders that could be used to identify future invaders, especially in different taxonomic groups (Mack *et al.*, 2000). Answering this question will contribute to knowledge of the traits that define a successful invader, especially amongst aquatic plants.

Furthermore, the answers garnered would assist in management efforts being undertaken to address IAS, more specifically in terms of prevention. Ricciardi and Rasmussen (1998) stressed that there is a continuous need for research on the identity of future invaders. Knowing the characteristics of future invaders, they noted, was the best preventative step against invasion threats, and should be a common precedence amongst scientists and policy makers. Accordingly, knowing the traits that make one invader more successful than another may allow strategies to be developed (e.g. risk assessment) that would prevent and/or limit the introduction of species into new environments. Wittenberg and Cock (2001) stated that risk assessments are to be conducted for every proposed intentional introduction. Risk assessment, they suggested, supported the exclusion of species based on their perceived risk as well as assessed their potential impact on species already established. Moreover, the assessments serve to predict whether or not a species is likely to become established, to be invasive, and to generate a relative ranking of the risk.

1.4 Purpose and objectives

The purpose and objectives of the research paper are to understand and analyze what are the traits of a successful aquatic invader given the fact that: 1) there is a problem using biological traits on their own, 2) there is a possible relationship between traits and the likelihood for introduction, and 3) unsuccessful aquatic plants may utilise the same strategies or share the same biological traits as invaders yet not become invasive themselves. In order to understand how biological traits contribute to the formation of a successful aquatic invader, one has to examine the morphological, reproductive and physiological strategies that are employed by aquatic plants to be successful in aquatic environments. The research paper will utilise these strategies to answer the following questions:

1. Do the morphological strategies of aquatic plants (e.g. life form) sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?
2. Do the reproductive strategies of aquatic plants (e.g. asexual reproduction) sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?
3. Do the physiological strategies of aquatic plants (e.g. physiological tolerance) sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?

Given that the aquarium and ornamental pond industries are being examined as the likely pathways for the introduction of aquatic plant invaders, other research questions to be answered are:

4. Do the aquarium and ornamental pond industries have the potential to contribute to the success and/or failure of aquatic plant invaders based on the presence of aquatic plants with specific traits in the trade that increase their chances for introduction and invasion?
5. If these industries do contribute to the success of aquatic plant invaders, what is the legislative framework within Ontario that governs the introduction of these plants and how can it be amended or enforced to sufficiently address the problems posed by the industries?

The answers to these questions are important as they will serve to complement the findings of what makes one aquatic plant invader more successful than the other, and more specifically, in the formation of tools that can serve as a basis for the risk assessment proposed as a means of preventing IAS introduction. In addition, knowledge of the traits of a successful invader allows different management options to be identified to tackle aquatic plants in various settings (e.g. tropical versus temperate).

In terms of the aquarium and ornamental pond industries, which have been identified “as the highest risk of IAS introductions” (Kerr *et al.*, 2005, p. 25), knowledge of the traits of

successful invaders would encourage the use of other aquatic species that can be utilized in the aquarium and ornamental pond industries, thereby reducing and/or eliminating IAS impacts on the natural environment. Moreover, species could be traded that would pose a lesser environmental risk if released or permitted to escape.

2.0 LITERATURE REVIEW

2.1 *General Introduction*

Aquatic plants are adapted to live permanently or seasonally in wet environments and grow partially or completely in water. Also known as aquatic macrophytes or hydrophytes, aquatic plants can be found as one of three groups: emergent, floating-leaved or free floating and submerged (Lacoul and Freedman, 2006; Madsen, 2009). Aquatic plants are also found to be more species rich in temperate areas than in tropical areas (Crow, 1993). This paper will focus solely on freshwater aquatic plants.

Aquatic plants vary in their ability to become established in new environments as they differ in their capabilities to spread and disperse their propagules (Sculthorpe, 1967). In nature, aquatic plants are dispersed by three vectors: water (hydrochory), wind (anemophilous), and animals (zoochory); for example, plants or propagules may be dispersed by floating seeds and stems, free-floating plants, aerodynamic seeds, hard-coated seeds that survive animal digestion, or fruits with burrs (Lacoul and Freedman, 2006). Overall, these examples relate to the dispersal mechanisms used by aquatic plants and as such, may represent likely traits that contribute to the success of aquatic plant invasions.

In general, aquatic plants provide food, serve as a habitat for fish, wildlife and other aquatic organisms, stabilize sediments, and improve water clarity. When aquatic plants become invasive their presence results in both economic and ecological harm. Ecologically, invasive aquatic plants may threaten the structure and function of the aquatic ecosystem by reducing dissolved oxygen levels and shading out sunlight necessary for photosynthesis by submerged plants thus leading to death of other organisms (Schmitz *et al.*, 1993; Catling *et al.*, 2003; Madsen, 2009). Moreover, invasive aquatic plants can: degrade water quality; reduce species diversity; change sediment chemistry; increase detritus build up and alter animal community interactions (Madsen, 2009). Economically, invasive aquatic plants may prevent the use of waterways for navigation, fishing and swimming by their prolific growths, increase the risk of flooding (frequency, duration and intensity), reduce property

value (Simberloff *et al.*, 1997; Wilson *et al.*, 2007; Madsen, 2009), impair drinking water, and create a habitat for insect-borne disease vectors that threatens public health (e.g. malaria) (Madsen, 2009).

European frog-bit, Eurasian watermilfoil and *Cabomba* are examples of aquatic plants that are ecological and economical nuisances. Studies conducted on European frog-bit in Ontario, Canada and New York State, USA revealed that due to the presence of large free-floating mats of intertwined plants, European frog-bit prevents sunlight from getting to other submersed aquatic plants below. As a result, submersed aquatic plants face limited growth and access to nutrients and dissolved gases (Catling *et al.* 1988; O'Neill, 2007). In addition, the change in plant diversity may also affect native aquatic fauna (O'Neill, 2007). In the fall, European frog-bit can break apart and settle to the bottom of the lake. Subsequently, the breakdown of a large amount of vegetation in the water may lead to the depletion of oxygen levels and the death of fish and other aquatic organisms (O'Neill, 2007; OFAH, 2010). European frog-bit also blocks the movement of large fish and diving ducks as well as recreational uses such as boating and swimming (OFAH, 2010).

Aiken *et al.* (1979) reported that wherever Eurasian watermilfoil was located in Canada, species displacement occurred as the stands of Eurasian watermilfoil were often extensive covering water depths of 1m to 10m. In the Kawartha Lakes, Ontario, Eurasian watermilfoil covered approximately 80% of the water surface (Aiken *et al.*, 1979). Infestations of Eurasian watermilfoil affected human use of waterways especially for recreation, water transportation, and clogged potable water systems (Aiken *et al.*, 1979; White *et al.*, 1993). These infestations were also considered public safety and health hazards as swimmers could become entangled in the plant's dense stands or these stands could foster the increase of mosquito populations (Aiken *et al.*, 1979; White *et al.*, 1993). *Anopheles quadrimaculatus* is considered the chief vector of malaria in North America and "prefers habitats with well-developed beds of submergent, floating leaf, or emergent aquatic vegetation" (GISD, n.d.b); as such, the extensive stands of Eurasian watermilfoil could serve as a habitat for this mosquito.

Cabomba is a persistent, competitive and invasive aquatic plant that has been found to have significant impacts on aquatic ecosystems in its introduced range (Wilson *et al.*, 2007). Once established, *Cabomba* was found to grow quickly and form dense populations that displaced native species, and affected the use of waterways for industrial, recreational, and domestic purposes (Wilson *et al.*, 2007). Infestations of *Cabomba* also altered nutrient regimes by efficiently absorbing nutrients (nitrogen and phosphorus) directly from the water via its shoots, leaves and stems (Wilson *et al.*, 2007). In Kashiabog Lake near Peterborough, Ontario, *Cabomba* affected over 600 lakefront cottages, homes, and small businesses by impeding navigation, discouraging swimming, and altering the aesthetics of shoreline property (Wilson *et al.*, 2007). Ecologically, *Cabomba* may have excluded native aquatic vegetation, altered water quality, and affected faunal communities and commercial and sports fisheries. Moreover, the presence of *Cabomba* in the Great Lakes system would interfere with water-based industries such as power generation or aquaculture (Wilson *et al.*, 2007).

2.2 Pathways of introduction for aquatic plants

Although, aquatic plants have three main dispersal vectors, namely water, wind and animals, humans are the foremost vectors for some species, and are responsible for the deliberate or accidental introduction of aquatic IAS beyond their natural range (Lacoul and Freedman, 2006). The aquarium industry, internet, mail parcels/order catalogues, and ornamental ponds³ have been recognised as pathways that are used by humans for the introduction of aquatic plants into new environments. It is important to note that even though the aquarium and ornamental pond industries may use similar aquatic plants, they are often discussed separately in literature. So, in keeping with that tendency, the industries will be presented separately in this literature review unless the information was presented jointly by the author of the paper.

³ Ornamental ponds are synonymous with water gardens.

2.2.1 Aquarium industry

The aquarium industry is a pathway of concern for the proliferation and continued introduction of IAS into new environments since the trade has the potential to import an unknown number of species and individuals from around the world as invertebrates, fish, aquatic plants (marine and freshwater), and other organisms used as pets, displays, or in education or research (Carlton, 2001).

Elodea (*Elodea canadensis*) is one example of an aquatic plant introduced for display purposes. GISD (n.d.c) reported that *Elodea* is “introduced via the trade in live aquarium plants and is sold in garden centre shops as oxygen weed for private ponds to improve water quality and pond scenery.” *Elodea* is also used extensively in research studies relating to plant cellular structure, living protoplasm, respiration, photosynthesis, and physiological and developmental processes (Catling *et al.*, 1986). While not invasive in Canada, *Elodea* is considered a noxious weed in Europe, Australia, Africa, Asia, and New Zealand (Washington State Department of Ecology, n.d.). Brazilian waterweed (*Egeria densa*), another aquatic plant distributed by the aquarium industry is widely used in teaching botany classes and plant research especially in relation to cytoplasmic streaming as well as plant physiological and plant chemical research (Catling *et al.*, 1986; Lui, *et al.*, 2008). Owing to the extensive use of *Elodea* and Brazilian waterweed in research studies, these plants have been widely distributed outside of their native range. Moreover, they are now generally established without cultivation in areas such as North America, Central America, Africa, Australia, Europe, and Asia (Cook *et al.*, 1984).

Padilla and Williams (2004) interpreted the Lowe *et al.* (2004) list of invaders to say that the aquarium industry is primarily responsible for one-third of the world’s 100 worst invasive taxa. Of this list, Padilla and Williams (2004, p. 133) reports that about “150 species of vertebrates, invertebrates, microbes, and plants that have invaded natural ecosystems have been documented to come from aquarium or ornamental releases.” Accordingly, Padilla and Williams (2004) noted that the aquarium industry poses a serious and unrecognized threat to marine and freshwater ecosystems as a source of aquatic IAS.

Moreover, the threat caused by aquarium species is “increasing as the industry is unregulated and because of their extremely pervasive dispersal to homes and businesses after importation” (Padilla and Williams, 2004, pp. 131-132). Reichard and White (2001, p. 107) also reported that “aquatic weeds introduced for horticulture or private aquaria are often overlooked by persons focusing on the larger terrestrial plant trade, even though aquatic weeds are considered a critical pathway of pest species introductions.” Additionally, “because of the interconnected nature of aquatic systems, aquatic species can spread quickly, and can become very expensive to control” (Reichard and White, 2001, p. 107).

In retrospect, the likely outcomes of aquarium species are determined by the consumers who use and dispose of aquatic plants in an unregulated manner; for example, species distributed by the aquarium trade can enter the natural environment via dumping of unwanted organisms, escape from tanks, and the drainage of water containing organisms from tanks and public aquariums (Wittenberg and Cock, 2001; Padilla and Williams, 2004). Aquatic species such as *Cabomba*, water moss (*Salvinia* spp.), mosquito fern, parrot feather (*Myriophyllum aquaticum*), and Brazilian waterweed, are examples of plants that are generally distributed by the aquarium trade that may have entered waterways via the dumping of aquarium contents (Lui *et al.*, 2008). Reichard and White (2001) also noted that the aquarium trade was responsible for the introduction of Eurasian watermilfoil, which has been considered the “most troublesome aquatic invader in North America” (Claudi *et al.*, 2002, p. 35).

It is important to note that there are some arguments as to the actual pathway of introduction of Eurasian watermilfoil in the Great Lakes Basin. Mills *et al.* (1993, p. 27) reports that, Eurasian watermilfoil “most likely entered the Great Lakes Basin through aquarium release and transport in (ballast water) or attached to boats and ships.” The hypothesis postulated by Mills *et al.* (1993) regarding the source of Eurasian watermilfoil introduction was also supported by Aiken *et al.* (1979) and Lui *et al.* (2008). However, Westbrooks (1998) indicated that Eurasian watermilfoil had spread to Canada from the USA in water currents and by aquarists and motorboats. Notwithstanding the source of

introduction of Eurasian watermilfoil into the Great Lakes Basin (e.g. aquarium release, ballast water, or attached to boats or ships), this aquatic invader is considered a nuisance plant in the provinces of Ontario, Quebec, and British Columbia (White *et al.*, 1993).

Aside from *Cabomba*, water moss, mosquito fern, parrot feather, and Brazilian waterweed, other submerged aquatic plants of the genera *Sagittaria* sp., *Vallisneria* sp., *Lagarosiphon* sp., *Ceratophyllum* sp., *Myriophyllum* sp., and *Limnophila* sp. were found to be mainly used in the aquarium trade (Sculthorpe, 1967; Pieterse and Murray, 1990). Moreover, emergent and amphibious species that are able to tolerate complete immersion are used. Examples of these plants are: *Acorus* sp., *Bacopa* sp., *Cardamine* sp., *Cryptocoryne* sp., *Echinodorus* sp., *Heteranthera* sp., *Hygrophila* sp., *Lagenandra* sp., *Micranthemum* sp., *Nomaphila* sp., *Rorippa* sp., *Samolus* sp., and *Synnema* sp. (Sculthorpe, 1967; Pieterse and Murray, 1990).

The invasion of *Caulerpa taxifolia* is a famous example of an escapee from an aquarium. *Caulerpa*, also known as the death weed, was introduced to the Mediterranean, probably as a waste from the Monaco Aquarium (Lowe *et al.*, 2004). This strain of *Caulerpa* was found to tolerate colder waters and was a hardier clone of the original tropical seaweed (Lowe *et al.*, 2004). *Caulerpa* became a serious threat to native marine flora and fauna as small fragments of the plant were found to readily survive and grow into new plants vegetatively, smother seagrass beds (Lowe *et al.*, 2004) and reduce fishery resources (GISP, 2004). *Caulerpa* has been regarded as one of the 100 worst invaders based on the plant's impact on biological diversity (Lowe *et al.*, 2004). Padilla and Williams (2004) noted that control of *Caulerpa* has been ineffective especially in relation to the import, possession, or trade of this alga as the species continues to be distributed by aquarium stores.

In Canada, the aquarium and ornamental pond industries has been recognised as the source for intentional and unintentional release of aquatic organisms such as fish, invertebrates, amphibians, reptiles, and plants (CCFAM, 2004). The authors noted that although a majority of the species introduced for aquariums are tropical and do not survive Canadian winters, there are widespread examples of species that have been introduced and spread as a result of aquarium releases. Of increased concern is the fact that there are

hardly any steps being taken to address aquarium releases and the aquarium industry remains largely unregulated. In addition, there is limited enforcement to prevent the illegal release of any aquatic organism into the wild (CCFAM, 2004). There are also “very few regulations that specifically address the concerns associated with introductions of aquatic organisms from the aquarium and ornamental pond industries” (CCFAM, 2004, p. 14). Other concerns reported by the authors include the fact that temperate species are available in the trade, the internet allows for long range movement of plants used in ornamental ponds, and there is the potential introduction of pathogens with aquarium organisms (CCFAM, 2004).

In Ontario, Canada, the aquarium and ornamental pond industries have also been recognised as the perpetrators for the continued introduction and spread of IAS. Funnell *et al.* (2009) surveyed 525 pet stores and garden centres in the major cities of Ontario as well as their surrounding regions in the Lake Ontario basin. Based on the frequency of occurrences for known IAS generated by the OFAH and Ministry of Natural Resources (MNR), *Cabomba* was identified as the most common invasive aquatic plant sold (Funnell *et al.*, 2009). Other invasive plants recorded during the survey included yellow iris (*Iris pseudacorus*), flowering rush, water hyacinth, water lettuce, *Hydrilla*, water moss, parrot feather, water soldier (*Stratiotes aloides*), yellow floating heart (*Nymphoides peltata*) and Eurasian watermilfoil. Funnell *et al.* (2009) also noted that while some of the plant species found were already established in Ontario (e.g. *Cabomba*), others were not, and posed a considerable threat of invasion or had the potential to become invasive since they were found in isolated populations (e.g. floating heart, parrot feather, water lettuce and water soldier).

Marson *et al.* (2009a) also conducted a survey of about 917 aquarium owners in Ontario. From the survey, eight invasive aquatic plants on the Global Invasive Species Database were sold by aquarium owners. These species were: Brazilian waterweed, Eurasian watermilfoil, *Cabomba*, *Hydrilla*, water fern, water hyacinth, parrot feather, and water lettuce. Given the presence of the aforementioned species, Marson *et al.* (2009a) concluded that the aquarium trade may serve as a pathway for the introduction of invasive aquatic

species into Canadian freshwaters. In addition, Marson *et al.* (2009a) concluded that the use of risk assessment studies would assist in providing information on the probability of invasive species to survive in Canadian ecosystems as well as the level of disturbance that would be expected in the event there were successful introductions of invasive aquatic species from this pathway.

Cohen *et al.* (2007), recognizing that the aquarium trade is a common pathway for non-indigenous plants, attempted to quantify the propagule pressure as an invasion pathway from each plant species introduced. Using the aquarium plant trade in Montreal, Canada, Cohen *et al.* (2007) discovered that there were thousands of non-indigenous plant propagules being introduced annually to the St Lawrence Seaway, through the Montreal aquarium trade alone. This determination was achieved by: approximating the total amount of propagules of each species that use a particular pathway/year, determining the transition probability between each step, and converting this data into a value of propagule pressure for each species by means of Bayesian statistical analysis (Figures 1 and 2).

First, an assumption was made that all plants ordered from a distributor are sold and is therefore equal to the number of plants purchased/year. The total amount of propagules for each species used by a particular pathway/year was achieved by obtaining copies of invoices from distributors, as well as the quantity of each species sold/year by aquarium stores. The stores were divided into two: those that provided quantities for each species (12) and those that were able to report the total number of plants sold/year (4). Data from the 12 stores were used to estimate the proportion of each individual species sold/year (Step 1 in Figure 1 and Figure 2). This data, in conjunction with the total plants sold/year were used to determine species specific propagule pressures (Step 2 in Figure 1 and Figure 2). The proportion of plants entering each disposal sub-pathway was also identified using a customer survey. Eight types of disposal sub-pathways were reported: garbage, return to store, left on the street, flush down the toilet, return to the wild, and backyard burial (Steps 3 in Figure 1). These eight pathways were later divided into four major pathways: direct, waste, storm, and other.

Figure 1: Schematic showing the method used to determine propagule pressure contributed by the aquarium trade on the St. Lawrence Seaway (Cohen *et al.*, 2007)

Figure 2: Schematic showing steps to calculate propagule pressure (Cohen *et al.*, 2007)

The survey data were then used to estimate behaviour probabilities for the aquarium owners through each disposal sub-pathway into the St. Lawrence (Step 4 in Figure 1). The probabilities were estimated using Bayesian statistics, specifically, multinomial distribution. From the observed number of individuals using each disposal pathway, a posterior probability distribution was obtained. Subsequently, the proportion entering each disposal sub-pathway was multiplied by the probability of introduction associated with that particular sub-way, then summed across the sub-pathways, and finally multiplied by the total number of plants sold/year. This final figure represented the propagule pressure in the St. Lawrence (Step 5 in Figure 1). Cohen *et al.* (2007) reported that Brazilian waterweed and *Cabomba* were the two aquatic invaders found with the highest measured propagule pressure. In addition, the actual number of plants introduced would probably depend on the characteristics of the species (e.g. growth and reproductive rate) and whether the plant was able to survive in the new environment.

The invasion risk of macrophytes, fish, and molluscs sold by the aquarium industry on the Great Lakes was investigated by Rixon *et al.* (2005). In the study, several criteria were used: biological (i.e. temperature tolerance of the vegetative plant and over-wintering ability imparted by vegetative propagules for plants and a survivorship below 5.5°C for fish), invasion history, and propagule pressure. Frequency of occurrence was used as a proxy for propagule pressure. Twenty aquarium and pet stores were surveyed in close proximity to Lake Erie and Lake Ontario; namely: Macomb County, Michigan (USA), and Windsor, Belle River, Leamington, Guelph, Elgin [sic], St. Thomas, Kitchener, and Toronto (Ontario, Canada). Species found in more than 20% of the stores surveyed were considered high risk invaders. Modified filter models from Ricciardi and Rasmussen (1998) and Kolar and Lodge (2002) were used to predict the species that had the potential to establish populations. Of note, the modified model from Kolar and Lodge (2002) was used for fish species while the Ricciardi and Rasmussen (1998) model was used for macrophytes (Figure 3). The findings of the latter will be presented here.

Figure 3: Modified filter model for macrophytes to determine high risk invaders (Rixon *et al.*, 2005)

Of the 66 plant taxa identified in the survey, eight plant species had the potential to survive in the Great Lakes based on their overwintering capabilities, thermal tolerances, invasion histories, and opportunities for introduction. These species were: *Vallisneria americana*, coontail or hornwort (*Ceratophyllum demersum*), *Cabomba*, *Hygrophila polysperma*, parrot feather, *Myriophyllum heterophyllum*, and Brazilian waterweed. *Cabomba* has already invaded the Great Lakes and coontail or hornwort and *Vallisneria americana* are native species. Of the four remaining species, *Myriophyllum heterophyllum* was considered a low risk species since the frequency of occurrence in the survey was low.

Rixon *et al.* (2005) also indicated that there were two reasons why invasion threats from the aquarium industry would increase with time. First, was the fact that the group of potential invaders would continue to expand since the industry was always looking for new species that would be popular in the market. Second, most species being used in the industry are of tropical and sub-tropical origin and with an increase in climatic warming, the likelihood of these species becoming established in the Great Lakes should increase. Rixon *et al.* (2005) also noted that given the presence of these high-risk invaders, practices of the aquarium industry, and other pathways of invasions into the Great Lakes and other aquatic ecosystems should be addressed (e.g. trade restrictions on sale).

2.2.2 Internet, mail parcels/order catalogues

The internet and mail parcels/order catalogues have also been identified as a pathway for the introduction of taxa for aquariums and ornamental ponds. Kay and Hoyle (2001) reported that aquarium species are mostly available through mail order and over the internet. GISP (2004) concurred, noting that with the growth of internet mail ordering services, aquatic organisms and foreign seeds have also become widely available, especially via internet sites. GISP (2004) further noted that the use of international mail parcels has made the aquarium trade a world-wide business as parcels containing aquarium species have increased by over 30% in recent years, and are increasingly shipped by express courier companies. In terms of aquatic plants, Maki and Galatowitsch (2004) indicated that mail order catalogues and the internet has not only resulted in improved transport of aquatic plants but has also contributed to their increased sales. Consequently, aquatic

plants are repeatedly introduced, sometimes on a large scale, into new locales, which increases the potential of the introduced plant to become invasive.

In order to determine the role played by the internet and mail order in the distribution of invasive aquatic plants, Kay and Hoyle (2001) conducted a survey of the internet over a three year period, to determine the number of sites offering aquatic plants for exchange or sale, and mail order catalogues of nurseries and supply houses that sold aquatic plants. From the survey, Kay and Hoyle (2001, p. 88) observed that “with the advent of consumer access to the internet and the development of e-commerce, the spread of invasive aquatic plants has been made worse worldwide ... as there were numerous listings in online nursery catalogues as well as hobbyist groups selling or swapping aquatic invasive plants.” Some of the plants found included Eurasian watermilfoil, Brazilian waterweed, water hyacinth, purple loosestrife, water lettuce, giant *Salvinia*, mosquito fern, parrot feather, *Hydrilla*, alligator weed (*Alternanthera philoxeroides*), African waterweed (*Lagarosiphon major*), and water chestnut amongst others. Owing to the availability of the aforesaid invasive aquatic plants over the internet and through mail order catalogues, Kay and Hoyle (2001) stressed the significant concerns that should be raised about the likely impacts that these sources would have on the introduction, distribution, and spread of aquatic invasive plants worldwide. Conversely, Marson *et al.* (2009a, b) found that few persons used the internet or mail parcels/order catalogues as a source for invasive aquatic plants. Thus, the internet and mail parcels/order catalogues may not play as important a role in the distribution of invasive aquatic plants as perceived by other authors.

Even though Kay and Hoyle (2001) focused on the internet and mail order catalogues as avenues for the introduction of invasive aquatic plants, they also noted that hobbyists and aquarists often disposed of unwanted aquatic plants improperly into ponds, streams, ditches, and lakes rather than destroying the plants; thus making hobbyists and aquarists an important vector for the distribution and spread of invasive aquatic plants (Kay and Hoyle, 2001). In addition, Kay and Hoyle (2001) indicated that the exchange and purchase of aquatic plants amongst aquarium and water garden hobbyists posed a serious threat to

inland water resources as well as encouraged the probability for the release of invasive aquatic plants.

2.2.3 Ornamental ponds

Water gardens, Kay (2000) reported, have increased in popularity in arboreta, botanical gardens, and backyard gardens due to the arrival of hobbyist magazines, mail order catalogues, internet sales, and propagation information, that encourage the use of invasive aquatic plants. Maki and Galatowitsch (2004) noted that the horticultural trade can assist in the long-range movement of invasive aquatic plants that are banned and those that are not. Furthermore, “the extent to which horticultural trade may contribute to expanding the distribution of aquatic plants needs to be more comprehensively characterized to contribute to improved risk assessment; in particular, the rate at which known invasive aquatic plants are sold regardless of a country’s regulations” (Maki and Galatowitsch, 2004, p. 390).

In a survey conducted on the water garden industry (~752 water garden owners) in Ontario, Canada, Marson *et al.* (2009b) concluded that at least eight aquatic plant species have been introduced that were either invasive or posed a significant threat of becoming an IAS. These species were European frog-bit, *Cabomba*, yellow floating heart, flowering rush, parrot feather, water hyacinth, water lettuce, and water fern (*Salvinia minima*). Marson *et al.* (2009b) further noted that although the use of invasive aquatic plants in water gardens did not automatically result in introductions into new environments, it is important to recognize that these species pose a threat if released accidentally (e.g. during natural disasters such as a flood) or deliberately into areas that are IAS free. Accordingly, Marson *et al.* (2009b) concluded that the water garden should not be disregarded as a pathway for the introduction of invasive aquatic species into Canadian freshwaters.

The water hyacinth has been regarded as one of the worst aquatic plant invaders in the world (Riemer, 1984; Lowe *et al.*, 2004) and is a prime example of an aquatic plant introduced for water gardens. Tabitha *et al.* (1962) indicated that water hyacinth was

introduced to Florida in 1884 by a visitor returning from an exposition in New Orleans who placed the plant in a lawn fountain on the banks of the St. Johns River Basin near Palatka. The plant grew rapidly and the excess was thrown into the river. Subsequently, the water hyacinth spread to all inland waters within the state. Lowe *et al.* (2004) described the biology and impacts of water hyacinth by stating that the water hyacinth is a very fast growing plant that can double in population within 12 days and limits boat traffic, swimming, and fishing; prevents sunlight and oxygen from reaching the water column and submerged plants; shades and crowds out native aquatic plants; and noticeably reduces biodiversity in aquatic environments.

Aside from the water hyacinth, other aquatic plants have been recorded for use in water gardens. Riemer (1984) reported that floating and emergent aquatic plants, because of their attractive flowers and foliage, are useful for pool and pond decoration in parks, golf courses, and home grounds; indoor pools in malls, restaurants, and public places. Examples include water lilies such as yellow floating heart and pickerelweed (*Pontederia cordata*). Other examples include the emergents, *Butomus* sp., *Cyperus* sp., *Menyanthes* sp., *Nelumbo* sp., *Pontederia* sp., *Sagittaria* sp., *Typha* sp., and other aroids. Floating leaved and free-floating representatives include *Aponogeton* sp., *Hydrocleys* sp., *Nuphar* sp., *Nymphaea* sp., *Nymphoides* sp., *Azolla* sp., *Ceratopteris* sp., *Pistia* sp., *Salvinia* sp., *Stratiotes* sp., and *Trapa* sp. (Sculthorpe, 1967).

2.3 Invasion success of aquatic plants

2.3.1 Plant invasions

Even though aquatic plants are introduced via the aquarium industry, mail parcels/order catalogues, internet or ornamental ponds, there is no guarantee that these species will become established or, if they survive, are even able to reproduce and eventually, become invaders. Dehnen-Schmutz *et al.* (2007) noted that the success of plant invasions is encouraged by the presence of factors such as repeated local introductions through market outlets, and the development of traits via plant breeding that would increase the likelihood of establishment if the plant escaped.

In contrast, Calado and Chapman (2006) indicated that if sufficient numbers of individual species are released together, there is a greater chance of reproduction, either sexually or asexually, and accordingly, for the introduced species to compete successfully for the habitat against the native species already established in the waters. Additionally, Williamson (1996), made reference to the “tens rule” in which 10% of imported species will be introduced into new environments, 10% of these will become established, and 10% of these will become pests. In essence, this rule suggests that 0.1% of all aquarium species (plants and animals) will actually become introduced pests.

Cronk and Fuller (1995), in describing plant invasions, noted that there are several stages that plants (aquatics included), must undergo in order to become established. These stages were identified as introduction, naturalization, facilitation, spread, and interaction with other plants and animals:

- Introduction: plants become established accidentally or deliberately by human actions;
- Naturalization: invasiveness occurs when plants become established beyond the initial point of introduction and form self-sustaining populations. These populations are dependent on the population size, the plant’s biological features (e.g. breeding system, successful reproduction), and environmental conditions (e.g. climate, seasonality, and soil conditions);
- Facilitation: plant invasiveness occurs via the use of a suitable dispersal agent, the presence of disturbance in the ecosystem, and/or the lack of pest and diseases;
- Spread: the invasive spread of plants is dependent on the intrinsic growth and reproductive rates of the plant, the nature of the invaded habitat, and the presence of suitable places for reproduction. Efficient seed dispersal is important and successful plant invaders are known to have adaptations for short and long distance dispersal, short distance bulking up of existing populations, and long distance establishment of new foci for further spread that is remote from the original site of invasion; and
- Interaction with animals and other plants: the interaction between native plants and animals decides whether the invader will fit in, be pushed out, or have an impact on the ecosystem’s processes, composition, and structure.

Heger (2001) throws a spin on the issue of plant invasions by stating that there is one central problem with the approaches (e.g. examining the characteristics of invading species and the ecosystem being invaded) put forward to describe the causes and mechanisms of biological invasions. The central problem was that “many cases have shown that every single process of invasion seems to be unique, and for every rule, an exception seems to exist” (Heger, 2001, p. 3). In order to solve this problem, Heger (2001) suggested a plant invasion model that would depict the entire invasion process and not just one part of it. The model is depicted as a staircase in which there is a sequence of stages and steps and uses an underlying hypothesis that “the complexity of invasions is due to a varying influence of different factors during the process” (Heger, 2001, p. 3-4) (Figure 4). Each stage in the staircase is reached by overcoming a specific step. The four steps represent the problems that a plant would have to overcome in the course of the invasion (Heger, 2001).

Heger (2001, p. 6) stated that the «staircase of invasion» [sic], was an “idealised model of an invasion process, which is able to serve as a tool for interpreting the invasion process.” Furthermore, the model explained why a species with a lot of specific characteristics is likely to become a successful invader, while conversely; a species might be successful without having similar characteristics. Moreover, “species with a lot of favourable characteristics is nonetheless likely to become a successful invader, especially if it is repeatedly introduced; the more often a species is able to reach the first step, the more probable it is that the plant will be able to overcome the second step and the other steps thereafter” (Heger, 2001, p. 8).

Ashton and Mitchell (1989, p. 113) concurred with Heger (2001) regarding the process of invasions by stating that “each step in the progression from first arrival of the invader to successful colonization of new habitats requires that a series of abiotic and biotic barriers be overcome by the invader.” In the case of aquatic plants, Ashton and Mitchell (1989) identified three main stages of invasions: arrival of an individual or propagule, establishment of the population through reproduction, and dispersal to new localities. In addition, adaptation of the new invader to the new locale may favour the selection of new genetic strains (Figure 5).

Figure 4: Schematic showing stages and steps of a plant invasion (Adapted from Heger, 2001)

Figure 5: Stages in the invasion and establishment of aquatic plants (Ashton and Mitchell, 1989)

In describing each stage of the invasion, Ashton and Mitchell (1989) pointed out that each stage involved a series of interactions between the physical, chemical, and biological features of the environment and the biological characteristics of the invader. Moreover, Ashton and Mitchell (1989, p. 117) indicated that the “rate at which the invasion occurs will depend on the number of individuals or propagules present in the initial inoculum and in the dispersal stage.” In light of these statements, Ashton and Mitchell (1989, p. 113) further noted that “the geographical distance between the source of the invading plant and the eventual site of invasion represented perhaps the greatest barrier to natural invasions by aquatic plants; as such, the production of resistant seeds and propagules by many aquatic plants provided the only viable means whereby aquatic plants may survive transport by biotic and abiotic mechanisms.”

Arthington and Mitchell (1986), further indicated that the interactions between the environment and the invader can either promote, delay, or prevent the successful completion of the stages as was defined by Ashton and Mitchell (1989), and that an exponential increase in the number of individuals present and the numbers involved in the dispersal stage ensured an exponential acceleration in the apparent rate at which the invasion would take place until the environmental factors became limiting.

Mitchell and Gopal (1991), in contrast to Ashton and Mitchell (1989), indicated that there were five different stages in aquatic plant invasions: introduction, establishment (involving local colonisation), survival, widespread dispersal, and production of numerous propagules (Table 2). Mitchell and Gopal (1991) further reported that any failure or incompleteness of any four stages would result in the failure of the invasion; and the invasion would remain localised and fail eventually, if the last stage did not occur. Moreover, all the stages of the invasion were repeated until the invader was considered naturalised and the dispersal stage served as the forerunner to the initial stage of introduction in the new environment (Mitchell and Gopal, 1991).

Table 2: The process of biological invasion in aquatic plants (Mitchell and Gopal, 1991)

Environmental determinants	Stage(s)	Plant attributes
Intercontinental barriers	Introduction	Attractiveness to humans
Ecosystem susceptibility	Establishments and local colonisation	Broad habitat requirements, rapid growth, vegetative reproduction, competitive ability
Safe sites	Survival	Stress tolerance, resistant propagules
	Production of numerous propagules	High reproductive capacity
Regional barriers	Widespread dispersal	Attractiveness, effective dispersal mechanisms

In summary, plant invasions appear to occur using several stages: introduction, naturalization or establishment, dispersal, and adaptation to the environment. If, however, one of these stages failed to occur, then the likely outcome would be a failure in the invasion process. Notwithstanding, the number of individuals introduced to the environment along with their reproductive potential were found to play an intricate role in the invasion process.

2.3.2 Traits of successful aquatic plant invaders

As presented, plant invaders have to go through a number of processes and employ the use of various strategies in order to become established in a new environment. Once established, however, plant invaders have been found to exhibit a number of shared characteristics. Within aquatic environments, Cronk and Fuller (1995, pp. 32-33) highlighted that aquatic plant invaders generally are “tolerant of a wide variety of aquatic conditions; have very effective means of vegetative reproduction; exhibit rapid growth and have a free-floating habit; are often perennials and herbaceous; often dioecious, but are capable of vigorous asexual reproduction if one sex is absent; and in species where sexual reproduction is utilised, seeds are efficiently dispersed by water (e.g. water hyacinth, *Hydrilla*, and Eurasian watermilfoil).”

Like Cronk and Fuller, Pieterse and Murray (1990) indicated that aquatic plant invaders exhibited rapid vegetative growth especially, if the nutrient content of the water, light, temperature or water movement did not have a limiting effect; if the plants were able to regenerate asexually via fragmentation or vegetative hibernating organs such as turions and tubers; if the plants had the potential to be primary colonizers; and if the plant were spread mainly by human activities. Other characteristics of aquatic plant invaders include the ability to use wind and/or water to disperse of seeds and spores (e.g. *Typha* spp., and *Phragmites australis*), fragments of plants, winter buds, turions, and other propagules (Wade, 1990); are generalists, opportunists, or pioneer species and have high stress tolerance and morphological plasticity (Mitchell and Gopal, 1991).

Thiébaud (2007) also stated that majority of aquatic invasive plants shared some or all of the following characteristics: short life cycle, rapid growth rate, high level of energy allocated to reproduction, efficient dispersal mechanisms, high population growth rate, wide distribution, high phenotypic plasticity, and flexible uses of environmental resources. Of note, the mention of short life cycle as a trait of aquatic plant invaders contradicts that listed by Cronk and Fuller (1995), who reported that invaders were mainly perennials. This contradiction suggests that there is still some uncertainty about the traits of an aquatic plant invader and as such, is part of the reason for this research.

Even though aquatic plant invaders tend to share common characteristics, Mitchell and Gopal (1991, p. 148) remarked that “the possession of a suite of invasive characteristics by a particular species does not on its own make it a successful invader of an alien system. The penetration of a barrier in the absence of natural enemies may be more important in providing an opportunity window for the invading species to exploit.” Notwithstanding, several traits of successful aquatic invaders have been described, of which; the most important is reproduction and perennation. The others include: life form and growth characteristics, morphological plasticity, boom-and-bust, and propagule pressure.

2.3.2.1 Reproduction and perennation

The survival of an invasive plant has been found to be dependent on the success and/or failure of the reproduction mechanism employed. Ashton and Mitchell (1989, p. 126) pointed out that in “virtually every case of a biological invasion by plants, success in the initial stages depends largely on the invader’s reproductive capacity.” However, Ashton and Mitchell (1989) indicated that the reproductive effort put out by plants could not be the only reason for all invasions since not all invaders were equally prolific; as such, the success of plant invasions depended greatly on the invader being able to compete for available resources and possessing rapid vegetative growth.

Nevertheless, in the case of aquatic plants, Ashton and Mitchell (1989, p. 121) reported that aquatic plant invaders “have demonstrated a marked capacity for advective spread when introduced into new environments that is linked to factors associated with dispersal and

reproductive mechanisms.” These factors included: vegetative reproduction, which is the usually the most common method of reproduction in aquatic plants; dispersal of aquatic plants between and within countries by humans; fast reproductive rates that eventually make aquatic plants become nuisance weeds; and sexual sterility of aquatic plants that may become locally naturalized unless they are intentionally spread by humans or have small vegetative propagules that can be dispersed by other means (Ashton and Mitchell, 1989).

Cronk and Fuller (1995), in their discussion on plant invasions, stated that aquatic plants employed what is called a breeding system. In this system, a high number of invasive aquatic plants were either monoecious or dioecious. Some successful dioecious aquatic plants such as parrot feather, *Hydrilla*, and African waterweed, have either developed ways of combating the disadvantages associated with dioecy or have been introduced in large numbers that reduced the problems of initial seed settling. One way identified of overcoming the problems of dioecy was reproducing primarily by vegetative means and dispersal by water (Cronk and Fuller, 1995). In terms of monoecious plants, aquatic invaders such as water hyacinth were found to be self-compatible that allow seeds to be produced when the plant was isolated or at low population levels. Water hyacinth also reproduces vegetatively (Cronk and Fuller, 1995).

Invasive aquatic plants were also found to exhibit strategic traits in terms of reproduction. MacArthur and Wilson (1967) noted that free-floating species such as water hyacinth and giant *Salvinia* and submerged species such as *Hydrilla* and *Elodea* had high reproductive rates and are opportunistic R-strategists; that is, these plants were capable of prolific vegetative reproduction, especially from one viable plant to start a new colony. In addition, Wade (1990) pointed out that R-strategist plants were likely to become aquatic weeds⁴ when their habitat was subjected to habitual disturbance.

Aquatic invasive plants have also been described as R- or C- strategists or competitors. Using Grime’s (1979) C-S-R model that described the life history strategies of plants, Lacoul

⁴ A term used to refer to invasion ecology theory (Colautti and MacIsaac, 2004).

and Freedman (2006, p. 106) pointed out that competitors were found in “fertile, infrequently disturbed habitats, have high productivity, and often cast a dense shade.” Examples include water hyacinth, *Elodea*, *Hydrilla*, and Eurasian watermilfoil. In addition, aquatic plant invaders were found to be able to exclude other submerged aquatic plants because of their superior ability to secure light, space, and nutrients (Lacoul and Freedman, 2006). Furthermore, because of the extreme variability of aquatic environments, plants are selected if they have a high degree of reproductive plasticity and multiple adaptations for regeneration (Grime, 1979).

Like Ashton and Mitchell, Thiébaud (2007) also reported that the mode of propagation may be responsible for the spread of aquatic plants by affecting their evolutionary potential and dispersal ability. The mode of propagation used by aquatic plants was described by Sculthorpe (1967) who remarked that aquatic plants have a tendency to replace sexual reproduction with vegetative reproduction, which is especially advantageous to plants living in deeper water. In addition, the use of “vegetative propagules probably contributed significantly to the dissemination of species about the globe based on the ease with which they are accidentally transported by floods, waterfowl, other animals and man” (Sculthorpe, 1967, p. 334) (Table 3).

Table 3: Vegetative propagules used by aquatic plants (Sculthorpe, 1967)

Type of vegetative propagules	Brief description of vegetative propagule
Rhizomes	Formed below the substrate surface
Rootstocks	Formed from an abbreviated axis found in an erect position or below the soil level. Stores food reserves
Stolons or Runners	Travels away from the parent and forms a new plant that is anchored by adventitious roots
Stem tubers	Produced from stolons or runners as terminal swollen structures that grows into new plants
Dormant apices and offsets	Apices develop into new plants under favourable conditions. Offsets are young plants borne by stolons close to the parent; when the stolon decays, the young plant becomes independent
Specialised turions	Turions occur on lateral branches and become detached when the parents shoot system decays. Under favourable conditions, the new plant is anchored by adventitious roots

Vegetative propagules such as tubers, rhizomes, or suckers, Thiébaud (2007) noted, gave introduced aquatic plants a competitive advantage over other species by having an early start in growth at the required time. Additionally, Sculthorpe (1967) pointed out that colonisation by aquatic plants involved the use of rhizomes, stolons, and runners that were widespread, used to store food reserves and functioned as a hibernacula thus enabling the plant to survive conditions unfavourable to vegetative growth. Some temperate aquatic plants, Sculthorpe (1967) indicated, produced organs which were not developed during normal vegetative growth but were formed in response to depleted nutrient supply or abnormal conditions and served for perennation. For example, *Sagittaria* and *Potamogeton* formed small tubers on the ends of stolons or lateral branches, *Myriophyllum*, *Utricularia*, and *Hydrocharis* developed specialised dwarf shoots called turions, and *Ceratophyllum* dense shoot apices. All these organs, tubers, turions, and apices, were protected by mucilage or a thick cuticle and were loaded with food reserves and remained dormant throughout the winter (Sculthorpe, 1967).

Sculthorpe (1967) reported that aquatic plants also use gemmipary as a means of vegetative multiplication. Gemmipary, Sculthorpe (1967) noted, occurred in some species naturally while in others, was induced because of isolation of, or injury to, a leaf. Aquatic plants such as *Cardamine* sp. and *Rorippa* sp. that are used in the aquarium trade exhibit gemmipary. In these plants, fragments of leaflets can produce young plants, or as buds present on the plants elongate, adventitious roots develop at the base and anchor the new individual (Sculthorpe, 1967).

Regeneration is another strategy used by aquatic plants to increase their numbers in the new environment. Sculthorpe (1967) pointed out that in free-floating species and submerged plants regeneration from any small part bearing a bud is a common practice after fragmentation of the plant body. In floating species such as *Salvinia*, mosquito fern, and members of the Lemnaceae family (e.g. water lettuce), the most minute part of the stem that bears an axillary bud or a fragment with a vegetative bud pouch gives rise to a new individual (Sculthorpe, 1967).

In the case of submerged aquatic plant invaders such as Brazilian waterweed, coontail, *Elodea*, *Hydrilla*, Eurasian watermilfoil, and African waterweed, the vegetative organs are very brittle and could be easily broken into a myriad of fragments following disturbance (e.g. currents, wind, and animals). Once a fragment was detached, any part of the axis is potentially viable and capable of yielding a new plant. The new plant would appear, especially if that part of the plant bears a dormant lateral bud from which new growth could occur or any other bud, or part of a node from which a new individual could be regenerated (Sculthorpe, 1967). Thiébaud (2007) concurred when she reported that aquarium species, such as *Elodea* spp., Brazilian waterweed, and *Myriophyllum* spp., were able to multiply by fragmentation using vegetative buds or cuttings, which made these plants efficient in spreading to new areas, providing that they could survive the winter months.

In terms of sexual reproduction, Spencer and Bowes (1990, p. 59) state that “seed production was an important means to aid survival during periods of adverse environmental conditions and to improve the chances for successful invasion of a new area”. Van Vierssen (1990) reported that aquatic plants produce high numbers of seeds that can germinate the season after they are produced (e.g. *Ruppia* sp.) or low number of seeds or none at all. The latter is seen in aquatic plants that produce tubers, turions, or stem fragments in unfavourable conditions (e.g. Eurasian watermilfoil). Additionally, seeds of aquatic plants remain viable for long periods and are a trait of species that normally depend on vegetative propagules (e.g. water hyacinth) (van Vierssen, 1990). Sculthorpe (1967) noted that seeds produced from submerged species were usually small, contained small carbohydrate reserves, and remained viable for several years. Furthermore, seeds enhanced the survival of submerged plants during adverse conditions; for example, drought, cold, and salinity (Sculthorpe, 1967).

Sculthorpe (1967) also noted that water was the main medium of spread for seeds since there was a buoyancy stage that allowed vegetative propagules to be carried away from the competition of the parental habitat. In submerged and floating aquatic plants, the fruits and seeds produced did not have large powers of floatation and either sank immediately

(e.g. *Ceratophyllum* sp.) or floated for a short time facilitating dispersal from the parent plant (e.g. *Myriophyllum* sp.). In emergent plants, water also distributed the buoyant fruits and seeds produced onto adjacent terrestrial soils or into estuarine or coastal waters (Sculthorpe, 1967). Wade (1990) pointed out that in addition to seeds water also transports plant fragments, winter buds, turions, and other propagules, assisted by the wind and currents.

2.3.2.2 Life form and growth characteristics

The variability of the aquatic environment (e.g. alternate periods of wetting and drying over seasonal or short-term and a seasonal or long-term cycles, temperature, day length) was found to play a major role in the regulation of aquatic plant growth and was deemed critical to the success or failure of an invasion (Ashton and Mitchell, 1989). Nevertheless, aquatic plants whether floating, submerged, or emergent were found to exhibit traits that contributed to their success as aquatic invaders. In the case of free-floating aquatic invasive plants such as the water hyacinth, mosquito fern, giant *Salvinia*, and coontail, Ashton and Mitchell (1989, p. 125) reported that these plants exhibited specific traits that contribute to their success as invaders. These traits included “the capacity for extremely rapid vegetative multiplication, the ability to regenerate from small portions of vegetative thalli, complete or partial independence of sexual reproduction, a growth morphology that produces the largest possible area of photosynthetic tissue in relation to the whole plant, and spreads over the entire water surface, independence of substrate conditions and water levels, and in space limited areas, the ability to accumulate organic matter that promotes the development of emergent type vegetation by acting as primary colonizers.”

For emergents and submerged aquatic invaders, Sculthorpe (1967) reported that because these plants were rooted and depended on a more stable hydrological regime for survival than free-floating species, the attributes of success were different. Submerged species such as Eurasian watermilfoil, *Elodea*, Brazilian waterweed, *Hydrilla*, and African waterweed were known only to grow in areas where a suitable substratum existed, light penetrated the water column, and were affected by increased turbidity and populations of planktonic algae. In light of these conditions, submerged aquatic invaders were restricted to certain

environmental conditions, occupied all available habitats, and quickly colonized new areas (Ashton and Mitchell, 1989).

Moreover, submerged aquatic plants that were successful invaders generally were found: to possess intercellular lacunal systems that provided buoyancy to the photosynthetic organs, have reduced structural rigidity; to be able to remain dormant or over-winter in unfavourable environmental conditions; to be capable of regenerating from small stem fragments; to be completely independent of sexual reproduction; to manufacture large numbers of vegetative propagules (e.g. tubers, turions, and dormant apices) that are important in the recolonization of cleared areas and invasions of new areas (Sculthorpe, 1967); and to persist for a rather short time and then are replaced by other species (Cook, 1990).

Emergent invaders such as common reed (*Phragmites australis*) and *Typha* spp. possessed long-lived, resistant rhizomes, which acted as nutrient stores during unfavourable periods and produced tall, structurally rigid stems and leaves, which shade out competing species (Ashton and Mitchell, 1989). These plants also have variable vegetative growth patterns that prevent the entry of competing species or rapidly exploit new colonization sites (Lovett-Doust, 1981; Hutchings and Bradbury, 1986), manufacture large amounts of minute seeds suited for long-range dispersal, regenerate after cutting (Westlake, 1963), and use diaspores for long-range dispersal (Cook, 1990).

Apart from the individual attributes that have been identified that make floating, emergent, and submerged aquatic plant invaders successful, Ashton and Mitchell (1989) also noted that another factor that contributed to their success is the fact that most aquatic plant invaders are taxonomically related to endogenous species, which are not invasive. In addition, aquatic plant invaders can also resemble other plants that may occupy the same habitat but are not always invasive (Ashton and Mitchell, 1989). Based on this fact, it can be surmised that misidentification of invasive aquatic plants increases the probability of their spread and distribution worldwide. One example cited by Ashton and Mitchell (1989) was the water hyacinth and anchored water hyacinth (*Eichhornia azurea*). Both species are

closely related and distributed by the water garden industry. They also have similar distribution patterns but differ in terms of their invasiveness, as only the water hyacinth has caused serious problems (Ashton and Mitchell, 1989).

Another example of taxonomically related species was described by Sculthorpe (1967). The family Hydrocharitaceae contained aquatic plant invaders that were taxonomically close such as *Elodea*, *Hydrilla*, Brazilian waterweed, and African waterweed. These aquatic plant invaders were found to exhibit similar morphology of whorls of short sessile leaves and stems with short internodes, and as such, are often confused with each other even though these aquatic plants have different native distributions. Arthington and Mitchell (1986) also realised that although the aforesaid aquatic plants have been responsible for major invasions outside of their native distribution, there are other members of the family with similar morphology that do not show invasive traits; however, there is no clear explanation for the mechanisms of the invasions or the lack of invasions exhibited by other members of the family.

2.3.2.3 Morphological plasticity

Aquatic plants invaders were also found to exhibit a trait called morphological plasticity. Ashton and Mitchell (1989, p. 127) described morphological plasticity as the “ability of a species to modify the shape, and size of its vegetative structures when grown under different environmental conditions.” Moreover, the presence of morphological plasticity provided aquatic plants with the ability to adapt its phenotype to suit any habitat and gave invaders the competitive edge over other aquatic plants for a wide range of habitats and promoted the dominance of the invader once the habitat was occupied (Ashton and Mitchell, 1989).

Water hyacinth is one example of an aquatic plant invader that exhibits this trait. Ashton and Mitchell (1989) reported that water hyacinth produces two distinct growth forms based on the habitat in which they are found. One growth form is called the colonizing form, which has spherical float-like petioles and flattened, circular laminae. This form is found in open water habitats that has no space restriction and multiplies rapidly by the use

of stolons. The other growth form is mat-like with long elongated petioles and vertically arranged orbicular laminae that are held together by closely interlinked stolons (Ashton and Mitchell, 1989). Gopal (1987) revealed that if either of these water hyacinth growth forms were moved from their original habitat, the plant would change its morphology within 10-20 days to suit the new habitat.

Giant *Salvinia* is another aquatic plant invader that exhibits morphological plasticity. Ashton and Mitchell (1989) reported that giant *Salvinia* has three growth forms: a survival form with four to five pairs of flattened leaves (1–2cm in length) spaced out on a short rhizome, a colonizing form that resembles the survival form but is four to five times larger, and a mat form with large erect leaves, closely pressed to each other and closely spaced on the rhizome. Ashton and Mitchell (1989) further noted that the survival form is found in adverse conditions (e.g. low nutrient levels) and has low growth rates whereas the colonizing form is found in open water where space is not restricted and has high growth rates. The mat form is found in established mat formations with relatively low *in situ* growth rates.

2.3.2.4 Boom-and-bust and propagule pressure

Williamson (1996) reported that there were some factors that favoured success of aquatic plant invasions, for instance, boom-and-bust and propagule pressure. Boom-and-bust has been used to describe when an invading species increases to peak density and then declines.

The presence of *Elodea* in the British Isles has been cited as a classic example of boom-and-bust (Elton, 1958; Simpson, 1984; Williamson, 1996). Elton (1958) outlined that *Elodea* was noticed in a pond in 1842 on the Scottish border. Subsequently thereafter, *Elodea* was found in canals, ditches, lochs, and ponds all over the country, was carried downstream or along canals, on birds and introduced as scientific curiosity. Simpson (1984) noted that based on the prolific growth of *Elodea*, by 1855 the plant was blocking drains, sluices, navigable sections of rivers. It had spread as far as Ireland by 1866 and Scotland by 1880. Simpson (1984) further reported that once *Elodea* became established in an area, the plant

would increase to pest proportions within three to four years; the population would maintain itself for another three to ten years after which the population would decline to a lower problem status. The cause of the rapid decline in *Elodea* remains unknown. However, Elton (1958) and Williamson (1996) surmised that the decline of the *Elodea* population could have resulted from low availability of resources, interactions between the invader and prey species, or genetics.

In terms of propagule pressure, Williamson (1996) pointed out that as the number of propagules produced by the invading plant increased, the greater the chances of the species becoming established. If the number of propagules produced is small, even though they may get dispersed, the probability of some propagules finding suitable habitat and becoming established decreases, and the resulting plants may be diffuse and not have the opportunity to reproduce sexually. With greater propagule numbers, however, the probability of finding a suitable habitat increases, success of reproduction increases, and avoiding difficulties from weather phenomena increases (Williamson, 1996).

Several authors have described the attributes or traits that have made aquatic plants successful invaders. These traits were mainly focused on the morphology, reproduction, and physiology of aquatic plants. In order to put the traits of a successful aquatic invader in perspective, the characteristic traits have been summarized and presented in Table 4.

Table 4: Summary of the general attributes of successful aquatic plant invaders

<i>Morphological traits</i>	
<ul style="list-style-type: none"> • Free floating habit • Perennials and herbaceous • Short life cycle • Spreading growth form • Primary colonizers 	<p>Ashton and Mitchell, 1989; Cronk and Fuller, 1995 Cronk and Fuller, 1995 Cook, 1990; Thiébaud, 2007 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989; Pieterse and Murray, 1990</p>
<i>Reproductive traits</i>	
<ul style="list-style-type: none"> • Uses vegetative (asexual) reproduction (e.g. vegetative propagules) • Dioecious or monoecious • Efficient dispersal mechanisms (e.g. seeds, spores, plant fragments and vegetative propagules are dispersed by water and/or wind) • Regenerate asexually using fragmentation or vegetative hibernating organs • Fast reproductive rates (high energy allocated to reproduction) • Sexual reproduction • Remain dormant in unfavourable conditions • Large number of vegetative propagules produced • Large number of seeds produced for long-range dispersal 	<p>MacArthur and Wilson, 1967; Sculthorpe, 1967; Ashton and Mitchell, 1989; Cronk and Fuller, 1995; Thiébaud, 2007 Cronk and Fuller, 1995 Wade 1990; Cronk and Fuller, 1995; Thiébaud, 2007</p> <p>Sculthorpe, 1967; Ashton and Mitchell, 1989; Pieterse and Murray, 1990; Thiébaud, 2007 Ashton and Mitchell, 1989; Thiébaud, 2007</p> <p>Ashton and Mitchell, 1989; Spencer and Bowes, 1990; Cronk and Fuller, 1995 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989; Van Vierssen, 1990</p>
<i>Physiological traits</i>	
<ul style="list-style-type: none"> • Tolerant of a wide variety of environmental conditions • Rapid vegetative growth • Morphological plasticity • High phenotypic plasticity • High stress tolerance • Boom-and-bust 	<p>Ashton and Mitchell, 1989; Cronk and Fuller, 1995; Thiébaud, 2007 Ashton and Mitchell, 1989; Pieterse and Murray, 1990; Cronk and Fuller, 1995; Thiébaud, 2007 Mitchell and Gopal, 1991 Thiébaud, 2007 Mitchell and Gopal, 1991 Williamson, 1996</p>
<i>Other traits</i>	
<ul style="list-style-type: none"> • Generalists, opportunists, pioneers • Spread by humans activities • Widely distributed • Propagule pressure • Taxonomically related 	<p>Mitchell and Gopal, 1991 Pieterse and Murray, 1990 Thiébaud, 2007 Williamson, 1996 Ashton and Mitchell, 1989</p>

2.4 Legislative framework for the introduction of aquatic plants into Ontario

2.4.1 Canadian Food Inspection Agency

Importation of plants into Ontario is regulated by the Canadian Food Inspection Agency (CFIA). The CFIA is one arm of the federal government, responsible for food inspection, protecting the environment in terms of plant protection and animal health, and consumer protection as it relates to food (CFIA, 2010a; CFIAA, 1997). Formed in 1997 under the *Canadian Food Inspection Agency Act* (CFIAA), the CFIA's strategic outcomes include and are not limited to:

- Managing and minimizing public health risks associated with foods and the transmission of animal disease to humans;
- Creating a safe and sustainable plant and animal resource base; and
- Applying science and standards to ensure consumer protection and market access.

In terms of plant protection, the CFIA oversees a number of products and sectors such as: biotechnology, fertilizers, forestry, grains and field crops, horticulture, plant breeders' rights, plant pests, potatoes, seeds, and variety registration (CFIA, 2010b). The Agency also designs and administers programmes and services with the aim of protecting Canada's plant resource bases. These programmes and services include and are not limited to: taking part in international standard setting for phytosanitary measures, conducting surveillance of pests and plant health risk assessments, making sure that plant and plant product exports meet foreign requirements, ensuring the plant and plant product imports meet Canadian requirements, and providing information on fact sheets and policies addressing plant pests (CFIA, 2010b).

Incidentally, there are approximately 73 plant pests that the CFIA provides information on that are mainly agricultural or forestry related (CFIA, 2010c). The CFIA also regulates pests that pose a quarantine risk or were determined through a risk assessment to be quarantine pests for Canada. Approximately 240 quarantine pests are regulated. Of the

240 pests, seven are plants (Figure 6). These plants are barberry (*Berberis* sp.), dodder (*Cuscuta* sp.), barberry (*Mahoberberis* sp.), barberry (*Mahonica* sp.), broomrape (*Orobanche* sp.), buckthorn (*Rhamnus* sp.), and withchweed (*Striga* sp.) (CFIA, 2010d).

It is important to note that the CFIA does not provide a definition of the term “pest”. There is, however, a definition for a “quarantine pest” in accordance with the *International Plant Protection Convention* (IPPC), which is an international agreement on plant health that aims to protect cultivated and wild plants by stopping the introduction and distribution of pests (FAO, n.d.). Under the Convention, a quarantine pest is defined as “a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled” (FAO, 2010, p. 15). The Convention also defines the term “pest”, which is “any species, strain or biotype of plant, animal or pathogenic agent injurious to plant or plant products” (FAO, 2010, p. 12). Based on the definition of a pest under the IPPC, it can be deduced that invasive aquatic plants can be described as pests since they impact native species. The term pest is also one of the many adjectives used to describe IAS in general (Colautti and MacIsaac, 2004). There are, however, no aquatic plant pests on the CFIA plant pest or quarantine plant pest lists.

2.4.1.1 CFIA and invasive plants

In addressing invasive plants, the CFIA has undertaken two initiatives: the preparation of an *Invasive Plants Policy* and *Canada’s Least Wanted Plants Pilot Project*. The Agency also has responsibilities under the Government of Canada’s *An Invasive Species Strategy for Canada* (2004).

Invasive Plants Policy

The *Invasive Plants Policy* is a draft document prepared following consultation held in 2010 (CFIA, 2010e). The aim of the policy is to “develop and implement regulations and phytosanitary measures as they apply to the importation and domestic movement of invasive plants designated as pests and/or prohibited noxious weeds” (CFIA, 2010e).

Figure 6: Pie chart showing relative proportions of quarantine pests regulated by the CFIA (CFIA, 2010d)

Of note, plant pests are designated under the *Plant Protection Act* (1990) and prohibited noxious weeds, under the *Weed Seeds Order* (2005) of the *Seeds Act* (2009). The policy also reported that the decision to regulate a plant as a pest was based on science and other appropriate deliberations as is Canada's obligations required under the World Trade Organization (WTO) Agreement, on the application of Sanitary and Phytosanitary Measures (SPS) and as a signatory to the IPPC (CFIA, 2010e).

The scientific basis used for regulating invasive plants is pest risk analysis (PRA). Under the IPPC, a PRA is "the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it" (FAO, 2010, p. 13). In general, persons introducing plants or plant products into Canada complete an import permit form under the *Plant Protection Act* (Appendix 1). If the plant being imported has not been previously introduced, a PRA is conducted in order to determine whether or not the species could be designated as a regulated pest. If the plant has significant risks, the plant is then elected for regulation and subjected to public consultation. At the consultation, risk management documents (RMD) developed from weed risk assessments on the species in question are presented for comments. A final decision is then made by the CFIA (taking into account the public's comments) and the species designated as a regulated pest is added to the *Pests Regulated by Canada* list.

Plants designated as pests are subjected to regulatory control or action that include and are not limited to: prohibition (import and domestic movement), an import permit that allows the material contaminated with the regulated article to enter or move within Canada for a specific end use under specific conditions, phytosanitary certification from the exporting country, combination of import permit and phytosanitary certification, and destruction, treatment or ordered to be returned to origin (CFIA, 2010e). Risk mitigation measures are also determined and implemented based on the pathway, end-use of the plant, or plant product (CFIA, 2010e). There are five major pathways through which species to be regulated arrive and spread in Canada: seed for propagation, plants to be planted (e.g. ornamentals), grains, hay, straw and packing material, and soils (CFIA, 2010e). In

situations where the plant has been previously imported and is later determined to be a regulated pest, the CFIA would then forbid any further importation or local movement of that particular species or any plant products that may have been contaminated by said species (CFIA, 2010e).

All regulatory decisions on the specific plant pest are posted on the CFIA website, in the *Plant Protection Policy Directives* and the *Automated Import Reference System* (AIRS). The AIRS is a searchable database hosted by the CFIA of import requirements. Approximately 96 policy directives are listed on the CFIA website for the years 1994 to 2010. There are also five RMDs for the years 2007, 2008 and 2010. Of the directives and RMDs listed, there are none specific to aquatic plants or the aquarium and ornamental pond industries.

Canada's Least Wanted Plants Pilot Project

Under *Canada's Least Wanted Plants Pilot Project*, 25 RMDs were prepared (Table 5). Each plant was detailed under various subjects, namely: hardiness zone, distribution, sector(s)/habitat affected, agricultural, horticultural, environmental and/or societal impacts, pathways, and CFIA recommendation. Of the 25 plants listed, only one species, sessile joy weed (*Alternanthera sessilis*) is used as an aquarium and/or ornamental pond plant in the Greater Toronto Area (GTA). However, this species is listed as absent in Canada (CFIA, 2010f). Further, the hardiness zone of sessile joy weed was determined to be a seven (mild) which fell only within the south-western region of British Columbia (NRC, 2003). Sessile joy weed is regulated as a quarantine pest under the *Plant Protection Act* and is located on the *Pests Regulated by Canada* list (CFIA, 2010f). This plant is also regulated under the *Seeds Act* (1985) as a Class 1, Prohibited Noxious Weed (WSO-1) on the *Weed Seeds Order* (2005). Of concern, is that in spite of these listings, sessile joy weed continues to be sold in the GTA.

Table 5: Canada's least wanted invasive plants (CFIA, 2010)

Scientific Name	Common Name
<i>Aegilops cylindrical</i>	Jointed goat grass
<i>Alopecurus myosuroides</i>	Slender foxtail
<i>Alternanthera sessilis</i>	Sessile joy weed
<i>Bothriochloa ischaemum</i>	Yellow blue stem
<i>Cenchrus echinatus</i>	Southern sandbur
<i>Centaurea iberica</i>	Iberian star thistle
<i>Centaurea solstitialis</i>	Yellow star thistle
<i>Crupina vulgaris</i>	Common crupina
<i>Cyperus rotundus</i>	Purple nut sedge
<i>Dioscorea polystachya</i>	Chinese yam
<i>Echinochloa colona</i>	Jungle rice
<i>Galega officinalis</i>	Goat's rue
<i>Halogeton glomeratus</i>	Halogeton
<i>Microstegium vimineum</i>	Japanese stilt grass
<i>Milium vernal</i>	Spring millet grass
<i>Nassella tenuissima</i>	Mexican feather grass
<i>Nassella trichotoma</i>	Serrated tussock
<i>Paspalum dilatatum</i>	Dallis grass
<i>Peganum harmala</i>	African rue
<i>Persicaria perfoliata</i>	Mile-a-minute
<i>Pueraria montana</i>	Kudzu
<i>Senecio inaequidens</i>	South African ragwort
<i>Senecio madagascariensis</i>	Fireweed
<i>Solanum elaeagnifolium</i>	Silver-leaf nightshade
<i>Zygophyllum fabago</i>	Syrian bean-caper

Invasive Species Strategy of Canada

The *Invasive Species Strategy of Canada* (2004) “seeks to protect Canada’s aquatic and terrestrial ecosystems, and their native biological diversity and domestic plants and animals, from the risk of IAS” (GOC, 2004, p. 7). The Strategy response to IAS includes preventing new invasions, detecting and responding rapidly to new invaders, managing established and spreading invaders through containment, eradication, and control (GOC, 2004), as well as preventing the introductions of IAS from other countries, or from other areas within Canada (CFIA, 2010g).

The CFIA has the responsibility of implementing the Strategy in relation to invasive alien plants and plant pests by focusing on prevention through science-based regulations, plant surveillance, pest eradication, risk management, and public awareness (CFIA, 2010g) in keeping with their mandate. Accordingly, the CFIA works to prevent the entry and/or establishment of new plant pests, limit the distribution of pests already present, and to certify plant and plant products for pest-free domestic and international trade (CFIA, 2010g).

2.4.1.2 Administration and enforcement of the CFIA

The CFIA reports to the Minister of Agriculture and Agri-Food and is responsible for the administration and enforcement of the *Agriculture and Agri-Food Administrative Monetary Penalties Act* (1995), *Canada Agricultural Products Act* (1985), *Fertilizers Act* (2009 – Chapter F10), *Fish Inspection Act*, *Health of Animals Act* (2009 – Chapter F12), *Meat Inspection Act* (1985), *Plant Breeders' Act* (1990), *Plant Protection Act* (1990), and the *Seeds Act* (2009 – Chapter S8). Of these, the *Plant Protection Act* (1990) and the *Seeds Act* (2009) pertain to plant imports and will be discussed here.

The Plant Protection Act (1990)

The *Plant Protection Act*, 1990 (PPA) was written with the intent to “protect plant life and the agricultural and forestry sectors by preventing the importation, exportation, and spread of pests and by controlling or eradicating pests within Canada” (PPA, 2009, p. 1). Under the Act, the term pest relates to “anything that may be injurious or potentially injurious, directly or indirectly, to plants, plant products or plant by-products” (PPA, 2009, p. 2). The term also relates to plants that can be described as pests.

Sections 6 and 7 of the Act make provisions for the control and importation and exportation of pests. Of note are subsections 6(1) and 7(1). Subsection 6(1) speaks to the prohibition of a person growing, raising, culturing, or producing or moving anything that is a pest, is or could be infested with a pest, or could be a biological problem to the control of a pest, except as allowed by provisions under the Act or regulations. Subsection 7(1)

indicates that there shall be no importation of anything that is a pest, is or could be infested with a pest, or could be a biological problem to the control of a pest, unless:

- the item being imported is in accordance with subsection 7(2);
- the importer has shown all permits, certificates and related documents as required by the regulations; and
- the item is imported/exported in accordance with the regulations.

The PPA also works in conjunction with several regulations that were formed under Section 47 of the Act. There are 12 regulations under the PPA. These regulations relate mainly to the agricultural sector, such as eggplant and tomato production, golden nematode (*Globodera rostochiensis*), potato production and sale, potato wart (*Synchytrium endobioticum*), and plum pox virus, which affects fruit trees. There are also regulations relating to forest pests, fungal pathogens (e.g. *Phytophthora ramorum*, which causes sudden oak disease) and ash-free zones (DOJ Canada, 2011). The regulations of concern to this paper are the *Plant Protection Regulations*.

The Plant Protection Regulations (2009)

The *Plant Protection Regulations*, 2009 (PPR) like the PPA, was intended to prevent “the importation, exportation, and spreading of pests injurious to plants and provisions for their control and eradication, and for the certification of plants” (PPR, 2009, p. 1). Eradication and prevention of the spread of pests are controlled by means of a pest risk assessment. This assessment is done in accordance with the *International Standards for Phytosanitary Measures, Part I – Import Regulations, Guidelines for Pest Risk Analysis*, which allow for:

- determining pest(s);
- recommending actions to prevent the introduction, spread, eradication, or control of a pest into, within, and from Canada;
- identifying potential adverse effects on the environment by the pest; and
- minimizing environmental degradation with respect to Canadian flora (PPR, 2009).

In terms of importation, the PPR stipulates that “no person shall import into Canada anything that is a pest, is or could be infested or constitute a biological obstacle to the control of a pest” without a valid permit or phytosanitary certificate (PPR, 2009, p. 15). This permit is issued by the Minister who has reasonable grounds to believe “that the importation of a thing will or would likely result in the introduction or spread within Canada, of a thing that is a pest, is or could be infested or constitutes or could constitute a biological obstacle to the control of a pest ... determines that every precaution necessary to prevent the introduction into or spread within Canada of any pest or biological obstacle to the control of a pest can and will be taken” (PPR, 2009, p. 19). Further, the regulations speak to the prohibition of things into or en route to Canada that may be described as a pest and/or infested with a pest (PPR, 2009). The provision outlined for issuing an import permit based on a risk assessment appears contradictory given that a risk assessment is supposed to exclude species based on their perceived risk.

The PPR also contains two Schedules: prohibited movement within Canada (Schedule I) and restricted movement within Canada (Schedule II). Within each schedule, plants are described under four column headings: thing, place of origin, destination, and pest. For Schedule II, another column, requirements, was added, which speaks to movement within Canada. Of note, there are no aquatic plants distributed by the aquarium or ornamental pond industries listed on either Schedule I or Schedule II. Other issues addressed by the PPR include and are not limited to the quarantine, investigation, survey, processing or treatment of potential pest or pest areas, prohibition, restriction or control of pest movement, seizure and detention, disposition, and declaration (PPR, 2009).

The Seeds Act (2009)

The *Seeds Act*, 2009 is intended to address the “testing, inspection, quality, and sale of seeds” into, within, and from Canada (*Seeds Act*, 2009, p. 1). Under Section 4(1) of the Act, regulations can be made by the Governor in Council with respect to seed grades, inspection, purity and quality of seeds, seed testing, registration of seed varieties, disposition of items forfeited and detention amongst others (*Seeds Act*, 2009).

Seeds Regulations (2009)

Under the *Seeds Act*, the *Seeds Regulations*, 2009, was written with the intention of “respecting the quality of seeds including seed potatoes, and the testing, inspection, and sale thereof” (*Seeds Regulations*, 2009, p. 1). The regulations contain seven Schedules: seed of the kinds and species – minimum weed seed and other crop seed standards (Schedule I), seed of a kind set that can be sold under variety name (Schedule II), species, kinds or types of crops subject to variety registration (Schedule III), grades or seed potatoes (Schedule IV), and Schedules V to VI that were repealed. The invasive aquatic plants reed canary grass (*Phalaris arundinacea*) and water cress (*Nasturtium officinale*) were listed on Schedules I – III and Schedule I, respectively. Of concern is that both invasive aquatic plants are allowed to be sold within the GTA and on the wider scale, Canada.

Weed Seeds Order (2005)

The *Weed Seeds Order*, 2005 (WSO), falls under Subsection 4(2) of the *Seeds Act*, 2009. The Order is intended to address weed seeds, that are, “the seeds of the species of plants that are deemed to be weed seeds for the purpose of establishing grades under the *Seeds Act*” (WSO, 2005). These weed seeds were listed under six classes: prohibited noxious weed seeds (Class 1), primary noxious weed seeds (Class 2), secondary noxious weed seeds (Class 3 and Class 4), noxious weed seeds (Class 5), and other weed seeds (Class 6). There are 20 species listed under Class 1, 17 under Class 2 and Class 3, 5 under Class 4, and 10 under Class 5. Other weed seeds refer to “all seeds in a mixture that are not considered noxious and are not crop seeds (White *et al.*, 1993, p. 93). There were, however, no aquatic plants distributed by the aquarium and ornamental pond industries listed on the WSO.

The current legislative framework of Canada appears to be more focused on addressing the importation of plant pests that are mainly agricultural or forestry related. In view of this, it would suggest that the legislation pertaining to the importation or introduction of IAS are not effective, thus creating an obstacle in controlling the establishment and spread of these species.

2.5 Risk assessment

Risk assessment is defined as the identification, characterization, and quantification of risk (Slovic, 1987). Risk, on the other hand, has two meanings depending on the context in which it is used. First, risk can refer to a hazard or a danger and second, the chance of experiencing a loss or an unfavourable outcome (Whyte and Burton, 1980). Risk can also be defined as the probability of the event happening (P) times the magnitude of damage should it happen or the consequence of an adverse or hazardous event (M) (Whyte and Burton, 1980). On a broader scale and for purposes of environmental management, risk means “a hazard or danger with adverse, probabilistic consequences for man or his environment” (Whyte and Burton, 1990, p. 3).

Suter (1993, p. 3-4) reports that there are several advantages of using risk assessment in environmental decision-making, such as:

providing the quantitative bases for comparing and prioritizing risks and a systematic means of improving and understanding risks; results expressed as probabilities acknowledges uncertainty in predicting future environmental states and thus makes the assessment more credible; estimating clear endpoints; providing a means for parties to environmental decisions to compare the implications of their assumptions and data rather than negotiating on the basis of political clout; separating clearly the scientific process of estimating the magnitude and probability of effects (risk analysis) from the process of choosing among alternatives and determining acceptability of risks (risk management).

There are two categories of risk assessment: retroactive and predictive assessments (Newman and Unger, 2003). Retroactive assessment deals with an existing condition whereas predictive assessment deals with a planned or proposed condition (Newman and Unger, 2003). The process of risk assessment involves three components: risk identification, risk estimation, and risk evaluation. Both risk identification and risk estimation aims to gather information on: “the nature and extent of the source, the chain of events, pathways and processes that connect the cause to the effects, and the relationship between the characteristics of the impact (dose) and the types of response (effects)” (Whyte and Burton, 1990, p. 41).

Risk evaluation is where decisions are made about the meaning and suitability of the risk probabilities and consequences derived (Whyte and Burton, 1990). Kates (1978) in discussing risk assessment reported that the three main elements, identification, estimation, and evaluation, were not distinct categories but overlapped (Figure 7). Further, risk assessment also included social evaluation, which is geared to “avoid some risk at all costs (aversive risk), balance some risks with others (balanced risk), or weigh the risks encountered with benefits obtained (benefit-risk) and with other costs (cost-benefit)” (Kates, 1978, p. 12).

Figure 7: Schematic showing the elements of risk assessment (Kates, 1978)

2.5.1 CFIA and risk assessment

In Canada, plant health risk assessments are carried out by the Plant Health Risk Assessment (PHRA) Unit for the CFIA. The risk assessments are conducted in order to determine if commodities entering Canada are carrying pests, diseases, or weeds that could become established in Canada (CFIA, 2009). Risk assessments are also carried out for species that have the potential to become a quarantine pest in Canada. The assessment is conducted based on the biology of the organism and whether it would be able to live and survive in Canada (CFIA, 2009).

Risk assessments are conducted in accordance with the IPPC, particularly, ISPM No. 11 (K. Pauk, pers. comm., 2011) (Appendix 2). Under this ISPM, there are three main stages to conducting an assessment or a PRA: process initiation, risk assessment, and risk management (FAO, 2006). In process initiation, the pest(s) are identified that require phytosanitary measures and/or the pathway of concern that represents a potential pest hazard (FAO, 2006). Under risk assessment (stage 2), there are three areas to be addressed: pest categorization, assessment of the probability of introduction and spread, and assessment of potential economic consequences inclusive of environmental impacts (FAO, 2006).

Factors considered in pest categorization are: pest identification, presence or absence in the PRA area (in this case, Canada), regulatory status, potential for establishment and spread in the PRA area, and potential for economic and environmental consequences in the PRA area (FAO, 2006). Upon completion of this step, if a pest is deemed a quarantine pest, the next step, assessment of the probability of introduction and spread is conducted. If the pest is not deemed a quarantine pest, the PRA can be halted (FAO, 2006).

Assessment of the probability of introduction and spread examines several aspects: pathway analysis (e.g. areas of entry), survival during transport, storage or pest management procedures, transference to a suitable host, availability, quantity and distribution of hosts in the PRA area, potential adaptation of the pest, reproductive strategy of the pest, pest survival methods, cultural practices and control measures, environmental suitability, and probability of spread after establishment amongst others (FAO, 2006). Finally, in the assessment of potential economic consequences, there is an examination of pest effects (direct and indirect), and an analysis of the consequences (e.g. economical, commercial, environmental, and non-commercial) (FAO, 2006).

In the third stage, risk management, the conclusion from stage 2 (PRA) is used to determine whether risk management is required as well as the strength of the measures to be used (FAO, 2006). Other areas examined include level of acceptable risk, and identification of appropriate management options (FAO, 2006). Daehler and Denslow

(2007) quoting C. Wilson O'Driscoll (pers. comm.) reported that the risk assessment process used by CFIA is similar to the United States Department of Agriculture's (USDA) Animal and Plant Health Inspection Service (APHIS). The USDA APHIS uses a qualitative pest risk assessment that determines whether or not a plant species should be listed or de-listed from the respective legislation. In the case of the USA, it would be their noxious weed regulations (Appendix 3). This assessment uses eight basic steps: documenting the initiating event, identifying and citing previous risk assessments, establishing the identity of the weed, verifying the quarantine pest status, assessing the economic and environmental importance, assessing likelihood of introduction, determining pest risk potential, and documenting the PRA (USDA APHIS, 2004).

The eight steps are used in conjunction with five risk elements: potential habitat suitability, reproduction and spread, economic harm, ecological harm, and likelihood of introduction. Each risk element is rated high, medium, low, or negligible, which has a pre-assigned score (i.e. 3, 2, 1, and 0). Finally, scores are calculated for consequences of introduction and likelihood of introduction and then an overall score of pest risk potential is derived (USDA APHIS, 2004). This overall score serves to inform the decision of whether to allow or deny a plant from being imported (Daehler and Denslow, 2007). There are however, drawbacks to this type of assessment. It is, for example, time consuming. Daehler and Denslow (2007, p. 39) further noted that "there are no data on which to judge how well the APHIS risk assessment procedure excludes true pest plants and allows entry of non-pests ... the APHIS system has never been tested by evaluating known pests and non-pests and calculating the rates of correct decisions."

Notwithstanding the type of risk assessment process used by the CFIA, these assessments are not conducted on a regular basis especially for aquatic plants being imported into Canada (C. Wilson O'Driscoll, pers. comm., 2011). This action is contrary to one of the critical strategic goals listed in the *Invasive Species Strategy of Canada*, which is to "ensure that risk assessments are conducted of all pathways and potential pathways of unintentional introductions, including commodities and transportation vectors, and all proposed introductions of alien species and all currently traded alien species" (GOC, 2004,

p. 22). There is, however, an interim arrangement that the CFIA will conduct risk assessments on aquatic plants pursuant to a request from the Department of Fisheries and Oceans (DFO) (C. Wilson O'Driscoll, pers. comm., 2011).

Between 1998 and 2002, 93 plants permits were issued by the CFIA. However, importers were not asked the purpose of the plant introduction and no permits have been issued since 2002. In addition, risk assessments were only conducted if the plant being imported had not been previously recorded in Canada (CFIA, pers. comm., 2010). In 2007, an advisory was released by the CFIA regarding a review of their policy on aquatic plants as part of the Government of Canada's initiative on IAS (Appendix 4). Fourteen plants were listed that require risk assessments prior to introduction. Of the 14 species listed, only two risk assessments have been written: for water chestnut in 2001 and yellow floating heart in 2008. It is important to note that the remaining plants on the list have already been recorded within Ontario (Liu *et al.*, 2008; Marson *et al.*, 2009). Risk assessments have also been completed for *Cabomba* (2001) and didymo or rock snot (*Didymosphenia geminata*) (2009). Appendix 5 illustrates the executive summary of the risk assessments conducted for *Cabomba*, water chestnut, and yellow floating heart.

2.6 Link between literature review and methodology

In 1996, Mack recommended that several approaches be formulated to determine the traits of a successful aquatic plant invader within the Greater Toronto Area (GTA). The GTA is defined as the city of Toronto and the surrounding regional municipalities of York, Halton, Peel, and Durham (City of Toronto, 2011). The approaches to be used in the research were guided based on the themes used in the literature review, namely: pathways of introduction for aquatic plants, invasion success of aquatic plants, specifically, traits of successful aquatic plant invaders, and the legislative framework for the introduction of aquatic plants into Ontario.

The pathways of introduction for aquatic plants revealed that the aquarium and ornamental pond industries are responsible for the continued introduction and spread of

IAS, especially aquatic plants. For this reason, the first approach to be taken is to identify the aquatic plants being introduced by the aquarium and ornamental pond industries. The second approach was defined based on the legislative framework in Canada as the current system does not effectively address the introduction of IAS. Accordingly, the approach to be taken is to discover the opportunities of introduction for aquatic plants. Finally, from the literature presented on the traits of aquatic plant invaders, there is still a level of inconclusiveness about what traits contribute to their success. In order to contribute to this knowledge gap, the third approach to be taken is to ascertain the traits that make aquatic plant invaders successful.

3.0 METHODOLOGY

3.1 Selection of potential aquatic plant invaders

A thorough review of literature was conducted to compile a list of potential aquatic plant invaders distributed by the aquarium and ornamental pond industries (e.g. Hiscock, 2003; Thierry and Piednor, 2005; Hargreaves, 2006; Cohen *et al.*, 2007; Marson *et al.*, 2009; GISD, n.d.). The species selected represented all three growth types of aquatic species, namely floating, emergent and submerged and were not restricted by their native origin (e.g. Asia, North America, and South America) or by their potential to be invasive. The origin and invasiveness of the plants were also noted. Opting for aquatic plants that denoted all growth types, diverse origins, and invasiveness, ensured that no particular feature was eliminated from the dataset that would be later used to determine the attributes of a successful invader. This initial list represented several of the potential aquatic plant candidates that may be released by the aquarium and ornamental pond industries, aquarists, and ornamental pond (water garden) enthusiasts into the natural environment either accidentally or deliberately.

3.2 Determining likelihood of introduction

Two proxies were used to determine the possibility of introduction of aquatic plants into the natural environment: volume of sales and usage (indoor aquaria and outdoor ornamental ponds). The premise was that the higher the volume of sales, the greater the use of the plant in aquariums and ornamental ponds, the greater the probability of the plant being released into the new environment.

Data on the volume of sales and usage of aquatic plants were obtained from stores that sell aquatic plants for aquariums and ornamental ponds. These stores were identified using the GTA Aquarium Online Store Listing and Yellow Pages Canada category listings “aquariums” and “water gardens”. For each category listing, the location was selected in order to identify the stores for that section of the GTA. The individual lists were then merged and a final list of stores that sold aquatic plants was generated. Other stores were

also suggested by store owners. In total, 78 stores were identified that sold aquatic plants for aquariums and ornamental ponds. These stores were contacted via telephone in order to confirm if they sold aquatic plants. Upon verification that a store sold aquatic plants, the name of the manager and/or owner was ascertained and recorded. The managers and/or owners of the 62 stores identified as selling aquatic plants were sent letters of introduction that outlined the nature of the research and how the stores could participate (e.g. provide a list of aquatic plants sold, volume of sales, or a customer survey). Responses were received from 35 stores on the volume of sales and/or usage of aquatic plants (response rate of 56.4%).

The list of aquatic plants sold by the stores was merged with the inventory of aquatic plants obtained from the literature review. Thus, creating a final list of potential aquatic plant invaders distributed by the aquarium and ornamental pond industries within the GTA. For those stores that agreed to provide information on the volume of sales of aquatic plants, annual data was requested. The provision of annual data was not possible for some stores. In these cases, volume of sales was provided daily, weekly, biweekly, monthly or half-yearly. Sales reported daily, weekly, biweekly, monthly and half-yearly were extrapolated to annual sales.

3.3 Survey of aquarium and ornamental pond customers

A survey was conducted to gather data from customers that buy and/or use aquatic plants from the aforementioned aquarium and ornamental pond stores (Appendix 6). The survey was designed to collect data on the use, source of, and disposal of aquatic plants, which would reflect the consumers' contribution to the spread of potential aquatic invaders. Approximately 600 customers were targeted to complete the questionnaires. The sample size was determined using an online survey tool, *The Survey System*. For the survey of aquarium and ornamental pond customers, a 95% confidence level and a confidence interval of 4 were used. The confidence interval (CI) or the margin of error provides information on the degree of accuracy within which a population parameter has been estimated (Evans, 1992). The CI uses a lower and an upper limit ($\pm$) within which the

population parameter is expected to lie in relation to the confidence interval (Evans, 1992). Ideally, a large sample size would ensure that responses received from the survey would accurately reflect the population. The unstated rule is that the larger the sample size, the smaller the CI. In the case of the GTA, a sample size of 600 allows one to have a CI of ± 4 with a confidence of 95%. This number, while not ideal, was considered to be representative of the population of the GTA, given the time frame in which to complete and analyze the survey data.

In view of the sample size and the number of stores targeted, each store would receive 10 questionnaires. Initially, two of the 62 stores agreed to participate in the survey. They each took 20 questionnaires for a period of two months. Of the 40 questionnaires issued, only 4 were completed. The remaining stores declined to participate in the survey. As a result, the survey was discontinued. In order to obtain data on the source and disposal of aquatic plants, surveys conducted by Marson *et al.* (2009a, b) on aquarium and ornamental ponds within Canada were used.

3.4 Determining characteristics of selected aquatic plants

As previously discussed in Section 2.3.2, aquatic plant invaders use morphological, reproductive, and physiological strategies that allow them to be successful in invading new environments (Table 4). In order to determine the attributes of potential aquatic plant invaders, quantifiable species traits or variables had to be identified. These variables were identified by looking at the traits listed under each strategy and categorizing them by those particular traits (Table 6). In some cases, two or more traits of a successful aquatic invader as presented in Table 4 were conflated to be investigated in determining the common traits of a successful invader. For example, morphologically, aquatic plant invaders have been reported to be either annuals or perennials. Both terms relate to the life cycle of a plant; as such, life cycle is a variable that can be examined as a morphological attribute of a potential invader. A similar approach was taken for the remainder of the morphological and reproductive traits.

For the physiological traits, since aquatic plant invaders are tolerant of a variety of environmental conditions, environmental parameters were used to determine if a specific parameter promoted invasion success. Physiologically, aquatic plant invaders also exhibit plasticity, which is a response to the environment they are in. For this reason, plant features and flowering period were used to determine a physiological response. In total, 29 traits were identified to obtain information of each aquatic plant distributed by the aquarium and ornamental pond industries in the GTA.

Table 6: Attributes observed to identify potential aquatic plant invaders

<i>Morphological traits</i>	Attributes to be observed
<ul style="list-style-type: none"> • Free floating habit • Perennials or annuals 	Growth form Life cycle
<i>Reproductive traits</i>	Attributes to be observed
<ul style="list-style-type: none"> • Uses vegetative (asexual) and/or sexual reproduction • Large number of vegetative propagules produced • Regenerate asexually using vegetative hibernating organs • Efficient dispersal mechanisms (water and/or wind) • Dioecious or monoecious • Large number of seeds produced for long-range dispersal 	Number of reproductive strategies used Number of propagation strategies used Type of propagation strategies used Number of vegetative propagules produced per biomass Type of vegetative propagule used Number of dispersal mechanisms employed by plant Type of dispersal mechanism used Breeding system Number of seeds or spores produced per biomass
<i>Physiological traits</i>	Attributes to be observed
<ul style="list-style-type: none"> • Tolerant of a wide variety of environmental conditions • Rapid vegetative growth • Morphological plasticity • Phenotypic plasticity 	Temperature, light suitability, salinity, nutrient content, pH Growth rate Number of phenotypic forms produced Plant features (i.e. stem length, stem width, leaf length, leaf width, flower length, flower width, fruit length, fruit width, fruit type, seed size, time to flower)

For each aquatic plant, information on the variables was obtained by means of a thorough literature review. In the case of aquatic plants that were cultivars, information on these was recorded and researched based on their genus (e.g. *Crinum* spp.). The underlying

assumption was that there would be a paucity of information on the biological traits of these plants. Of note, a genus could represent any given number of cultivars; for example, *Nymphaea* spp. represented approximately 70 cultivars.

While information on the plant's biological traits was being obtained, two issues arose. First, some stores were not aware of the scientific names of the plants sold and only provided common names. When this occurred, the scientific name of the plant was found using the common name. It was found, however, that the common name of the plant did not accurately identify the plant being investigated. An ideal example was the Java moss. In the aquarium industry, Java moss is known both as *Vesicularia dubyana* and *Taxiphyllum barbieri*. For years, this plant was known as *V. dubyana* until 1982 when it was reclassified (Tan *et al.*, 2005); however, this plant is still traded under its former name. In instances when the common name did not match the scientific name, the species was flagged, and the correct scientific name confirmed using *The Integrated Taxonomic System* (ITIS), and *The PLANTS Database*.

In order to avoid further confusion in using common names, the plant's scientific name was used to obtain information on the biological traits. Conversely, based on the literature, it became apparent that the scientific names of some of the plants had changed. Accordingly, a verification of the botanical nomenclature was conducted using the taxonomic databases, *Tropicos*, *International Plant Name Index* (IPNI) and ITIS. The verification was conducted by inputting the scientific name of the aquatic plant as sold in the aquarium and ornamental pond industries into the databases. The search was also conducted using the genus of the species. For *Tropicos* and *ITIS*, the current botanical name was marked as "legitimate" or "accepted" respectively. In the case of IPNI, the scientific name was listed along with its synonym and basionym.

3.4.1 Data analysis

Of the 29 aforementioned traits, 13 were categorical variables. Some of the categorical variables were bimodal (e.g. breeding system) and some were divided into multiple

categories (e.g. life cycle, growth form, number of seeds, type of dispersal mechanisms, growth rate, fruit type, time to flower, light, salinity, and nutrient content). In some cases, each category represented a range in the trait (e.g. temperature (range), and pH). For example, the pH of a particular aquatic plant was calculated using composite pH ranges obtained from the extensive literature review conducted. Categorical variables were numerically coded (e.g. 1 or 2) to permit inclusion in regression analysis (Appendix 7).

Of the 16 remaining traits, 11 were continuous variables. These variables were: number of dispersal mechanisms used, stem length, stem width, leaf length, leaf width, flower length, flower width, fruit length, fruit width, seed length, and seed width. For the stem, leaf, flower, fruit and seed lengths and widths, the average of the range given (e.g. 1.2–10cm long = 5.6cm long) or the actual measurement (e.g. 12cm long) was recorded. In terms of temperature, the values were recorded as a minimum and a maximum in order to ascertain the growth temperature of the aquatic plants.

The propagation strategies used by the aquatic plants were divided into four categories: A and B, C, D and E, which are described below.

- Categories A and B = species that produced daughter plants from the fragments or whole of roots, rhizomes, or runners (initially separate categories, merged prior to analysis);
- Category C = species that produced daughter plants from offshoots of above ground mass (e.g. offshoots, side shoots, sprig, budding, and adventitious shoots);
- Category D = species that produced daughter plants from fragments of above ground mass (e.g. fragments, cuttings, division of tufts or stem, or adventitious plantlets); and
- Category E = species that produced daughter plants from seed or spore.

In association with the variable, type of vegetative propagule used, the four categories (A to E) were populated using a presence (Y/N) approach, where presence of this propagation strategy was coded Y and absence coded N.

The three remaining traits: number of reproductive strategies used, number of phenotypic forms produced, and number of vegetative propagule produced per biomass, were excluded at the onset as they did not provide enough information that allowed for a clear differentiation between the species and therefore, would limit the number of cases that could be included in the analysis. A similar approach was taken with the variables stem width, leaf width, flower width, fruit width, and seed width.

3.5 Grouping of aquatic plants

In order to determine if there were any common traits between the aquatic plants distributed within the GTA, the plants were divided into three categories: alien aquatic plants (Category 1), native aquatic plants (Category 2), and cosmopolitan aquatic plants (Category 3) based on their origin. Categories 1 and 2 were further subdivided into aquatic invaders and aquatic non-invaders since not all alien plants are invasive and native plants to Canada can be invasive elsewhere (Figure 8). Invasive and non-invasive aquatic plants were verified based on the thorough literature review that was conducted.

There were four final identifiable groups included in the analysis of common traits, groups into which the aquatic plants sold within the GTA could be placed: Group 1 - alien and invasive (AI), Group 2 - alien and non-invasive (ANI), Group 3 - native and invasive (NI), and Group 4 - native and non-invasive (NNI). Group identity served as a categorical (or grouping) variable in logistic regression analysis described below (Appendix 7).

Figure 8: Schematic showing how plants distributed by the aquarium and ornamental pond industries was grouped based on native, non-native, and invasive potential

3.6 Statistical analysis

Logistic regression analysis included group identity as a categorical variable and initially, the 21 traits described above as independent or predictive variables (i.e. predictive of group identity in the regression model). Logistic regression analysis and all other statistical analysis described below were performed using SYSTAT version 13 (Systat, Inc., Chicago, IL).

Continuously distributed variables (stem, leaf, flower, fruit, and seed lengths as well as volume of sales) were tested for normality of distribution (Kolmogorov-Smirnov Lilliefors tests), and to determine the appropriateness of inclusion in linear regression models. Data were transformed as necessary ($\log(\text{value}+1)$) to meet these assumptions. Subsequently, multivariate statistical analysis, specifically, logistic regression modelling (LRM) was conducted. The LRM is a predictive tool used to discover the best-fit model that describes the relationship between a dependent (outcome or response) variable and a set of independent (predictor, explanatory) variables or covariates (Hosmer and Lemeshow, 2000). Described more simply, the LRM has the ability to use continuous, categorical, or a mixture of categorical and continuous variables to predict a discrete outcome. In most

cases, the relationship being tested is between a categorical (outcome) dependent variable and one or more categorical or continuous (predictor) variables (Peng *et al.*, 2002).

In this research, the dependent variable was the aquatic plant groupings (group identity) and the predictor variables were the plant traits and sales volume. The aquatic plant groupings were selected as the dependent variable since the aim of the research is to determine what common traits distinguish a successful invader from other groups of aquatic plants, particularly alien aquatic plants that are not successful invaders. Multinomial logistic regression modelling (MLRM) was performed iteratively, with the initial iteration including all predictor variables, and with subsequent iterations removing the predictor variable with the least contribution to the model's predictive power ($\alpha = 0.15$) in at least one pair-wise group identity comparison (multinomial logistic regression model). In these analyses, with each iteration, a prediction success table was generated.

In order to achieve more effective discrimination between specific groups (here AI versus ANI species), binomial logistic regression modelling (BLRM) was performed iteratively, as above. The overall predictive value of the BLRM was determined from the prediction success table generated with the final model.

4.0 RESULTS AND DISCUSSION

4.1 Store data

Sixty-two stores that sold aquatic plants for aquarium and ornamental ponds were contacted in order to identify the aquatic plants sold, and the two proxies of introduction: volume of sales and usage. Of the 62 stores, 35 provided information on only the names of the aquatic plants sold whereas 20 provided information on both the names of the aquatic plants sold and the volume of sales.

4.1.1 Aquatic plants sold

The preliminary list of potential aquatic plant invaders compiled from published literature revealed that there were 161 taxa that could be sold by the stores in the GTA. The store data, however, revealed that there were 642 taxa that were sold (Appendix 8). The large difference between the two lists indicates that there are significantly more taxa in the trade that are not documented by the literature that could be released into the natural environment either accidentally or deliberately by the aquarium and ornamental pond industries, aquarists and ornamental pond enthusiasts.

Of the 642 taxa sold, 265 were cultivars. In view of the underlying assumption that there would be a paucity of information on the biological traits of cultivars, 212 of these species were consolidated under their respective genera. Following this consolidation, the number of taxa was reduced to 430. Since some of the scientific names of the taxa had changed, a taxonomic consolidation was done. This consolidation involved combining the two or more names under which a single species (or taxon) was sold. As a result, the number of taxa was reduced to 388. Another reduction occurred as 40 taxa were excluded due to a lack of sales volume data, thus resulting in a final number of 348, which were used to determine the traits of a successful invader (Appendix 9).

4.1.2 Volume of sales of aquatic plants sold

The research operated on the premise that the higher the volume of sales, the greater the probability of the taxa being released into the new environment. A total of 331,857 individual plants were sold per year by the 20 stores reporting sales volume in the GTA (Appendix 10). Sales volume data were grouped (Figure 9). Three invasive species were identified that had the highest volume of sales (10,000-50,000 plants per year) and greatest potential for release into the environment (Figure 9). These were water hyacinth, water lettuce, and hornwort. Conversely, 115 taxa sold by the 20 stores had the lowest volume of sales (1-50 plants per year) and the least potential for release. The remaining taxa, based on the volume of sales, would have an intermediate potential for release.

Any taxa with sales volume greater than 500 plants per year may be assumed would also have a high probability of release into the environment. Based on the volume of sales reported by the 20 stores, 100 taxa had volumes >500 plants per year and therefore, have a high probability of being released either accidentally or deliberately. Of these 100 taxa, 55 were alien non-invasive, 28 invasive (alien and native), 16 native non-invasive, and 1 cosmopolitan. The invasive taxa with the highest probability of being released into the environment are presented in Table 7.

4.1.3 Use of aquatic plants

The survey instrument designed for this research sought to determine the consumer's role in the spread of potential invaders. However, due to limited participation, the survey was discontinued. In order to gain an understanding about the consumer's role, data from Marson (2009a, b) was used as a proxy to discuss the use, source and disposal of aquatic plants for aquariums and ornamental ponds.

Figure 9: Number of plants per year sold by 20 stores in the GTA per volume category

Table 7: Invasive taxa with the highest volume of sales (>500 total taxa sold per year in 20 stores reporting sales volume)

Scientific name	Common name	Volume of sales
<i>Eichhornia crassipes</i>	Water hyacinth	32633
<i>Pistia stratiotes</i>	Water lettuce	16374
<i>Ceratophyllum demersum</i> *	Hornwort, Common hornwort	13204
<i>Vallisneria americana</i>	Corkscrew vallisneria, Jungle val	7595
<i>Cabomba caroliniana</i>	Cabomba, Fanwort	6146
<i>Sagittaria latifolia</i> *	Duck potato	6078
<i>Egeria densa</i>	Brazilian waterweed	5144
<i>Nymphaea odorata</i> *	Fragrant white water lily	5000
<i>Myriophyllum aquaticum</i>	Parrot feather	4107
<i>Lemna minor</i>	Duckweed	2967
<i>Iris pseudacorus</i>	Yellow flag iris, Yellow water iris	2935
<i>Canna</i> spp.	Canna	2644
<i>Hygrophila polysperma</i>	Dwarf hygrophila, Green hygrophila	2017
<i>Typha laxmanii</i>	Dwarf or Slender cattail	1953
<i>Myosotis scorpioides</i>	Water forget-me-not	1439
<i>Cyperus haspan</i>	Dwarf papyrus	1434
<i>Bacopa monnieri</i>	Baby tears, Moneywort	1389
<i>Nasturtium officinale</i>	Water cress	1388
<i>Juncus glaucus</i>	Blue rush	1360
<i>Butomus umbellatus</i>	Flowering rush	1350
<i>Zantedeschia aethiopica</i>	Calla lily, White arum lily	1155
<i>Ceratopteris thalictroides</i>	Water sprite, Indian fern	1093
<i>Vallisneria spiralis</i>	Straight val, vallis, or vallisneria	1053
<i>Rotala indica</i>	Indian tooth cup	1001
<i>Azolla caroliniana</i>	Water fern, Fairy moss	931
<i>Limnophila sessilifolia</i>	Dwarf ambulia, Asian marshweed	766
<i>Alternanthera ficoidea</i>	Cherry hedge, Joseph's coat	756
<i>Salvinia natans</i>	Salvinia, Floating fern	546

* Taxa, which are native and invasive

Higher volume of sales not only increases the probability of taxa being released into the new environment but also implies greater use of taxa in aquariums and ornamental ponds. Marson *et al.* (2009a, b) reported data compiled from 1,669 completed surveys of whom 794 persons owned aquariums and 359 owned ornamental ponds. These survey participants were from across Canada. The survey found extensive use of invasive taxa for aquariums and ornamental ponds. Although these studies did not examine volume of sales but frequency of occurrence, several of the invasive taxa listed in Table 7 were used by

more than 80 respondents in the survey, which indicates a relatively high use of these species. These taxa were *Cabomba*, which was used by 85 respondents, water hyacinth 286 respondents, water lettuce 246 respondents, hornwort 214 respondents, parrot feather 115 respondents and duckweed (*Lemna minor*) 170 respondents (Marson *et al.*, 2009a, b).

The number of invasive taxa bought and/or used per year was calculated using the volume of sales, the number of persons that buy a specific taxon, and the total number of persons that have aquariums and ornamental ponds. This calculated figure is also equivalent to the maximum number of plants in each taxon that could be released into the natural environment each year either deliberately or accidentally. This does not suggest, of course, that this number will be released each year, but the relative magnitudes are expected to correspond with relative risk of release into the environment. As previously indicated, of the 1,669 survey respondents within Canada that buy and/or use taxa for aquarium and ornamental ponds (Marson *et al.*, 2009a, b), 286 persons used water hyacinth (Marson *et al.*, 2009a, b). Based on the average sales volume per customer, 5,592 water hyacinths are purchased and/or used per year in the GTA, representing the number that can potentially be released into the environment. Aside from water hyacinth, the top five invasive taxa that could be released into the environment were water lettuce (2,982), hornwort (1,693), *Cabomba* (313), and *Vallisneria americana* (200). With the exception of *Vallisneria americana* and *Cabomba*, the top three invasive taxa identified in this study based on sales volume within the GTA were found to correspond with Marson's top three plants based on frequency of occurrence.

4.1.4 Source and disposal of aquatic plants

The potential spread of invasive taxa as well as other taxa that are potential invaders (e.g. alien plants that possess similar traits as invasives) by the aquarium and ornamental pond industries is also linked to their source and disposal. Cumulatively, Marson *et al.* (2009a, b) found that the main sources of taxa for aquarium and ornamental ponds were garden centres or nurseries, pet stores, from a friend, and from the wild. Other sources included aquarium clubs, internet/mail order, trade shows or other (e.g. fish auctions) (Figure 10).

During the winter or when taxa were no longer needed, most were discarded into the garbage or compost (Marson *et al.*, 2009a, b). Taxa were also left in the ornamental ponds, brought indoors, given to others, released to the wild, or returned to the store (Figure 11).

4.1.5 Status of aquatic plants sold in GTA

The 348 taxa included in the logistic regression analysis were categorized as invasive or non-invasive. For invasive taxa, two sub-categories were alien and invasive (AI) and native and invasive (NI). Similarly, non-invasive plants were sub-categorized. There were 62 taxa that were AI to Ontario and other parts of the world. On the other hand, there were 11 that were native to Ontario but invasive in other parts of the world (Figure 12). The list of invasive aquatic plants sold by the aquarium and ornamental pond industries in the GTA is presented in Appendix 11.

4.2 Multinomial logistic regression model

The final multinomial LRM was able to successfully predict group identity 63% of the time (Table 8). The model was operated using 344 cases with Group 4 (AI) acting as the reference group for paired comparisons. The remaining four cases represented the cosmopolitans, which were excluded prior to analysis since they could not be clearly distinguished into alien or native species based on their origin. The model was able to effectively resolve aquatic plants that were native and non-invasive (NNI) (Group 1) from those that were AI (Group 4). However, the model was generally poor at discriminating between Groups 2 (NI) and 4 (AI). This poor discrimination between NI and AI is not surprising if it is assumed that invasive species, regardless of geographic origin, have some shared traits. More problematic was the low success in correctly distinguishing between alien non-invasive (ANI) species and AI species, as the ability to distinguish traits in alien species that will likely lead to invasion success versus traits that are unlikely to lead to success would benefit, for example, habitat protection.

Figure 10: Sources of taxa used in aquarium and ornamental ponds in Canada (Marson *et al.*, 2009a, b)

Figure 11: Disposal methods of taxa used in aquarium and ornamental ponds in Canada (Marson *et al.*, 2009a, b)

Figure 12: Status of taxa distributed by the aquarium and ornamental industries based on sales data from 20 stores in the GTA

Table 8: Multinomial LRM prediction success table

Actual Choice	Predicted Choice				Actual Total
	1	2	3	4	
Group 1	21.020	2.087	17.114	5.779	46.000
Group 2	2.302	2.290	3.227	3.180	11.000
Group 3	17.186	3.222	172.427	32.166	225.000
Group 4	5.546	3.328	31.624	21.502	62.000
Predicted Total	46.055	10.927	224.391	62.627	344.000
Correct	0.457	0.208	0.766	0.347	
Success Index	0.323	0.176	0.112	0.167	
Total Correct	0.632				

4.2.1 NNI versus AI

Four variables were considered most important in distinguishing between NNI and AI ($p < 0.05$). These were types of propagation strategy used, number of propagation strategies used, growth rate, and minimum temperature (Table 9). The variables time to flower and pH were marginally significant ($p = 0.059$ and $p = 0.121$ respectively) in distinguishing NNI and AI. For purposes of discussion, variables with $p < 0.15$ are considered as marginally significant.

Table 9: Parameter estimates and p-values of NNI versus AI

Parameter	Estimate	Standard Error	Z	p-value	95% Confidence Interval	
					Lower	Upper
Category A and B	2.178	0.792	2.750	0.006	0.626	3.730
Category C	2.295	0.631	3.638	0.000	1.059	3.531
Category D	2.173	0.669	3.247	0.001	0.861	3.484
Category E	1.770	0.942	1.879	0.060	-0.076	3.615
Number of propagation strategies used	1.570	0.485	3.236	0.001	0.619	2.520
Growth rate	-1.417	0.358	-3.963	0.000	-2.118	-0.716
Time to flower	-0.221	0.117	-1.889	0.059	-0.450	0.008
Minimum temperature	-0.045	0.013	-3.449	0.001	-0.071	-0.020
pH	-0.803	0.517	-1.553	0.121	-1.818	0.211

Generally, production of new plants from offshoots of above ground biomass or from fragments (Categories C and D) were traits more commonly associated with AI species (34/62 and 30/62 taxa exhibiting these traits, respectively) than with NNI species (16/46 and 11/46 taxa exhibiting these traits, respectively). AI species generally had more propagation strategies per taxa, with 39/62 taxa able to reproduce by three or more different strategies. Among NNI taxa only 19/46 had three or more propagation strategies.

AI species typically had higher growth rates, with 59/62 species in moderate or high growth rate categories (36/62 classified as high growth rate), whereas NNI species had only 31/46 taxa in the moderate and high growth rate categories (7/46 classified as high growth rate). NNI species were generally more cold tolerant than AI species, as indicated by minimum growth temperatures. Among the native taxa, 33/46 had minimum growth temperatures $<0^{\circ}\text{C}$, and 39/46 had minimum growth temperatures $<10^{\circ}\text{C}$. In contrast, only 16/62 AI taxa had minimum growth temperatures $<0^{\circ}\text{C}$, and 31/62 had minimum growth temperatures $<10^{\circ}\text{C}$. AI taxa generally had longer flowering periods, with 10/62 taxa capable of flowering year-round. None of the native taxa are capable of flowering year-round. Finally, AI species were generally tolerant of a broader pH range. While both AI taxa and NNI taxa were most commonly found in moderately acidic water, 27/62 alien taxa can grow in neutral to moderately alkaline conditions, whereas only 7/46 of the native taxa included in the aquarium trade grow under neutral conditions, and none grow under moderately alkaline conditions.

4.2.2 NI versus AI

Minimum temperature was the only variable that strongly distinguished NI from AI ($p<0.05$) (Table 10), while number of propagation strategies used was marginally significant ($p=0.073$) in distinguishing between the Groups.

AI taxa were generally less cold tolerant than NI taxa, as indicated by minimum growth temperatures. Among the AI taxa, 16/62 had minimum growth temperatures $<0^{\circ}\text{C}$, and 31/62 had minimum growth temperatures $<10^{\circ}\text{C}$. In contrast, only 6/11 NI taxa had minimum growth temperatures $<0^{\circ}\text{C}$, and 9/11 had minimum growth temperatures $<10^{\circ}\text{C}$.

AI taxa commonly had more propagation strategies per taxa, with 39/62 taxa able to reproduce by three or more different strategies. Among NI plants only 4/11 had three or more propagation strategies.

Table 10: Parameter estimates and p-values of NI versus AI

Parameter	Estimate	Standard Error	Z	p-value	95% Confidence Interval	
					Lower	Upper
Minimum temperature	-0.052	0.021	-2.487	0.013	-0.093	-0.011
Number of propagation strategies used	-1.585	0.885	-1.792	0.073	-3.319	0.149

4.3 Binary logistic regression model

There was low success in accurately distinguishing between ANI and AI taxa in the multinomial logistic regression model as displayed in Table 8. The ability to discern the traits that distinguish these groups is critical, especially in preventing invasions. In order to achieve this, the binary LRM (BLRM) was used as a better predictive tool to discriminate specifically between these groups (in the absence of trying to discriminate among all four groups simultaneously). The BLRM revealed that ANI and AI taxa can be effectively discriminated 77% of the time using 287 cases in the analysis (Table 11).

The model also does a better job of classifying ANI as ANI (192/225 times) than classifying AI as AI (30/62 times). However, the model misclassified AI and ANI taxa, 32/62 times. This misclassification has management implications, especially in the introduction of aquatic plants. AI taxa can be imported or introduced if incorrect common names are used, which has been shown to be unreliable in species identification. AI introduction can also be facilitated through the continual use of scientific names that have been taxonomically revised, plant identification only to the genus level (if no flower and/or fruit are present), or inaccurate identification at the species level. The variables that allow for effective discrimination were type of propagation strategies, number of propagation strategies used, number of dispersal mechanisms used, minimum temperature, and volume of sales of aquatic plants (Table 12).

Volume of sales of aquatic plants was used in order to determine what characteristics of a plant make them more likely to become invasive by examining not only biological traits but opportunities for introduction. Thus, volume of sales acts as a proxy for opportunity for plants to become invasive through release into the environment. It is therefore appropriate that this variable be included in the analysis along with biological traits as a factor that may make one species more likely to successfully invade. One has to take into consideration that some plants are alien but not invasive just because they do not have high sales volume. If the preference patterns of consumers change and given their biological traits, then some of these species may in fact become invasive.

Table 11: BLRM prediction success table

Actual Choice	Predicted Choice		Actual Total
	Response	Reference	
Response	192.142	32.858	225.000
Reference	32.450	29.550	62.000
Predicted Total	224.592	62.408	287.000
Correct	0.854	0.477	
Success Index	0.070	0.261	
Total Correct	0.772		

Table 12: Parameter estimates and p-values of ANI versus AI

Parameter	Estimate	Standard Error	Z	p-value	95% Confidence Interval	
					Lower	Upper
Category A and B	1.794	0.512	3.505	0.000	0.791	2.797
Category C	1.896	0.429	4.416	0.000	1.054	2.737
Category D	2.001	0.433	4.621	0.000	1.153	2.850
Category E	1.754	0.508	3.452	0.001	0.758	2.750
Number of propagation strategies	1.076	0.264	4.074	0.000	0.558	1.594
Number of dispersal mechanisms	-1.366	0.231	-5.907	0.000	-1.819	-0.913
Minimum temperature	0.041	0.013	3.097	0.002	0.015	0.067
Volume of sales	-0.184	0.090	-2.047	0.041	-0.361	-0.008

In general, production of new plants from below ground biomass (Categories A and B) or from seed (Category E) were traits commonly used by both AI taxa (51/62 and 54/62 taxa exhibiting these traits, respectively) and with lower frequency in ANI taxa (175/225 and 158/225 taxa exhibiting these traits, respectively). AI species generally had more propagation strategies per taxa, with 61/62 taxa able to reproduce by two or more different strategies. Among ANI taxa only 188/225 had two or more propagation strategies. AI species typically used two or more methods of dispersal (48/62), whereas only 151/225 ANI species used more than one method of dispersal. Further, AI taxa used three or more methods of dispersal (43/62) more frequently than ANI taxa (49/225) that used similar dispersal methods. Therefore, a higher percentage of AI taxa use three or more dispersal mechanisms than ANI taxa.

ANI taxa were generally less cold tolerant than AI species, as indicated by minimum growth temperatures. Among the ANI taxa, 26/225 had minimum growth temperatures $<0^{\circ}\text{C}$, and 51/225 had minimum growth temperatures $<10^{\circ}\text{C}$. In contrast, only 16/62 AI taxa had minimum growth temperatures $<0^{\circ}\text{C}$, and 31/62 had minimum growth temperatures $<10^{\circ}\text{C}$. AI species were typically sold in relatively large numbers for the volume categories 101-500 and 1,001-5,000 taxa (32/62). Sixteen AI taxa were sold per year in these categories, a smaller number of plants in comparison to the 28 AI that were sold with high sales volume >500 plants per year (Table 7). The 16 AI taxa sold per year in the volume category 1,001-5,000 coincided with those already listed in Table 7, while plants sold between 101-500 per year (>100 inclusive) are presented in Table 13. Among the ANI taxa, the largest numbers sold were for the volume categories 1-50 and 101-500 (141/225). AI taxa were sold for volumes greater than 10,000 (2/62) (water hyacinth and water lettuce), whereas none were sold of the ANI.

4.4 Traits of a successful invader

Examination of the biological traits that distinguished AI from ANI revealed that type of propagation strategy used, number of propagation strategies used, number of dispersal mechanisms employed per plant, and minimum temperature were the most important. In

addition, purchasing decisions by consumers contributed to invasion success (as sales volume was an important discriminator between AI and ANI taxa). The aforementioned biological attributes were mainly reproductive and physiological and were found to be in agreement with other studies that identified these traits as contributing to the success of aquatic invaders. Unlike previous studies, volume of sales of aquatic plants was found to be important by this research in determining the success of aquatic invaders (Table 14).

Table 13: Invasive taxa with volume of sales (100-500 total taxa sold per year in 20 stores reporting sales volume)

Scientific name	Common name	Volume of sales
<i>Trapa natans</i>	Water chestnut	360
<i>Rotala rotundifolia</i>	Dwarf rotala, Round leaf rotala	280
<i>Sagittaria platyphylla</i>	Giant sagittaria, Delta arrowhead	271
<i>Schoenoplectus tabernaemontani</i>	Soft stem bulrush, Bulrush	265
<i>Mimulus guttatus</i>	Monkey flower	255
<i>Limnobium spongia</i>	American frog-bit	248
<i>Ludwigia octovalvis</i>	Mexican primrose willow	192
<i>Rumex sanguineus</i>	Bloody dock, Red-veined spatterdock	182
<i>Gymnocoronis spilanthoides</i>	Spade leaf plant, Water daisy	162
<i>Limnobium laevigatum</i>	Amazon frog-bit	158
<i>Cotula coronopifolia</i>	Golden buttons, Brass buttons	148
<i>Ophiopogon japonicas</i>	Mondo grass	144
<i>Mentha aquatica</i>	Water mint	115
<i>Salvinia cucullata</i>	Asian water moss	112
<i>Shinnersia rivularis</i>	Mexican oak leaf	108
<i>Hygrophila costata</i>	Sword leaf stricta	102

Table 14: Comparison of studies exhibiting traits that determine a potential invader

<i>TRAITS</i>	<i>REFERENCES</i>	SIGNIFICANT TRAITS FOUND IN THIS STUDY
<i>Morphological</i>		
<ul style="list-style-type: none"> • Free floating habit • Perennials and herbaceous • Short life cycle • Spreading growth form • Primary colonizers 	Ashton and Mitchell, 1989; Cronk and Fuller, 1995 Cronk and Fuller, 1995 Cook, 1990; Thiébaud, 2007 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989; Pieterse and Murray, 1990	
<i>Reproductive</i>		
<ul style="list-style-type: none"> • Uses vegetative (asexual) reproduction (e.g. vegetative propagules) • Regenerate asexually using fragmentation or vegetative hibernating organs • Sexual reproduction • Dioecious or monoecious • Efficient dispersal mechanisms (e.g. seeds, spores, plant fragments and vegetative propagules are dispersed by water and/or wind) • Fast reproductive rates • Remain dormant in unfavourable conditions • Large number of vegetative propagules produced • Large number of seeds produced for long-range dispersal 	MacArthur and Wilson, 1967; Sculthorpe, 1967; Ashton and Mitchell, 1989; Cronk and Fuller, 1995; Thiébaud, 2007 Sculthorpe, 1967; Ashton and Mitchell, 1990; Pieterse and Murray, 1990; Thiébaud, 2007 Ashton and Mitchell, 1989; Spencer and Bowes, 1990; Cronk and Fuller, 1995 Cronk and Fuller, 1995 Wade 1990; Cronk and Fuller, 1995; Thiébaud, 2007 Ashton and Mitchell, 1989; Thiébaud, 2007 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989 Ashton and Mitchell, 1989; Van Vierssen, 1990	Type of propagation strategy used Number of propagation strategies used Number of dispersal mechanisms used
<i>Physiological</i>		
<ul style="list-style-type: none"> • Tolerant of a wide variety of environmental conditions • Rapid vegetative growth • Morphological plasticity • High phenotypic plasticity • High stress tolerance • Boom-and-bust 	Ashton and Mitchell, 1989; Cronk and Fuller, 1995; Thiébaud, 2007 Ashton and Mitchell, 1989; Pieterse and Murray, 1990; Cronk and Fuller, 1995; Thiébaud, 2007 Mitchell and Gopal, 1991 Thiébaud, 2007 Mitchell and Gopal, 1991 Williamson, 1996	Minimum temperature
<i>Other traits</i>		
<ul style="list-style-type: none"> • Generalists, opportunists, pioneers • Spread by human activities • Widely distributed • Propagule pressure • Taxonomically related 	Mitchell and Gopal, 1991 Pieterse and Murray, 1990 Thiébaud, 2007 Williamson, 1996 Ashton and Mitchell, 1989	

There were some traits, however, that did not prove to be important predictors of invasion success; as such, it can be perceived that there is still a level of uncertainty with regards to what traits actually determine a successful invader or that the generalized traits listed in Table 14 may not all apply to the specific condition of an aquatic plant species in Ontario. Nevertheless, unlike previous studies, this analysis was conducted on a very large sample of taxa within a small group that is, aquatic plants, and as such, makes the findings of what contributes to the success of an aquatic invader significant. The distinguishing attributes between AI and ANI will be discussed hereafter.

The propagation strategies used by both ANI and AI taxa were the production of new taxa from below ground biomass and seeds. This was expected since successful invaders are known to mainly use asexual reproduction, for example, production of vegetative propagules and regeneration from fragments. Most of the ANI and AI taxa used vegetative propagules such as turions, tubers, winter buds, rhizomes, rootstock, and stolons. However, ANI taxa were found to use additional vegetative propagules such as bulbs, bulbils, corms, cormels, and cormlets, which were not observed in AI taxa. Propagules are mainly found underground, and serve to anchor the plant, store food reserves, and function as hibernacula, thus allowing the taxa to survive unfavourable conditions (e.g. winter) by remaining dormant for periods of time. Sculthorpe (1967) concurred when he reported that vegetative propagules functioned as hibernacula, which enabled them to survive periods of unfavourable conditions. The likelihood of spread of ANI and AI taxa also increases as both produce seeds that can over-winter. Comparable to below ground biomass, seeds are able to remain dormant for extensive periods of time until favourable conditions arise. In the case of ANI taxa, production of seeds that over-winter increases the probability of these plants becoming successful invaders.

Another factor that increased the likelihood of ANI taxa becoming successful invaders was the number of propagation strategies used. AI and ANI taxa were found to use two or more propagation strategies, which were expected since successful invaders tend to use one to three propagation strategies (Table 14). The research showed that AI taxa typically used three propagation strategies whereas ANI taxa used two (Section 4.3). This would indicate

that AI taxa use more strategies to ensure their survival and spread if released into the environment. While ANI taxa use fewer propagation strategies, it is actually the types of propagation strategies used that dictates their potential to become invaders. As previously discussed, ANI taxa use vegetative propagules and seeds that are able to survive unfavourable conditions. Consequently, the presence of these structures increases the probability of ANI taxa becoming successful invaders.

The likelihood of invasion also increases with the number of dispersal mechanisms used. In the literature, successful invaders are known to use one or two efficient dispersal mechanisms (Table 14). In contrast, the research revealed that AI taxa used multiple dispersal mechanisms (two or more), which would increase their range of spread and potential to be released into the environment either deliberately or accidentally. ANI taxa, on the other hand, were found to use one or two dispersal mechanisms as described in the literature. While ANI taxa utilized fewer dispersal mechanisms than AI taxa, the use of more than one dispersal method increases their ability to spread to new areas, thus increasing the area in which they could become potential invaders. Furthermore, a majority of these plants produce seeds and vegetative propagules that can be transported over large distances by water, wind, animals (e.g. birds), and humans. The role played by vegetative propagules and seeds in the dispersal of species were described by Sculthorpe (1967) and Spencer and Bowes (1990). Sculthorpe (1967) reported that vegetative propagules were the most likely cause of the distribution of species worldwide since they could be easily carried by floods, waterfowl, animals, and man. Seed production, Spencer and Bowes (1990) noted, aided in plant survival especially during adverse conditions and improved the chances for successful invasion in a new area.

Aside from the aforementioned reproductive strategies, ANI taxa and to a lesser degree, AI taxa have adapted tolerance to minimum temperatures as a physiological strategy in their invasion success (Table 14). Although minimum temperature was not individually listed in the literature, it still influences the success of invaders. Temperature, for instance, has been regarded as a key climatic factor that affects aquatic plants (Lacoul and Freedman, 2006). Both AI and ANI are able to tolerate temperatures $<0^{\circ}\text{C}$ and $<10^{\circ}\text{C}$, which is likely

since some of the species distributed by the aquarium and ornamental pond industries are temperate. Not only are these species able to withstand cold temperatures, but they can produce over-wintering structures, possibly as a result of depleted nutrient supply or abnormal conditions (Sculthorpe, 1967). In addition, some of these species are invasive in other temperate countries or areas that have cold environments. As a result, these plants have the ability to survive Ontario's climate and become invasive. Examples of these species are water hawthorn (*Aponogeton distachyos*), golden buttons (*Cotula coronopifolia*), giant pennywort (*Hydrocotyle bonariensis*), *Jussiaea grandiflora*, snowflake (*Leucojum aestivum*), monkey flower (*Mimulus guttatus*), water cress, yellow snowflake (*Nymphoides geminata*), floating fern (*Salvinia natans* or *Salvinia auriculata*), and white arum lily (*Zantedeschia aethiopica*). From the research, four other temperate AI taxa that are able to become established in Ontario even though their minimum temperature is $>10^{\circ}\text{C}$ are Joseph's coat (*Alternanthera ficoidea*), *Hygrophila costata*, mondo grass (*Ophiopogon japonicus*), and *Sagittaria montevidensis*.

Keller and Lodge (2007) expressed concern about species in the Great Lakes that were known to be invasive in temperate or colder environments and regarded them as potential invaders. The species observed in that study were water hawthorn, chameleon plant (*Houttuynia cordata*), water fern (*Marsilea mutica*), mondo grass, greater spearwort (*Ranunculus lingua*), and floating fern. Incidentally, chameleon plant and greater spearwort are sold for aquarium and ornamental ponds in the GTA. Other species observed by Keller and Lodge to have temperate zone impacts were *Cabomba*, Brazilian waterweed, manna grass (*Glyceria maxima*), European frog-bit, yellow iris, moneywort (*Lysimachia nummularia*), water shamrock (*Marsilea quadrifolia*), water forget-me-not (*Myosotis scorpioides*), parrot feather, Eurasian watermilfoil, lesser naiad (*Najas minor*), yellow floating heart, curly-leafed pondweed (*Potamogeton crispus*), water chestnut, and narrow-leaved cattail (*Typha angustifolia*). With the exception of manna grass, Eurasian watermilfoil and curly-leafed pondweed, all the other plants are sold by the aquarium and ornamental pond industries in the GTA.

There is also the perception that tropical and sub-tropical species that are AI and ANI will not negatively impact the environment if released, as these taxa are not expected to survive Ontario's temperate climates to become invasive (CCFAM, 2004). As such, this perception may confer some sort of reassurance that potential invaders are not being introduced into new environments. This should not be the case as Rixon *et al.* (2005) pointed out in their study that invasion histories and over-wintering abilities play a role in the likely success of invaders. Moreover, with the increasing effects of climate change, there is an increased likelihood that tropical and sub-tropical AI and ANI taxa could become established. The probability of success of the invasion process also increases since AI and ANI tropical and sub-tropical taxa produce seeds and vegetative propagules that are able to over-winter and resist drying; thus giving them the advantage to survive in Ontario's temperate climate. Case in point: water hyacinth and water lettuce usually die with the onset of colder temperatures in the GTA. Holm *et al.* (1997) reported that the vegetative tissues of these species are susceptible to freezing and would seldom survive the winter of temperate climates. The use of the word "seldom" by Holm *et al.* does not preclude a likely invasion. Further, if the precautionary approach recommended by the CBD (2010) is to be applied, then one may infer that both water hyacinth and water lettuce have the potential to be invasive in Ontario.

4.4.1 Opportunity for introduction

Aside from reproductive and physiological strategies, the volume of sales of taxa as an opportunity of introduction differed between AI and ANI taxa. No ANI taxa were sold in volumes greater than 10,000, thereby suggesting that ANI taxa had the lesser potential of being released into the environment. Total store data gathered on volume of sales of taxa revealed that 40% (25/62) of the AI taxa had a high volume of sales (>500 plants per year) and therefore, the highest probability of being released into the environment. Of the 28, water hyacinth, water lettuce, and hornwort along with *Cabomba*, and *Vallisneria americana* were shown to be the top five invasive taxa based on volume of sales (opportunity of introduction) (Table 14).

The higher volumes of AI taxa observed suggests that using volume of sales of aquatic plants as a proxy of opportunity for introduction is a factor that clearly distinguishes AI from ANI taxa. This distinction is not because people choose to trade in AI taxa, but because high trade in ANI taxa gives them greater opportunity to be released into the environment. Furthermore, high trade makes it more likely that ANI taxa would transition from being ANI to AI based on the biological traits they possess. The aforementioned five AI taxa may be very invasive as they have the biological attributes that contribute to their invasive success. In addition, they may be well liked by aquarists and ornamental pond enthusiasts and as such, are traded in high volumes. Therefore, it is not surprising, but rather expected, that so many species with high sales volume were also invasive.

4.5 The aquarium and ornamental pond industries

In view of the fact that a large volume of taxa are sold by the aquarium and ornamental pond stores, of which ANI and AI taxa are the most dominant (Figure 12), it can be concluded that the aquarium and ornamental pond industries remains a pathway of concern for the introduction of AI taxa and potential invaders into Ontario. From the literature, several authors had expressed concern about these industries as a source for the introduction of AI (Sections 2.2.1 and 2.2.3). Seventy-three AI taxa were recorded for sale by aquarium and ornamental pond stores in the GTA. An additional 12 were observed during the research, but lacked sales volume (Appendix 12). Considering the high numbers of AI taxa introduced by the aquarium and ornamental pond industries, these species have a high potential for accidental or deliberate release into the natural environment. In addition, the high numbers of AI and ANI taxa may indicate that these plants have specific traits (e.g. fast growth rates and robustness) that are favoured by the aquarium and ornamental pond industries but which encourage invasivity if released deliberately or accidentally into the environment.

While examining the aquatic plants sold by the aquarium and ornamental pond industries, identifying 85 AI taxa is by far the highest number recorded in comparison to similar studies conducted on these industries in Canada. The AI numbers observed are

attributable to the small geographic area in which the research was conducted as well as the thorough literature review performed in order to identify the species that were invasive. Funnell *et al.* (2009) recorded 11 invasive species in natural waters within major cities and the surrounding regions of the Lake Ontario basin. These species were also identified using a list prepared by the MNR and OFAH. Like Funnell *et al.*, Marson *et al.* (2009a, b) recorded 11 species using the GISD. Rixon *et al.* (2005) conducted research in the Great Lakes watershed and listed nine invasive species. Species identification was conducted using only three references, Mills *et al.* (1993), Baensch and Riehl (1996) and Hiscock (2003).

The use and disposal of taxa for aquariums and ornamental ponds also contributes to the likely spread of AI and ANI taxa (Section 4.1.4). The majority of the taxa used in aquariums and ornamental ponds were disposed of in the garbage or compost (Marson *et al.*, 2009a, b). Discarding taxa in the garbage is in keeping with the disposal guidelines provided by the MNR and OFAH (1996); however, there is no guarantee that persons are completely drying these species or freezing them prior to disposal. As a result, there is the likelihood that live AI taxa and ANI that have similar traits as AI are unintentionally being released into the natural environment. The unintentional release of AI and ANI taxa are also possible by persons that use compost or over-winter plants in their ornamental ponds. Seeds of AI taxa are able to withstand drying and freezing (MNR and OFAH, 1996), also whole plants can be transported to adjacent water bodies during flood events (Marson *et al.*, 2009a, b). The enforcement by government officials of the proper disposal of AI and ANI taxa, while important, will prove difficult and there is already limited enforcement that prevents the release of illegal aquatic organisms (CCFAM, 2004).

The sale of AI and ANI taxa for aquariums and ornamental ponds contradicts the government's desire to control the introduction and spread of these species in Canada as expressed in the literature (CCFAM, 2004; GOC, 2004). If the government wishes to control the introduction and spread of AI taxa as well as species that have the potential to become invaders, why are they allowed to enter the country? Discussions held with the managers

and/or owners of the aquarium and ornamental pond stores during the research revealed that few aquatic plants are grown locally while most are imported.

There was no rationale for the use and sale of ANI and AI taxa by aquarium and ornamental pond stores during the research. One could surmise that maybe the relevant agencies were not aware that these taxa were being sold. However, this was found not to be the case, since most of the aquatic plants used by aquariums and ornamental ponds are imported. Further, knowledge on the sales of AI taxa for aquariums and ornamental ponds has been reported from as far back as 1993 (Mills *et al.*, 1993). Lack of knowledge on the impacts of IAS was considered another reason. This hypothesis was excluded as store owners and/or managers have been asked to hand out brochures (ascertained during data collection) on the use and disposal of aquatic plants for aquarium and ornamental ponds. The provision of brochures and other educational materials to the aquarium and ornamental pond stores and, indirectly, consumers, is an outreach initiative by the Invading Species Programme (ISP) (Funnell *et al.*, 2009). The brochure contains information on 11 invasive aquatic plants and includes steps to prevent the spread of invasive taxa in general. Ten of the 11 invasive aquatic plants discussed in the brochure are sold by aquarium and ornamental pond stores in the GTA.

An additional hypothesis is that ANI taxa are more accessible, preferred by aquarium and ornamental pond owners, or provide economic gain. MNR and OFAH (1996) in their study also found that there are “thousands” of exotic species and varieties of taxa that originated from other parts of the world, added beauty and diversity to home aquariums and ornamental ponds, and were accessible to aquarium and ornamental pond enthusiasts. The ease in which ANI taxa can be accessed poses a problem. If, for instance, any of these ANI taxa had the attributes that favoured the success of invasions (as previously discussed), and were released into the environment, the likely outcome would be the introduction and spread of a potential invader, which is further enhanced given the ease with which they can be purchased as well as their widespread use. In terms of economic

gain, using the USA as the example⁵, Padilla and Williams (2004) reported that hobbyists in the USA alone supported a \$25 billion per year worldwide industry. If this substantial amount of money can be earned from the sale of AI and ANI taxa, then there would be no impetus to address the sale of these species; as such, the possible impacts of these species on the environment would be ignored.

Another hypothesis is that owners of aquarium and ornamental ponds are not encouraged to buy native plants. Of the 62 stores contacted during the research, only four sold NNI taxa. The limited sale of NNI taxa is surprising since temperate areas are reported to be more species rich than tropical areas (Crow, 1993). Therefore, there should be much more NNI taxa available to the public for use in aquariums and ornamental ponds. Currently 13% of the plants sold for aquarium and ornamental ponds are NNI. The MNR and OFAH through their ISP do encourage the use of native species for aquariums and ornamental ponds. However, in light of the fact that AI and ANI taxa are still being sold by aquarium and ornamental pond stores, it would appear that the programme is not effective. Funnell *et al.* (2009) also found that the ISP was ineffective as they reported that 30% of the retailers were supportive of the programme. Support of the programme was mainly from small independently run operators and not the larger retailers. High employee turnover rates and inexperienced seasonal staff were also identified as factors that limited the effectiveness, continuity, and success of the programme.

From the literature, it was concluded that the legislative framework in Canada does not effectively address the issue of IAS (Section 2.4.1.2). This conclusion is further substantiated with the continued sale of AI and ANI taxa. ANI and AI taxa are introduced using an import permit under the *Plant Protection Act* (1990). Applicants for plant imports are required to provide the common and scientific names of the plant being imported, purpose of importation (e.g. commercial or resale, educational, scientific purposes), source of import, and the item being introduced (e.g. seeds). As the import permit requires the applicant to provide both the common and scientific names of the plant being introduced, it

⁵ There are no available statistics on the economic costs of aquatic plants introduced by the aquarium and ornamental pond industries in Ontario.

is expected that the CFIA is aware that ANI as well as AI taxa that are prohibited from importation into Canada are being introduced into Ontario. This approach contradicts their mandate in addressing AI and ANI taxa. Moreover, failure to prevent the importation of AI and ANI taxa continues to put Ontario's natural environment at risk.

ANI and AI taxa are expected to be subjected to risk assessments prior to introduction. These assessments have been discussed in the literature as a means of preventing the introduction of potential invaders. Unfortunately, risk assessments are not conducted on a regular basis by the CFIA and so far, only a limited number have been conducted (C. Wilson O'Driscoll, pers. comm. 2011). No risk assessments for ANI taxa introduced through the aquarium and ornamental pond industries have been conducted. In view of the findings that these species have the potential to become invaders, not doing risk assessments for all taxa being introduced is a serious oversight by the government and an indictment on the legislative framework in Canada. Once again, this practice operates contrary to the government's desire to address the issue of the aquarium and ornamental pond industries as a pathway for potential invaders. The three risk assessments conducted recommended that *Cabomba*, and yellow floating heart be added to the list of aquatic species prohibited from Canada. Water chestnut is already on the list. The other aquatic plants prohibited from Canada are: Brazilian waterweed, *Hydrilla*, *Myriophyllum* spp., and *Trapa* spp (Appendix 5). It is important to note that all of the aforementioned species are still being sold by aquarium and ornamental pond stores even though they are prohibited from being imported into Canada. In view of this information, no steps have been taken to prevent the introduction of AI and ANI into the natural environment.

5.0 RECOMMENDATIONS

Given the failures observed within the legislative framework with regards to the importation of plants, the government of Canada has to take a more aggressive stance in enforcing regulations surrounding the aquarium and ornamental pond industries. This is especially so as the majority of the aquatic plants used in aquariums and ornamental ponds are imported. Funnell *et al.* (2009, p. 111) noted, “there is a suite of federal legislation managing invasive species and few control the importation and sale of potentially harmful species related to the aquarium and water garden industry.” In addition, “aquatic plants have fallen through the cracks at both the federal and provincial level.” There are also several complexities surrounding the aquarium and ornamental pond industries in Ontario. Not only do these industries have the potential to contribute to Ontario’s economic sector, they also have the potential to impact its waterways. Nevertheless, there are three approaches that can be taken with regards to plant importation: allow all and any species, prohibit the introduction of new species, or screen species for the likelihood of becoming invasive and only allowing species that are ranked low risk. The first approach, based on the data collected in this research, is currently in place but does little to prevent the introduction of either AI taxa or ANI taxa. Second, banning the introduction of new species would not be feasible as it may restrict the trade unnecessarily.

The third approach, seems the most appropriate, but would include a modification of the present risk assessment used by the CFIA. The present risk assessment involves ranking species in terms of likelihood of introduction, establishment and natural spread potential, and potential economic and environmental impacts. The overall risk of the species is then computed and recommendations are put forward. This assessment is not comprehensive as it does not include screening the plants based on the biological attributes of the plants to be imported. Biological attributes as an ideal predictor of successful potential invaders was indicated by the BLRM. Key biological attributes that should be taken into consideration during the risk assessment are type of propagation strategies used, number of propagation strategies used, number of dispersal mechanisms employed per plant, growth rate, and minimum temperature.

A model that can be modified and used in Canada is the weed risk assessment (WRA) model that is used in Australia and New Zealand that screens species based on their weed status, climate and environmental preferences and biological attributes prior to introduction (Pheloung *et al.*, 1999). In this model 49 questions are answered that relate to the attributes and impacts of weeds (Appendix 13). The questions relate to the history/biogeography (e.g. distribution, climate preferences, invasive potential), and biology/ecology (e.g. undesirable traits, plant type, reproduction, dispersal mechanisms and persistence attributes) of the species being introduced. Species can either be assigned a score of 0, 1, or 2 in response to a question. The decision to reject, evaluate further, or accept a species for introduction is recommended based on a plant achieving a critical score between 0 and 6 (Pheloung *et al.*, 1999).

In light of the traits of a successful invader identified by the BLRM, the WRA could be modified to make it suitable for Canada. The question “reproduction by vegetative propagation” (category: reproduction), should be changed to “reproduction by vegetative propagation using vegetative propagules”, in order to account for the presence of below ground biomass, which is an attribute of a successful invader. The question “species suited to Australian climate” (category: climate and distribution) and “effective natural enemies present in Australia” (category: persistence attributes) should also be changed to “species suited to Canadian climate” and “effective natural enemies present in Canada” to suit the geographic region. The other attributes that discriminate between ANI and AI taxa, namely number of propagation strategies used, number of dispersal mechanisms used, and minimum temperature are addressed in some way by the modified WRA (Appendix 13).

Daehler and Denslow (2007) also suggested that a modified WRA could be used in Canada but its use is dependent on the government’s objective with regards to plant introductions. If the objective is to assess all proposed plant introductions, then a modified WRA is the most feasible since this model has been used successfully in other temperate regions, and can accurately identify more than 90% major pests and 70-90% non-pests (Daehler and Denslow, 2007). If, however, the converse is true, then the present system (USDA-APHIS) should remain, as it allows for consideration of unique information or circumstances rather

than being restricted to specific questions (Daehler and Denslow, 2007). While the modified WRA appears better than the BLRM in terms of accurately predicting ANI and AI taxa, there is no perfect model. There are similarities between the biological traits used in the modified WRA as well as those identified to best discriminate between ANI and AI taxa using the BLRM. The differences between the two are how the attributes are used, and the assigning of scores to determine introduction. For example, in the modified WRA, dispersal mechanisms are named while in the BLRM they are grouped.

In light of the information presented, the government of Canada has several options to consider in terms of risk management. Since the present system does not appear to be working as AI and ANI taxa are still being introduced into Canada, as shown by this research, then it is recommended that a modified WRA be developed and implemented to screen all plant imports. The only taxa to be allowed entry would be those regarded as low risk to the environment. The WRA model could be used for a defined period of time and comparisons made between the two models in terms of accurate identification of AI and ANI taxa. Given that the sale of AI and ANI taxa is a thriving business, the screened WRA would have to be applied over a phased basis in order to give owners of aquariums and ornamental pond stores time to identify alternative plants that can be sold to their customers. The WRA could be first done to eliminate the AI taxa from the industry and then the ANI taxa could be targeted. The government in turn could also provide aquarium and ornamental pond owners with a list of acceptable species for the trade. One suggested example is the *Grow me instead* guide developed for Southern Ontario (OIPC, 2011). This document also contains links to other publications and websites that discuss native alternatives for AI taxa. Caution should be taken, however, in using the OIPC document, as some of the alternatives recommended are AI taxa in Ontario and other parts of the world, for example, common cattail (*Typha latifolia*), hornwort, common mare's tail (*Hippuris vulgaris*), Brazilian waterweed, and fragrant water lily (*Nymphaea odorata*).

Another strategy that could be undertaken by the government is to conduct both a projected cost and a cost benefit analyses of the AI and ANI taxa distributed by the aquarium and ornamental pond industries in Ontario and on the wider scale, Canada.

These analyses would consider both environmental and economic factors and are important considering that there is limited, if any, statistics about these industries in Ontario. The large sums of monies expended to date to mitigate and control AI taxa in Ontario, and Canada overall, could be used to project the likely economic costs for addressing AI taxa presently being sold, if they became established. In the case of the ANI taxa, the analysis would have to determine the costs and benefits of having these taxa in the trade and the likely impact of their removal. Additionally, the analysis should determine the costs associated with their likelihood of spread, since the ANI taxa being sold have the potential to become invaders. Considerations would also have to be given to the direct costs for implementing the modified WRA.

Partnerships should also be fostered with importers and retailers of aquatic plants to discuss the proposed implementation of the modified WRA and to get their input. Stakeholders already involved in the process such as the Canadian Association of Aquarium Clubs (CAOAC), the Pet Industry Joint Advisory Council (PIJAC), OFAH, and Ontario Streams should also be included in the discussions. These partnerships also have the potential to identify why AI and ANI taxa are preferred over native species. Obtaining this information gives the government other avenues that need to be addressed in the aquarium and ornamental pond industries that were not previously recognised.

Along with the recommended changes in the legislative framework, another option that could be considered is the implementation of a behavioural change campaign (BCC). A BCC or as it is more widely known, community-based social marketing, is used to affect change in behaviour when an information campaign has not achieved the desired results. The MNR/OFAH has implemented a public education and awareness campaign, that reaches over a million persons each year and raises public awareness of invading species through public participation, demonstrations, and educational campaigns (e.g. brochures, posters, wallet cards) (Funnell *et al.*, 2009); however, despite the large target audience reached by the programme, AI and ANI taxa are still being used and have the potential to be released into the natural environment.

Community-based social marketing uses a pragmatic approach in order to affect behaviour change. The approach includes: identifying the barriers to sustainable behaviour, designing a strategy that uses behaviour change tools, piloting the strategy in the community, and evaluating the impact of the programme following implementation (McKenzie-Mohr, 1999). For the GTA, the target audience would have to be the persons importing, buying and using AI and ANI taxa for aquariums and ornamental ponds. Children would not be the main focus group of the campaign but they would not be excluded. Identification of the barriers (internal and external) would require the use of focus groups, community meetings, review of literature and survey research. Knowledge of the barriers indicates the areas to be addressed by the campaign; for example, why are AI and ANI taxa widely used in aquarium and ornamental ponds? This information could be gathered by conducting a detailed assessment that would inform the BCC. Changes in behaviour would be achieved through oral or written commitment as a means of getting people to agree to make changes. This commitment could be obtained from a selected community that will act as the pilot before the campaign is taken on a wider-scale. Moreover, use of a smaller group allows the desired approach to be tested and modified accordingly. Once the aforementioned steps are done, then the pilot would have to be evaluated. The SMART⁶ approach could be used.

For children (though applicable to adults), the campaign could target the smaller kids since they are the future generation. From personal observations, when kids know the dos and don'ts in relation to the environment, they can change their parent's way of thinking. In order to reinforce that IAS and other potential invaders are detrimental to the environment, first-hand-experiences may be useful; for example, field trips to affected sites via boats or buses, and clean-up programmes of affected areas. Live exhibits could also be constructed about invasive aquatic species (plants and animals) and placed in areas of easy access, for example, museums.

⁶ Specific, measurable, achievable/attainable, relevant and timely

In terms of the methodology used in this research, as previously discussed, the BLRM did a good job of classifying ANI as ANI than AI as AI. However, the model misclassified AI and ANI taxa, which has management implications, especially in the introduction of aquatic plants. In order to address this limitation, further studies could be conducted that examine closely the attributes of aquatic plant invaders. This could be achieved by increasing the number of attributes or identifying other attributes that can be examined to determine what other traits contribute to the success of invaders. In addition, a better predictive model that can clearly distinguish between ANI and AI taxa could be developed, which would prevent the introduction of high risk species. The other predictive model used in the research, the LRM, indicated that morphological strategies were not significant in determining the likelihood of success aquatic plant invaders. Therefore, future research should be conducted in order to determine if morphological strategies contribute to the success of potential invaders, that is, do they operate alone or in conjunction with other factors.

Finally, based on the findings in this research, the following are important areas that the government needs to address:

- The aquarium and ornamental pond industries as a source for AI and ANI taxa;
- The legislation that regulates the introduction or importation of taxa should be enforced;
- Risk assessments should be conducted for ALL taxa being introduced in order to allow only the introduction of low risk species;
- Native species should be included within the widely sold aquarium and ornamental pond industries;
- A behaviour change campaign should be instituted; and
- A projected cost and cost benefit analyses for the AI and ANI taxa distributed by the aquarium and ornamental pond industries.

6.0 CONCLUSION

The purpose and objectives of this research were to determine if there are common traits of a successful aquatic invader. There were five research questions, three related to the strategies employed by aquatic plants and two on the role played by the aquarium and ornamental pond industries in the introduction of aquatic plant invaders.

6.1 *Answer to research questions context*

Do the morphological strategies of aquatic plants sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?

Two morphological strategies, life cycle and growth form, were investigated during the research. Life cycle examined whether aquatic plants were annuals or perennials, whereas growth form determined if the plants were submerged, floating, or emergent. Unlike several authors that indicated that life cycle and growth form were important traits of successful invaders, the predictive models revealed that these morphological strategies were not significant in determining the likelihood of success of aquatic plants as invaders.

Do the reproductive strategies of aquatic plants sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?

Nine reproductive strategies were investigated during the research. These strategies were number of reproductive strategies used, type of propagation strategies used, number of propagation strategies used, number of dispersal mechanisms employed by plant, type of dispersal mechanism used, number of vegetative propagules produced per biomass, type of vegetative propagules used, breeding system, and number of seeds or spores produced per biomass. Of the nine, three were considered significant in determining the success of likely aquatic invaders, especially between ANI and AI taxa. These were type of propagation strategies used, number of propagation strategies used and number of dispersal

mechanisms employed by plant. In light of these results, reproductive strategies do relate to the likelihood of success of aquatic invaders.

Do the physiological strategies of aquatic plants sold by the aquarium and ornamental pond industries relate to the likelihood of success as invaders?

Fourteen physiological strategies were investigated during the research. These strategies were temperature, salinity, pH, nutrient content, light suitability, growth rate, number of phenotypic forms produced, stem length, stem width, leaf length, leaf width, flower length, flower width, fruit length, fruit width, fruit type, seed size, and time to flower. Of these, one, minimum temperature, was considered significantly important in determining the success of likely aquatic invaders, especially between ANI and AI taxa. In view of this result, physiological strategy do relate to the likelihood of success of aquatic invaders.

Do the aquarium and ornamental pond industries have the potential to contribute to the success and/or failure of aquatic plant invaders based on the presence of aquatic plants with specific traits in the trade that increases their chances for introduction and invasion?

Aquarium and ornamental pond stores in the GTA mainly sold ANI and AI taxa. Majority of ANI and AI taxa were found to possess similar biological traits, with the exception of minimum growth temperature. However, since AI and ANI taxa are able to withstand low temperatures, these taxa are able to survive Ontario's climate and have the potential to become invasive. Volume of sales of aquatic plants was also found to be significant as a proxy of opportunity for introduction of ANI and AI taxa. AI taxa had the highest sales volume with the greatest potential of release in comparison to ANI taxa, which had the lesser potential for being released. In light of the aforementioned findings, the aquarium and ornamental pond industries does contribute to the success of aquatic plant invaders by distributing aquatic plants with specific traits that increases their chances for introduction and invasion.

If these industries do contribute to the success of aquatic plant invaders, what is the legislative framework within Ontario that governs the introduction of these plants and how can it be amended or enforced to sufficiently address the problems posed by the industries?

Aquatic plants and plants in general, are introduced into Canada under the *Plant Protection Act* (1990). There is however, a perceived breakdown of the legislative framework as ANI and AI taxa continue to be imported into Canada. One recommendation to address this problem is to apply a modified WRA to all plants being introduced into Canada. Applying this type of risk assessment would only allow species considered of low risk to the environment to be imported. Native species should also be encouraged for use in aquariums and ornamental ponds. Partnerships between the government, importers and retailers and other non-governmental organizations involved in the aquarium and ornamental pond industries should also be created and/or maintained. Such a partnership would ensure that these organizations have an input in any decisions made by the government. Finally, a behaviour change campaign should be implemented, which focuses on achieving sustainable behaviour amongst persons who own aquariums and ornamental ponds.

7.0 APPENDICES

Appendix 1: Permit used for plant importation under the *Plant Protection Act*, 1990 (CFIA)

Canadian Food Inspection Agency Agence canadienne d'inspection des aliments	Page 1 of 3 000000
APPLICATION FOR PERMIT TO IMPORT PLANTS AND OTHER THINGS UNDER THE PLANT PROTECTION ACT		
* Mandatory fields		
Type of application		
New Permit ☐ I am submitting my application by fax or email (I will mail the original copy)* ☐ I am submitting my application by mail only		
Amendment ☐ I am submitting my application by fax or email (I will mail the original copy)* ☐ I am submitting my application by mail only		
Renewal ☐ I am submitting my application by fax or email (I will mail the original copy)* ☐ I am submitting my application by mail only		
*Subsection 10(2) of the Plant Protection Regulations: "Where a document referred to in subsection (1) is furnished in electronic form, an original hard copy of the document shall be furnished to the Minister or an inspector within a reasonable period after the document is furnished in electronic form."		
IMPORTANT NOTICE ALL APPLICATIONS THAT ARE SUBMITTED BY FAX OR EMAIL MUST BE FOLLOWED BY A MAILED APPLICATION OF THE ORIGINAL FORM. TO AVOID BEING BILLED MORE THAN ONCE, PLEASE ENSURE THE ABOVE SECTION IS PROPERLY COMPLETED.		
Importer Preferences		
Importer is ☐ an individual ☐ a business / institution	Reference Number 000000	
Language of Permit Requested ☐ English ☐ French		
Receive Permit By ☐ Fax ☐ Canada Post		
Importer ⓘ		
* Name of Importer		* Street Address
E-mail address	* Postal Code	* City
		* Province
* Telephone No.	Ext.	* Facsimile No.
		Contact
		Producer Licence / DRC membership number ⓘ
Exporter ⓘ		
* Name of Exporter		Street Address
City	Postal Code / Zip Code	* Country
		Province / State
Telephone No.	Facsimile No.	E-mail address
		Contact
Origin of Items ⓘ		
* Country	Place or County	Province / State

Producer			
Name of Producer		Street Address	
City	Postal Code / Zip Code	Country	Province / State
Telephone No.	Facsimile No.	E-mail address	Contact
List of Canadian Destination as per existing: <input type="button" value="i"/> Add <input type="button" value="i"/>			
Same as Importer's Address <input type="button" value="v"/>			
End Use <input type="button" value="i"/>			
☐ Commercial or Retail <input type="button" value="i"/> ☐ Personal Use <input type="button" value="i"/> ☐ Industrial <input type="button" value="i"/>			
☐ Scientific Research <input type="button" value="i"/> ☐ Educational Purpose <input type="button" value="i"/> ☐ Other			
Description <input type="button" value="i"/>			
☐ Grain and Field crops <input type="button" value="i"/> ☐ Canada's Growing Media Program <input type="button" value="i"/> ☐ Plant/Plant Parts Not for Planting/Propagation <input type="button" value="i"/> ☐ Potatoes <input type="button" value="i"/>			
☐ Wood Products <input type="button" value="i"/> ☐ Soil & Related Matter <input type="button" value="i"/> ☐ Plant/Plant Parts for Planting/Propagation <input type="button" value="i"/>			
☐ Mushroom Spores <input type="button" value="i"/> ☐ Plants/Plant Parts for Consumption <input type="button" value="i"/> ☐ Living Invertebrates and Micro-organisms <input type="button" value="i"/>			
Does this shipment require a Plant Risk Assessment? <input type="button" value="i"/>			
☐ Yes ☐ No			
Is any of the material a product of biotechnology or a plant with a novel trait (PNT)? <input type="button" value="i"/>			
☐ No ☐ Yes			
Is this shipment commercially packaged?			
☐ Yes ☐ No			

Internet Links

Automated Import reference System (AIRS)

http://airs-airi.inspection.gc.ca/Airs_External/Default.aspx

CRA Plant and Plant Products Imports

<http://www.inspection.gc.ca/english/plaveg/imports.html>

Frequently Asked Questions About Permits to Import

<http://www.inspection.gc.ca/english/plaveg/spm/applem.html>

Application, procedures, issuance and use of a permit to import under the plant protection act (D-97-04)

<http://www.inspection.gc.ca/english/plaveg/protect/din/d-97-04a.html>

List of propagative plant material and other commodities that require an import permit if originating from the continental US (D-94-14)

<http://www.inspection.gc.ca/english/plaveg/intemat/d-94-14a.html>

Prohibited plants & plant material from countries other than the continental US

<http://www.inspection.gc.ca/english/plaveg/spm/prohibint.html>

I certify that I am the applicant on this application and that I comply with the requirements of the [Plant Protection Act](#) and the Plant Protection Regulations including section 61 of those Regulations and that the information provided in this Application for Permit is true, correct and complete.

The information collected on this form may be accessible or protected under the provisions of the Access to Information Act and the Privacy Act.

Applicant Signature

Date

Print your name here

Organization Name/Company Name

Canadian Food
Inspection Agency

Agence canadienne
d'inspection des aliments

Page 3 of 3
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Where to send the completed application: [\(CLICK HERE FOR IMPORTANT NOTICE\)](#)

BY MAIL:
CANADIAN FOOD INSPECTION AGENCY
PLANT HEALTH DIVISION
PERMIT OFFICE
519 CAMELOT DRIVE
OTTAWA, ONTARIO K1A0Y9

BY FAX:
613-773-7229

The information you provide on this document and associated attachments is collected by the CFIA under the authority of the Plant Protection Act for the purpose of issuing an import permit. Personal information will be protected under the provisions of the Privacy Act and will be stored in Personal Information Bank (PIA) / PFI-113. Information may be accessible or protected under the provisions of the Access to Information Act and the Privacy Act.

Method of Payment (Client must complete this area) [i](#)

PST Registration No. 10-2000-1400 (Quebec only)

GST/WT Registration No. 121 461 007 810620

IMPORTANT REMINDER: To avoid being billed more than once, please ensure the 'type of application' field at the beginning of this form is properly filled out.

Reference Number 000000

[i](#) ☐ Pre-authorized CFIA account

Don't have an account number? [Click Here](#)

Don't remember your account number? [Click Here](#)

☐ Federal Government

☐ Cash

☐ Cheque

Payable to: Receiver General for Canada

☐ Same as Importer

* Name

* Street Address

City

* Province

* Postal Code

* Telephone No.

Ext.

Facsimile No.

E-mail

Reset Form

Print Form

Appendix 2: Pest risk analysis for quarantine pests (FAO, 2006)

1. Stage 1: Initiation

The aim of the initiation stage is to identify the pest(s) and pathways which are of quarantine concern and should be considered for risk analysis in relation to the identified PRA area.

S2 Some LMOs may present a phytosanitary risk and therefore warrant a PRA. However other LMOs will not present phytosanitary risks beyond those posed by related non-LMOs and therefore will not warrant a complete PRA. Thus, for LMOs, the aim of the Initiation stage is to identify those LMOs that have the characteristics of a potential pest and need to be assessed further, and those which need no further assessment under ISPM No. 11.

S2 LMOs are organisms that have been modified using techniques of modern biotechnology to express one or more new or altered traits. In most cases, the parent organism is not normally considered to be a plant pest but an assessment may need to be performed to determine if the genetic modification (i.e. gene, new gene sequence that regulates other genes, or gene product) results in a new trait or characteristic that may present a plant pest risk.

S2 A plant pest risk from LMOs may be presented by:

- the organism(s) with the inserted gene(s) (i.e. the LMO)
- the combination of genetic material (e.g. gene from plant pests such as viruses) or
- the consequences of the genetic material moving to another organism.

1.1 Initiation points

The PRA process may be initiated as a result of:

- the identification of a pathway that presents a potential pest hazard
- the identification of a pest that may require phytosanitary measures
- the review or revision of phytosanitary policies and priorities.

S1 The initiation points frequently refer to "pests". The IPPC defines a pest as "any species, strain or biotype of plant, animal, or pathogenic agent, injurious to plants or plant products." In applying these initiation points to the specific case of plants as pests, it is important to note that the plants concerned should satisfy this definition. Pests directly affecting plants satisfy this definition. In addition, many organisms indirectly affecting plants also satisfy this definition (such as weeds/invasive plants). The fact that they are injurious to plants can be based on evidence obtained in an area where they occur. In the case of organisms where there is insufficient evidence that they affect plants indirectly, it may nevertheless be appropriate to assess on the basis of available pertinent information, whether they are potentially injurious in the PRA area by using a clearly documented, consistently applied and transparent system. This is particularly important for plant species or cultivars that are imported for planting.

S2 The types of LMOs that an NPP0 may be asked to assess for phytosanitary risk include:

- plants for use (a) as agricultural crops, for food and feed, ornamental plants or managed forests; (b) in bioremediation (as an organism that cleans up contamination); (c) for industrial purposes (e.g. production of enzymes or bioplastics); (d) as therapeutic agents (e.g. pharmaceutical production)
- biological control agents modified to improve their performance in that role
- pests modified to alter their pathogenic characteristic and thereby make them useful for biological control (see ISPM No. 3: Code of conduct for the import and release of exotic biological control agents)
- organisms genetically modified to improve their characteristics such as for biofertilizer or other influences on soil, bioremediation or industrial uses.

S2 In order to be categorized as a pest, an LMO has to be injurious or potentially injurious to plants or plant products under conditions in the PRA area. This damage may be in the form of direct effects on plants or plant products, or indirect effects. For guidance on the process of determining whether an LMO has the potential to be a pest, refer to Annex 3, Determining the potential for a living modified organism to be a pest.

1.1.1 PRA initiated by the identification of a pathway

The need for a new or revised PRA of a specific pathway may arise in the following situations:

- international trade is initiated in a commodity not previously imported into the country (usually a plant or plant product, including genetically altered plants) or a commodity from a new area or new country of origin
- new plant species are imported for selection and scientific research purposes
- a pathway other than commodity import is identified (natural spread, packing material, mail, garbage, passenger baggage, etc.).

A list of pests likely to be associated with the pathway (e.g. carried by the commodity) may be generated by any combination of official sources, databases, scientific and other literature, or expert consultation. It is preferable to prioritize the listing, based on expert judgement on pest distribution and types of pests. If no potential quarantine pests are identified as likely to follow the pathway, the PRA may stop at this point.

S2 The phrase “genetically altered plants” is understood to mean plants obtained through the use of modern biotechnology.

1.1.2 PRA initiated by the identification of a pest

A requirement for a new or revised PRA on a specific pest may arise in the following situations:

- an emergency arises on discovery of an established infestation or an outbreak of a new pest within a PRA area
- an emergency arises on interception of a new pest on an imported commodity
- a new pest risk is identified by scientific research
- a pest is introduced into an area

- a pest is reported to be more damaging in an area other than in its area of origin
- a pest is repeatedly intercepted
- a request is made to import an organism
- an organism is identified as a vector for other pests
- an organism is genetically altered in a way which clearly identifies its potential as a plant pest.

S2 The phrase “genetically altered” is understood to include obtained through the use of modern biotechnology.

1.1.3 PRA initiated by the review or revision of a policy

A requirement for a new or revised PRA originating from policy concerns will most frequently arise in the following situations:

- a national decision is taken to review phytosanitary regulations, requirements or operations
- a proposal made by another country or by an international organization (RPPO, FAO) is reviewed
- a new treatment or loss of a treatment system, a new process, or new information impacts on an earlier decision
- a dispute arises on phytosanitary measures
- the phytosanitary situation in a country changes, a new country is created, or political boundaries have changed.

1.2 Identification of PRA area

The PRA area should be defined as precisely as possible in order to identify the area for which information is needed.

1.3 Information

Information gathering is an essential element of all stages of PRA. It is important at the initiation stage in order to clarify the identity of the pest(s), its/their present distribution and association with host plants, commodities, etc. Other information will be gathered as required to reach necessary decisions as the PRA continues.

Information for PRA may come from a variety of sources. The provision of official information regarding pest status is an obligation under the IPPC (Art. VIII.1c) facilitated by official contact points (Art. VIII.2).

S1 For environmental risks, the variety of sources of information will generally be wider than traditionally used by NPPOs. Broader inputs may be required. These sources may include environmental impact assessments, but it should be recognized that such assessments usually do not have the same purpose as PRA and cannot substitute for PRA.

S2 For LMOs, information required for a full risk analysis may include:

- name, identity and taxonomic status of the LMO (including any relevant identifying codes) and the risk management measures applied to the LMO in the country of export
- taxonomic status, common name, point of collection or acquisition, and characteristics

- of the donor organism
- description of the nucleic acid or the modification introduced (including genetic construct) and the resulting genotypic and phenotypic characteristics of the LMO
- details of the transformation process
- appropriate detection and identification methods and their specificity, sensitivity and reliability
- intended use including intended containment
- quantity or volume of the LMO to be imported.

S2 Information regarding pest status is an obligation under the IPPC (Article VIII.1c) facilitated by official contact points (Article VIII.2). A country may have obligations to provide information about LMOs under other international agreements such as the Cartagena Protocol on Biosafety to the Convention on Biological Diversity (2000; Cartagena Protocol). The Cartagena Protocol has a Biosafety Clearing-house that may contain relevant information. Information on LMOs is sometimes commercially sensitive and applicable obligations with regard to release and handling of information should be observed.

1.3.1 Previous PRA

A check should also be made as to whether pathways, pests or policies have already been subjected to the PRA process, either nationally or internationally. If a PRA exists, its validity should be checked as circumstances and information may have changed. The possibility of using a PRA from a similar pathway or pest, that may partly or entirely replace the need for a new PRA, should also be investigated.

1.4 Conclusion of initiation

At the end of Stage 1, the initiation point, the pests and pathways of concern and the PRA area will have been identified. Relevant information has been collected and pests have been identified as possible candidates for phytosanitary measures, either individually or in association with a pathway.

S2 For LMOs at the end of Stage 1 an NPPO may decide that the LMO:

- is a potential pest and needs to be assessed further in Stage 2 or
- is not a potential pest and needs no further analysis under ISPM No. 11 (but see also the following paragraph).

S2 PRA under the IPPC only relates to the assessment and management of phytosanitary risks. As with other organisms or pathways assessed by an NPPO, LMOs may present other risks not falling within the scope covered by the IPPC. For LMOs, PRA may constitute only a portion of the required overall risk analysis. For example, countries may require the assessment of risks to human or animal health or to the environment beyond that covered by the IPPC. When an NPPO discovers potential for risks that are not phytosanitary it may be appropriate to notify the relevant authorities.

2. Stage 2: Pest Risk Assessment

The process for pest risk assessment can be broadly divided into three interrelated steps:

- pest categorization
- assessment of the probability of introduction and spread
- assessment of potential economic consequences (including environmental impacts).

In most cases, these steps will be applied sequentially in a PRA but it is not essential to follow a particular sequence. Pest risk assessment needs to be only as complex as is technically justified by the circumstances. This standard allows a specific PRA to be judged against the principles of necessity, minimal impact, transparency, equivalence, risk analysis, managed risk and non-discrimination set out in ISPM No. 1: Principles of plant quarantine as related to international trade (FAO, 1995).

S2 For LMOs, from this point forward in PRA, it is assumed that the LMO is being assessed as a pest and therefore "LMO" refers to an LMO that is a potential quarantine pest due to new or altered characteristics or properties resulting from the genetic modification. The risk assessment should be carried out on a case-by-case basis. LMOs that have pest characteristics unrelated to the genetic modification should be assessed using the normal procedures.

2.1 Pest categorization

At the outset, it may not be clear which pest(s) identified in Stage 1 require a PRA. The categorization process examines for each pest whether the criteria in the definition for a quarantine pest are satisfied.

In the evaluation of a pathway associated with a commodity, a number of individual PRAs may be necessary for the various pests potentially associated with the pathway. The opportunity to eliminate an organism or organisms from consideration before in-depth examination is undertaken is a valuable characteristic of the categorization process.

An advantage of pest categorization is that it can be done with relatively little information, however information should be sufficient to adequately carry out the categorization.

2.1.1 Elements of categorization

The categorization of a pest as a quarantine pest includes the following primary elements:

- identity of the pest
- presence or absence in the PRA area
- regulatory status
- potential for establishment and spread in PRA area
- potential for economic consequences (including environmental consequences) in the PRA area.

2.1.1.1 Identity of pest

The identity of the pest should be clearly defined to ensure that the assessment is being performed on a distinct organism, and that biological and other information used in the assessment is relevant to the organism in question. If this is not possible because the causal

agent of particular symptoms has not yet been fully identified, then it should have been shown to produce consistent symptoms and to be transmissible.

The taxonomic unit for the pest is generally species. The use of a higher or lower taxonomic level should be supported by scientifically sound rationale. In the case of levels below the species, this should include evidence demonstrating that factors such as differences in virulence, host range or vector relationships are significant enough to affect phytosanitary status.

In cases where a vector is involved, the vector may also be considered a pest to the extent that it is associated with the causal organism and is required for transmission of the pest.

S2 In the case of LMOs, identification requires information regarding characteristics of the recipient or parent organism, the donor organism, the genetic construct, the gene or transgene vector and the nature of the genetic modification. Information requirements are set out under section 1.3.

2.1.1.2 Presence or absence in PRA area

The pest should be absent from all or a defined part of the PRA area.

S2 In the case of LMOs, this should relate to the LMO of phytosanitary concern.

2.1.1.3 Regulatory status

If the pest is present but not widely distributed in the PRA area, it should be under official control or expected to be under official control in the near future.

S1 Official control of pests presenting an environmental risk may involve agencies other than the NPPO. However, it is recognized that ISPM No. 5 Glossary of phytosanitary terms, Supplement No. 1 on official control, in particular Section 5.7, applies.

S2 In the case of LMOs, official control should relate to the phytosanitary measures applied because of the pest nature of the LMO. It may be appropriate to consider any official control measures in place for the parent organism, donor organism, transgene vector or gene vector.

2.1.1.4 Potential for establishment and spread in PRA area

Evidence should be available to support the conclusion that the pest could become established or spread in the PRA area. The PRA area should have ecological/climatic conditions including those in protected conditions suitable for the establishment and spread of the pest and where relevant, host species (or near relatives), alternate hosts and vectors should be present in the PRA area.

S2 For LMOs, the following should also be considered:

- changes in adaptive characteristics resulting from the genetic modification that may increase the potential for establishment and spread

- gene transfer or gene flow that may result in the establishment and spread of pests, or the emergence of new pests
- genotypic and phenotypic instability that could result in the establishment and spread of organisms with new pest characteristics, e.g. loss of sterility genes designed to prevent outcrossing.

S2 For more detailed guidance on the assessment of these characteristics, see Annex 3.

2.1.1.5 Potential for economic consequences in PRA area

There should be clear indications that the pest is likely to have an unacceptable economic impact (including environmental impact) in the PRA area.

S1 Unacceptable economic impact is described in ISPM No. 5, Glossary of phytosanitary terms, Supplement No. 2: Guidelines on the understanding of potential economic importance and related terms.

S2 In the case of LMOs, the economic impact (including environmental impact) should relate to the pest nature (injurious to plants and plant products) of the LMO.

2.1.2 Conclusion of pest categorization

If it has been determined that the pest has the potential to be a quarantine pest, the PRA process should continue. If a pest does not fulfil all of the criteria for a quarantine pest, the PRA process for that pest may stop. In the absence of sufficient information, the uncertainties should be identified and the PRA process should continue.

2.2 Assessment of the probability of introduction and spread

Pest introduction is comprised of both entry and establishment. Assessing the probability of introduction requires an analysis of each of the pathways with which a pest may be associated from its origin to its establishment in the PRA area. In a PRA initiated by a specific pathway (usually an imported commodity), the probability of pest entry is evaluated for the pathway in question. The probabilities for pest entry associated with other pathways need to be investigated as well.

For risk analyses that have been initiated for a specific pest, with no particular commodity or pathway under consideration, the potential of all probable pathways should be considered.

The assessment of probability of spread is based primarily on biological considerations similar to those for entry and establishment.

S1 With respect to a plant being assessed as a pest with indirect effects, wherever a reference is made to a host or a host range, this should be understood to refer instead to a suitable habitat⁷ (that is a place where the plant can grow) in the PRA area.

⁷ In the case of organisms that affect plants indirectly, through effects on other organisms, the terms host/habitat will extend also to those other organisms.

- S1 The intended habitat is the place where the plants are intended to grow and the unintended habitat is the place where the plants are not intended to grow.
- S1 In the case of plants to be imported, the concepts of entry, establishment and spread have to be considered differently.
- S1 Plants for planting that are imported will enter and then be maintained in an intended habitat, probably in substantial numbers and for an indeterminate period. Accordingly, Section 2.2.1 on Entry does not apply. The risk arises because of the probability that the plant may spread from the intended habitat to unintended habitats within the PRA area, and then establish in those habitats. Accordingly, section 2.2.3 may be considered before section 2.2.2. Unintended habitats may occur in the vicinity of the intended habitat in the PRA area.
- S1 Imported plants not intended to be planted may be used for different purposes (e.g. used as bird seed, as fodder, or for processing). The risk arises because of the probability that the plant may escape or be diverted from the intended use to an unintended habitat and establish there.
- S2 Assessing the probability of introduction of an LMO requires an analysis of both intentional or unintentional pathways of introduction, and intended use.

2.2.1 Probability of entry of a pest

The probability of entry of a pest depends on the pathways from the exporting country to the destination, and the frequency and quantity of pests associated with them. The higher the number of pathways, the greater the probability of the pest entering the PRA area.

Documented pathways for the pest to enter new areas should be noted. Potential pathways, which may not currently exist, should be assessed. Pest interception data may provide evidence of the ability of a pest to be associated with a pathway and to survive in transport or storage.

- S1 In the case of plants to be imported, the plants will enter and an assessment of probability of entry will not be required. Therefore this section does not apply. However, this section does apply to pests that may be carried by such plants (e.g. weed seeds with seeds imported for planting).
- S2 This section is not relevant to LMOs imported for intentional release into the environment.

2.2.1.1 Identification of pathways for a PRA initiated by a pest

All relevant pathways should be considered. They can be identified principally in relation to the geographical distribution and host range of the pest. Consignments of plants and plant products moving in international trade are the principal pathways of concern and existing patterns of such trade will, to a substantial extent, determine which pathways are relevant. Other pathways such as other types of commodities, packing materials, persons, baggage, mail, conveyances and the exchange of scientific material should be considered

where appropriate. Entry by natural means should also be assessed, as natural spread is likely to reduce the effectiveness of phytosanitary measures.

S2 For LMOs, all relevant pathways of introduction should be considered (intentional and unintentional).

2.2.1.2 Probability of the pest being associated with the pathway at origin

The probability of the pest being associated, spatially or temporally, with the pathway at origin should be estimated. Factors to consider are:

- prevalence of the pest in the source area
- occurrence of the pest in a life-stage that would be associated with commodities, containers, or conveyances
- volume and frequency of movement along the pathway
- seasonal timing
- pest management, cultural and commercial procedures applied at the place of origin (application of plant protection products, handling, culling, roguing, grading).

2.2.1.3 Probability of survival during transport or storage

Examples of factors to consider are:

- speed and conditions of transport and duration of the life cycle of the pest in relation to time in transport and storage
- vulnerability of the life-stages during transport or storage
- prevalence of pest likely to be associated with a consignment
- commercial procedures (e.g. refrigeration) applied to consignments in the country of origin, country of destination, or in transport or storage.

2.2.1.4 Probability of pest surviving existing pest management procedures

Existing pest management procedures (including phytosanitary procedures) applied to consignments against other pests from origin to end-use, should be evaluated for effectiveness against the pest in question. The probability that the pest will go undetected during inspection or survive other existing phytosanitary procedures should be estimated.

2.2.1.5 Probability of transfer to a suitable host

Factors to consider are:

- dispersal mechanisms, including vectors to allow movement from the pathway to a suitable host
- whether the imported commodity is to be sent to a few or many destination points in the PRA area
- proximity of entry, transit and destination points to suitable hosts
- time of year at which import takes place
- intended use of the commodity (e.g. for planting, processing and consumption)
- risks from by-products and waste.

Some uses are associated with a much higher probability of introduction (e.g. planting) than others (e.g. processing). The probability associated with any growth, processing, or disposal of the commodity in the vicinity of suitable hosts should also be considered.

S2 For LMOs, the probability of gene flow and gene transfer should also be considered, when there is a trait of phytosanitary concern that may be transferred.

2.2.2 Probability of establishment

In order to estimate the probability of establishment of a pest, reliable biological information (life cycle, host range, epidemiology, survival etc.) should be obtained from the areas where the pest currently occurs. The situation in the PRA area can then be compared with that in the areas where it currently occurs (taking account also of protected environments such as glass- or greenhouses) and expert judgement used to assess the probability of establishment. Case histories concerning comparable pests can be considered. Examples of the factors to consider are:

- availability, quantity and distribution of hosts in the PRA area
- environmental suitability in the PRA area
- potential for adaptation of the pest
- reproductive strategy of the pest
- method of pest survival
- cultural practices and control measures.

In considering probability of establishment, it should be noted that a transient pest (see ISPM No. 8: Determination of pest status in an area) may not be able to establish in the PRA area (e.g. because of unsuitable climatic conditions) but could still have unacceptable economic consequences (see IPPC Art. VII.3).

S1 In the case of plants to be imported, the assessment of the probability of establishment concerns the unintended habitats.

S2 For LMOs, the survival capacity without human intervention should also be considered.

S2 In addition, where gene flow is a concern in the PRA area, the probability of expression and establishment of a trait of phytosanitary concern should be considered.

S2 Case histories concerning comparable LMOs or other organisms carrying the same construct can be considered.

2.2.2.1 Availability of suitable hosts, alternate hosts and vectors in the PRA area

Factors to consider are:

- whether hosts and alternate hosts are present and how abundant or widely distributed they may be
- whether hosts and alternate hosts occur within sufficient geographic proximity to allow the pest to complete its life cycle

- whether there are other plant species, which could prove to be suitable hosts in the absence of the usual host species
- whether a vector, if needed for dispersal of the pest, is already present in the PRA area or likely to be introduced
- whether another vector species occurs in the PRA area.

The taxonomic level at which hosts are considered should normally be the "species". The use of higher or lower taxonomic levels should be justified by scientifically sound rationale.

2.2.2.2 Suitability of environment

Factors in the environment (e.g. suitability of climate, soil, pest and host competition) that are critical to the development of the pest, its host and if applicable its vector, and to their ability to survive periods of climatic stress and complete their life cycles, should be identified. It should be noted that the environment is likely to have different effects on the pest, its host and its vector. This needs to be recognized in determining whether the interaction between these organisms in the area of origin is maintained in the PRA area to the benefit or detriment of the pest. The probability of establishment in a protected environment, e.g. in glasshouses, should also be considered.

Climatic modelling systems may be used to compare climatic data on the known distribution of a pest with that in the PRA area.

2.2.2.3 Cultural practices and control measures

Where applicable, practices employed during the cultivation/production of the host crops should be compared to determine if there are differences in such practices between the PRA area and the origin of the pest that may influence its ability to establish.

S2 For plants that are LMOs, it may also be appropriate to consider specific cultural, control or management practices.

Pest control programs or natural enemies already in the PRA area which reduce the probability of establishment may be considered. Pests for which control is not feasible should be considered to present a greater risk than those for which treatment is easily accomplished. The availability (or lack) of suitable methods for eradication should also be considered.

2.2.2.4 Other characteristics of the pest affecting the probability of establishment

These include:

- *Reproductive strategy of the pests and method of pest survival* - Characteristics, which enable the pest to reproduce effectively in the new environment, such as parthenogenesis/self-crossing, duration of the life cycle, number of generations per year, resting stage etc., should be identified.
- *Genetic adaptability* - Whether the species is polymorphic and the degree to which the pest has demonstrated the ability to adapt to conditions like those in the PRA area

should be considered, e.g., host-specific races or races adapted to a wider range of habitats or to new hosts. This genotypic (and phenotypic) variability facilitates a pest's ability to withstand environmental fluctuations, to adapt to a wider range of habitats, to develop pesticide resistance and to overcome host resistance.

- *Minimum population needed for establishment* - If possible, the threshold population that is required for establishment should be estimated.

S2 For LMOs, if there is evidence of genotypic and phenotypic instability, this should be considered.

S2 It may also be appropriate to consider proposed production and control practices related to the LMO in the country of import.

2.2.3 Probability of spread after establishment

A pest with a high potential for spread may also have a high potential for establishment, and possibilities for its successful containment and/or eradication are more limited. In order to estimate the probability of spread of the pest, reliable biological information should be obtained from areas where the pest currently occurs. The situation in the PRA area can then be carefully compared with that in the areas where the pest currently occurs and expert judgement used to assess the probability of spread. Case histories concerning comparable pests can usefully be considered. Examples of the factors to consider are:

- suitability of the natural and/or managed environment for natural spread of the pest
- presence of natural barriers
- the potential for movement with commodities or conveyances
- intended use of the commodity
- potential vectors of the pest in the PRA area
- potential natural enemies of the pest in the PRA area.

S1 In the case of plants to be imported, the assessment of spread concerns spread from the intended habitat or the intended use to an unintended habitat, where the pest may establish. Further spread may then occur to other unintended habitats.

The information on probability of spread is used to estimate how rapidly a pest's potential economic importance may be expressed within the PRA area. This also has significance if the pest is liable to enter and establish in an area of low potential economic importance and then spread to an area of high potential economic importance. In addition it may be important in the risk management stage when considering the feasibility of containment or eradication of an introduced pest.

S1 Certain pests may not cause injurious effects on plants immediately after they establish, and in particular may only spread after a certain time. In assessing the probability of spread, this should be considered, based on evidence of such behaviour.

2.2.4 Conclusion on the probability of introduction and spread

The overall probability of introduction should be expressed in terms most suitable for the data, the methods used for analysis, and the intended audience. This may be quantitative or qualitative, since either output is in any case the result of a combination of both quantitative and qualitative information. The probability of introduction may be expressed as a comparison with that obtained from PRAs on other pests.

2.2.4.1 Conclusion regarding endangered areas

The part of the PRA area where ecological factors favour the establishment of the pest should be identified in order to define the endangered area. This may be the whole of the PRA area or a part of the area.

2.3 Assessment of potential economic consequences

Requirements described in this step indicate what information relative to the pest and its potential host plants should be assembled, and suggest levels of economic analysis that may be carried out using that information in order to assess all the effects of the pest, i.e. the potential economic consequences. Wherever appropriate, quantitative data that will provide monetary values should be obtained. Qualitative data may also be used. Consultation with an economist may be useful.

In many instances, detailed analysis of the estimated economic consequences is not necessary if there is sufficient evidence or it is widely agreed that the introduction of a pest will have unacceptable economic consequences (including environmental consequences). In such cases, risk assessment will primarily focus on the probability of introduction and spread. It will, however, be necessary to examine economic factors in greater detail when the level of economic consequences is in question, or when the level of economic consequences is needed to evaluate the strength of measures used for risk management or in assessing the cost-benefit of exclusion or control.

- S2 In the case of LMOs, the economic impact (including environmental impact) should relate to the pest nature (injurious to plants and plant products) of the LMO.
- S2 For LMOs, the following evidence should also be considered:
 - potential economic consequences that could result from adverse effects on non-target organisms that are injurious to plants or plant products
 - economic consequences that could result from pest properties.
- S2 For more detailed guidance on the assessment of these characteristics, see Annex 3.

2.3.1 Pest effects

In order to estimate the potential economic importance of the pest, information should be obtained from areas where the pest occurs naturally or has been introduced. This information should be compared with the situation in the PRA area. Case histories concerning comparable pests can usefully be considered. The effects considered may be direct or indirect.

S1 The basic method for estimating the potential economic importance of pests in this section also applies to:

- pests affecting uncultivated/unmanaged plants
- weeds and/or invasive plants and
- pests affecting plants through effects on other organisms.

S1 In the case of direct and indirect environmental effects, specific evidence is needed.

S1 In the case of plants to be imported for planting, the long-term consequences for the intended habitat may be included in the assessment. Planting may affect further use or have a harmful effect on the intended habitat.

S1 Environmental effects and consequences considered should result from effects on plants. Such effects, however, on plants may be less significant than the effects and/or consequences on other organisms or systems. For example, a minor weed may be significantly allergenic for humans or a minor plant pathogen may produce toxins that seriously affect livestock. However, the regulation of plants solely on the basis of their effects on other organisms or systems (e.g. on human or animal health) is outside the scope of this standard. If the PRA process reveals evidence of a potential hazard to other organisms or systems, this should be communicated to the appropriate authorities which have the legal responsibility to deal with the issue.

2.3.1.1 Direct pest effects

For identification and characterization of the direct effects of the pest on each potential host in the PRA area, or those effects which are host-specific, the following are examples that could be considered:

- known or potential host plants (in the field, under protected cultivation, or in the wild)
- types, amount and frequency of damage
- crop losses, in yield and quality
- biotic factors (e.g. adaptability and virulence of the pest) affecting damage and losses
- abiotic factors (e.g. climate) affecting damage and losses
- rate of spread
- rate of reproduction
- control measures (including existing measures), their efficacy and cost
- effect on existing production practices
- environmental effects.

For each of the potential hosts, the total area of the crop and area potentially endangered should be estimated in relation to the elements given above.

S1 In the case of the analysis of environmental risks, examples of direct pest effects on plants and/or their environmental consequences that could be considered include:

- reduction of keystone plant species;
- reduction of plant species that are major components of ecosystems (in terms of abundance or size), and endangered native plant species (including effects below

- species level where there is evidence of such effects being significant);
- significant reduction, displacement or elimination of other plant species.

S1 The estimation of the area potentially endangered should relate to these effects.

2.3.1.2 Indirect pest effects

For identification and characterization of the indirect effects of the pest in the PRA area, or those effects that are not host-specific, the following are examples that could be considered:

- effects on domestic and export markets, including in particular effects on export market access. The potential consequences for market access which may result if the pest becomes established, should be estimated. This involves considering the extent of any phytosanitary regulations imposed (or likely to be imposed) by trading partners
- changes to producer costs or input demands, including control costs
- changes to domestic or foreign consumer demand for a product resulting from quality changes
- environmental and other undesired effects of control measures
- feasibility and cost of eradication or containment
- capacity to act as a vector for other pests
- resources needed for additional research and advice
- social and other effects (e.g. tourism).

S1 In the case of the analysis of environmental risks, examples of indirect pest effects on plants and/or their environmental consequences that could be considered include:

- significant effects on plant communities
- significant effects on designated environmentally sensitive or protected areas
- significant change in ecological processes and the structure, stability or processes of an ecosystem (including further effects on plant species, erosion, water table changes, increased fire hazard, nutrient cycling, etc.)
- effects on human use (e.g. water quality, recreational uses, tourism, animal grazing, hunting, fishing); and
- costs of environmental restoration.

S1 Effects on human and animal health (e.g. toxicity, allergenicity), water tables, tourism, etc. could also be considered, as appropriate, by other agencies/authorities.

2.3.2 Analysis of economic consequences

2.3.2.1 Time and place factors

Estimations made in the previous section related to a hypothetical situation where the pest is supposed to have been introduced and to be fully expressing its potential economic consequences (per year) in the PRA area. In practice, however, economic consequences are expressed with time, and may concern one year, several years or an indeterminate period. Various scenarios should be considered. The total economic consequences over more than one year can be expressed as net present value of annual economic consequences, and an appropriate discount rate selected to calculate net present value.

Other scenarios could concern whether the pest occurs at one, few or many points in the PRA area and the expression of potential economic consequences will depend on the rate and manner of spread in the PRA area. The rate of spread may be envisaged to be slow or rapid; in some cases, it may be supposed that spread can be prevented. Appropriate analysis may be used to estimate potential economic consequences over the period of time when a pest is spreading in the PRA area. In addition, many of the factors or effects considered above could be expected to change over time, with the consequent effects of potential economic consequences. Expert judgement and estimations will be required.

2.3.2.2 Analysis of commercial consequences

As determined above, most of the direct effects of a pest, and some of the indirect effects will be of a commercial nature, or have consequences for an identified market. These effects, which may be positive or negative, should be identified and quantified. The following may usefully be considered:

- effect of pest-induced changes to producer profits that result from changes in production costs, yields or prices
- effect of pest-induced changes in quantities demanded or prices paid for commodities by domestic and international consumers. This could include quality changes in products and/or quarantine-related trade restrictions resulting from a pest introduction.

2.3.2.3 Analytical techniques

There are analytical techniques which can be used in consultation with experts in economics to make a more detailed analysis of the potential economic effects of a quarantine pest. These should incorporate all of the effects that have been identified. These techniques may include:

- *partial budgeting*: this will be adequate, if the economic effects induced by the action of the pest to producer profits are generally limited to producers and are considered to be relatively minor
- *partial equilibrium*: this is recommended if, under point 2.3.2.2, there is a significant change in producer profits, or if there is a significant change in consumer demand. Partial equilibrium analysis is necessary to measure welfare changes, or the net changes arising from the pest impacts on producers and consumers
- *general equilibrium*: if the economic changes are significant to a national economy, and could cause changes to factors such as wages, interest rates or exchange rates, then general equilibrium analysis could be used to establish the full range of economic effects.

The use of analytical techniques is often limited by lack of data, by uncertainties in the data, and by the fact that for certain effects only qualitative information can be provided.

2.3.2.4 Non-commercial and environmental consequences

Some of the direct and indirect effects of the introduction of a pest determined in 2.3.1.1 and 2.3.1.2 will be of an economic nature, or affect some type of value, but not have an existing market which can be easily identified. As a result, the effects may not be

adequately measured in terms of prices in established product or service markets. Examples include in particular environmental effects (such as ecosystem stability, biodiversity, amenity value) and social effects (such as employment, tourism) arising from a pest introduction. These impacts could be approximated with an appropriate non-market valuation method. More details on environment are given below.

If quantitative measurement of such consequences is not feasible, qualitative information about the consequences may be provided. An explanation of how this information has been incorporated into decisions should also be provided.

- S1* Application of this standard to environmental hazards requires clear categorization of environmental values and how they can be assessed. The environment can be valued using different methodologies, but these methodologies are best used in consultation with experts in economics. Methodologies may include consideration of "use" and "non-use" values. "Use" values arise from consumption of an element of the environment, such as accessing clean water, or fishing in a lake, and also those that are non-consumptive, such as use of forests for leisure activities. "Non-use" values may be subdivided into:
- "option value" (value for use at a later date)
 - "existence value" (knowledge that an element of the environment exists) and
 - "bequest value" (knowledge that an element of the environment is available for future generations).
- S1* Whether the element of the environment is being assessed in terms of use or non-use values, methods exist for their valuation, such as market-based approaches, surrogate markets, simulated markets, and benefit transfer. Each has advantages, disadvantages and situations where it is particularly useful.
- S1* The assessment of consequences may be either quantitative or qualitative and in many cases, qualitative data is sufficient. A quantitative method may not exist to address a situation (e.g. catastrophic effects on a keystone species), or a quantitative analysis may not be possible (no methods available). Useful analyses can be based on non-monetary valuations (number of species affected, water quality), or expert judgement, if the analyses follow documented, consistent and transparent procedures.
- S1* Economic impact is described in ISPM No. 5: Glossary of phytosanitary terms, Supplement No. 2: Guidelines on the understanding of potential economic importance and related terms.

2.3.3 Conclusion of the assessment of economic consequences

Wherever appropriate, the output of the assessment of economic consequences described in this step should be in terms of a monetary value. The economic consequences can also be expressed qualitatively or using quantitative measures without monetary terms. Sources of information, assumptions and methods of analysis should be clearly specified.

2.3.3.1 Endangered area

The part of the PRA area where presence of the pest will result in economically important loss should be identified as appropriate. This is needed to define the endangered area.

2.4 Degree of uncertainty

Estimation of the probability of introduction of a pest and of its economic consequences involves many uncertainties. In particular, this estimation is an extrapolation from the situation where the pest occurs to the hypothetical situation in the PRA area. It is important to document the areas of uncertainty and the degree of uncertainty in the assessment, and to indicate where expert judgment has been used. This is necessary for transparency and may also be useful for identifying and prioritizing research needs.

- S1* It should be noted that the assessment of the probability and consequences of environmental hazards of pests of uncultivated and unmanaged plants often involves greater uncertainty than for pests of cultivated or managed plants. This is due to the lack of information, additional complexity associated with ecosystems, and variability associated with pests, hosts or habitats.

2.5 Conclusion of the pest risk assessment stage

As a result of the pest risk assessment, all or some of the categorized pests may be considered appropriate for pest risk management. For each pest, all or part of the PRA area may be identified as an endangered area. A quantitative or qualitative estimate of the probability of introduction of a pest or pests, and a corresponding quantitative or qualitative estimate of economic consequences (including environmental consequences), have been obtained and documented or an overall rating could have been assigned. These estimates, with associated uncertainties, are utilized in the pest risk management stage of the PRA.

3. Stage 3: Pest Risk Management

The conclusions from pest risk assessment are used to decide whether risk management is required and the strength of measures to be used. Since zero-risk is not a reasonable option, the guiding principle for risk management should be to manage risk to achieve the required degree of safety that can be justified and is feasible within the limits of available options and resources. Pest risk management (in the analytical sense) is the process of identifying ways to react to a perceived risk, evaluating the efficacy of these actions, and identifying the most appropriate options. The uncertainty noted in the assessments of economic consequences and probability of introduction should also be considered and included in the selection of a pest management option.

- S1* In considering the management of environmental risks, it should be stressed that phytosanitary measures are intended to account for uncertainty and should be designed in proportion to the risk. Pest risk management options should be identified, taking account of the degree of uncertainty in the assessment of economic consequences, probability of introduction, and the respective technical justification of those options. In this respect, the management of risks to the environment caused by plant pests does not differ from the management of other plant pest risks.

3.1 Level of risk

The principle of "managed risk" (ISPM No. 1: Principles of plant quarantine as related to international trade) states that: "Because some risk of introduction of a quarantine pest always exists, countries shall agree to a policy of risk management when formulating phytosanitary measures." In implementing this principle, countries should decide what level of risk is acceptable to them.

The acceptable level of risk may be expressed in a number of ways, such as:

- reference to existing phytosanitary requirements
- indexed to estimated economic losses
- expressed on a scale of risk tolerance
- compared with the level of risk accepted by other countries.

S2 For LMOs, the acceptable level of risk may also be expressed by comparison to the level of risk associated with similar or related organisms, based on their characteristics and behaviour in a similar environment to the PRA area.

3.2 Technical information required

The decisions to be made in the pest risk management process will be based on the information collected during the preceding stages of PRA. This information will be composed of:

- reasons for initiating the process
- estimation of the probability of introduction to the PRA area
- evaluation of potential economic consequences in the PRA area.

3.3 Acceptability of risk

Overall risk is determined by the examination of the outputs of the assessments of the probability of introduction and the economic impact. If the risk is found to be unacceptable, then the first step in risk management is to identify possible phytosanitary measures that will reduce the risk to, or below an acceptable level. Measures are not justified if the risk is already acceptable or must be accepted because it is not manageable (as may be the case with natural spread). Countries may decide that a low level of monitoring or audit is maintained to ensure that future changes in the pest risk are identified.

3.4 Identification and selection of appropriate risk management options

Appropriate measures should be chosen based on their effectiveness in reducing the probability of introduction of the pest. The choice should be based on the following considerations, which include several of the *Principles of plant quarantine as related to international trade* (ISPM No. 1):

- *Phytosanitary measures shown to be cost-effective and feasible* - The benefit from the use of phytosanitary measures is that the pest will not be introduced and the PRA area will, consequently, not be subjected to the potential economic consequences. The cost-benefit analysis for each of the minimum measures found to provide acceptable security may be estimated. Those measures with an acceptable benefit-to-cost ratio should be considered.

- *Principle of "minimal impact"* - Measures should not be more trade restrictive than necessary. Measures should be applied to the minimum area necessary for the effective protection of the endangered area.
- *Reassessment of previous requirements* - No additional measures should be imposed if existing measures are effective.
- *Principle of "equivalence"* - If different phytosanitary measures with the same effect are identified, they should be accepted as alternatives.
- *Principle of "non-discrimination"* - If the pest under consideration is established in the PRA area but of limited distribution and under official control, the phytosanitary measures in relation to import should not be more stringent than those applied within the PRA area. Likewise, phytosanitary measures should not discriminate between exporting countries of the same phytosanitary status.

S1 The principle of non-discrimination and the concept of official control also apply to:

- pests affecting uncultivated/unmanaged plants
- weeds and/or invasive plants and
- pests affecting plants through effects on other organisms.

S1 If any of these become established in the PRA area and if official control is applied, then phytosanitary measures at import should not be more stringent than the official control measures.

The major risk of introduction of plant pests is with imported consignments of plants and plant products, but (especially for a PRA performed on a particular pest) it is necessary to consider the risk of introduction with other types of pathways (e.g. packing materials, conveyances, travellers and their luggage, and the natural spread of a pest).

The measures listed below are examples of those that are most commonly applied to traded commodities. They are applied to pathways, usually consignments of a host, from a specific origin. The measures should be as precise as possible as to consignment type (hosts, parts of plants) and origin so as not to act as barriers to trade by limiting the import of products where this is not justified. Combinations of two or more measures may be needed in order to reduce the risk to an acceptable level. The available measures can be classified into broad categories which relate to the pest status of the pathway in the country of origin. These include measures:

- applied to the consignment
- applied to prevent or reduce original infestation in the crop
- to ensure the area or place of production is free from the pest
- concerning the prohibition of commodities.

Other options may arise in the PRA area (restrictions on the use of a commodity), control measures, introduction of a biological control agent, eradication, and containment. Such options should also be evaluated and will apply in particular if the pest is already present but not widely distributed in the PRA area.

3.4.1 Options for consignments

Measures may include any combinations of the following:

- inspection or testing for freedom from a pest or to a specified pest tolerance; sample size should be adequate to give an acceptable probability of detecting the pest
- prohibition of parts of the host
- a pre-entry or post-entry quarantine system - this system could be considered to be the most intensive form of inspection or testing where suitable facilities and resources are available, and may be the only option for certain pests not detectable on entry
- specified conditions of preparation of the consignment (e.g. handling to prevent infestation or reinfestation)
- specified treatment of the consignment - such treatments are applied post-harvest and could include chemical, thermal, irradiation or other physical methods
- restrictions on end use, distribution and periods of entry of the commodity.

Measures may also be applied to restrict the import of consignments of pests.

S1 The concept of consignments of pests may be applied to the import of plants considered to be pests. These consignments may be restricted to species or varieties posing less risk.

S2 For LMOs, as for other organisms, information may have been obtained concerning the risk management measures applied to the LMO in the country of export (see section 1.3). These should be assessed to determine if they are appropriate for the conditions in the PRA area and, if appropriate, the intended use.

S2 For LMOs, measures may also include procedures for the provision of information on the phytosanitary integrity of consignments (e.g. tracing systems, documentation systems, identity preservation systems).

3.4.2 Options preventing or reducing infestation in the crop

Measures may include:

- treatment of the crop, field, or place of production
- restriction of the composition of a consignment so that it is composed of plants belonging to resistant or less susceptible species
- growing plants under specially protected conditions (glasshouse, isolation)
- harvesting of plants at a certain age or a specified time of year
- production in a certification scheme. An officially monitored plant production scheme usually involves a number of carefully controlled generations, beginning with nuclear stock plants of high health status. It may be specified that the plants be derived from plants within a limited number of generations.

S2 Measures may be applied to reduce the probability that LMOs (or genetic material from LMOs) that pose a phytosanitary risk could be in other crops. These include:

- management systems (e.g. buffer zones, refugia)
- management of trait expression
- control of reproductive ability (e.g. male sterility)

- control of alternative hosts.

3.4.3 Options ensuring that the area, place or site of production or crop is free from the pest

Measures may include:

- pest-free area - requirements for pest-free area status are described in ISPM No. 4: *Requirements for the establishment of pest free areas*
- pest-free place of production or pest-free production site - requirements are described in ISPM No. 10: *Requirements for the establishment of pest free places of production and pest-free production sites*
- inspection of crop to confirm pest freedom.

3.4.4 Options for other types of pathways

For many types of pathways, the measures considered above for plants and plant products to detect the pest in the consignment or to prevent infestation of the consignment, may also be used or adapted. For certain types of pathways, the following factors should be considered:

- Natural spread of a pest includes movement of the pest by flight, wind dispersal, transport by vectors such as insects or birds and natural migration. If the pest is entering the PRA area by natural spread, or is likely to enter in the immediate future, phytosanitary measures may have little effect. Control measures applied in the area of origin could be considered. Similarly, containment or eradication, supported by suppression and surveillance, in the PRA area after entry of the pest could be considered.
- Measures for human travellers and their baggage could include targeted inspections, publicity and fines or incentives. In a few cases, treatments may be possible.
- Contaminated machinery or modes of transport (ships, trains, planes, road transport) could be subjected to cleaning or disinfestation.

3.4.5 Options within the importing country

Certain measures applied within the importing country may also be used. These could include careful surveillance to try and detect the entry of the pest as early as possible, eradication programmes to eliminate any foci of infestation and/or containment action to limit spread.

- S1 For plants to be imported, where there is a high level of uncertainty regarding pest risk, it may be decided not to take phytosanitary measures at import, but only to apply surveillance or other procedures after entry (e.g. by or under the supervision of the NPPO).
- S2 The potential for risk from LMO pests depends in part on the intended use. As for other organisms, certain intended uses (such as high security contained use) may significantly manage risk.

S2 For LMOs, as with other pests, options within the country also include the use of emergency measures related to phytosanitary risks. Any emergency measures should be consistent with Article VII.6 of the IPPC (1997).

3.4.6 Prohibition of commodities

If no satisfactory measure to reduce risk to an acceptable level can be found, the final option may be to prohibit importation of the relevant commodities. This should be viewed as a measure of last resort and should be considered in light of the anticipated efficacy, especially in instances where the incentives for illegal import may be significant.

3.5 Phytosanitary certificates and other compliance measures

Risk management includes the consideration of appropriate compliance procedures. The most important of these is export certification (see ISPM No. 7: *Export certification system*). The issuance of phytosanitary certificates (see ISPM No. 12: *Guidelines for Phytosanitary Certificates*) provides official assurance that a consignment is “considered to be free from the quarantine pests specified by the importing contracting party and to conform with the current phytosanitary requirements of the importing contracting party.” It thus confirms that the specified risk management options have been followed. An additional declaration may be required to indicate that a particular measure has been carried out. Other compliance measures may be used subject to bilateral or multilateral agreement.

S2 Information on Phytosanitary Certificates regarding LMOs (as with any other regulated articles) should only be related to phytosanitary measures (see ISPM No. 12: *Guidelines for phytosanitary certificates*).

3.6 Conclusion of pest risk management

The result of the pest risk management procedure will be either that no measures are identified which are considered appropriate or the selection of one or more management options that have been found to lower the risk associated with the pest(s) to an acceptable level. These management options form the basis of phytosanitary regulations or requirements.

The application and maintenance of such regulations is subject to certain obligations, in the case of contracting parties to the IPPC.

S1 Phytosanitary measures taken in relation to environmental hazards should, as appropriate, be notified to relevant competent authorities responsible for national biodiversity policies, strategies and action plans.

S1 It is noted that the communication of risks associated with environmental hazards is of particular importance to promote awareness.

3.6.1 Monitoring and review of phytosanitary measures

The principle of "modification" states: "As conditions change, and as new facts become available, phytosanitary measures shall be modified promptly, either by inclusion of prohibitions, restrictions or requirements necessary for their success, or by removal of

those found to be unnecessary" (ISPM No. 1: *Principles of plant quarantine as related to international trade*).

Thus, the implementation of particular phytosanitary measures should not be considered to be permanent. After application, the success of the measures in achieving their aim should be determined by monitoring during use. This is often achieved by inspection of the commodity on arrival, noting any interceptions or any entries of the pest to the PRA area. The information supporting the pest risk analysis should be periodically reviewed to ensure that any new information that becomes available does not invalidate the decision taken.

4. Documentation of Pest Risk Analysis

4.1 Documentation requirements

The IPPC and the principle of "transparency" (ISPM No. 1: *Principles of plant quarantine as related to international trade*) require that countries should, on request, make available the rationale for phytosanitary requirements. The whole process from initiation to pest risk management should be sufficiently documented so that when a review or a dispute arises, the sources of information and rationale used in reaching the management decision can be clearly demonstrated.

The main elements of documentation are:

- purpose for the PRA
- pest, pest list, pathways, PRA area, endangered area
- sources of information
- categorized pest list
- conclusions of risk assessment
 - ☐ probability
 - ☐ consequences
- risk management
 - ☐ options identified
- options selected.

Appendix 3: Weed initiated pest risk assessment guidelines for qualitative assessments (USDA, APHIS, 2004)

INTRODUCTION

The Animal and Plant Health Inspection Service (APHIS) regulates noxious weeds under the authority of the Plant Protection Act (PPA). APHIS names the regulated weeds in the noxious weed regulations (7 CFR 360) in order to ensure transparency. Listed kinds may not be imported into the United States, or moved interstate, without a special permit. APHIS uses risk assessments as a basis for weed exclusion decisions. This document presents guidelines for conducting pest-initiated, qualitative pest risk assessments specifically for determining whether or not a weed species should be listed in (or de-listed from) the noxious weed regulations.

In a qualitative assessment we estimate risk in terms such as high or low as opposed to numerical terms such as probabilities or frequencies. Plant Protection and Quarantine (PPQ) risk assessment procedures are harmonized with those of the North American Plant Protection Organization (NAPPO) and the International Plant Protection Convention (IPPC) of the United Nations Food and Agriculture Organization (FAO). Our use of biological and phytosanitary terms (*e.g.*, introduction, quarantine pest) conforms with the *NAPPO Compendium of Phytosanitary Terms* (NAPPO 1995) and the *Definitions and Abbreviations* (Introduction Section) in *International Standards for Phytosanitary Measures, Section 1—Import Regulations: Guidelines for Pest Risk Analysis* (FAO 1995).

Pest risk assessment is a component of pest risk analysis. FAO (1995) guidelines describe three stages in pest risk. This document provides a template for conducting FAO stages 1 and 2. APHIS completes eight basic steps in weed-initiated plant pest risk assessments:

- Stage 1: Initiating the process by identifying a pest that may qualify as a quarantine pest, and/or pathways that may allow introduction or spread of a quarantine pest.
- Stage 2: Assessing pest risk (determining which pests are quarantine pests, characterized in terms of likelihood of entry, establishment, spread, and economic importance).
- Stage 3: Managing pest risk (developing, evaluating, comparing, and selecting options for dealing with the risk).
- Step 4: Verifying quarantine pest status: Geographic and regulatory criteria.
- Step 5: Assess economic and environmental importance: Consequences of introduction.
- Step 6: Assess likelihood of introduction.
- Step 7: Conclusion/Determine pest risk potential (PRP) of weed.
- Step 8: Document the PRA, cite references.

METHODS: PEST RISK ASSESSMENT GUIDELINES

This section provides instructions for preparing the pest risk assessment.

Stage 1: Initiating Pest Risk Analysis Process

Step 1: Document the Initiating Event(s) for the Pest Risk Assessment

A new or revised pest risk assessment for a specific weed will be required in the following situations (including, but not limited to):

- discovery of an established infestation or an outbreak of a new weed
- through research, identification of a new weed risk
- proposal from outside APHIS for listing a new weed under the Plant Protection Act
- proposal for de-listing a weed already on the list.

Step 2. Identify and Cite Previous Risk Assessments.

Identify previous pest risk assessments for the same weed or a close relative. If an existing document adequately assesses the risks in question, determine if it is entirely or partly valid. If a previous assessment is entirely valid, the risk assessment stops here.

Step 3. Establish Identity of Weed

Define the weed as a taxon that can be adequately distinguished from other taxa of the same rank. Include:

Scientific Name: Order, Family, Genus, and species. (If the weed cannot be clearly distinguished from other taxa of the same rank, the assessment stops here.) Common name(s) Synonym(s) Description, morphology Weed biology (growth, development and reproduction) Climatic tolerance Native and current worldwide distribution Key characters for identification

Note: Step 3 can be created in a stand-alone format, and used as a pest data sheet. If this is done, add to the above a summary of detection and inspection methods, pest significance (i.e., economic and environmental impacts) and control/management options. Attach a separate bibliography for the data sheet.

Stage 2: Assessing Pest Risk

Step 4. Verify Quarantine Pest Status: Regulatory and Geographic Criteria

Determine whether or not the weed satisfies regulatory and geographic criteria as a quarantine pest.

Regulatory: APHIS accepts the FAO (1995) and NAPPO (1995) definition of a quarantine pest as one having “potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled” If a weed is present but not widely distributed, identify local, state, and federal control efforts for each occurrence of the species in the United States. If there are no current control efforts in place, you may discuss and recommend an official control program in the conclusion (Step 7) of the risk assessment.

Geographic: The weed-initiated risk assessment should first establish that the weed satisfies the geographic criteria. Describe the history of introduction and the weed’s

current distribution in the United States. If the weed is native, or has reached the limits of its ecological range (i.e., is widely distributed), then the weed does not satisfy the definition of a quarantine pest and the pest risk assessment stops here.

Step 5. Assess Economic and Environmental Importance: Consequences of Introduction.

Estimate the economic and environmental consequences of introduction, considering "... the establishment, spread and economic importance potential in the PRA area" (FAO, 1995). The weed-initiated risk assessment should establish that the weed is of potential economic importance by considering the consequences and likelihood of introduction. In qualitative pest risk assessments, we use five Risk Elements (RE) to estimate risk. RE #1-4 focus on the consequences of introduction and RE # 5 focuses on the likelihood of introduction.

Rate the potential consequences of introduction according to RE #1-5. These elements reflect the biology of the weed and its hosts. Rate each RE, from highest (3) to lowest (0). Discuss the rationale for each rating; cite references.

RE #1: Habitat Suitability

A weed may behave in its area of introduction as it does in its native area if climatic conditions are similar. For this element, we base estimates on suitable climate and habitat conditions. For a parasitic weed, the evaluation also considers the availability of host material. To rate this RE, you may consider the U.S. "plant hardiness zones" as described by the U.S. Department of Agriculture (USDA, 1990). You may use the climate matching software CLIMEX, which is available from the Hearne Scientific Software website at www.hearne.com.au.

Assign rating as follows:

Suitable climate and habitats (and availability of host plants, if the organism is a parasitic plant) would permit the weed to survive and establish:

Rating Numerical Score Explanation

High	3	In most or all of the United States (generally, in more than four plant hardiness zones).
Medium	2	Approximately one third to two thirds of the USA (generally, in (generally, in three or four plant hardiness zones).
Low	1	Approximately one third or less of the United States (generally, in one or two plant hardiness zone).
Negligible	0	No potential to survive and become established in the PRA area.

Discuss your rationale for the rating and the level of certainty. If the quarantine weed cannot become established in the PRA area because of unsuitable climate (or lack of hosts, if the weed is a parasite), the pest risk assessment stops here.

RE #2: Spread potential after establishment, Dispersal Potential.

Discuss the biological attributes of the species that allow it to spread and identify dispersal

mechanisms. For example, determine which of the following apply:

- Consistent and prolific seed production
- Rapid growth to reproductive maturity
- High germination rate under a wide range of conditions
- Ability to suppress the growth of other plants by releasing a chemical inhibitor
- Ability to persist as dormant long-lived propagules or underground parts, such as rhizomes, tubers, turions or stolons
- Seed dormancy
- Stress tolerance, including ability to resist herbicides
- Ability to colonize a wide variety of habitats
- Lack of natural control agents
- Well-developed storage tissue (for example, tap root)
- Dispersal by wind, water, machinery, animals, and/or humans

Assign rating as follows:

Rating Numerical score Explanation

High	3	Weed has potential for rapid natural spread throughout its potential range in the PRA area (<i>e.g.</i> , high reproductive potential AND highly mobile propagules)
Medium	2	Weed has potential for natural spread throughout a physiographic region of the PRA area within a year (<i>e.g.</i> , it has either high reproductive potential OR highly mobile propagules).
Low	1	Weed has potential for natural spread locally in the PRA area within a year (some reproductive potential and/or some mobility of propagules).
Negligible	0	Weed has no potential for natural spread in the PRA area

Discuss your rationale for the rating and the level of certainty.

RE #3: Economic Impact Rating

Introduced weeds can cause a variety of economic impacts. We divide these impacts into three primary categories (other types of impacts may occur):

- 1 Reduced crop yield (*e.g.*, by parasitism, competition, or by harboring other pests).
- 2 Lower commodity value (*e.g.*, by increasing costs of production, lowering market price, or a combination); or if not an agricultural weed, by increasing costs of control.
- 3 Loss of markets (foreign or domestic) due to presence of a new quarantine pest.

Assign ratings as follows:

Rating Numerical score Explanation

High	3	Weed causes all three of the above impacts, or causes any two impacts over a wide range (over 5 types) of economic plants, plant products, or animals.
Medium	2	Weed causes any two of the above impacts, or causes any one impact to a wide range (over 5 types) of economic plants, plant

		products, or animals.
Low	1	Weed causes any one of the above impacts.
Negligible	0	Weed causes none of the above impacts.

Discuss your rationale for the rating and the level of certainty.

RE #4: Environmental Impact

Consider whether or not the weed, if introduced, could:

- Cause impacts on ecosystem processes (alteration of hydrology, sedimentation rates, a fire regime, nutrient regimes, changes in productivity, growth, yield, vigor, etc.)
- Cause impacts on natural community composition (*e.g.*, reduce biodiversity, affect native populations, affect endangered or threatened species, impact keystone species, impact native fauna, pollinators, or microorganisms, etc.)
- Cause impacts on community structure (*e.g.*, change density of a layer, cover the canopy, eliminate or create a layer, impact wildlife habitats, etc.)
- Have impacts on human health such as allergies or changes in air or water quality.
- Have sociological impacts on recreation patterns and aesthetic or property values.
- Stimulate control programs including toxic chemical pesticides or introduction of a nonindigenous biological control agent.

Assign ratings as follows:

Rating Numerical Score Explanation

High	3	Three or more of the above. (Potential to cause major damage to the environment with significant losses to plant ecosystems and subsequent physical environmental degradation). (Population reduction of endangered or threatened species would elevate that one factor to a high rating.)
Medium	2	Two of the above. (Potential to cause moderate impact on the environment with obvious change in the ecological balance, affecting several attributes of the ecosystem, as well as moderate recreation or aesthetic impacts.)
Low	1	One of the above, unless the factor is potential to reduce populations of endangered or threatened species, which rates High. (Limited potential impact on environment.)
Negligible	0	None of the above. (No potential to degrade the environment or otherwise affect ecosystems.)

Discuss your rationale for the rating and the level of certainty.

ECONOMIC and ENVIRONMENTAL IMPORTANCE SUMMARY:

Consequences of Introduction: Cumulative Risk Element Score

Add together the numerical estimates for the four risk elements to produce an overall estimate of the Consequences of Introduction Risk Rating for the weed. The overall risk rating is used to assign a Consequences of Introduction Risk Score as follows:

Risk: Consequences of Introduction (Sum Risk Elements #1-4)

Cumulative Risk Element Score	Risk Rating	Risk Score
0 - 2	Negligible	0
3 - 6	Low	1
7 - 10	Medium	2
11 - 12	High	3

The Consequences of Introduction Risk Rating is an indicator of the potential of the weed to become established and spread, and its potential to cause economic and environmental impacts

Step 6. Assess Likelihood of Introduction/Spread

The final stage is an assessment of introduction and spread potential, which depends on the number of pathways from the exporting country to the destination and the subsequent opportunities to spread once an organism has arrived.

Consider:

- Interest in cultivation of the species for ornament, food, medicine, or other uses.
- Evidence of previous importation
- Species prevalence in area of origin
- Potential for contamination of commodities or conveyances by the species
- Whether the species can survive under the environmental conditions of shipment
- Ease or difficulty of detection through visual inspection
- Probability of surviving existing phytosanitary procedures
- Frequency and quantity of pest movement into the PRA area by named means
- Number and frequency of shipments of contaminated commodities
- Number of individuals of the species associated with each named conveyance or commodity
- Intended use of named commodities
- Season of arrival and distribution of commodities

Assign ratings as follows:

Rating Numerical Score Explanation:

High	3	Very likely or certain, given the combination of factors above
Medium	2	Likely
Low	1	Low, but clearly possible
Negligible	0	Extremely unlikely

Discuss the rationale for your rating and the level of certainty.

Step 7. Conclusion/Pest Risk Potential (PRP): Determine if weed should be listed

Produce an estimate of the pest risk potential by considering the Consequences of Introduction and the Likelihood of Introduction using the following table as a guide. The pest risk potential will be obtained from the combination of the scores for likelihood of introduction and consequences of introduction, and will be assigned as follows: negligible,

low, medium, medium-high and high: Discuss whether or not the species satisfies the definition of quarantine pest. Summarize the information from the previous six steps and discuss the rating.

Although this document focuses on risk assessment (*i.e.*, FAO Stages 1 & 2), the risk assessor may comment briefly on the related issue of risk management (FAO Stage 3). For instance, weeds with medium-high or high pest risk will likely be proposed for listing as Federal Noxious Weeds. Beyond this, the pest risk management phase is not discussed in this document.

Likelihood of Introduction (Rating and Score)	Consequences of Introduction (Rating and Score)	Overall Pest Risk Potential
Negligible (0)	Negligible (0)	Negligible
Negligible	Low	Negligible
Negligible (0)	Medium (2)	Negligible
Negligible (0)	High (3)	Negligible
Low (1)	Negligible (0)	Negligible
Low (1)	Low (1)	Low
Low (1)	Medium (2)	Low
Low (1)	High (3)	Low
Medium (2)	Negligible (0)	Negligible
Medium (2)	Low (1)	Low
Medium (2)	Medium (2)	Medium
Medium (2)	High (3)	Medium- High
High (3)	Negligible (0)	Negligible
High (3)	Low (1)	Low
High (3)	Medium (2)	Medium- High
High (3)	High (3)	High

Step 8. Document the PRA. Cite references.

Cite references in alphabetical order by author.

Appendix 4: Advisory from CFIA regarding importation of aquatic plants

February 2007

CFIA Import restrictions for certain aquatic plants

PIJAC Canada has been advised that the Canadian Food Inspection Agency (CFIA) is currently reviewing its policy on aquatic plants as part of the Government of Canada's initiative on invasive alien species. As a result, certain aquatic plants that may pose a risk of becoming invasive plants, will not be allowed entry into Canada until a pest risk assessment has been completed. Once completed, the CFIA's aquatic plants policy will be finalized and posted on the CFIA web site. Importers of aquatic plants will be notified accordingly.

CFIA officials have also indicated that, pending further notice, all applications for import permits for aquatic plant species will be evaluated on a case-by-case basis. If the species is deemed as posing no threat, CFIA will process the application and issue the permits. If the species is considered to be higher risk, it will be subject to a risk assessment. The risk assessment will be conducted by the CFIA, at no cost to the importer. If, further to the risk assessment, the species is deemed as posing no threat, the CFIA will allow importation. If it is deemed as posing a threat, importation will not be permitted.

The following plant species have been identified as requiring a risk assessment and will not be allowed into the country until the assessment has been completed:

- Cardamine impatiens* L.
- Crassula helmsii* A. Berger
- Hydrilla verticillata* (L. f.) Royle
- Limnophila indica* (L.) Druce
- Limnophila sessiliflora* (Vahl) Blume
- Ludwigia grandiflora* (M. Micheli) Greuter & Burdet
- Ludwigia peruviana* (L.) Hara
- Marsilea quadrifolia* L.
- Myriophyllum aquaticum* (Vell.) Verde.
- Najas minor* All.
- Nymphoides peltata* (Gmel.) O. Kuntze
- Sagittaria sagittifolia* L.
- Salvinia minima* Baker
- Trapa natans* L.

Appendix 5: Pest risk assessment summaries for *Cabomba*, *Trapa natans*, and *Nymphaeodes peltata*

***Cabomba caroliniana* - Summary**

The purpose of this weed (pest) risk assessment (PRA) was to evaluate the plant health risk associated with the aquatic weed fanwort (*Cabomba caroliniana* Gray). The Plant Health Risk Assessment Unit of the Science Division, CFIA has prepared this PRA at the request of the Plant Health and Production Division, CFIA. This PRA will help the CFIA decide whether or not to regulate the importation of fanwort. A Weed Facts Sheet is included. Major points discussed in this risk assessment are summarized below:

Fanwort is an aquatic weed and popular aquarium plant that is considered native to South America and possibly also the southeastern U.S. It has been introduced in Malaysia, India, Japan, New Guinea, Australia and England as a result of people discarding or deliberately planting aquarium plants in natural waterways. It is currently considered an invasive weed in Australia and Japan, due to its rapid growth and ability to form dense stands that clog waterways and squeeze out other vegetation. It is also considered a noxious weed in parts of the U.S. where its range is spreading.

Fanwort was recently identified in a lake northeast of Peterborough, Ontario, where it has successfully established and survived winter conditions since at least 1992. This is the only known population of fanwort to have established in Canada, and is also the furthest north that the plant has been known to survive. For this risk assessment, the PRA area is considered to be all of Canada.

Likelihood of introduction is rated “HIGH”, based on the fact that fanwort is regularly brought into Canada and sold in the aquarium trade, and the fact that in other countries, this has led to the introduction of fanwort in natural waterways. It is also possible that fanwort could enter Canada across the border from the U.S., as its U.S. range is approaching the Canadian border in many eastern states. Viable stem fragments, for example, could get caught unnoticed on a boat motor in the U.S., and then the boat towed across the border to a cottage on a Canadian lake. While it is not clear how fanwort came to be in Kasshabog Lake north of Peterborough, its presence there is further confirmation that the likelihood of introduction is high.

Establishment potential is rated “MEDIUM”. Fanwort is certainly capable of surviving and becoming established in Canada, and based on its presence in Kasshabog Lake, its potential range includes at least plant hardiness zones 4b, 5, and 6, as well as 7 and 8. These zones cover the southern ‘arm’ of Ontario and a small piece of south-western Québec, as well as Nova Scotia, southern Newfoundland, eastern New Brunswick and parts of British Columbia. In total, this comprises less than one third of the PRA area (all of Canada) and earns a “LOW” risk rating. However, in general fanwort appears to be highly adaptable and has already spread much farther north than would be expected based on descriptions of its habitat requirements in the literature. Its northern limits have not yet been established, and it is therefore possible that fanwort could establish in more than one third of Canada.

Natural spread potential is rated “MEDIUM”, as fanwort has high reproductive potential but not highly mobile propagules. Fanwort does not reproduce by seed in the northern parts of its range, but can multiply very rapidly by stem fragmentation, either naturally or as a result of any activity that cuts up the plants, such as boating, or pulling plants by hand. Any stem fragment with at least one pair of expanded leaves can grow into a new plant, and it is by this method that fanwort so quickly infests waterways. Evidence of its invasive nature can be seen in other countries where it has been introduced, although it is possible it could behave differently in the cooler climatic conditions of Canada. While fanwort can reproduce effectively through rapid growth and spread within connected waterways, stem fragmentation is a less effective means of dispersal between waterways.

Potential economic impacts are rated “HIGH”. The primary economic impacts of fanwort infestations would likely be losses of income or decreased property value when water use is affected in recreational and tourist areas. These could be significant if fanwort were to spread and infest lakes in Canada as it has in Australia and the U.S. In Ontario, for example, tourism is the third largest industry and accounts for billions of dollars of annual revenue. Of more significance from a plant health perspective are potential threats to wild rice production in Canada. Wild rice is sensitive to changes in light and resource availability, and could be outcompeted by fanwort if the two plants were to occur in the same water body. Fanwort also has the potential to affect aquaculture, navigation, power generation and other water uses, and large costs could be incurred in control programs. It should be noted that, while fanwort’s potential range may be limited to the more southern plant hardiness zones, it is in these areas that human population density and therefore water use is highest. That is, the parts of Canada where fanwort is certainly capable of becoming established are also the areas in which there is most potential for economic impact.

Potential environmental impact is rated “HIGH”. Fanwort is a serious environmental weed, and dense infestations can affect water levels, water quality, and nutrient regimes. Fanwort is capable of displacing other aquatic plants in natural water bodies, including native species, and this may also affect invertebrate, fish and wildlife populations. Sociological impacts are numerous and depend on the type of waterway infested. Fanwort stands in lakes can interfere with commercial and recreational uses, posing a danger to boaters and swimmers and reducing aesthetic and property values. Fanwort infestations in canals can affect irrigation and navigation, and in the U.S. and Australia, fanwort has also caused serious problems in potable water storages, decreasing water quality and increasing the costs of treatment. The various imperfect control methods available for use on fanwort also have associated ecological impacts and implications for water quality.

The overall risk associated with fanwort is calculated to be “MEDIUM”, which suggests that specific phytosanitary measures may be necessary. As a result of this assessment, it is recommended that fanwort be added to the list of aquatic weeds that are currently prohibited from Canada (*Elodea densa*, *Hydrilla verticillata*, *Myriophyllum* spp. and *Trapa* spp.). Initiation and/or support of an eradication program in Kaskabog Lake may also be appropriate. Early control of fanwort is important, as the longer infestations are left to establish and spread, the more difficult they are to eradicate. In general, the importance of public education and volunteer programs should also be recognized in the management of

aquatic plant invasions. Raising public awareness about invasive aquatic species could be an important element in reducing spread and the number of new infestations.

In view of the significant environmental impacts caused by fanwort, and its designation as an invasive species, as well as other implications for aquatic systems and water-based industries, it is recommended that other government departments should be made aware of this issue (such as, but not limited to: Environment Canada, Department of Fisheries and Oceans, Industry Canada, and provincial industry, tourism and natural resource departments). Collaboration on issues such as this could maximize resources and effectiveness, while minimizing duplication of efforts.

***Trapa natans* - Summary**

The purpose of this pest risk assessment (PRA) was to evaluate the plant health risk associated with the European water-chestnut (*Trapa natans* L.). The Plant Health Risk Assessment Unit of the Science Division, CFIA has prepared this PRA at the request of the Plant Health and Production Division, CFIA. This PRA will help the CFIA decide whether or not to continue to regulate the importation of European water-chestnut. A Weed Facts Sheet is included. Major points discussed in this document are summarized below:

Water-chestnut is a floating-leaved aquatic plant that is considered native to Europe, Asia, and Africa. It has a long history of being cultivated for its nuts, particularly in Asia where they are still an important food. Water-chestnut is listed as a strictly protected species in the Bern Convention (Council of Europe) due to the disappearance of populations from some parts of its native European range. By contrast, it is considered an invasive species in its introduced range in the north-eastern US, where its rapid growth creates dense stands that clog waterways and squeeze out other vegetation. It has been the subject of control and eradication programs in the US since the 1920s. It is currently reported from up to 11 north-eastern states.

For this risk assessment, the PRA area is considered to be all of Canada. Water-chestnut was recently identified in Rivière du Sud in south-western Québec, where it has survived winter conditions and continues to spread. This is the first reported occurrence of water-chestnut in Canada, and it also represents a northward expansion of the plant's range in North America.

Likelihood of introduction is rated "HIGH". Factors that are favourable for the introduction of water chestnut into Canada include: 1) The presence of water-chestnut infestations in the north-eastern US, 2) the number of watersheds that straddle the Canada-US border, 3) the constant movement of people and vehicles across the Canada-US border, and 4) the plant's ability to spread both within and between watersheds due to the natural expansion of existing populations, and the dispersal of seeds by way of water currents, birds, animals, and human activities. The presence of water-chestnut in Rivière du Sud confirms that at least one of these pathways is effective.

Establishment potential is rated “HIGH”. Water-chestnut is certainly capable of surviving and becoming established in Canada and based on its presence in Rivière du Sud its potential range includes at least plant hardiness zones 5 and 6. These zones cover the southern ‘arm’ of Ontario, and a small piece of south-western Québec, as well as all of Nova Scotia, southern Newfoundland, eastern New Brunswick and parts of BC. In total, this comprises less than one third of the PRA area (all of Canada) and earns a “LOW” risk rating. However, it is possible that water-chestnut could continue to spread northwards, and populations in north-eastern China and eastern Russia suggest that it may also be able to survive zones 1, 2, 3, and 4, and possibly 0b. This range covers a much larger portion of central and northern Canada, including all but the most extreme arctic areas.

Natural spread potential is rated “MEDIUM”. Water-chestnut behaves as a true annual in North America and overwinters by seed. At the beginning of each growing season, plants use clonal propagation to rapidly colonize new areas and cover the water surface with leafy rosettes. These rosettes produce large numbers of seeds that drop to the substrate and overwinter. A portion will germinate the following spring, and a portion will remain in the seed bank. It is estimated that a single plant can produce up to 300 seeds a year, and seeds can remain viable for up to 12 years. Seeds can be dispersed locally by water currents, or regionally by birds and animals. As illustrated by its behaviour in the US, water-chestnut has effective means of vegetative spread, seed reproduction, and both local and regional dispersal. Human activity is an additional factor not included in the risk rating, as seeds can “hitchhike” on boats and fishing gear.

Potential economic impacts are rated “HIGH”. The primary economic impacts of water-chestnut would likely be loss of income or decreased property value when water use is affected in recreational or tourist areas, and costs of control. These could be significant if water-chestnut were to spread and infest lakes in Canada as it has in the US. In Ontario, for example, tourism is the third largest industry and accounts for billions of dollars of annual revenue. Of more significance from a plant health perspective are potential threats to wild rice production in Canada. Two varieties of wild rice could be lost if water chestnut were to become established throughout the Richelieu River watershed, with long term implications for crop development and production. Water-chestnut also has the potential to affect aquaculture, navigation, power generation and other water uses. It should be noted that, even if water chestnut’s range in Canada were to be limited to plant hardiness zones 5 and 6, it is in these areas that population density and therefore water use is the highest. That is, the parts of Canada where water chestnut is certainly capable of becoming established are also the areas in which there is most potential for economic impact.

Potential environmental impact is rated “HIGH”. Water-chestnut is a serious environmental weed, and dense infestations can cause rapid sedimentation and water pollution. It is a highly competitive plant, and tends to shade out and displace other aquatic plants in natural water bodies, including native species. The effects of this on invertebrate, fish and wildlife population require further study, but a reduction in plant biodiversity in an aquatic system will certainly have impacts throughout the food chain. Sociological impacts are numerous and depend on the type of waterway infested. Water-chestnut stands in lakes can interfere with commercial and recreational uses, posing a danger to boaters and

swimmers and reducing aesthetic and property value. Infestations in rivers and canals can affect navigation, and water-chestnut can also cause pollution problems in reservoirs and other sources of drinking water. The various imperfect control methods available also have associated ecological implications.

The overall risk associated with water-chestnut is calculated to be “HIGH”, which indicates that specific phytosanitary measures are strongly recommended. As a result of this assessment, it is recommended that water-chestnut remain on the list of aquatic weeds that are currently prohibited from Canada. Support of the control program currently underway in Rivière du Sud may also be appropriate. Early control of water-chestnut is important, as the longer infestations are left to establish and spread, the more difficult they are to eradicate. In general, the importance of public education and volunteer programs should also be recognized in the management of aquatic plant invasions. Raising public awareness about invasive aquatic species could be an important element in reducing spread and the number of new infestations. Water-chestnut in the US provides examples of volunteers working successfully to remove plants and control infestations in recreational areas.

In view of the significant environmental impacts caused by water-chestnut, and its designation as an invasive species, as well as other implications for aquatic systems and water-based industries, it is recommended that other government departments should be made aware of this issue (such as, but not limited to: Environment Canada, Department of Fisheries and Oceans, Industry Canada, and provincial industry, tourism and natural resource departments). Collaboration on issues such as this could maximize resources and effectiveness, while minimizing duplication of efforts.

***Nymphoides peltata* - Summary**

The purpose of this weed risk assessment (WRA) was to evaluate the plant health risk associated with *Nymphoides peltata* (S. G. Gmel.) Kuntze (yellow floating heart). The Plant Health Risk Assessment Unit of the Science Advice Division, CFIA has prepared this WRA at the request of the Environment and Biodiversity Science Section of Fisheries and Oceans Canada. This WRA will help risk managers develop an appropriate action plan regarding yellow floating heart. A weed fact sheet is included.

Yellow floating heart is a rooted aquatic perennial herb of the buckbean family (Menyanthaceae), native to Eurasia and currently present in North America in several U.S. states, including in New England, where it is considered invasive. A population has been present in Canada, in the two ponds of Brown's Inlet, Ottawa, ON, for some years. High densities of the plant have recently prompted concern from the local residents and from Parks Canada, and some control efforts have been attempted. New reports of populations in Nova Scotia and Newfoundland have also raised concern that the species may be spreading.

Probability of entry is rated “HIGH” as the most likely pathway for introduction into Canada is the intentional importation of plants for planting. Yellow floating heart is an attractive ornamental plant that is commonly sold for planting in aquaria and water gardens. It can be

imported and sold in Canada without restrictions, and is already known to have naturalized outside of cultivation at one site in NF and several sites in NS, ON, QC and BC. All sites are thought to be the result of escape from deliberate plantings or aquarium dumping.

Probability of establishment is rated “HIGH”. Yellow floating heart grows in still or slow moving water in rivers, lakes, reservoirs, ditches, ponds and swamps, primarily in eutrophic, alkaline backwaters 1-2 m deep. It is already known to be established at a number of sites in Canada. Based on the distribution of these sites, it is able to survive in at least plant hardiness zones 8-4. In Europe, the northern climatic limit of the species is roughly delineated by the 16°C July isotherm. In Canada, this suggests an area that includes a larger portion of the country, up to and including plant hardiness zone 1.

Probability of spread is rated “MEDIUM”. Yellow floating heart can reproduce both vegetatively and by seed. Natural dispersal is primarily by water currents. Flowers are distylous, and there are indications of a weak incompatibility system limiting self and intra-morph fertilization. In North America, only one flower morph is known to be present, and it is speculated that reproduction here is largely vegetative. Large numbers of seeds are produced but survivorship of seedlings is unknown. Overall, natural spread in North America to date has been relatively slow. Introduction of the other flower morph in conditions that allow cross-pollination could change this. Currently in North America, deliberate movements by humans together with escape from cultivation are the most important factors in the long-distance dispersal of yellow floating heart.

Potential economic consequences are rated “MEDIUM”. Yellow floating heart does not have direct economic effects on agriculture or forestry, but does have the potential to cause significant economic losses to water-based industries such as tourism (by impeding the recreational use of water bodies), aquaculture, and power generation. Costs of controlling yellow floating heart are likely to be locally significant, particularly where a combination of methods needs to be applied, and/or where infestations require repeated treatment over time. Once established, aquatic weeds are notoriously difficult to control.

Potential environmental and social consequences are rated “HIGH”. Yellow floating heart can grow rapidly and form dense populations in water bodies, with a continuous surface canopy of leaves that reduce water flow and light penetration, lower oxygen levels, and alter nutrient cycling. Yellow floating heart can also compete with and exclude native aquatic vegetation, reducing biodiversity, altering water quality and affecting faunal communities. Potential indirect effects include the environmental impacts of associated control measures (manual, mechanical, chemical) as well as the social impacts on tourism and recreation, property values, and water-based industries such as aquaculture, discussed above.

Overall, there is relatively little uncertainty involved in assessing the risk of yellow floating heart. The probability of entry and establishment in Canada is known, as the plant is sold through the aquatic plant nursery trade and has already been introduced and occurs in several locations. There is some uncertainty about the exact extent of its potential range, but in any case it is known to survive in five provinces, and several plant hardiness zones.

Potential spread involves a bit more uncertainty, as it is not known why spread has been relatively slow in North America to date. North American data on seed production, seedling viability, and relative contributions of sexual versus vegetative reproduction in expanding populations, would all be helpful. If spread is in fact being limited by the presence of only one flower morph, additional effort could be focused on excluding the other flower morph from Canada. Field research on existing populations in Canada would be helpful in answering some of these questions.

A greater degree of uncertainty exists in predicting the consequences of yellow floating heart introduction, as they are not described or quantified in any detail in the literature. Economic consequences can be predicted based on information from other, similar aquatic plant infestations, and their magnitude will depend on the particular water bodies and industries affected, and the extent of control efforts applied. Likewise, environmental consequences can be easily predicted in a general sense (e.g., will affect water quality, will exclude native species), but are not described in any detail (e.g., how will it affect water quality, what species will be excluded). These too, will vary from site to site and will depend largely on where the plant becomes established. Overall, it is fairly certain that the impacts will occur, but less certain exactly how they might manifest themselves in Canada.

The overall risk associated with yellow floating heart is calculated to be “HIGH”, which suggests that specific phytosanitary measures may be necessary. As a result of this assessment, it is recommended that the importation and sale of yellow floating heart in Canada be prohibited. Initiation and/or support of eradication programs for the small number of known sites may also be appropriate. Early control of yellow floating heart is important, as the longer the infestations are left to establish and spread, the more difficult they will be to eradicate. In general, the importance of public education and volunteer programs should also be recognized in the management of aquatic plant invasions. Raising public awareness about invasive aquatic species could be an important element in reducing spread and the number of new infestations.

Appendix 6: Questionnaire for aquarium and water garden stores survey

SURVEY OF AQUARIUM AND WATER GARDEN STORES

ONLY FOR AQUATIC PLANT USERS

Disclaimer: The survey of aquarium and water garden stores is being conducted by Shakira Azan (shakira.azan@ryerson.ca), a graduate student of Ryerson University in partial fulfilment of the Master of Applied Science degree in Environmental Applied Science and Management. The survey serves to gather information on the purchase, use and disposal of aquatic plants sold by the aquarium and water garden industries within the Greater Toronto Area (GTA). The data gathered will provide information on the possibility of introduction of aquatic plants into the natural environment based on the sales and disposal practices used by participants.

Kindly note that participation in the survey is voluntary and respondents can choose to opt out of a question without consequence. Responses provided by the participants will be held in strictest confidence and used only for research purposes. Moreover, any data collected will only be presented in aggregate; stored electronically and password protected for five years; and names or identifying information will not be used in any publications. Hard copy data will be stored in a locked cabinet on Ryerson premises.

As a sign of appreciation for completing the survey, a random draw for four \$50 gift cards from a participating store will be carried out. If you wish to take part in the aforementioned, please contact Shakira Azan, shakira.azan@ryerson.ca and provide your name, either your telephone number or email address, and the name of the participating store. The information provided will only be used to contact you and to verify your identity in the event that you are a winner of a gift certificate.

If you have any queries regarding your participation in this survey, kindly contact Shakira Azan, shakira.azan@ryerson.ca. However, if you have a concern regarding the conduct of the study, please contact the Ryerson University Research Ethics Board c/o Office of the Vice President, Research and Innovation; 350 Victoria Street, Toronto, Ontario, M5B 2K3 or by telephone 416-979-5042.

Please indicate with a tick (✓) your answer(s).

1. Do you buy or use aquatic plants?

If your response to this question is 'No', please do not continue with the questionnaire.

☐ Yes

☐ No

2. What is/are the **main source(s)** of the aquatic plants you obtained within the last year?

- ☐ Pet/aquarium store
- ☐ Water garden/garden store/nursery
- ☐ From the wild
- ☐ Internet/mail order
- ☐ Trade show
- ☐ From a friend, family, neighbour
- ☐ Other (please specify) _____

3. For what purpose do you obtain aquatic plants? *Choose all that apply.*

- ☐ Indoor aquarium
- ☐ Outdoor water garden
- ☐ Other (please specify) _____

4. How many of each type of aquatic plants did you obtain within the last year? *Choose all that apply.*

	0 – 5	6 – 10	11 – 15	More than 16
a. Floating	☐	☐	☐	☐
b. Submerged	☐	☐	☐	☐
c. Emergent	☐	☐	☐	☐

Other (please specify) _____

5. How many aquatic plants did you dispose of (alive or dead) within the last year?

- ☐ 0 - 5
- ☐ 6 - 10
- ☐ 11 – 15
- ☐ More than 16

6. How did you dispose of your aquatic plants when they died or you no longer wanted them? *Choose all that apply.*

	Floating	Submerged	Emergent
a. Garbage/compost	☐	☐	☐
b. Discard into the wild	☐	☐	☐
c. Give to a friend, family, or neighbour	☐	☐	☐
d. Flush down the toilet	☐	☐	☐

Other (please specify) _____

7. Please list the names and quantities of the plants you purchased or obtained within the last 6 months? *Common and scientific names acceptable.*

THANK YOU FOR YOUR PARTICIPATION

**“PLEASE REMOVE THIS PAGE IF YOU ARE
PARTICIPATING IN THE RANDOM DRAW. OTHERWISE
LEAVE BLANK’.**

***“IF YOU WISH TO PARTICIPATE IN THE DRAW, PLEASE CONTACT SHAKIRA
AZAN (shakira.azan@ryerson.ca) BY FEBRUARY 14, 2011. TYPE ‘RANDOM
DRAW’ IN THE SUBJECT AREA, AND PROVIDE THE FOLLOWING
INFORMATION.***

First Name: _____

Telephone No.: _____ **OR** **Email:** _____

Name of the store where you purchased goods & filled out the questionnaire: _____

Appendix 7: Coding of categorical variables used in logistic regression analysis

Species trait	Category	Category Number
Life cycle	annual	1
	perennial	2
	either perennial or annual	3
	perennial or biannual	4
	perennial, annual, or biannual	5
	perennial, biennial, or annual	6
Growth form	submerged	1
	floating	2
	emergent	3
	floating, emergent	4
	amphibious (submerged, emergent)	5
	submerged, floating	6
	submerged, floating, emergent	7
	epiphyte	8
# of seeds	1 – 20 seeds	1
	21 – 40 seeds	2
	41 – 60 seeds	3
	61 – 80 seeds	4
	81 – 100 seeds	5
	>101 seeds	6
Type of dispersal mechanisms	humans	1
	humans, water	2
	humans, animals	3
	humans, wind	4
	humans, water, animals	5
	humans, water, wind	6
	humans, animal, wind	7
	humans, water, animals, wind	8
Growth rate	slow	1
	moderate	2
	fast	3
Fruit type	berry, syncarp	1
	capsule	2
	achene	3
	schizocarp	4
	follicle, loment, pod, silicle	5
	utricle	6
	caryopsis	7
	cypselae	8

Species trait	Category	Category Number
Fruit type cont'd	sporocarp, cone, sori	9
Time to flower	winter to spring	1
	spring	2
	spring to summer	3
	summer	4
	summer to autumn	5
	autumn	6
	autumn to winter	7
	winter	8
	year round flowering	9
Temperature range	small (1 – 3 divisions)	1
	medium (4 – 6 divisions)	2
	broad (>7 divisions)	3
Light	low	1
	medium	2
	high	3
	very high	4
	broad range	5
Salinity	none/low tolerance	1
	moderate tolerance	2
	tolerant	3
pH	strongly acidic (pH 1 – 3)	1
	moderately acidic (pH 4 – 6)	2
	neutral (pH 7)	3
	moderately alkaline (pH 8 – 10)	4
	strongly alkaline (pH 11 – 14)	5
pH tolerance	narrow range (1 or < divisions)	1
	mid range (2 divisions)	2
	high range (>3 divisions)	3
Nutrient content	low nutrients	1
	medium nutrients	2
	high nutrients	3
	broad range of nutrients	4
Breeding system	monoecious	1
	dioecious	2
Grouping of aquatic plants	native and non-invasive	1
	native and invasive	2
	alien and non-invasive	3
	alien and invasive	4

Appendix 8: List of taxa sold by aquarium and ornamental pond stores in the GTA

SCIENTIFIC NAME	COMMON NAME
<i>Achillea ptarmica</i>	Sneezewort, Sneezeweed
<i>Acorus americanus</i>	Sweet flag
<i>Acorus calamus</i> 'Variegata'	Variegated sweet flag
<i>Acorus gramineus</i>	Japanese sweet flag, Green and white acorus
<i>Acorus gramineus</i> 'Minimus Aureus'	Dwarf golden Japanese sweet flag
<i>Acorus gramineus</i> 'Oborozuki'	Golden sweet flag
<i>Acorus gramineus</i> 'Ogon'	Golden Japanese sweet flag
<i>Acorus gramineus</i> 'Variegatus'	Variegated Japanese sweet flag
<i>Aeschynomene fluitans</i>	Floating sensitive plant
<i>Agapanthus africanus</i>	African lily, Lily of the Nile
<i>Agapanthus praecox</i> subsp. <i>orientalis</i> 'Storm Cloud'	Storm cloud agapanthus
<i>Alisma plantago aquatica</i>	Water baby's breath, Water plantain, American water plantain
<i>Althernanthera bettzickiana</i> 'Red'	Parrot leaf
<i>Alternanthera cardinalis</i>	
<i>Alternanthera ficoidea</i>	Cherry hedge, Green hedge, Joseph's coat
<i>Alternanthera reineckii</i> 'Lilacina'	
<i>Alternanthera reineckii</i>	Amazon temple plant, Red hygrophila, Copperleaf, Scarlet Temple, Telanthera, Scarlet hygro, Water amaranth
<i>Alternanthera reineckii</i> 'Pink'/'Rosaefolia'	
<i>Alternanthera sessilis</i>	Scarlet hygro, Beetroot hygro, Sessile joy weed
<i>Ammannia senegalensis</i>	Red ammannia
<i>Ammannia</i> sp. 'Bonsai'	
<i>Andromeda polifolia</i>	Bog rosemary
<i>Anemopsis californica</i>	Yerba mansa
<i>Anubias afzelii</i>	
<i>Anubias barteri</i>	Giant anubias, Broadleaf Anubias
<i>Anubias barteri</i> var. <i>angustifolia</i>	
<i>Anubias barteri</i> var. <i>barteri</i>	
<i>Anubias barteri</i> 'Broad Leaf'	
<i>Anubias barteri</i> var. <i>caladiifolia</i>	
<i>Anubias barteri</i> var. <i>coffeefolia</i>	
<i>Anubias congensis</i>	Congo anubias
<i>Anubias</i> 'Frazeri'	
<i>Anubias gigantean</i>	
<i>Anubias gracilis</i>	Dwarf arrowhead anubias
<i>Anubias hastifolia</i>	

SCIENTIFIC NAME	COMMON NAME
<i>Anubias heterophylla</i>	
<i>Anubias lanceolata</i>	Lance anubias
<i>Anubias minima</i>	
<i>Anubias nana</i> (syn. <i>Anubias barteri</i> var. <i>nana</i>)	Dwarf anubias
<i>Anubias nana</i> 'Petite'	
<i>Aponogeton boivinianus</i>	
<i>Aponogeton capuronii</i>	
<i>Aponogeton crispus</i>	Crinkled aponogeton, Ruffled aponogeton
<i>Aponogeton distachyos</i>	Water hawthorn, Cape pondweed
<i>Aponogeton longiplumulosus</i>	
<i>Aponogeton madagascariensis</i>	Madagascar lace plant, Lace leaf
<i>Aponogeton natans</i>	Natans, Australian pondweed
<i>Aponogeton rigidifolius</i>	Rigidifolius
<i>Aponogeton ulvaceus</i>	Compact aponogeton, Ulvaceus, Madagascar water lettuce
<i>Aponogeton undulatus</i>	
<i>Arundo donax</i> 'Variegata'	
<i>Arundo donax</i> 'Peppermint Stick'	Arundo peppermint stick
<i>Asclepias incarnata</i>	Swamp milkweed
<i>Aster puniceus</i>	Swamp aster, Swamp/Purple-stem aster
<i>Azolla caroliniana</i>	Water velvet, Water fern, Fairy moss
<i>Azolla filiculoides</i>	Azolla, Moss fern, Fairy moss, Water fern
<i>Bacopa amplexicaullis</i>	Water hyssop
<i>Bacopa australis</i>	
<i>Bacopa caroliniana</i>	Giant bacopa, Bacopa, Lemon bacopa
<i>Bacopa lanigera</i>	
<i>Bacopa monnieri</i>	Dwarf bacopa, Baby tears, Moneywort
<i>Bacopa myriophylloides</i>	
<i>Bacopa rotundifolia</i>	Round bacopa
<i>Barclaya longifolia</i>	Orchid lily
<i>Barclaya longifolia</i> 'Red Form'	
<i>Bletilla striata</i>	Hardy orchid, Chinese ground orchid
<i>Blyxa aubertii</i>	
<i>Blyxa japonica</i>	Japanese rush
<i>Bolbitis heteroclita</i>	Philippine fern
<i>Bolbitis heudelotii</i>	African fern, Congo fern, Bolbitis, Water fern
<i>Butomus umbellatus</i>	Flowering rush
<i>Cabomba aquatica</i>	Yellow cabomba, Giant cabomba
<i>Cabomba asiatica</i>	Yellow cabomba
<i>Cabomba caroliniana</i>	Green cabomba, Fanwort
<i>Cabomba piauihyensis</i> (syn. <i>Cabomba furcata</i>)	Red cabomba

SCIENTIFIC NAME	COMMON NAME
<i>Cabomba palaeformis</i>	Red-brown cabomba
<i>Cabomba pulcherrima</i>	Purple cabomba
<i>Calladium</i> sp.	Calladium
<i>Calla palustris</i>	Arrow, Bog arum
<i>Caltha palustris</i>	Marsh marigold
<i>Caltha palustris</i> 'Flore Pleno'	Double flower marsh marigold
<i>Canna australis</i>	Red leaf canna
<i>Canna</i> 'African Sunset'	African sunset canna
<i>Canna</i> 'Black Knight'	Black knight canna
<i>Canna</i> 'Chocolate Cherry'	Chocolate cherry canna
<i>Canna</i> 'Cleopatra'	Cleopatra canna
<i>Canna</i> 'Emerald Sunset'	Emerald sunset canna
<i>Canna</i> 'Flaccida'	
<i>Canna</i> 'Florence Vaughan'	Florence Vaughan canna
<i>Canna</i> 'Intrigue'	
<i>Canna</i> 'Paton'	
<i>Canna</i> x <i>generalis</i> 'Pretoria' (<i>Canna pretoria</i> 'Variegatus')	Bengal tiger canna
<i>Canna</i> x <i>generalis</i> 'Australia'	Australia canna
<i>Canna glauca</i> 'Erebus' (Peach)	Erebus canna
<i>Canna glauca</i> hybrid	Longwood 'Endeavour'
<i>Canna</i> 'Milk festival'	Milk festival canna
<i>Canna</i> 'Pink Sunburst'	Pink sunburst canna
<i>Canna</i> 'Pritzer's Chinese Coral'	Chinese coral canna
<i>Canna</i> 'Ra'	
<i>Canna</i> x 'Stuttgart'	Stuttgart canna
<i>Cardamine lyrata</i>	Chinese ivy, Japanese cress, Cardamine
<i>Carex albula</i> (syn. <i>Carex comans</i>)	Carex frosted curls
<i>Carex buchananii</i>	Leather leaf sedge
<i>Carex crinita</i>	Fringed sedge
<i>Carex dolichostachya</i> 'Gold Fountain'	
<i>Carex elata</i> 'Aurea'	Bowles' golden sedge
<i>Carex glauca</i> (syn. <i>Carex flacca</i>)	Flacca blue sedge, Heath sedge
<i>Carex grayi</i>	Gray's sedge
<i>Carex muskingumensis</i> 'Ice Fountains'	
<i>Carex muskingumensis</i> 'Oehme'	
<i>Carex morrowii</i> 'Goldband'	
<i>Carex phyllocephala</i> 'Sparkler'	
<i>Carex retrorsa</i>	Knotsheath sedge, Backward sedge, Retorse sedge
<i>Ceratophyllum demersum</i>	Hornwort, Common hornwort
<i>Ceratopteris pteroides</i> (syn. <i>Ceratopteris cornuta</i>)	Floating fern, Floating water sprite, Water fern

SCIENTIFIC NAME	COMMON NAME
<i>Ceratopteris siliquosa</i>	Indian fern
<i>Ceratopteris thalictroides</i>	Water sprite, Indian fern, Water horn fern, Floating antler fern
<i>Cladophora aegropila</i>	Marimo moss ball
<i>Chlorophytum bichetii</i>	Pongol sword
<i>Colocasia antiquorum</i> 'Illustris'	Imperial taro
<i>Colocasia calamistratum</i>	
<i>Colocasia esculenta</i>	Green taro, Rhubarb taro
<i>Colocasia esculenta</i> 'Black Magic'	Black Magic taro
<i>Colocasia esculenta</i> 'Black Marble'	Black Marble taro
<i>Colocasia esculenta</i> 'Elena'	Elena taro
<i>Colocasia esculenta</i> 'Fontanesa'	Red stem taro, Violet stem taro
<i>Colocasia esculenta</i> 'Hilo Beauty'	
<i>Colocasia esculenta</i> 'Mojito'	Mojito taro
<i>Colocasia esculenta</i> 'Rhubarb'	Rhubarb taro
<i>Colocasia multiflora</i>	Black marble taro
<i>Colocasia</i> spp.	Red stem taro
<i>Cordyline</i> 'Red Edge'	
<i>Cotula coronopifolia</i>	Golden buttons, Brass buttons
<i>Crassula helmsii</i>	
<i>Crinum calamistratum</i>	
<i>Crinum menhune</i>	Red bog lily
<i>Crinum natans</i>	African onion plant, African spider lily
<i>Crinum thaianum</i>	Onion plant, Asiatica spider lily
<i>Cryptocoryne albida</i>	
<i>Cryptocoryne affinis</i>	
<i>Cryptocoryne balansae</i>	Crypt
<i>Cryptocoryne beckettii</i>	Beckett's cryptocoryne
<i>Cryptocoryne beckettii</i> 'Petchii'	
<i>Cryptocoryne blassii</i>	
<i>Cryptocoryne ciliata</i>	Crypt ciliata
<i>Cryptocoryne cordata</i>	Giant cryptocoryne
<i>Cryptocoryne griffithii</i>	
<i>Cryptocoryne lingua</i>	
<i>Cryptocoryne lucens</i>	
<i>Cryptocoryne lutea</i>	
<i>Cryptocoryne parva</i>	Tiny cryptocoryne
<i>Cryptocoryne petchii</i>	
<i>Cryptocoryne pontederiifolia</i>	Sarawak crypt
<i>Cryptocoryne pygmaea</i>	
<i>Cryptocoryne retrospiralis</i>	
<i>Cryptocoryne spiralis</i> (syn. <i>Arum spirale</i>)	Corkscrew crypto
<i>Cryptocoryne tonkinensis</i>	

SCIENTIFIC NAME	COMMON NAME
<i>Cryptocoryne undulata</i>	Undulate cryptocoryne
<i>Cryptocoryne wendtii</i>	Tiny crypto, Cryptocoryne wendtii, Wendt's water trumpet
<i>Cryptocoryne wendtii</i> 'Red'	Red wendtii
<i>Cryptocoryne wendtii</i> 'Brown'	Brown crypt
<i>Cryptocoryne wendtii</i> 'Mi Oya'	
<i>Cryptocoryne wendtii</i> 'Green'	Green wendtii
<i>Cryptocoryne wendtii</i> 'Green x Tall'	
<i>Cryptocoryne wendtii</i> 'Green Gecko'	
<i>Cryptocoryne wendtii</i> 'Bronze'	Bronze wendtii
<i>Cryptocoryne wendtii</i> 'Tropica'	
<i>Cryptocoryne willisii</i>	
<i>Cyperus albostratus</i> 'Starburst'	Variegated umbrella palm
<i>Cyperus albostratus</i> 'Variegatus'	
<i>Cyperus alternifolius</i> (syn. <i>Cyperus involucratus</i>)	Umbrella palm, Umbrella plant, Umbrella flat sedge
<i>Cyperus alternifolius nanus</i> 'Gracilis'	Dwarf umbrella palm
<i>Cyperus haspens</i>	Dwarf papyrus
<i>Cyperus helferi</i>	
<i>Cyperus longus</i>	Sweet galingale
<i>Cyperus papyrus</i>	Papyrus
<i>Cyperus papyrus</i> 'Dwarf'	Dwarf Egyptian papyrus
<i>Cyperus papyrus</i> 'Percamenthus'	Little giant papyrus
<i>Cyperus percamenthus</i>	Dwarf giant papyrus
<i>Cyperus percamenthus</i> 'Little Giant'	Little giant papyrus
<i>Dichromena colorata</i> (syn. <i>Rhynchospora colorata</i>)	Star grass, Star rush white top
<i>Didiplis diandra</i> (syn. <i>Peplis diandra</i>)	Water hedge, Blood star grass, Water purslane
<i>Dracaena fragrans</i>	Fragrant dracaena
<i>Dracaena fragrans</i> 'Compacta'	Pineapple plant
<i>Dracaena sanderiana</i>	Lucky bamboo (straight & curled), White ribbon plant, Ribbon plant
<i>Dracaena</i> 'Variegatus'	Gold ribbon plant
<i>Drosera intermedia</i>	Sundew, Spoon leaf sundew
<i>Drosera linearis</i>	Slender leaf sundew
<i>Drosera rotundifolia</i>	Round leaf sundew
<i>Dulichium arundinaceum</i>	Water bamboo, Three way sedge
<i>Echinodorus amazonicus</i>	Amazon sword plant
<i>Echinodorus angustifolia</i>	
<i>Echinodorus argentinensis</i>	Argentine sword
<i>Echinodorus barthii</i>	Red melon sword
<i>Echinodorus bleheri</i>	Broadleaved Amazon sword or sword plant,

SCIENTIFIC NAME	COMMON NAME
	Giant Mother Plant/Pot
<i>Echinodorus cordifolius</i> (syn. <i>Echinodorus radicans</i>)	Radicans sword plant, Long leaf amazon sword, Burr-head, Creeping burr-head
<i>Echinodorus cordifolius</i> 'Marble Queen'	Marble Queen radican sword
<i>Echinodorus cordifolius</i> 'Rubin'	
<i>Echinodorus gabrielli</i>	
<i>Echinodorus grisebachii</i>	
<i>Echinodorus grandiflorus</i> 'Micheli'	Ruffled Amazon sword
<i>Echinodorus latifolius</i>	
<i>Echinodorus major</i>	Ruffled Amazon sword plant, Ruffle sword
<i>Echinodorus muricatus</i>	Americana sword
<i>Echinodorus martii</i>	Ruffle sword, Waving leaf sword
<i>Echinodorus osiris</i>	Red Amazon sword plant, Melon sword
<i>Echinodorus</i> 'Ozelot Green'	Ozelot melon sword
<i>Echinodorus palaefolius</i>	
<i>Echinodorus</i> par. 'Tropica'	
<i>Echinodorus paniculatus</i>	
<i>Echinodorus quadricostatus</i>	Broad-leaf chain sword
<i>Echinodorus quadricostatus</i> 'Magdalenensis'	
<i>Echinodorus</i> 'Aquatrica'	
<i>Echinodorus</i> 'Indian Red'	
<i>Echinodorus</i> 'Kleiner Bar'	
<i>Echinodorus</i> 'Oriental'	
<i>Echinodorus</i> 'Red Diamond'	
<i>Echinodorus</i> 'Red Flame'	
<i>Echinodorus</i> 'Red Special'	
<i>Echinodorus rigidifolius</i>	Rangeri sword, Radican sword
<i>Echinodorus</i> 'Rose'	
<i>Echinodorus</i> 'Rubin Narrow Leaf'	
<i>Echinodorus</i> sp. 'Long Leaf'	
<i>Echinodorus tenellus</i> (syn. <i>Helanthium tenellum</i>)	Pygmy chain sword plant, Narrow leaf chain sword, Mud babies
<i>Echinodorus uruguayensis</i>	Uruguay Amazon sword plant, Uruguayan sword
<i>Egeria densa</i> (syn. <i>Elodea densa</i>)	Elodea, Pondweed, Anacharis, Common waterweed, Brazilian elodea, Water thyme, Brazilian waterweed, South American waterweed
<i>Egeria najas</i> (syn. <i>Elodea najas</i>)	Narrow-leaved Elodea
<i>Eichhornia azurea</i>	Blue water hyacinth, Anchored water hyacinth, Rooted water hyacinth
<i>Eichhornia crassipes</i>	Water hyacinth, Common water hyacinth,

SCIENTIFIC NAME	COMMON NAME
	Floating water hyacinth
<i>Eichhornia diversifolia</i>	Variable leaf water hyacinth
<i>Eleocharis acicularis</i>	Hair grass, Dwarf hair grass, Needle spike rush, Needle spike hedge
<i>Eleocharis montevidensis</i>	Needle rush, Sand spike rush
<i>Eleocharis parvula</i>	Dwarf hair grass, Dwarf spike rush, Dwarf spike sedge, Little head spike rush
<i>Eleocharis vivipara</i>	Umbrella grass, Fine hair grass, Viviparous spike rush
<i>Elodea canadensis</i>	Canadian pondweed, Pondweed, Water thyme, Canada waterweed, Canadian waterweed, Broad waterweed
<i>Equisetum hyemale</i>	Horsetail rush, Horsetail, Scouring rush, Scouring rush horsetail, Western scouring rush
<i>Equisetum hyemale</i> var. <i>robustum</i> (syn. <i>Equisetum hyemale</i> var. <i>affine</i>)	Giant horsetail
<i>Equisetum japonicum</i>	Horsetail
<i>Equisetum palustre</i>	Field horsetail, Marsh horsetail
<i>Equisetum scirpoides</i>	Dwarf horsetail, Dwarf scouring rush
<i>Equisetum telmateia</i>	Giant horsetail rush, Giant horsetail
<i>Eriocaulon cinereum</i>	Ashy pipewort
<i>Eriophorum angustifolium</i>	Cotton grass, Narrow leaf cotton sedge, Tall cotton grass
<i>Eupatorium purpureum</i> (syn. <i>Eutrochium purpureum</i>)	Mist flower or Joe-pye-weed, Sweet scented joe-pye-weed
<i>Fontinalis antipyretica</i>	Willow moss, Anti-fever fontinalis moss
<i>Geum rivale</i>	Water avens, Purple avens
<i>Glossostigma elatinoides</i>	Glossostigma, Glosso
<i>Glyceria maxima</i> 'Variegata'	Variegated manna grass
<i>Gunnera manicata</i>	Gunnera, Giant rhubarb
<i>Gymnocoronis spilanthoides</i>	Spade leaf plant, Water daisy
<i>Hemarthria uncinata</i>	Mat grass
<i>Hemianthus callitrichoides</i> (syn. <i>Micranthemum umbrosum</i>)	Helzine, Giant baby tears, Shade mud flower
<i>Hemianthus callitrichoides</i> 'Cuba'	
<i>Hemianthus micranthemoides</i> (syn. <i>Micranthemum micranthemoides</i>)	Pearl weed, Baby tears, Nuttall's mud flower
<i>Hemigraphis exotica</i>	Purple crinkle, Purple waffle
<i>Hemigraphis repanda</i>	Dragon flame
<i>Hesperantha coccinea</i>	Scarlet river lily
<i>Heteranthera zosterifolia</i>	Star grass
<i>Hibiscus acetosella</i>	Red-leaf hibiscus, African rose mallow

SCIENTIFIC NAME	COMMON NAME
<i>Hibiscus coccineus</i>	Water hibiscus, Red water hibiscus, Scarlet rose mallow
<i>Hibiscus moscheutos</i>	Rose mallow, Swamp rose mallow, Crimson eyed rose mallow
<i>Hibiscus moscheutos</i> 'Luna Red'	Dwarf aqua red
<i>Hibiscus moscheutos</i> 'Dwarf aqua pink'	
<i>Hippurus vulgaris</i>	Mare's tail
<i>Hottonia inflata</i> (syn. <i>Prosperpinaca pectinata</i>)	Featherfoil, American featherfoil
<i>Hottonia palustris</i>	Water violet
<i>Houttuynia cordata</i> 'Chameleon'	Chameleon plant, Chameleon houttuynia
<i>Houttuynia</i> 'Flora Plena'	Flora plena houttuynia
<i>Hydrilla verticillata</i>	
<i>Hydocharis morsus-ranae</i>	European frog-bit
<i>Hydrocleys nymphoides</i> (syn. <i>Limncharis humboldtii</i>)	Water poppy
<i>Hydrocotyle bonariensis</i>	Giant pennywort, Large leaf pennywort
<i>Hydrocotyle leucocephala</i>	Brazilian pennywort
<i>Hydrocotyle sibthorpioides</i>	Lawn marsh pennywort
<i>Hydrocotyle umbellata</i>	Pennywort, May flower marsh pennywort, Umbrella penny royal
<i>Hydrocotyle</i> 'Variegatum'	Variegated pennywort
<i>Hydrocotyle vulgaris</i>	Common pennywort, Marsh pennywort, Water pennywort
<i>Hydrotriche hottoniflora</i>	
<i>Hygrophila angustifolia</i>	Fine leaf hygro
<i>Hygrophila balsamica</i>	
<i>Hygrophila corymbosa</i>	Giant hygrophila, Blue hygro, Star horn
<i>Hygrophila corymbosa</i> 'Stricta'	
<i>Hygrophila corymbosa</i> 'Siamensis'	
<i>Hygrophila corymbosa</i> 'Kompakt/Compact'	
<i>Hygrophila costata</i>	Sword leaf stricta
<i>Hygrophila difformis</i> (syn. <i>Synnema triflorum</i>)	Water wisteria
<i>Hygrophila lacustris</i>	Gulf swamp weed
<i>Hygrophila polysperma</i>	Dwarf hygrophila, Green hygrophila, East Indian hygrophila, Indian swamp weed, Miramar weed
<i>Hygrophila polysperma</i> 'Broad Leaf'	
<i>Hygrophila polysperma</i> 'Rosanervig'	Sunset hygrophila
<i>Hygrophila poly</i> 'Rosa Nervis'	
<i>Hygrophila siamensis</i> 'Small Leaf'	

SCIENTIFIC NAME	COMMON NAME
<i>Hygrophila stricta</i> (syn. <i>Nomaphila stricta</i>)	Thai stricta, Green stricta, Giant hygrophila
<i>Hymenocallis lirisome</i>	Spider lily, Spring spider lily
<i>Hymenocallis lirisome</i> 'Variegata'	
<i>Impatiens capensis</i>	Spotted touch-me-not, Jewel weed
<i>Imperata cylindrica</i>	Japanese blood grass, Blady grass, Cogon grass
<i>Iris ensata</i> 'Lady in waiting'	Lady in waiting iris
<i>Iris kaempferi</i> (syn. <i>Iris ensata</i>)	Japanese iris, Russian iris
<i>Iris kaempferi</i> 'Variegata'	Variegated Japanese iris
<i>Iris ensata</i> 'Imperial Magic'	
<i>Iris ensata</i> 'Mount Fujiyama'	
<i>Iris ensata</i> 'Pink Lady'	
<i>Iris ensata</i> 'Royal Robes'	
<i>Iris ensata</i> 'Shogun'	
<i>Iris laevigata</i> 'Rose Queen'	Rose Queen Japanese iris
<i>Iris Louisiana</i> 'Ann Chowning'	
<i>Iris Louisiana</i> 'Black Gamecock'	Black Gamecock iris
<i>Iris Louisiana</i> 'Colorific'	Colorific Louisiana iris
<i>Iris Louisiana</i> 'Dixie Deb'	
<i>Iris Louisiana</i> 'Dural White Butterfly'	
<i>Iris Louisiana</i> 'Her highness'	Her highness iris
<i>Iris Louisiana</i> 'Jack Attack'	Jack attack iris
<i>Iris Louisiana</i> 'Peaches & Wine'	
<i>Iris Louisiana</i> 'Professor Claude'	
<i>Iris Louisiana</i> 'Sun Fury'	
<i>Iris Louisiana</i> 'Wow factor'	
<i>Iris pseudacorus</i>	Yellow flag iris, Yellow water iris, Pale yellow iris
<i>Iris pseudacorus</i> 'Flora Plena'	Double yellow flag iris
<i>Iris pseudacorus</i> 'Variegata'	Variegated yellow flag iris
<i>Iris sibirica</i> 'Dance Ballerina Dance'	Siberian iris
<i>Iris sibirica</i> 'Silver Edge'	Siberian iris
<i>Iris versicolor</i>	Blue flag iris, Blue water iris, Harlequin blue flag
<i>Iris virginica</i>	Southern blue flag iris, Virginia iris
<i>Isolepis cernua</i>	Fibre optic grass, Salt marsh bulrush, Low bulrush
<i>Juncus decipiens</i> 'Curly Wurly'	Curly wurly corkscrew
<i>Juncus effusus</i>	Soft rush, Common rush, Lamp rush
<i>Juncus effusus</i> 'Gold Strike'	Gold Strike rush
<i>Juncus effusus</i> 'Lemon Twist' + Frenzy	Striped Spiral Rush
<i>Juncus effusus</i> 'Spiralis'	Corkscrew rush, Spiral rush, Lesser

SCIENTIFIC NAME	COMMON NAME
	corkscrew rush
<i>Juncus effusus</i> 'Unicorn'	Unicorn corkscrew, Spiral rush
<i>Juncus effusus</i> 'Variegata'	Yellow line rush
<i>Juncus ensifolius</i> 'Flying Hedgehogs'	
<i>Juncus inflexus</i> 'Afro'	Blue medusa corkscrew, Blue medusa rush
<i>Juncus inflexus</i> 'Hard Rush'	
<i>Juncus glaucus</i>	Blue rush
<i>Juncus repens</i>	Lesser creeping rush
<i>Jussiaea diffusa</i> (syn. <i>Ludwigia peploides</i> ssp. <i>glabrescens</i>)	Primrose creeper, Floating primrose willow
<i>Jussiaea grandiflora</i> (syn. <i>Ludwigia uruguayensis</i>)	Large flowered primrose, Water primrose, Uruguay water primrose, Uruguayan primrose willow
<i>Lagarosiphon madagascarensis</i>	
<i>Lagarosiphon major</i>	African water weed. African elodea, Oxygen weed, South African oxygen weed
<i>Leucojum aestivum</i>	Snowflake, Loddon lily, Summer snowflake
<i>Lemna minor</i>	Duckweed, Common duckweed, Least duckweed, Lesser duckweed
<i>Lemna trisulca</i>	Ivy-leaf duckweed, Star duckweed
<i>Leptodictyum riparium</i>	Stringy moss, Streamside leptodictyum moss
<i>Lilaeopsis brasiliensis</i>	Micro sword, Grass plant
<i>Lilaeopsis mauritiana</i>	
<i>Lilaeopsis novae-zelandiae</i>	New Zealand grass plant
<i>Limnobium laevigatum</i>	Amazon frogbit, Frogbit
<i>Limnobium spongia</i>	American frogbit, American sponge plant, Frogbit
<i>Limnophila aquatica</i>	Giant ambulia
<i>Limnophila aromatica</i>	
<i>Limnophila hippuroides</i>	
<i>Limnophila indica</i> (syn. <i>Hottonia indica</i>)	Ambulia, Indian ambulia, Indian marsh weed
<i>Limnophila sessiliflora</i>	Dwarf ambulia Asian ambulia, Asian marsh weed, Ambulia
<i>Lobelia cardinalis</i>	Scarlet lobelia, Cardinal flower, Red lobelia
<i>Lobelia</i> 'Elm Fire'	
<i>Lobelia</i> 'La fresco'	La fresco lobelia
<i>Lobelia sessilifolia</i>	Blue lobelia
<i>Lobelia syphilitica</i>	Blue cardinal flower, Lobelia great blue, Great blue lobelia
<i>Lobelia syphilitica</i> 'Alba'	White cardinal flower
<i>Ludwigia arcuata</i>	Piedmont primrose yellow

SCIENTIFIC NAME	COMMON NAME
<i>Ludwigia brevipes</i>	Long beach primrose yellow
<i>Ludwigia glandulosa</i>	Glandular ludwigia, Red star ludwigia, Creeping seed-box, Cylindric fruit primrose willow
<i>Ludwigia inclinata</i>	
<i>Ludwigia inclinata</i> 'Green'	
<i>Ludwigia inclinata</i> var. <i>verticillata</i> 'Cuba'	
<i>Ludwigia mullertii</i>	Red ludwigia
<i>Ludwigia octovalvis</i>	Mexican primrose willow
<i>Ludwigia palustris</i>	Broadleaf ludwigia, Water primrose, Water purslane, Green ludwigia, Marsh primrose willow, Marsh seed-box
<i>Ludwigia peruensis</i>	Red star ludwigia
<i>Ludwigia repens</i> (<i>L. natans</i>)	Creeping ludwigia, Narrow-leaf ludwigia, Broad leaf ludwigia, Primrose creeper, Creeping primrose willow, Creeping water purslane
<i>Ludwigia sedioides</i>	
<i>Ludwigia</i> sp. 'Guinea'	
<i>Lycopodium obscurum</i>	Princess pine, Ground pine, Rare club moss, Tree club moss
<i>Lycoris radiata</i>	Red spider Lily
<i>Lysimachia congestiflora</i> 'Outback Sunset'	Dense flowered loosestrife
<i>Lysimachia nummularia</i>	Creeping Jenny, Lloydia, Moneywort
<i>Lysimachia nummularia</i> 'Aurea'	Golden moneywort, Golden creeping jenny
<i>Lysimachia punctata</i> 'Alexander'	Alexander loosestrife
<i>Lysimachia quadrifolia</i>	Whorled loosestrife, Whorled yellow loosestrife, Four flower yellow loosestrife
<i>Lysimachia terrestris</i>	Swamp candle, Earth loosestrife
<i>Marsilea angustifolia</i>	
<i>Marsilea crenata</i>	Clover fern
<i>Marsilea drummondii</i>	Four leaf water clover
<i>Marsilea hirsuta</i>	Rough water clover
<i>Marsilea quadrifolia</i>	Four leaf water clover, European water clover
<i>Marsilea schelpiana</i>	Cut leaf water clover
<i>Mayaca fluviatilis</i>	Mayaca, Stream bog moss
<i>Mayaca sellowiana</i>	
<i>Mentha aquatica</i>	Water mint, Water spearmint
<i>Menyanthes trifoliata</i>	Bog bean, Buck bean
<i>Microcarpaea minima</i>	
<i>Micromeria brownei</i>	Creeping Charlie, Aquatic mint, West Indian

SCIENTIFIC NAME	COMMON NAME
	thyme, Browne's savory
<i>Microsorium pteropus</i>	Java fern
<i>Microsorium pteropus</i> 'Thin Leaf'	
<i>Microsorium pteropus</i> 'Windelov'	Windelov fern
<i>Microsorium pteropus</i> var. 'Narrow'	
<i>Microsorium umbrosum</i>	
<i>Mimulus guttatus</i>	Monkey flower, Common monkey flower
<i>Mimulus luteus</i>	Water musk, Yellow monkey flower
<i>Mimulus ringens</i>	Lavender musk, Ringen monkey flower, Allegheny monkey flower
<i>Musa</i> 'Bajoo'	Japanese banana
<i>Musa</i> sp.	Dwarf banana tree
<i>Myosotis scorpioides</i> (syn. <i>Myosotis palustris</i>)	Water forget-me-not
<i>Myosotis scorpioides</i> 'Mermaid'	Mermaid forget-me-not
<i>Myosotis scorpioides</i> 'Variegata'	Variegated water forget-me-not
<i>Myriophyllum aquaticum</i> (syn. <i>Myriophyllum proserpinacoides</i> , <i>Myriophyllum brasiliense</i>)	Brazilian milfoil, Milfoil, Parrot feather, Parrot feather milfoil
<i>Myriophyllum matogrossense</i>	
<i>Myriophyllum papillosum</i> var. <i>pulcherrima</i>	Dwarf parrot feather
<i>Myriophyllum tuberculatum</i>	Red myriophyllum, Red milfoil
<i>Myriophyllum tuberculatum</i> 'Red'	
<i>Najas indica</i>	
<i>Nasturtium officinale</i> (syn. <i>Rorippa nasturtium aquaticum</i>)	Watercress
<i>Nelumbo</i> 'Alba Striata' Empress	Empress
<i>Nelumbo</i> 'Asiatic'	
<i>Nelumbo</i> 'Chawan Basu' (ivory/pink)	
<i>Nelumbo</i> 'Giant Sunburst'	
<i>Nelumbo</i> 'Momo Botan'	
<i>Nelumbo lutea</i> 'Rosea Plena'	Mrs. Perry D. Slocum
<i>Nelumbo</i> 'Perry's Giant Sunburst'	
<i>Nelumbo</i> 'Rosea Plena' (double rose pink)	
<i>Nelumbo</i> 'Roseum Plenum'	
<i>Nelumbo</i> 'Sacred Pink'	
<i>Nelumbo nucifera</i>	Sacred pink, sacred lotus
<i>Nelumbo nucifera</i> var. <i>capsicum</i>	Russian lotus
<i>Nesaea crassicaulis</i>	
<i>Nesaea pedicellata</i>	
<i>Nesaea pedicellata</i> 'Gold'	Nesaea golden

SCIENTIFIC NAME	COMMON NAME
<i>Nesaea</i> sp. 'Red'	
<i>Nomaphila augustifolia</i>	
<i>Nomaphila capri</i>	Blood stricta
<i>Nomaphila siamensis</i>	Special blue stricta
<i>Nomaphila siamensis</i> 'Mini'	
<i>Nomaphila stricta</i>	Giant hygro, Temple plant
<i>Nuphar lutea</i>	Yellow pond lily, Spatterdock, Yellow cow lily
<i>Nuphar stellata</i>	Red dwarf lily, Dwarf lily
<i>Nymphaea</i> 'Albert Greenburg'	
<i>Nymphaea</i> 'Almost Black'	Black princess
<i>Nymphaea</i> 'American Star'	
<i>Nymphaea</i> 'Arc En Ciel'	
<i>Nymphaea</i> 'Attraction'	Attraction water lily
<i>Nymphaea</i> 'August Koch'	
<i>Nymphaea</i> 'Aurora'	
<i>Nymphaea</i> 'Berit Strawn'	
<i>Nymphaea</i> 'Black Princess'	
<i>Nymphaea</i> 'Blue Beauty'	
<i>Nymphaea</i> 'Blue Triumph'	
<i>Nymphaea</i> 'Burgundy Princess'	
<i>Nymphaea</i> 'Charlene Strawn'	
<i>Nymphaea</i> 'Charles De Meurville'	
<i>Nymphaea</i> 'Chromatella'	
<i>Nymphaea</i> 'Colorado'	
<i>Nymphaea</i> 'Comanche'	
<i>Nymphaea</i> 'Crystal'	
<i>Nymphaea</i> 'Daubeniana'	
<i>Nymphaea</i> 'Denver'	
<i>Nymphaea</i> 'Director Moore'	
<i>Nymphaea</i> 'Escarboule'	
<i>Nymphaea</i> 'Evelyn Randig'	
<i>Nymphaea</i> 'Fireopal'	
<i>Nymphaea</i> 'Firecrest'	
<i>Nymphaea</i> 'Mrs. G. C. Hitchcock'	
<i>Nymphaea</i> 'Georgia Peach'	Georgia Peach water lily
<i>Nymphaea</i> 'Gladstone'	Gladstone lily
<i>Nymphaea</i> 'Glorie du temple-sur-Lot'	
<i>Nymphaea</i> 'Green'	
<i>Nymphaea</i> 'Gonnere'	
<i>Nymphaea</i> 'Hollandia'	
<i>Nymphaea</i> 'James Bryden'	
<i>Nymphaea</i> 'Joanne Pring'	

SCIENTIFIC NAME	COMMON NAME
<i>Nymphaea</i> 'Joey Tomocik'	Joey Tomocik water lily
<i>Nymphaea</i> 'Laydekeri fulgens'	
<i>Nymphaea</i> 'Laydekeri purpurat'	
<i>Nymphaea</i> 'Lemon Mist'	
<i>Nymphaea</i> 'Little Sue'	
<i>Nymphaea lotus</i>	Tiger lotus, White Egyptian lotus
<i>Nymphaea lotus</i> var. <i>rubra</i>	Red tiger lotus
<i>Nymphaea</i> 'Madame Wilfron Gonnere'	
<i>Nymphaea</i> 'Marlia'	
<i>Nymphaea</i> 'Mayla'	
<i>Nymphaea mexicana</i>	Yellow water lily, Banana water lily
<i>Nymphaea</i> 'Midnight Blue'	
<i>Nymphaea micrantha</i>	
<i>Nymphaea</i> 'Norma Gedye'	
<i>Nymphaea odorata</i>	Fragrant white water lily, American water lily, American white water lily, White water lily
<i>Nymphaea odorata</i> 'Alba'	
<i>Nymphaea pygmea</i> 'Helvola'	
<i>Nymphaea</i> 'Panama Pacific'	
<i>Nymphaea</i> 'Peaches & Cream'	
<i>Nymphaea</i> 'Pearl of the Pool'	
<i>Nymphaea</i> 'Perry's Baby Red'	
<i>Nymphaea</i> 'Perry's Double'	
<i>Nymphaea</i> 'Pink Sensation'	Pink Sensation water lily
<i>Nymphaea</i> 'Red Flare'	
<i>Nymphaea</i> 'Red Spider'	
<i>Nymphaea</i> 'Rembrandt'	
<i>Nymphaea</i> 'Rene Gerard'	
<i>Nymphaea</i> 'Rose Arey'	
<i>Nymphaea</i> 'Rose Nymphaea'	
<i>Nymphaea</i> 'Sioux'	
<i>Nymphaea</i> 'Shirley Bryne'	
<i>Nymphaea</i> 'Sunny Pink'	
<i>Nymphaea</i> 'Texas dawn'	
<i>Nymphaea</i> 'Tiger Lotus'	
<i>Nymphaea</i> 'Virginalis'	
<i>Nymphaea</i> 'Woods White Knight'	
<i>Nymphaea</i> 'Yellow Sensation'	
<i>Nymphaea</i> 'Yuh Ling'	
<i>Nymphaea stellata</i>	Red and blue water lily, Lotus water lily, Dwarf lily
<i>Nymphaea zenkeri</i>	Green tiger lotus

SCIENTIFIC NAME	COMMON NAME
<i>Nymphaea zenkeri</i> 'Red'	
<i>Nymphaea zenkeri</i> 'Tiger Red Lotus'	
<i>Nymphoides aquatica</i>	Banana plant, Big floating heart
<i>Nymphoides geminata</i>	Yellow snowflake
<i>Nymphoides hydrocharioides</i>	Snowflake orange
<i>Nymphoides peltata</i>	Yellow floating heart, Floating heart
<i>Oenanthe aquatica</i>	Fine-leaf water dropwort, Water parsley
<i>Oenanthe fistulosa</i> 'Flamingo'	Flamingo plant, Variegated water dropwort
<i>Oenanthe javanica</i>	Water parsley, Variegated water celery, Java water dropwort
<i>Oenanthe javanica</i> 'Flamingo'	Variegated water celery, Rainbow water celery
<i>Ophiopogon japonicus</i>	Green mondo grass, Dwarf mondo grass, Kyoto grass, Dwarf lily turf
<i>Orontium aquaticum</i>	Golden club
<i>Peltandra virginica</i>	Arrow arum, Green arrow arum, Virginia peltandra
<i>Phalaris arundinacea</i>	Ribbon grass, Eel grass, Reed canary grass
<i>Phalaris arundinacea</i> 'Feesey's Form'	Dwarf ribbon grass
<i>Phalaris arundinacea</i> 'Strawberries & Cream'	
<i>Phragmites australis</i>	Common reed
<i>Phragmites australis</i> 'Aurea'	Variegated dwarf common reed
<i>Phragmites australis</i> 'Variegata'	Variegated reed, Golden rush reed
<i>Phragmites karka</i> 'Variegata'	Japanese variegated reed
<i>Physostegia virginiana</i>	Obedient plant
<i>Pilea</i> spp.	Aluminium plant
<i>Pistia stratiotes</i>	Water lettuce
<i>Plantago atropurpurea</i>	Red leaf plantain
<i>Pogostemon helferi</i>	
<i>Pogostemon stellata</i>	
<i>Polygonum amphibium</i>	Water knot grass, Water knot weed, Water smart weed
<i>Pontederia cordata</i>	Pickerelweed, Blue pickerel rush, Pickerel rush
<i>Pontederia cordata</i> 'Alba'	White pickerel weed
<i>Pontederia dilatata</i>	Royal blue pickerel rush
<i>Pontederia</i> spp. 'Singapore Pink'	
<i>Potamogeton malaianus</i>	Tropical pondweed
<i>Potamogeton octandrus</i>	
<i>Potamogeton perfoliatus</i>	Clasping leaf pondweed
<i>Primula x bulleesiana</i>	Candelabra primrose bulleesiana
<i>Primula japonica</i>	Primrose japonica, Japanese primrose

SCIENTIFIC NAME	COMMON NAME
<i>Primula vialii</i>	Orchid primrose, Chinese pagoda primrose
<i>Proserpinaca palustris</i> 'Cuba'	
<i>Prostanthera microphylla</i>	Small leaf mint bush
<i>Ranunculus flammula</i>	Lesser spearwort, Small creeping spearwort, Spearwort buttercup, Greater creeping spearwort
<i>Ranunculus lingua</i> 'Grandiflorus'	Spearwort
<i>Ranunculus papulentus</i>	
<i>Ranunculus repens</i>	Golden creeping buttercup, Creeping buttercup
<i>Riccia fluitans</i>	Crystalwort
<i>Rorippa aquatica</i> (syn. <i>Neobeckia aquatica</i>)	
<i>Rotala indica</i> 'Green'	
<i>Rotala macrandra</i>	Giant red rotala, Red rotala
<i>Rotala macrandra</i> 'Green Narrow Leaf'	
<i>Rotala magenta</i> (R. <i>macrandra</i> var. 'Narrow leaf'	
<i>Rotala nanjenshan</i>	
<i>Rotala rotundifolia</i> (R. <i>indica</i>)	Dwarf rotala, Round leaf rotala, Indian tooth cup
<i>Rotala</i> sp. 'Vietnam'	
<i>Rotala wallichii</i>	Whorly rotala
<i>Ruellia brittoniana</i>	Dwarf blue bell, Blue bell dwarf, Britton's wild petunia
<i>Ruellia brittoniana</i> 'Chi Chi'	Pink bell flowers, Hardy pink petunia
<i>Ruellia brittoniana</i> 'Katie'	Dwarf blue bell
<i>Rumex alpinus</i>	Munk's rhubarb
<i>Rumex patientia</i>	Patience dock
<i>Rumex sanguineus</i>	Red veined spatterdock, Wood dock, Red vein spatterdock
<i>Rumex sanguineus</i> var. <i>sanguineus</i>	Bloody water dock, Bloody dock, Bloody wood dock
<i>Sagittaria australis</i> 'Benni'	Silk stocking arrowhead
<i>Sagittaria japonica</i>	Double flowering arrowhead
<i>Sagittaria latifolia</i>	Duck potato, Broad leaf arrowhead, Common arrowhead
<i>Sagittaria montevidensis</i>	Ruby eyed arrowhead, California arrowhead, Giant arrowhead
<i>Sagittaria natans</i>	
<i>Sagittaria pusila</i>	Dwarf sagittaria
<i>Sagittaria platyphylla</i>	Giant sagittaria, Chilensis sagittaria, Broad leaf sagittaria, Chilensis, Delta arrowhead

SCIENTIFIC NAME	COMMON NAME
<i>Sagittaria subulata</i> (syn. <i>Sagittaria lorata</i>)	Needle sagittaria, Floating arrowhead, Dwarf subulata, Narrow leaf sag
<i>Salvinia cucullata</i>	Floating plant
<i>Salvinia minima</i>	Water fern, Water spangles
<i>Salvinia natans</i>	Salvinia, Floating fern, Floating water moss
<i>Salvinia oblongifolia</i>	
<i>Salvinia rotundifolia</i> (syn. <i>Salvinia auriculata</i>)	Giant Salvinia, Eared water moss
<i>Samolus parviflorus</i>	Water pimpernel
<i>Samolus valerandi</i>	Water cabbage, Seaside brookweed
<i>Sarracenia purpurea</i>	Pitcher plant, Purple pitcher plant
<i>Sarracenia purpurea</i> 'Dana's Delight'	Pitcher plant Dana's Delight
<i>Sarracenia purpurea</i> 'Judith Hindle'	Pitcher plant Judith Hindle
<i>Saururus cernuus</i>	Lizard's tail
<i>Saururus cernuus</i> 'Red Stem'	Red-stem lizard's tail
<i>Schizostylis coccinea</i> 'Major'	Kaffir lily
<i>Schoenoplectus tabernaemontani</i> (syn. <i>Scirpus validus</i> ,	Soft stem bulrush, Great bulrush
<i>Scirpus lacustris</i> (syn. <i>Schoenoplectus lacustris</i>)	Bulrush, Lakeshore bulrush
<i>Scirpus lacustris</i> 'Albescens'	White bulrush, White rush
<i>Scirpus lacustris</i> var. <i>tabernaemontani</i> 'Zebrinus' (syn. <i>Scirpus zebrinus</i>)	Striped bulrush, Zebra rush
<i>Selaginella wilddenowii</i>	Peacock fern, Willdenow's spike moss
<i>Shinnersia rivularis</i>	Mexican oak leaf
<i>Sisyrinchium californicum</i>	Golden eyed grass, Golden blue eyed grass
<i>Sparganium eurycarpum</i>	Giant burr reed, Broad fruit burr reed,
<i>Spathiphyllum tassion</i>	Brazilian sword, Brazil sword
<i>Spathiphyllum wallisii</i>	Peace lily, Umbrella plant
<i>Stachys palustris</i>	Marsh woundwort, Marsh hedge nettle
<i>Stratiotes aloides</i>	Water Soldier
<i>Symplocarpus foetidus</i>	Skunk cabbage
<i>Syngonium podophyllum</i> var. 'Regina Red'	Arrowhead red
<i>Taxiphyllum</i> sp. 'Flame Moss'	
<i>Taxiphyllum</i> sp. 'Giant Moss'	
<i>Taxiphyllum</i> sp. 'Peacock Moss'	
<i>Terminalia catappa</i>	Indian almond leaves (used in aquarium with betta fish)
<i>Teucrium scorodonia</i>	Wood sage, Woodland germander
<i>Thalia dealbata</i>	Tropical water canna, Hardy water canna, Water canna, Powdered thalia, Powdery alligator flag

SCIENTIFIC NAME	COMMON NAME
<i>Thalia geniculata</i>	Red-stem water canna, Bent alligator flag
<i>Tonina</i> sp. 'Fluviatilis'	Tonina fluviatilis
<i>Tonina</i> sp. 'Belem'	
<i>Trapa natans</i>	Water chestnut
<i>Trichomanes javanicum</i>	Aqua fern, Borneo fern
<i>Tulbaghia violacea</i>	Society garlic, Wild garlic
<i>Tulbaaghia violacea</i> 'Variegata'	Variegated society garlic
<i>Typha angustifolia</i>	Lesser reedmace, Narrow leaf cattail, Graceful cattail
<i>Typha latifolia</i>	Greater reedmace, Common cattail, Cattail, Broadleaf cattail
<i>Typha latifolia</i> 'Variegata'	Variegated cattail
<i>Typha laxmanii</i> (syn. <i>Typha stenophylla</i>)	Small reedmace cattail, Dwarf cattail, Slender cattail
<i>Typha minima</i>	Dwarf cattail, Micro miniature cattail
<i>Utricularia graminifolia</i>	
<i>Utricularia vulgaris</i> (syn. <i>Utricularia macrorhiza</i>)	Bladderwort, Common bladderwort, Greater bladderwort
<i>Vallisneria americana</i> (syn. <i>Vallisneria asiatica</i>)	Dwarf vallisneria, Corkscrew vallisneria, Jungle vallis, American eel grass, Water celery, Twisted vallis, Contortion vallis
<i>Vallisneria americana</i> var. <i>americana</i> (syn. <i>Vallisneria neotropicalis</i>)	
<i>Vallisneria americana</i> var. <i>biwaensis</i>	Corkscrew vallisneria
<i>Vallisneria gigantea</i>	Giant vallisneria, Giant vallis, Jungle vallisneria, Giant torta, Jungle Val, Eel grass
<i>Vallisneria gigantea</i> 'Green'	
<i>Vallisneria gigantea</i> 'Rubra'	
<i>Vallisneria rubra</i> (syn. <i>Vallisneria spiralis</i> 'Red')	Red vallis spiralis, Red torta
<i>Vallisneria</i> 'Rubra Serpenta'	
<i>Vallisneria spiralis</i>	Straight vallisneria, Italian vallis, Straight vallis, Straight Val, Straight torta, Italian Val
<i>Vallisneria spiralis</i> 'Leopard'	
<i>Veronica beccabunga</i>	European brooklime, European speedwell
<i>Vesicularia dubyana</i>	Java moss, Singapore moss
<i>Vesicularia montagnei</i> 'Christmas Moss'	Christmas moss, Mini Christmas
<i>Xanthosoma atrovirens</i>	Dwarf green taro
<i>Xanthosoma mafaffa</i>	Lemon lime taro
<i>Zantedeschia aethiopica</i>	Calla lily, White arum lily
<i>Zephyranthes candida</i>	Dwarf onion, Zephyr lily, Autumn zephyr lily

**Appendix 9: Biological information for aquatic plants sold by the aquarium and
ornamental pond industries**

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Acorus americanus</i>	perennial	emergent	2	unknown	rhiz	3	rhiz, root [Cat.A], seed [Cat. E], sprig [Cat. C]	1 - 3 - 6/berry [1 - 6 - 14]	2	human, animal	moderate	1	1.2m L	0.61 - 1.5m L, 0.3 - 1.2cm W	3.3 - 7.5 - 10.2cm L, 2 - 3mm across	berry, 3 - 4 - 6mm L	2 - 3 - 4 - 6mm L	Flwr June to July (AON)/May to August	minimum -38°, 10 to 24	moderate to high	<0.5‰	5.6 - 7.2	nutrient rich	M	FONA, 1993; Rook, 2002; Meades <i>et al.</i> , 2004; Beck, 2005; USDA, NRCS, 2011
<i>Acorus gramineus</i>	perennial	emergent	2	unknown	rhiz, rootstock	2	rhiz, rootstock divsn [Cat.A], seed [Cat. E]	numerous	1	human	moderate to fast	1	20.3 - 30.5cm L	(15-)20-45(-55)cm L × (0.3)-0.5-1(-1.4) cm W	1.8 - 2mm D	berry, 3-3.5mm L × 2.2-2.5 mm W	(2)-2.5-3 mm L × (0.8-)1-1.2 mm W	Flwr Feb/June to July, seed ripe July-Aug	15 - 21	moderate to very high	tolerant	6 to 7	nutrient rich	M	Cook, 1974; Speichert & Speichert, 2004; Beck, 2005; Efforas, 2008a; Floridata, 2010; MBG, 2010; PPAF, 2010
<i>Acorus</i> spp.	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1 to 6 to 14	1	human	moderate	1	to 90cm L	>1.5cm L	spadix: 4 - 10cm L	berry, (3.5-)4-4.5 × 2-3(-3.5) mm	2.5-3(-4) × 1-1.2(-1.8) mm	Flwr May to July	>10°, 15 - 20	moderate to high	<0.5‰	5.0 - 6.0	nutrient rich	M	FONA, 1993; Winterton & Scher, 2007
<i>Aeschynomene fluitans</i>	perennial	floating or emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	5 to 10	2	human, water	fast	1	1 - 4.5m L	to 8cm L	3.5 - 10cm L	1 - 1.5 - 2 - 5cm L, 3 - 6mm W	(+/-) 8.5mm L, (+/-) 5mm W	Flwr June to August	min: 12 to 4.4, >16, 22 - 30	very high	low tolerance	5.0 - 8.0	low to high nutrients	D but less often M	Gillett <i>et al.</i> , 1971; Speichert & Speichert, 2004; Kirkbride <i>et al.</i> , 2006; Dave's Garden, 2011; USGS, 2011b
<i>Agapanthus africanus</i>	perennial	emergent	2	unknown	rhiz, tuber, corm, bulb	2	seed [Cat. E], rhiz [Cat. A]	4	2	human, wind	slow to moderate	1	2m L	10 - 35 - 60cm L, 0.6 - 1.5 - 2cm W	2 - 2.5 to 3.8 - 5.4cm L, 0.9 - 2.5 to 5cm W	capsule, 25 - 45 x 10 - 12mm, neck 5 - 8mm L	moderately large, 4 - 7mm	Flwr June to July, Dec to April	18 - 21	moderate to very high	low [0.2 - 0.3‰]	6.6 - 7.5	low nutrients	M	Duncan, 2004; Jamieson, 2004; Snoeijer, 2004; MBG, 2010; PPAF, 2010; Dave's Garden, 2011
<i>Agapanthus</i> spp.	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	~7	2	human, wind	moderate	1	0.61 - 1 - 1.8m L	50 - 60cm L x 3cm W	15.2 - 20.3cm W, 61cm L	capsule, 25 - 45mm L x 10 - 12mm W	4 - 7mm L	seed germe 14 - 30dys after sowing, Flwr July to August/Sept to Oct	>-6°, 4 - 15	moderate to high	moderately tolerant	neutral, alkaline, acid/5.1 - 6.0 - 6.5	nutrient rich (needs nutrients for next flwrg season)	M	Snoeijer, 2004; Botany.com, 2010; Lemke, 2011
<i>Alisma plantago-aquatica</i>	perennial	emergent	2	unknown	rhiz, bulb	2	rhiz [Cat. A], seed [Cat. E]	4	3	human, animal, water	moderate	1	10 - 70 - 91cm L	10 - 15.2 - 20.3 - 25cm L, 7 - 10.2cm W	0.64 - 1cm L	achene, 2 - 3mm L	nutlet, 0.41cm D, 0.2 - 0.34cm L	Flwr June to Sept	27 to -13° (min)	very high	<0.5‰	6.3 - 7.5	nutrient rich	D	Cook, 1974; Keddy & Constabel, 1986; Rook, 2002; Doronina, 2009; RBG, 2011; USDA, NRCS, 2011
<i>Alternanthera ficoidea</i> (syn. <i>Gomphrena ficoidea</i>)	annual or perennial	emergent	2	unknown	stem cuttings	2	seed [Cat. E], cuttings [Cat. D]	1	1	human	fast	1	3 - 10dm L	2 - 6cm L, 0.6 - 2cm W	5 - 10mm L, 5 - 7mm W	utricle, 1 - 1.5mmL	0.8 - 1.2mm W	Flwr March to April	20 - 25	moderate to very high	moderate	6.0 - 8.0	best in moderate, but can take high	M	Duke, 1962; Watson & Dalhwitz, 1992; USFS,PIER, 2007; Christenhaus, 2008; USDA, NRCS, 2011; Glen <i>et al.</i> , n.d.
<i>Alternanthera reineckii</i> (syn. <i>Alternanthera cardinalis</i>)	annual or perennial	emergent (best), submerged	2	unknown	rhiz	3	cuttings [Cat. D], seed [Cat. E], rhiz [Cat. A]	1	1	human	slow to moderate to fast	1	25 - 50cm L, 10 - 15cm W	10cm L, 1cm W	tiny	utricle, 1.3 - 1.7mm	0.9 - 1.1mm	Flwr mid summer (June)	20 - 22 - 28 - 30	moderate to high to very high	tolerant	slight acidic (5.0 - 7.2/5.0 - 8.0/5.6 - -7.5)	nutrient rich	M	Cook, 1974; FONA, 1993; Hiscock, 2003; Thierry & Piednor, 2005; APC, 2009; Dave's Garden, 2011
<i>Alternanthera</i> spp.	annual or perennial	submerged or emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	1	1	human	slow	1	to 20cm L	blade: 1-6 × 0.5-2 mm	<15.2cm L	utricle	unknown	Flwr March	>10°, 13 - 18, 17 - 28	moderate to high	<0.5‰	5.6 - 7.5	moderate to high	M	Speichert & Speichert, 2004; APC, 2009; RUIC, 2010
<i>Ammania senegalensis</i> (syn. <i>Ammannia auriculata</i>)	annuals or short-lived perennials	submerged or emergent	2	unknown	rhiz	3	rhiz [Cat. E], cuttings [Cat. D], seed [Cat. E]	many	2	human, animal	slow	1	5 - 10cm W, 10 - 30 - 45cm L	6 - 60mm L, 1.75 - 8mm W	hypanthium: 1.5 - 3mm L, 1.25 - 3.5mm W	capsule, 2 - 3mm L, 1 - 2 - 3mm W	0.4 - 1mm L	Flwr Aug to Sept	20 - 21 - 28	low to moderate to high	0.5 - 30‰	6.5 - 7.5	high nutrient	M	Cook, 1974; Graham, 1985; Hargreaves, 2006; Efforas, 2008b; RUIC, 2010
<i>Ammania</i> spp.	annual or short-lived perennial	submerged or emergent	1	none	none	1	seed [Cat. E]	ca. 250/capsule	2	human, animal	slow	1	10dm or less L	3 - 8cm L	small, insipicuous	capsule	ca. 1mm L	Flwr July to Oct	20 - 28	moderate	0.5 - 30‰	6.0 - 7.5	nutrient rich	M	Graham, 1985; RUIC, 2010; UCIPM, 2010; Graham, 2011
<i>Andromeda polifolia</i>	perennial	emergent	2	unknown	rhiz, rootstock	2	rhiz, rootstock [Cat. A], seed [Cat. E]	25 - 35	3	water, animal, human	slow	1	5 - 80cm L	1 - 2.5 - 3.8 - 5cm L x 1 - 8mm W	5 - 8mm L x 3.5 - 7mm W	capsule, 4 - 8mm L, 3 - 6mm D	1mm L	Flwr May to July	23 to -21° (min)	moderate to very high	moderate	3.0 - 7.9	nutrient poor	M	FONA, 1993; NCSU, 2005; Evergreen, 2011; USDA, NRCS, 2011; USDAFS, n.d.
<i>Anemopsis californica</i>	perennial	emergent	2	unknown	rhiz, tuber, corm, bulb, offsets from stolon	3	rhiz [Cat. A], offshoot [Cat. C], seed [Cat. E]	18 - 40	1	human	moderate to fast	1	8 - 80cm L	5 - 60cm L	1 - 3cm L	capsule, 5 - 7mm	1 - 15 x 0.8 - 1mm	Flwr early spring to summer	37 to -5°	moderate to very high	moderate (don't do well above 10 - 15‰)	6.5 - 9.0	low nutrients	M	FONA, 1993; USDA, NRCS, 2011; Dave's Garden, 2011; Yensen, 2011; Anderson & Roderick, n.d.
<i>Anubias afzelii</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (1 - 4cm thick)	3	rhiz frag [Cat. B], cuttings [Cat. D], seed [Cat. E]	numerous	1	human	slow	1	15 - 30 - 50cm L	blade: 13 - 35cm L, 3 - 13cm W, 2.5 - 8x as L as W	spadix: 5 - 8 - 12cm L (male on top, female below)	berry	2mm L, 1 - 1.5mm W (1.3 - 1.7x as L as W)	Flwr March to July, fruit April to Sept	22 - 28 - 30	moderate	<0.5‰	6.0 - 8.0	low nutrients	M	Crusio, 1979; Boorman, 2003a; Aqua-fish.net, 2011
<i>Anubias barteri</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (0.2 - 1cm thick)	3	rhizome division [Cat. A], seed [Cat. E], cuttings [Cat. D]	numerous	1	human	slow	polymorphic (see varieties below)	leaf stem: 32 - 83cm L	6cm L, 3cm W	spadix: 1.5 - 7cm L [0.75 - 3 or 3 - 12cm L]	berry	0.5 - 1mm L, 0.4 - 0.8mm W (1.3 - 2.2 x as L as W)	Flwr & fruit thru' out year	22 - 28	low to moderate to high light	0 - 4‰	slight acidic (6.5 - 7.5 - 8.0)	low nutrients	M	Cook, 1974; Crusio, 1979; Hiscock, 2003; Thierry & Piednor, 2005; Liveaquaria.com, 2011
<i>Anubias barteri</i> var. <i>angustifolia</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	numerous	1	human	slow	1	10 - 15cm L (leaf stem: to 32cm L)	blade: 8 - 18cm L, to 3.5cm W, 5 - 9x as L as W	spadix: 0.75 - 3cm L or 1.95 - 7.8cm L	berry	unknown	unknown	20 - 30	very low to high	<0.5‰	5.5 - 8.0	low nutrients	M	Crusio, 1979; Tropica, n.d.
<i>Anubias barteri</i> var. <i>barteri</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	3	side shoots [Cat. C], dividng rhizs [Cat. A], seed [Cat. E]	numerous	1	human	slow	1	25 - 45cm L	blade: 7 - 23cm L, 4 - 11cm W, 2.5x as L as W	spadix: 2.25 - 9cm L	berry	unknown	unknown	20 - 22 - 28 - 30	all light	<0.5‰	5.5 - 9.0	low nutrients	M	Cook, 1974; Crusio, 1979; Hiscock, 2003; APC, 2009; Tropica, n.d.
<i>Anubias barteri</i> var. <i>caladifolia</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	numerous	1	human	slow	1	7 - 30cm L (leaf stem: to 54cm L)	blade: 10 - 23cm L, 5 - 14cm W, 1.5 - 2.5x as L as W	spadix: 2.25 - 9cm L	berry	unknown	unknown	20 - 27	low to high	<0.5‰	5.5 - 8.0	low nutrients	M	Crusio, 1979; APC, 2009; Tropica, n.d.
<i>Anubias barteri</i> var. <i>glabra</i> (syn. <i>Anubias lanceolata</i> , <i>Anubias minima</i>)	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	3	rhiz [Cat. A], cuttings, by division of tufts [Cat. D], seed [Cat. E]	numerous	1	human	slow	1	40cm high, 3 - 5cm W (leaf stem: to 35cm L)	blade: 6 - 21cm L, 1.5 - 9cm W (2 to >4x as L as W)	spadix: 1.5 - 6cm L	berry	unknown	unknown	20 to 30/32	low	<0.5‰	5.0 - 8.0	low nutrients	M	Cook, 1973; Mondadori, 1976; Crusio, 1979; Hiscock, 2003; Thierry & Piednor, 2005; The Planted Tank, 208
<i>Anubias barteri</i> var. <i>nana</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	3	side shoots [Cat. C], dividng rhizs [Cat. A], seed [Cat. E]	numerous	1	human	slow	1	5 - 10cm L (leaf stem: to 5cm L)	blade: to 6 - 12cm L, 3cm W	spadix: (+/-) 1.5 - 6cm L	berry	unknown	unknown	20 - 22 - 28 - 30	undemanding	<0.5‰	5.5 - 6 - 7.5 - 8	low nutrients	M	Cook, 1974; Crusio, 1979; Hiscock, 2003; Pongchawee <i>et al.</i> , 2006; Liveaquaria.com, 2011; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Anubias congenis</i> (syn. <i>Anubias heterophylla</i>)	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (5 - 7mm thick)	3	side shoots [Cat. C], dividing rhizs [Cat. A], seed [Cat. E]	numerous	1	human	slow	1	30 - 50cm L	10 - 15 - 21.6 - 38cm L, 3 - 5.7 - 10 - 13cm W	spadix: 1.5 - 4.5cm L	berry	0.8 - 1.5mm L, 0.5 - 1mm W (~ 1.3 - 1.7x as L as W)	Flwr July to Jan, fruit July to March	22 - 28	undemanding	<0.5‰	5.5 - 6.0 - 8.0	low nutrients	M	Cook, 1974; Crusio, 1979; Hiscock, 2003; Aqua-fish.net, 2009; Diszhak, 2009; Liveaquaria.com, 2011
<i>Anubias gigantea</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (1 - 3cm thick)	3	rhiz [Cat. A], cuttings [Cat. D], seed [Cat. E]	numerous	1	human	slow	1	to 83cm L	blade: 13 - 30 - 40cm L, 5 - 14cm W	spadix: to 9cm L, 5 - 10mm W	berry	1.5 - 1.8mm L, 0.9 - 1.2mm W (1.3 - 2x as L as W)	Flwr Feb to April	22 - 28	low	<0.5‰	6.4 - 7.2	low nutrients	M	Crusio, 1979; AAG, 2009
<i>Anubias gracilis</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	rhizome division [Cat. A], seed [Cat. E]	numerous	1	human	slow	1	20 - 30cm L	blade: 7 - 12cm L, (+/-) 4 - 10cm W	spadix: to 3cm L	berry	unknown	Flwr Feb to May	22 - 26/20 - 30	moderate to high	<0.5‰	5.5 - 8.0	low to rich nutrients	M	Cook, 1974; Crusio, 1979; Hiscock, 2003
<i>Anubias hastifolia</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (0.5 - 1.5cm thick)	3	rhiz [Cat. A], cuttings [Cat. D], seed [Cat. E]	numerous	1	human	slow	1	30 - 50cm L	blade: 10 - 33cm L, 3 - 14cm W	spadix: 1.5 - 4cm L, 2 - 5mm thick	berry	1.7 - 2.5mm L, 1.2 - 1.6mm W (1.4 - 1.8x as L as W)	Flwr thru' out year, fruit Sept to Jan	22 - 28	moderate	<0.5‰	5.5 - 9.0	low nutrients	M	Crusio, 1979; Liveaquaria.com, 2011
<i>Anubias</i> spp.	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	4	side shoots [Cat. C], dividing rhizs [Cat. A], seed [Cat. E], stem frag [Cat. D]	numerous	1	human	slow	1	5 - 90cm L	~10cm L, 2.08cm W	unknown	berry	small	unknown	22 - 30	low	<0.5‰	5.0 - 9.0	low nutrients	M	Crusio, 1979; Pongchawee <i>et al.</i> , 2006
<i>Aponogeton boivinianus</i>	perennial	submerged	2	unknown	tubers (3cm)	2	pollination or from seed [Cat. E], tuber/tubercle [Cat. A]	(3-)6(-7)	3	human, wind, water	fast then slow	1	none reported	60cm L, 8 cm W, blade: 6 - 30 x 1.5 - 5(-8)cm (subm)	tepals: (+/-) 2.75 x 1.25mm, spikes: to 20cm L	dry fruit (schizo), 8 x 4mm	(+/-)3 x 1mm	Flwr Sept to Feb	20 - 26/16 - 30	high	<0.5‰	6.8 - 7.5/6 - 8	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997; Hiscock, 2003; Tropica, n.d.
<i>Aponogeton capuronii</i>	perennial	submerged	2	unknown	tubers (2cm)	2	tuber/tubercle [Cat. A], seed [Cat. E]	(2-)4	3	human, wind, water	moderate	1	none reported	blades: 20 - 40 x 3 - 4.5cm (subm)	spikes: to 14cm, tepals: 1.5 - 1.75 x 0.75 - 1.75mm	dry fruit (schizo), 6 x 3mm	3.25 x 1.5mm	Flwr thru' out year	20 - 27/16 - 26	moderate to high	<0.5‰	5.5 - 8.0	nutrient rich	M	van Bruggen, 1968, 1969, 1970, 1973; McKinnon, 1997; The Planted Tank, 2008
<i>Aponogeton crispus</i> (syn. <i>Aponogeton elongatus</i>)	perennial	submerged	2	unknown	tubers (2.5cm)	2	pollination or from seed [Cat. E], tuber/tubercle [Cat. A]	4 to 8	3	human, wind, water	fast then slow	2 (floating & subm)	rhiz - 2 to 3cm D	2.5 - 55 x 0.5 - 5cm (subm), 10 - 15 x 1.5 - 4cm (floa)	spike: to 20cm L, tepals: 1.5 - 2.5 x 0.75 - 1.5mm	dry fruit (schizo), 5 - 6 - 12 x 3 - 4 - 5mm	5 - 6mm L, 2mm D	fruit matures in 2 months, Flwr Marc, April, Sept, June - July, Nov & Dec	22 - 30/15 - 30	high	<0.5‰, to 6.6‰	prefer acidic but tolerate alkaline (6.5 - 7.5)/5.5 - 8	high nutrient	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997; Hiscock, 2003; APC, 2009; Gruppe, 2010; Tropica, n.d.
<i>Aponogeton distachyos</i>	perennial	submerged	2	unknown	tuber (6cm D)	2	tuber/tubercle [Cat. A], seed [Cat. E]	4	3	human, wind, water	moderate (fast in shallow ponds)	1	none reported	6 - 23 - 32.5cm L x 1.5 - 7.5 - 8.6cm W	10 - 15mm L x 3.5 - 6mm W (to 30mm L in fruit)	schizocarp, up to 22mm L x 6mm W, beak 5mm L	15 - 18mm L x 4 - 7mm W	Flwr March - April & Oct - Now	<21° [opt: 12 - 18], seed germinate 1 - 2mths @20°C	high to very high	<0.5‰	6 - 7.5 [optm]	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; FUNA, 1993; McKinnon, 1997; Heliquist & Jacobs, 1998; Speichert & Speichert, 2004; FAO, 2007
<i>Aponogeton longiplumulosus</i>	perennial	submerged	2	unknown	tubers (2cm)	2	seed [Cat. E], tuber/tubercle [Cat. A]	2	2	human, water	moderate to fast	1	rhiz - 2 to 3cm D	to 12cm, blades: 20 - 35 x up to 1.5cm	spikes: to 10cm, tepals: 2 - 2.5 x 1mm	dry fruit (schizo), up to 4 x 1.5mm	up to 3 x 1mm	Flwr thru' out year	18 - 26	high	<0.5‰	5.7 - 7.9	high nutrient	M or D	van Bruggen, 1968, 1969, 1970, 1973; McKinnon, 1997; Winterton & Scher, 2007; Aqua-fish.net, 2011
<i>Aponogeton madagascariensis</i>	perennial	submerged	2	unknown	tubers (3cm)	2	seed [Cat. E], tuber/tubercle [Cat. A]	2 or 4	3	human, animal, water	moderate to fast	1	1.5 - 3cm D	15 - 55cm L, 5 - 16cm W (subm)	tepals: 2 x 1.5 - 1mm, inflor: 9 - 20cm L	dry fruit (schizo), 8.5 x 5mm	(+/-)3.5 x 1.25mm	Flwr thru' out year, germn 1dy to several weeks	20 - 22 - 24/15 - 30	all light/AQM shade	<0.5‰	6.0 - 7.0/5.5 - 6.5/5.0 - 7.5	low to rich nutrients	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997; Hiscock, 2003; APC, 2009; Liveaquaria.com, 2011; Tropica, n.d.
<i>Aponogeton natans</i>	perennial	submerged	2	unknown	tubers (to 2cm)	2	tuber/tubercle [Cat. A], seed [Cat. E]	(+/-) 8	3	human, wind, water	moderate to fast	1	none reported	6.5 x 1.5cm (subm), 11.5 x 3cm (floa)	spike: to 7cm L, tepals: 1.5 - 2 x 0.5 - 1mm	dry fruit (schizo), 4 x 2.25mm, beak 1mm	(+/-)1.75 x 0.75mm	Flwr June to Feb	24 - 30	low to high	<0.5‰	6.0 - 8.0	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997
<i>Aponogeton rigidifolius</i>	perennial	submerged	2	unknown	rhiz (to 1cm)	2	new plants from rhizome [Cat. A], seed [Cat. E]	2	3	human, wind, water	slow	1	rhiz - 1cm D	20 - 60cm L, 2.5 - 4cm W (subm)	spike: 15cm L, tepals: 2 - 3.25 x 1.75 - 2mm	dry fruit (schizo), 12 x 6mm	11(-14) x 4 - 5mm	Flwr March, April & Sept	22 - 28/23 - 25	high to very high	<0.5‰	5.5 - 8.0/7.2	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997; Hargreaves, 2006
<i>Aponogeton ulvaceus</i>	perennial	submerged	2	unknown	tubers (3cm)	3	seed [Cat. E], divsn offshoots fr. rhiz [Cat. C], tuber/tubercle [Cat. A]	4 to 6	3	human, wind, water	moderate to fast	1	rhiz - 30mm D	20 - 50 - 60cm L, 3 - 10cm W, blades: 12 - 35 x 2 - 8cm (subm)	spikes: to 15cm, tepals: 1.5 - 2.5 x 0.75mm	dry fruit (schizo), 3.5 - 5 x 2 - 3mm	1.5 - 3 x 0.5 - 1mm	Flwr October to April	20 - 22 - 28 - 30	moderate to high	<0.5‰	neutral pH (5.5 - 8)	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; Mondadori, 1976; McKinnon, 1997; Hiscock, 2003; Tropica, n.d.
<i>Aponogeton undulatus</i>	perennial	submerged	2	unknown	tubers (6 - 25mm)	3	adventitious plantlets [Cat. D], tuber/tubercle [Cat. A], seed [Cat. E]	2	3	human, wind, water	slow to moderate	1	rhiz - 5cm L x 2.5cm W	10 - 15 - 25 x 0.8 - 4.2cm (subm), 20 x 3.5cm (emerg)	tepals: (2-)3.5 - 6 (- 12) x 1 - 2.5(- 4)mm, spike: to 10cm	dry fruit (schizo), 5 - 7 x 4mm	5 x 2mm	Flwr July, Aug & Nov	22 - 28	moderate to high	<0.5‰	6.8 - 7.2	nutrient rich	M rarely D	van Bruggen, 1968, 1969, 1970, 1973; Cook, 1974; McKinnon, 1997; Hiscock, 2003
<i>Arundo</i> spp.	perennial	emergent	2	unknown	rhiz (0.5 - 8m)	2	rhiz [Cat. A], seed [Cat. E], rhiz frag [Cat. B]	1	3	human, wind, water	moderate	1	culms to 1 - 3 - 4.5 - 8 - 13m L, 0.5 - 6cm thick	30 - 60 - 100cm L, 3 - 7cm W	rarely flowers, spikelet: 10 - 15mm or 2 - 8cm L	caryopsis	non-viable seed, rarely produced	Flwr late summer to early fall	min of -23°, 21 - 32	high to very high	0.5 - 30‰	5.5 - 7.8	nutrient rich	M	Johansson <i>et al.</i> , 2006; Winterton & Scher, 2007; Eforas, 2008a
<i>Asclepias incarnata</i>	perennial	emergent	2	unknown	rhiz, tuber, corm, bulb	2	seed [Cat. E], rhiz [Cat. A]	1200/plant	4	wind, human, animal, water	slow	1	91.4 - 122/30 - 150cm L	4.5 - 7.5 - 10.2 - 16 - 17.8 - 20cm L, 1 - 4 - 5cm W	6 - 7mm L or 7.6 - 10.2mm L	follicles/pod, 5 - 9 - 12.7cm L, 25cm W	0.8 - 0.95cm L	Flwrs bloom July to Sept, reproe June to Aug, seed produced Aug to Sept	20 to -38°	very high	<0.5‰	netural to slight acid (5 - 8)	nutrient rich	M	Alex, 1998; Rook, 2002; Meades <i>et al.</i> , 2004; USGS, 2006a; Dave's Garden, 2011; LBJWC, 2011
<i>Aster puniceus</i> (syn. <i>Symphotrichum puniceum</i>)	perennial	emergent	2	unknown	rhiz	3	sprig [Cat. C], rhiz [Cat. A], seed [Cat. E]	1	3	human, animal, wind	slow	1	30 - 213cm L, 5 - 11mm D	7.5 - 15cm L, 1.3 - 3.8 - 4.45cm W, blade: 30 - 10+ x 3 - 20+mm, (5.5-17-20(-22) x	0.83 - 2.5cm L, 2.5 - 3.8cm W	cypselsae or achene, 0.15 - 0.32 - 0.4cm L, (2-)2.5-3.5(-4) mm	pappi: 3.8 - 6mm	Flwr August to Oct/Nov	(-37) to (-40) (min), 24 - 29	moderate to high	<0.5‰	4.5 - 7.5	moderate nutrients	M	FONA, 1993; Rook, 2002; Hilty, 2011; USDA, NRCS, 2011; UWSPF, n.d.
<i>Azolla caroliniana</i>	annual & perennial	floating	2	unknown	runner	3	side shoots [Cat. C], spore [Cat. E], runner [Cat. A]	1 megasp, 8 - 40 microsporangia with 32 or 64 microsp.	3	human, animal, water	fast to very fast	1	0.5 - 1cm L	0.5mm L	non-flowering	sporocarp, 2mm D	female: 0.2 - 0.6mm, male 3µm (family)	germn May to Nov	18 - 24/5 - 26	moderate to high	non-tolerant (<0.5‰) [<0.1‰]	5.5 - 6.0 - 8.0	high	D (heterosporous)	Svenson, 1944; Moore, 1969; Cook, 1974; CTAHR, 2002; Hiscock, 2003; Beck, 2005; Aqua-fish.net, 2011; Invasive.org, 2011; Tropica, n.d.
<i>Bacopa australis</i>	perennial	submerged that can grow emergent (amphibious)	2	unknown	stem cuttings	2	side shoots [Cat. C], seed [Cat. E]	numerous	2	human, water	moderate to fast	1	7 - 15cm L	3 - 9mm L, 0.2 - 0.4mm W	(1-) 1.4 - 3.7cm L [to 4.8cm L in fruit]	capsule, 3.5mm L, 2mm D	0.1 - 0.3mm L (genus)	Flwr May	22 - 28/15 - 32	low to high	tolerant	6.0 - 8.0	nutrient rich	M	Barrett, 1978; Souza, 2001, 2009; Tenenbaum, 2003; Aqaascapingworld, n.d.
<i>Bacopa caroliniana</i> (syn. <i>Bacopa amplexicaulis</i>)	perennial	submerged that can grow emergent (amphibious)	2	unknown	stolons	4	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E], runner [Cat. A]	numerous	2	human, water	slow to moderate to fast	1	3 - 6cm W, 8 - 20cm L	(1.2-) 1.5 - 2.1cm L, 0.8 - 1.4cm W	0.35 - 0.55cm L (petal)	capsule, 0.4cm L, 0.25cm D	0.1 - 0.3mm L (genus)	Flwr June to August	20 - 22 - 28/15 - 30	high	0.5 - 30‰	neutral or slight acidic (5.0 - 8.0)	low to moderate	M	Cook, 1974; Barrett, 1978; Hiscock, 2003; Hargreaves, 2006; APC, 2009; Gann <i>et al.</i> , 2011; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Bacopa monnieri</i>	perennial	submerged that can grow emergent (amphibious)	2	unknown	stem cuttings	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	numerous	2	human, water	slow to moderate	1	5 - 10 - 31 - 50cm L, 3cm W	1 - 5 - 25mm L, 3 - 6 - 8 - 11mm W	8 - 10 - 12mm L (petal)	capsule, 0.35 - 0.45cm L, 0.25 - 0.35cm D OR 2 - 5mm L, (+/-) 2.5mm D	0.5 - 0.6mm L	Flwr May to Oct./Jan to June	22 - 30/15 - 30	high to very high	0.5 - 30‰	6.5 - 7.5/6 - 9	nutrient rich	M	Cook, 1974; Barrett, 1978; Hiscock, 2003; Hargreaves, 2006; Eforas, 2008a; APC, 2009; Souza, 2009; Liveaquaria.com, 2011; Tropica, n.d.
<i>Bacopa myriophylloides</i> (syn. <i>Herpestis myriophylloides</i>)	perennial	submerged	2	unknown	stem cuttings	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	numerous	2	human, water	moderate	1	3 - 20 - 30cm L	(0.15-) 0.35 - 0.6 - (0.8)cm L x 0.05 - 0.1cm W	0.2 - 0.4cm L (petal)	capsule, 0.25cm L x 0.15cm W	0.1 - 0.3mm L (genus)	Flwr June	22 - 26/15 - 30	moderate to high	tolerant	4.8 - 5.5 - 8.0	nutrient rich	M	Barrett, 1978; Souza, 2009; Aquapage.eu, 2010
<i>Bacopa rotundifolia</i>	perennial	submerged that can grow emergent (amphibious)	2	unknown	stolons	4	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E], stolon [Cat. A]	numerous	3	human, animal, water	moderate	1	2 - 6dm L &/or 5 - 40cm L	1 - 3.6cm L, 0.8 - 2.6cm W	4 - 10mm L	capsule, 0.5cm L, 0.3 - 0.4cm D	small [0.1 - 0.3mm L (genus)]	Flwr June to August/Sept	22 - 26	high	0 - 0.5 - 3‰ (<5‰)	5.4 - 7.8	nutrient rich	M	Cook, 1974; Barrett, 1978; Hiscock, 2003; Dolan, 2004; Souza, 2009; USDA, NRCS, 2011
<i>Barclaya longifolia</i> (syn. <i>Hydrostemma longifolium</i>)	perennial	submerged	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	30 - 50/locule (ovary 6 - 12 locular)	2	human, water	slow to moderate	[2 - depends on light conditions]	none reported	25.4 - 30.5cm L, blade: 12 - 28 x 2 - 6cm	1.5 - 2.5cm L	berry, 1 - 1.5cm D	minute, 1mm D	fruit mature in 7 wks to prod seeds, plant ready to flower in 1 yr, flwr in Aug	22 - 26/20 - 30 (best @25)	moderate to high	<0.5‰	neutral pH, 5.0 - 8.0	nutrient rich	M	Cook, 1974; Mondadori, 1976; Schneider, 1978; Hiscock, 2003; APC, 2009; Diszhalak, 2009; La-ongrsi <i>et al.</i> , 2009
<i>Barclaya</i> spp.	perennial	submerged or emergent	2	unknown	rhiz, corm	2	seed [Cat. E], corm, rhiz [Cat. A]	30 - 50/locule (ovary 8 - 14 locular)	2	human, water or animal	slow to moderate	1	none reported	blade: 12 - 28 x 2 - 6cm	1.5 - 2.5cm L	berry, 1 - 1.5cm D	minute, 1mm D	germ 2 - 3 dys	23 - 32	moderate to high	<0.5‰	5.5 - 8.0	nutrient rich	M	La-ongrsi <i>et al.</i> , 2009; Lok <i>et al.</i> , 2009; APC, 2009
<i>Bietilla striata</i>	perennial (geophyte)	emergent	2	unknown	corm (pseudobulb), rhiz	2	rhiz [Cat. A], seed [Cat. E]	numerous	2	human, wind	slow	1	3 - 25 - 30cm L, 1cm D	8 - 20 - 30cm L, 1.5 - 5.5cm W	2.5 - 5cm L, 4 - 6mm W, petal: 14 - 32 x 4 - 11mm	capsule, 3.4cm L	tiny, smlr than a dust speck	Flwr late spring to summer (May to August)	4 - 16 (tolerate wide range of tropic temps)	moderate	<0.5‰	5.6 - 7.5	nutrient rich	M	Dougherty, 2002; Eforas, 2008a; PFAF, 2010; Dave's Garden, 2011
<i>Blyxa aubertii</i>	annual	submerged	2	unknown	rhiz	4	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E], rhiz [Cat. A]	numerous [40 - 70]	3	human, wind, animal	moderate to fast	1	0.5 - 3 - 5cm L, 1cm D	2.5 - 60 (-/+10) cm L, 0.2 - 1.2cm W	17mm L, 0.5mm W (petals)	capsule, (20-) 30 - 50 (-80)mm L, 5mm W	1.3 - 1.8mm L, 0.9mm W	Flwr summer to Fall (June to Sept/Oct)	23 - 28	high	non-tolerant	5.0 - 7.0	nutrient rich	M	Cook & Lüönd, 1983; FONA, 1993; Jiang & Kadono, 2001; Aquafishnet, 2011; USGS, 2011c; Aquascapeworld, n.d.
<i>Blyxa japonica</i>	annuals or perennials	submerged	2	unknown	stem cuttings	2	side shoots [Cat. C], seed [Cat. E]	10 to numerous	3	human, wind, animal	slow to moderate	1	(1-) 10 - 20 (- 60)cm L	15 - 50 (-70)mm L x 0.75 - 3 (-4)mm W	3 - 8 (-10)mm L x 0.2 - 0.8 (-1)mm W (petal)	1 - 2 (-2.5)cm L, 2mm W, capsule	(1-) 1.5 - 2mm L	Flwr & fruit May to Oct	22 - 26	high to very high	<0.5‰	5.5 - 7.5	nutrient rich	M or D	Cook, 1974; Cook & Lüönd, 1983; Hiscock, 2003; Eforas, 2008a; Aquascapeworld, n.d.
<i>Bolbitis heteroclita</i>	perennial	submerged that can grow emergent (amphibious)	2	unknown	rhiz (c. 20cm L, 2 - 7 - 10mm thick)	2	rhiz [Cat. A], spore [Cat. E]	64	1	human	slow	1	none reported	sterile: 15 - 100cm L, pinnate 25 - 100cm L, simple: 15 - 45cm L, fertile: 14 - 75cm L	non-flowering	no fruit	20 - 34µm, 32 - 40µm, 20 x 30µm (genus)	6 - 8mths (genus)	22 - 27	low to moderate	<0.5‰	6.0 - 7.2	moderate nutrients	M (homosporous ferns)	Nayar & Kaur, 1971; Hennipman, 1977; Hoshizaki & Mora, 2001; Winterton & Scher, 2007
<i>Bolbitis heudelotii</i>	perennial	submerged	2	unknown	rhiz (to 20 - 25cm L, 3 - 10mm thick)	4	cuttings/advn pltls [Cat. D] rhizome/runner [Cat. A], side shoots [Cat. C], spore [Cat. E]	64	1	human	slow	1	none reported	14 - 40 - 50cm L, 15 - 25cm W/sterile leaves: 30 - 85cm L, fert leaves: 25 - 100cm	non-flowering	no fruit	10µm, 20 x 30µm (genus)	6 - 8mths (genus)	20 - 22 - 28	low to moderate	<0.5‰	5 - 7 (TROPICA), 6.3 - 7.2	low nutrients	M (homosporous ferns)	Nayar & Kaur, 1971; Hennipman, 1977; Hiscock, 2003; O'Neal, 2005; Winterton & Scher, 2007; Diszhalak, 2009; Tropica, n.d.
<i>Butomus umbellatus</i>	perennial	emergent	2	~300 bulbils/pl	bulbils, frag, rhiz	3	seed [Cat. E], bulbils, frag [Cat. D], rhiz [Cat. A]	1200 - 12k/pl - >20K/pl/yr (fert), 0 (sterile)	3	water, human, animal, wind	fast	1	0.5 - 1m L	2.7m L, 5 - 10mm W, 91.4cm L (emerg)	5 - 10cm L, 2 - 3 cm W	follicle, 1cm L	1mm L	Flwr July to Sept./June to Aug, seeds ripen Aug to Sept	18 - 27	high to very high	<0.5‰	acid, neutral, alkaline (6.5 - 7.5)	nutrient rich	M	FONA, 1993; Beck, 2005; Brown & Eckert, 2005; Kliber & Eckert, 2005; Liu <i>et al.</i> , 2008; McLean, 2009; GISD, n.d.d.
<i>Cabomba aquatica</i>	perennial	submerged	2	unknown	rhiz	3	cuttings [Cat. D], rhiz [Cat. A], seeds [Cat. E]	2 or 3	1	human	fast (5 - 7.6cm/wk)	1	30 - 100cm L	1 - 2cm W (flo), 0.1 - 0.4mm W (subm)	4.5 - 10mm L, 5 - 8mm D	follicle, 3mm L, 2mm W	2 - 3.5 L x 1.5 - 2.5mm W	Flwr May to Sept	24 - 30/18 - 25 (best@20)	high to very high	<0.5‰	6.4 - 6.5 or 6.5 - 7 (Mackey)/4 - 5 (Orgaard)	nutrient rich	M	Fassett, 1953; Oogard, 1991; Hiscock, 2003; Diszhalak, 2009
<i>Cabomba caroliniana</i> (syn. <i>Cabomba australis</i> , <i>Cabomba pulcherrima</i>)	perennial	submerged	2	unknown	frag, turion, rhiz	3	stem-shoot frag [Cat. D], rhiz [Cat. A], seed [Cat. E]	1 - 3/fruit	3	water, animal, human	fast/rapid [50mm/dy]	1	2-4mm D, 1-2m max, 10m L (short 2-5cm)	1 - 1.3 - 3.2 - 3.5cm L, 1.5 - 6cm W	0.6 - 1.2cm L, 0.6 - 1.5 - 1.9cm D	4 - 7mm L, follicle/pod	1.5 - 3 x 1 - 1.5mm	resume growth in April-leaves July- flwg peaks Aug- Sept-to Oct/Nov	22-28, opt. 13-27, also <0	moderate to high	<0.5‰	acid, alk:6.5 - 6.9, opt growth pH 4 to 6/ 5 - 7	high nutrient	M	Fassett, 1953; Oogard, 1991; Mackey, 1996; Hiscock, 2003; Wilson <i>et al.</i> , 2007; GISD, n.d.d.
<i>Cabomba palaeformis</i>	perennial	submerged	2	unknown	frag, rhiz	4	by division of stem [Cat. D], seed [Cat. E], lateral shoots [Cat. C]	1 - 3/fruit	1	human	fast	1	5 - 9cm W	5 - 13 x 0.7 - 1.2mm (lamina)	6 - 8.5mm L, 5 - 10mm L (Org)	follicle	1 - 2mm W x 0.2mm L	Flwr May to Sept	20 - 24	moderate to high	<0.5‰	neutral, 6.0 to 7.2	nutrient rich	M	Fassett, 1953; Oogard, 1991; Hiscock, 2003; Diszhalak, 2009
<i>Cabomba piashyensis</i> (syn. <i>Cabomba furcata</i>)	perennial	submerged	2	unknown	frag, rhiz	4	cuttings [Cat. D], seeds [Cat. E], stem frag [Cat. D], rhiz [Cat. A]	1 - 3/fruit	1	human	moderate to fast	1	to 80cm L	1cm W (flo), 3 - 7cm L, 3 - 8 cm W (submd)	6 - 9mm L	follicle, 3.6cm L	1.5 - 2mm L, 1 - 1.5mm W	Flwr May to Sept	24 - 28/18 - 26	very high	<0.5‰	4.0 - 7.0	nutrient rich	M	Fassett, 1953; Duke, 1962; Oogard, 1991; Hiscock, 2003; The Planted Tank, 2008; Aquascapeworld, n.d.
<i>Caladium</i> sp.	perennial	emergent	2	unknown	offsets	3	corm or tuber, roots [Cat. A], seed [Cat. E], offsets [Cat. C]	2 to 20	1	human	fast	1	40 - 90cm L (leaf-stems)	15 - 45 - 60cm L	female: <1.5mm W	berry	corm: 5.1cm L (plant not truly from seed)	no flwrg period grown for foliage, germn 1 - 3mths	max: 24 - 29, min: 13 - 18	low to moderate	low tolerance (sensitive to salt spray & soil salinity)	5.5 - 6.5	nutrient rich	D	Lecouffe, 1982; Plant Biology, 2011
<i>Galla palustris</i>	perennial	emergent	2	unknown	rhiz	3	division [Cat. C], rhiz [Cat. A], seed [Cat. E]	5 - 9/ovary	2	human, animal	moderate	1	10 - 20.3 - 30.5cm L	5 - 10 - 15.2 - 30cm L	1.5 - 2.5 - 6.4cm L (spadix)	berry, 5 - 10mm L	3 - 5mm L	Flwr late spring to summer (May to August)	avg. annual min temp -45.6°	moderate to high	<0.5‰	acidic (5 - 6.5)	nutrient rich	M	Hill, 1918; Cook, 1974; FONA, 1993; Rook, 2002; PFAF, 2010; USDA, NRCS, 2011
<i>Galtha palustris</i>	perennial	emergent, can be submerged	2	unknown	rhiz	2	division of root, rhiz [Cat. A], seed [Cat. E]	3000	2	human, animal	slow to moderate	1	20.3 - 61cm L	7.6 - 17.5 - 17.8cm W	1.5 - 2.5 - 5.1cm W or 10 - 45mm D	follicle, 0.8 - 1.5cm L x 0.3 - 0.45cm W	1.5 to 2.5mm L	Flwr March to April to June, April to July (FONA)	>-39° (min), 15 - 17 - 43	moderate to high	non-tolerant (<0.5‰)	acid (5 to 7)/4.9 - 6.8	nutrient rich	M	Hill, 1918; Cook, 1974; FONA, 1993; Rook, 2002; Meades <i>et al.</i> , 2004; Beck, 2005; USDA, NRCS, 2011
<i>Caltha</i> spp.	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	15 - 35/pistil	2	human, water	moderate	1	17.5 - 30cm L	1 - 1.2cm L, 10.2cm W	to 22cm L, 2.8cm W	follicle, 0.2 - 2mm L	1.5 - 2.4mm D	Flwr very early spring (Mar to April)	min (-38°), 36 - 40	moderate to very high	<0.5‰	4.9 - 8.0	nutrient rich	M	Millsbaugh, 1887; Hill, 1918; Kurmis <i>et al.</i> , 1986; FONA, 1993
<i>Canna</i> spp.	perennial	emergent	2	unknown	rhiz	3	division, offshoot [Cat. C], rhiz [Cat. A], seed [Cat. E]	5 - 25 - 75/capsule	2	human, water	fast	1	60.7 - 91.4 - 213.4cm L [1 - 2 - 5m L, 0.6 - 0.9mmW]	20 - 70cm L, 15 - 30cm W	4 - 15cm L	capsule, 1.5 - 6cm L, 2 - 4.5cm W	4 - 10mm L, 4 - 8mm W	Flwr June to August/Oct	min: 10 - 15°	high to very high	low (slightly)	6.0 - 7.0	nutrient rich	M	OSU, 2004; Simpson, 2006; UOT, 2010
<i>Cardamine lyrata</i>	annual or perennial	submerged that can grow emergent	2	unknown	rhiz	3	cuttings [Cat. D], seed [Cat. E], rhiz [Cat. A]	1 - 300 (genus)], 14 - 18	1	human	moderate to fast	1	20 - 30cm L, 2 - 4cm W	blade: (0.7-)1-2.2(-3) x 0.7-2(-2.3) cm	5 - 8cm W	capsule, (1.5-)2-3(-3.5) cm x 1.5-2 mm	2 - 3 x 1 - 2mm	Flwr Nov to March/ May to June [wild], seeds ripen thru Sept	15 - 22 - 24/10 - 25	low to moderate to high	non-tolerant (<0.5‰)	neutral pH (6 - 8)/6 - 6.5	nutrient rich	M	Cook, 1974; Mondadori, 1976; Hiscock, 2003; Eforas, 2008a; Diszhalak, 2009; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Carex albula</i>	perennial	emergent	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	1	1	human	slow to moderate	1	20 - 30.5cm L	to 25.4cm L, 1.6mm W	insignificant	achenes	unknown	Flwr mid summer	0 to -12° (min), 10 - 24	moderate to high	non-tolerant (<0.5‰)	5.5 - 6.5	nutrient rich	M	Palé, 2005; MBG, 2010; SMG, 2001; Dave's Garden, 2011
<i>Carex buchananii</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	1	human	moderate	1	30 - 60cm L	to 45 - 50cm L	5 - 30mm L	achenes	Flwr spring to summer	Flwr early - mid summer	frost (-22 to -9°), 15 - 20	moderate to very high	non-tolerant (<0.5‰)	5.0 - 8.5	moderate nutrients	M	Palé, 2005; MBG, 2010; Dave's Garden, 2011; PDL, 2011
<i>Carex crinita</i>	perennial	emergent	2	unknown	stem cuttings	2	seed [Cat. E], shoot/sprig [Cat. C]	1	3	human, animal, water	slow to moderate	1	40 - 150cm L	4 - 10mm W	male: 3 - 6mm W, female: 3 - 10cm L	achenes, 0.32cm L	2 - 4mm L	Flwr May to July, June to Aug	(-33°) (min), mean annual 7 - 9, mean monthly 18 - 24	low to moderate	<0.5‰	4.0 - 7.5	moderate nutrients	D	Andreas & Bryan, 1990; FONA, 1993; Palé, 2005; USGS, 2006a; LBW/C, 2011; Sagebud, 2011; USDA, NRCS, 2011
<i>Carex glauca</i> (syn. <i>Carex flacca</i>)	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, water, animal	slow	1	10 - 15 - 30 - 35 - 60cm L, 1.5mm W	15 - 20 - 35cm L, 3 - 4mm W	male: 15 - 30 - 40 - 50mm L, 1.5 - 3mm W; female: 10 - 50mm L, 4 - 6mm W	achenes, 1.6 - 2 - 2.5 - 4mm L, 1.1 - 1.6mm W	1.5 - 2.5mm L, 1 - 1.5mm W	Flwr June to July, fruit July	hardy to -18°, 4 - 22	low to high	tolerant	alkaline, neutral,acidic, 5.5 - 6.5	nutrient poor	D	Taylor, 1956; FONA, 1993; Faucon, 2003; Dave's Garden, 2011
<i>Carex grayi</i>	perennial	emergent	2	unknown	frag	3	seeds [Cat. E], rhiz [Cat. A], sprig [Cat. C]	1	3	animal, human, water	slow	1	(25-)40-90(-110) cm L	12 - 34cm L, 4 - 11mm W (blade)	male: 40 - 120cm L/1 - 6cm L; female: 12.5-20mm L, 2.5 - 4-8 mm W	achenes, 3.3 - 4.8mm L, 2.6 - 3.7mm W	7 - 10mm L	Fruit May to August, Flwr May to Oct	frost hardy, 10 - 24 - 30 (genus), germn 18 - 22	low to very high	non-tolerant (<0.5‰)	4.5 - 7.5/5.7 - 7.2	nutrient rich	M & D	Cook, 1974; FONA, 1993; Beck, 2005; MBG, 2010; Hilty, 2011; Sagebud, 2011; WSDE, n.d.
<i>Carex retrorsa</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, animal, water	moderate	1	10 - 105cm L	blade: 3 - 10mm W	inflor: 3 - 25cm L, male: 3 - 20 - 35cm L	achenes, 1.7 - 2.1mm L	unknown	Flwr June to August, fruit July to Aug	annual mean: 13.3 to -8, annual temp range: 26.5 - 52.9	moderate to very high	<0.5‰	3.0 - 7.9	moderate nutrients	D	FONA, 1993; CCFM, 2010; Humphrey & Colanelli, 2011; UWSFP, n.d.
<i>Carex</i> spp.	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, animal, water	moderate	1	to 1.8m L	>20mm W	minute	achenes, 3 - 4mm D	minute	Flwr in winter, April to May	15 - 24	moderate to very high	tolerant incl salt marshes	6.6 - 7.8, <6.0	nutrient poor to rich	D	Lewis, 1958; FONA, 1993; King & Oudolf, 1998; NCSU, 2005; Rotreklová et al., 2011; USDAPS, n.d. WSDE, n.d.
<i>Ceratophyllum demersum</i>	perennial	submerged to floating	2	unknown	turions formed in shoots	4	seeds [Cat. E], cuttings,frag [Cat D], side shoots [Cat. C]	1/fruit	2	human, water, animal	fast/rapid	1	3 - 4m L, 3 - 5cm W	1.5 - 4cm or 0.64 to 3.2cm L	(+/-1)mm L	4 - 7mm (egg shaped with 3 spines), nut/achene, 3.5-6 × 2-4 × 1-2.5 mm	4 x 2.5mm	Flwr June to Sept	10 - 18 - 28 - 30	moderate to high	<0.5‰	neutral or alkaline (6.2 - 7.5 - 8.6)	high nutrients	M	Duke, 1962; Cook, 1974; Rook, 2002; Hiscock, 2003; APC, 2009; RUC, 2010; Texas AgrLife, 2011; GISD, n.d.d.; WSDE, n.d.
<i>Ceratopteris thalictroides</i> (syn. <i>Ceratopteris siliquosa</i>)	annual or shortlived perennial	mainly rooted but can float	2	many	runner, vegetative buds	4	vegetative buds [Cat. C], adven plitits [Cat. D], spores [Cat. E], runner [Cat. A]	32 spores	3	human, animal, wind	fast	dimorphic fronds, highly polymorphic	(0.2 -) 2 - 31cm L, 0.7 - 8mm W [sterile], (0.8 -) 4 - 46cm L, 1 - 11mm W [fertile]	(2 -) 6.5 - 59cm L, 1.3 - 20cm W [sterile], (1.8 -) 9 - 117cm L, (0.6 -) 2.6 - 48cm W [fertile]	non-flowering	capsule	96 - 124µm D (spore)	unknown	17 - 22 - 26 - 28	high	<0.5‰, 6.6‰	5.5 - 6.5 - 8	nutrient rich	M	Ford, 1902; Benedict, 1909; Cook, 1974; Loyd, 1974; FONA, 1993; Thierry & Piedou, 2005; The Planted Tank, 2008; Invasive.org, 2011; Liveaquaria.com, 2011
<i>Cladophora aegagropila</i>	perennial	submerged or floating	2	unknown	stolon/rhizoids (cirrhoids), thallus frag	3	division [Cat. C]	numerous	1	human	slow	1	2 - 3/5 - 7cm D (ball)	filaments: 0.3 - 3.5cm L	non-flowering	no fruit	16 - 46 - 120µm D	float to surface April to May	20 - 28/15 - 27	very low to moderate to high	tolerant (5 - 6%), 0 - 4‰, 6.6 - 12‰	6.2 - 8.0/6.0 - 8.5	grows best in nutrient rich	D (algae)	Acton, 1916; van den Hoek, 1982; Diszhalak, 2009; Aqua-fish.net, 2010
<i>Colocasia esculenta</i>	perennial	emergent	2	unknown	corm & cormel	3	division [Cat. C], corm [Cat. A], seed [Cat. E]	numerous, 36 - 67 (FONA), seed set rare	2	human, water	fast	1	1 - 2m L	to 60 - 90cm L, 60 - 90cm W/blade:2.5-7 cm, 17-70 "10--40 cm	spadix: 6 - 14 - 35cm L	berry, 3 - 5mm D	1 - 1.5mm L	Flwr late spring to late fall	~20°, 21 - 30	moderate to very high	<0.5‰, non-tolerant	slight acidic, 5.5 - 6.5	nutrient rich	M	Cook, 1974; Gangaram & Philip, 1988; FONA, 1993; Klattisak & Richard, 1999; Lee, 1999; Beck, 2005; Floridata, 2010; Lemke, 2011b
<i>Colocasia</i> spp.	perennial	emergent	2	unknown	corm/tuber (3 - 5 - 15cm D)	2	corm [Cat. A], seed [Cat. E]	0 - 5 - 35	1	human	fast	1	underground stems = corm	20 - 150cm L, lamina: 25 - 85cm L, 20 - 60cm W	spadix: 6 - 14cm L	berry, ca. 4mm	20 x 30µm (genus)	Flwr in summer, germn 1 - 3wks	>10°, growth best 20 - 30	moderate to high	tolerant	5.6 - 7.5	nutrient rich	M	FONA, 1993; Lee, 1999; Onwueme, 1999
<i>Cordyline</i> spp.	perennial	emergent	2	unknown	stem cuttings	3	division [Cat. C], seed [Cat. E]	2 to 16	1	human	moderate to fast	1	<40cm - 1.8m - 4.6m L	mean: 286mm L, 69.6mm W	1cm D	berry, 5 - 15mm D	>2mm L	Flwr late spring to summer	16 - 25 - 32°	moderate to high to very high	tolerant	neutral, alkaline 6.0 - 8.0	nutrient rich	M	Brown, 1914; Eforas, 2008a; Sirisena, 2010; SMG, 2001
<i>Cotula coronopifolia</i>	perennial	emergent	2	unknown	runner	2	seed [Cat. E], stolon/runners [Cat. A]	many	4	wind, animal, human, water	slow	1	5 - 30 - 60cm L	1 - 2.5 - 6.4cm L, 1 - 10mm W	0.64 - 1.9cm L, 5 - 12 - 15mm D	cypselae, 1.2 - 1.8 - 2mm L	1 - 2mm L	Flwr March to December, seeds germn late fall or winter	low tolerance of frost, 8.7 -25	very high	0.5 - 30‰	7	nutrient rich	M	FONA, 1993; USFS,PIER, 2007; Humphrey & Colanelli, 2011; SVDPL 2011d; UAA, n.d.
<i>Crassula helmsii</i>	perennial	floating	2	unknown	stem frag (10mm), turions	3	frag [Cat. D], seed [Cat. E]	2 to 5	3	human, animal, water	fast	3	10 - 130cm L	4 - 20mm L x 0.7 - 1.6mm W	3 - 3.5mm D	follicle	0.5mm L	Flwr August to December	(-6) to 30	high to very high	<0.5‰	acidic to alkaline, 6.8 - 7.2	poor (oligo) to nutrient rich (eutro)	M	EPPO, 2007; VRSC, 2009; GISD, n.d.d.
<i>Crinum calamistratum</i>	perennial	submerged	2	unknown	bulbil, rhiz, bulb (3cm D)	2	rhiz [Cat. A], bulbil [Cat. D]	few	1	human	slow	1	to 80cm - 1m L	0.7 - 1.2 - 2m L, 0.2 - 0.7cm W	tepals: 7cm L, 0.5 - 0.8cm W, tube: 10 - 12cm L	capsule or berry	unknown	Flwr every 4 - 6wks	20 - 28/12 - 26	very high	0.5 - 30‰ (to 6.6‰)	5.5 - 8.0	nutrient rich	M	Nordal & Kwembeya, 2004; The Planted Tank, 2008; Diszhalak, 2009
<i>Crinum natans</i>	perennial	emergent	2	unknown	bulb (7 - 10 or 1 - 4.5cm D)	2	from daughter plants (bulb budding) [Cat. C]	1 - 20/fruit	1	human	slow, moderate to fast	1	50 - 100cm L	1 - 1.4m L, 3 - 5cm W	tepals:5 - 9cm L, 9 - 16mm W, flwr stalk: 90cm L, tube: 10 - 18cm L	capsule or berry, 0.5 - 2cm L	to 2cm L	unknown	15 - 20 - 24 - 28	moderate to high	0.5 - 30‰	5.5 - 8	nutrient poor	M	Cook, 1974; Hiscock, 2003; Nordal & Kwembeya, 2004; Aqua fish.net, 2010; Tropica, n.d.
<i>Crinum</i> spp.	perennial	emergent	2	unknown	rhiz, bulb (30cm D), corm, tuber	1	rhiz [Cat. A]	many	1	human	slow to moderate	1	61cm L	1.2m L, 2.5 - 5cm W	inflor: 1 - 1.5m L	capsule or berry, 2.5 - 7.6cm L	7.6cm W	Flwr summer/fall/year round	(-6) to (-4) min, 24 - 28	moderate to high	frsh to saline	6.0 - 7.5, 7.9 - 8.3	moderate nutrient rich	M	Hughes & Hughes, 1992; Riehl & Barsch, 1996; Nordal & Kwembeya, 2004; Yakandawala & Samarakoon, 2006; SMG, 2001
<i>Crinum thaianum</i>	perennial	emergent	2	unknown	bulb (7cm L, 6cm D)	2	from daughter plants (bulb budding) [Cat. C]	few	1	human	slow to moderate	1	none reported	to 0.5 - 1.5 - 4m L, 1 - 3cm W	inflor: 80cm L, tepal: 6.5 - 10cm L, 0.8 - 1.5cm W, tube 12 - 14cm L	capsule or berry	ca. 2.5cm L	Flwr in summer, Oct to Dec	22 - 30/18 - 28	moderate to high	0 - 4 - 12‰	6.0 - 8.0/ 5.5 - 8.0	nutrient rich	M	Schulze, 1972; Cook, 1974; Hiscock, 2003; Nordal & Kwembeya, 2004; Animal World, 2011; Soonthornawaphat & de Silva, n.d.; Tropica, n.d.
<i>Cryptocoryne affinis</i>	perennial	submerged or emergent	2	unknown	rhiz, runner	3	cuttings [Cat. D], side shoots [Cat. C], rhiz, runners [Cat. A]	1 - 40 - many (family)	1	human	moderate to fast	1	none reported	15 - 30cm L, blade: 5 - 20cm L	inflor: 25cm L	berry/capsule	unknown	unknown	22 - 28	very high	<0.5‰	6.8 - 7.0	nutrient rich	M	Cook, 1974; Jacobsen, 1976; 1979 1980, 1985, 1987; Hiscock, 2003
<i>Cryptocoryne albida</i>	perennial	submerged or emergent	2	unknown	rhiz (0.2 - 0.8cm thick), runner (0.1 - 0.3cm thick, 5 - 20cm L)	1	runners [Cat. A]	1 - 40 - many (family)	2	human, water	slow	1	none reported	10 - 30cm L, 1 - 2cm W	unknown	berry/capsule	unknown	Flwr Oct to Dec to Feb	20 - 28	high	<0.5‰	5.5 - 8.0	nutrient rich	M	Cook, 1974; Jacobsen, 1976; 1979 1980, 1985, 1987; Hiscock, 2003; Cullen et al., 2011

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Cryptocoryne beckettii</i> (syn. <i>Cryptocoryne petchii</i>)	perennial	submerged or emergent	2	unknown	rhiz (0.75cm thick), runner (5) 10 - 15cm L	3	adventitious plantlets [Cat. D], runners [Cat. A], side shoots [Cat. C]	1 - 40 - many (family)	1	human	moderate	1	none reported	blade: 3-9(-13)cm L, (1 -)1.5-3.5(-4)cm W	3 - 9cm L, 1 - 3.5cm W, spadix: 1cm L	berry/capsule	unknown	unknown	24 - 25 - 28/20 - 29	moderate to high	<0.5‰	neutral pH (6.5 - 7.5)	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Rosen, 2008; Hiscock, 2003; Thierry & Piednor, 2005; USDA, NRCS, 2011
<i>Cryptocoryne ciliata</i>	perennial	submerged or emergent	2	unknown	rhiz (5 - 10cm L, 1 - 3cm thick), runner (50cm L)	2	runners, rhiz [Cat. A], shoots [Cat. C]	1 - 40 - many (family)	1	human	slow	1	to 1m L	blade: 15 - 50cm L, 2 - 20cm W	unknown	berry/capsule	unknown	unknown	22 - 28	high to very high	to 6.6 - 12‰ (fresh & brackish)	6.8 - 7.8	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; Hargreaves, 2006; Aqua-fish.net, 2010
<i>Cryptocoryne cordata</i> (syn. <i>Cryptocoryne blassii</i>)	perennial	submerged or emergent	2	unknown	rhiz, runner	2	plantlets [Cat. D], runners [Cat. A]	1 - 40 - many (family)	1	human	slow	1	none reported	blade: 3 - 15cm L, 6.5cm W	unknown	berry/capsule	unknown	unknown	22 - 28	moderate	<0.5‰	5.5 - 7.0	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; Diszhalak, 2009; Aquapage.eu, 2010
<i>Cryptocoryne crispatula</i> (syn. <i>Cryptocoryne balansae</i> , <i>Cryptocoryne tonkinensis</i>)	perennial	submerged or emergent	2	unknown	rhiz (0.2 - 1cm thick), runner (0.1 - 0.3cm thick, 5 - 30cm L)	2	runners [Cat. A], form shoots @base of plant [Cat. C]	1 - 40 - many (family)	1	human	slow to moderate	2 leaf forms (aerial & subm)	none reported	blade: 10 - 70cm L, 0.2 - 4cm W	unknown	berry/capsule, 1 - 1.5mm	5 - 8mm L	Flwr Dec to Feb	23 - 25 - 28/20 - 28	undemanding but better in high	<0.5‰	5.0 - 7.0/6 - 8	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987; Efforas, 2008a
<i>Cryptocoryne griffithii</i>	perennial	submerged or emergent	2	unknown	rhiz, runner	1	rhiz [Cat. A]	1 - 40 - many (family)	1	human	slow	1	none reported	blade: 4 - 8cm L	unknown	berry/capsule	unknown	unknown	26 - 28	low to moderate	<0.5‰	6.0 - 7.0	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987; Boorman, 2063b
<i>Cryptocoryne lingua</i>	perennial	submerged or emergent	2	unknown	rhiz (1cm thick), runner	1	rhiz [Cat. A]	1 - 40 - many (family)	1	human	slow	1	none reported	blade: 2 - 4cm L, 1 - 2 - 2.5 - 3cm W	unknown	berry/capsule	0.5 - 1cm L	unknown	24 - 28	low to moderate	<0.5‰	6.0 - 8.0	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987; The Planted Tank, 2008
<i>Cryptocoryne parva</i>	perennial	submerged or emergent	2	unknown	rhiz (0.5cm thick), runner (1 - 5 - 10cm L)	2	rhiz, runners [Cat. A], side shoots [Cat. C]	1 - 40 - many (family)	1	human	slow to moderate	1	none reported	blade: 5 - 15mm L, 0.2 - 0.8cm W, to 6cm L	spadix: 0.5 - 0.8cm L	berry/capsule	unknown	unknown	25 - 28/20 - 29	very high	<0.5‰	5.5 - 8	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; APC, 2009; Tropica, n.d.
<i>Cryptocoryne pontederifolia</i>	perennial	submerged or emergent	2	unknown	rhiz, runner	1	rhiz, runners [Cat. A]	1 - 40 - many (family)	1	human	slow to moderate	1	none reported	blade: 5 - 10cm L, 10.2 - 12.7 - 30.5cm L	unknown	berry/capsule	unknown	unknown	20 - 28	low to moderate	<0.5‰	weak acid to neutral (6.0 - 7.2)	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; APC, 2009; Aqua-fish.net, 2010
<i>Cryptocoryne pygmaea</i>	perennial	submerged or emergent	2	unknown	rhiz, runner	1	rhiz [Cat. A]	1 - 40 - many (family)	1	human	slow	1	none reported	1.5 - 5cm L, 1 - 1.5cm W	unknown	berry/capsule, 3cm L	unknown	unknown	18 - 29	low to moderate	<0.5‰	6.5 - 7.0	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987
<i>Cryptocoryne retrorsipalis</i>	perennial	submerged or emergent	2	unknown	rhiz (0.5 - 1.5cm thick), runners (c. 0.3cm thick, 10 - 23cm L)	1	rhiz [Cat. A]	1 - 40 - many (family)	2	human, water	slow	1	none reported	15 - 40cm L, 0.3 - 1.0(-1.5)cm W	unknown	berry/capsule	unknown	Flwr Oct to Dec to Feb	20 - 28	low to high	<0.5‰	6.0 - 7.5	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987
<i>Cryptocoryne spiralis</i>	perennial	submerged or emergent	2	unknown	rhiz, runner	1	rooted rhizomes/rhiz divsn/runners [Cat. A]	6/berry	1	human	slow	1	none reported	blade: 15 - 30cm L, 1 - 1.5cm W	inflor: 11 - 12cm L	berry/capsule	unknown	Flwr Jan to Feb	22 - 28	low to moderate	<0.5‰	6.5 - 7.5	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Kulkarni <i>et al.</i> , 1983; Hargreaves, 2006; Liveaquaria.com, 2011
<i>Cryptocoryne</i> spp.	perennial	submerged or emergent	2	unknown	rhiz, runner	1	rhiz [Cat. A]	1 - 40 - many (family)	1	human	slow	1	none reported	75cm L	unknown	berry/capsule	unknown	unknown	20 - 33	low to moderate	<0.5‰	acid/neutral but can do alkaline, 6.0 - 8.5	nutrient rich	M	Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003
<i>Cryptocoryne undulata</i> (syn. <i>Cryptocoryne willisii</i>)	perennial	submerged or emergent	2	unknown	rhiz (1cm thick), runner (bulbil-like)	2	adventitious plantlets [Cat. D], rhiz [Cat. A]	1 - 40 - many (family)	1	human	slow to moderate	1	7 - 15cm L	5 - 15 - 20cm L, lamina: 3 - 7cm L, 1 - 1.5cm W, blade (0.5) 1 - 2 (3) x 3 - 10 (15)cm	spadix: c. 1cm L	berry/capsule	unknown	unknown	22 - 28/20 - 28	low to moderate to high	<0.5‰	5.5 - 8.0	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; Aquapage.eu, 2010
<i>Cryptocoryne wendtii</i>	perennial	submerged or emergent	2	unknown	rhiz (1cm thick), runner (10 - 20cm L)	2	shoots [Cat. C], runners [Cat. A]	1 - 40 - many (family)	1	human	slow to moderate to fast	1	none reported	blade: 3 - 15 - 25 x 1 - 3 - 6 - 8cm	spadix: to 1cm L	berry/capsule	unknown	unknown	24 - 28/22 - 30	low to moderate to high	0 - 4 - 12‰	neutral or slight alkaline (6.5 - 7.5)/ 5 - 7	nutrient rich	M	Cook, 1974; Jacobsen, 1976, 1979, 1980, 1985, 1987; Hiscock, 2003; The Planted Tank, 2008; Liveaquaria.com, 2011
<i>Cyperus alternifolius</i>	perennials	emergent	2	unknown	rhiz	4	division [Cat. C], plantlets [Cat. D], seed [Cat. E], rhiz [Cat. A]	1	3	human, water, animal	moderate	1	culm: 0.4 - 0.6 - 2 - 3m L, 4 - 7mm/2 - 3mm D	sheath-like, >30cm L	spike: 3.5-9 x c. 2 mm, spikelet: 4.1 - 7.2 - 20 (china) x 1.1 - 2.6mm	nut/achene c. 0.6 - 1.1 - 1.4mm L, 0.3- 0.5 mm W	small	Flwr in summer, flwr & fruit thru'out the year	21 - 27	moderate to high	tolerant	5.5 - 6.5 - 7.5	nutrient rich	M	Cook, 1974; Bajinath, 1975; FONA, 1993; Beck, 2005; Langeland <i>et al.</i> , 2008; Floridaa, 2010; Liveaquaria.com, 2011
<i>Cyperus haspan</i>	perennials or annuals	emergent	2	unknown	rhiz	3	division, sprigs [Cat. C], seed [Cat. E], rhiz [Cat. A]	1	2	human, water	moderate to fast	1	culm: (2) - 25 - 60 - (100 - 150)cm L x 1 - 4 mm W	sheath-like, (3-)10-30cm L x (1-)2.5-5mm W	spikelet: 3 - 18mm L, 1 - 1.6mm W	achene: 0.5-0.6(-0.7) x 0.3-0.4(-0.5) mm	small	Fruit in summer, Flwr summer and early fall	21 - 27, min >-14°	moderate to high to very high	high tolerance	4.5 - 6.5 - 7.5	nutrient rich	M	Cook, 1974; FONA, 1993; Beck, 2005; USFS, PIER, 2007; Efforas, 2008a; Liveaquaria.com, 2011
<i>Cyperus helferi</i>	perennials	emergent, can be submerged (amphibious)	2	unknown	rhiz	3	rhiz [Cat. A], daughter plants [Cat. C], seed [Cat. E]	1	2	human, water	slow	1	20 - 35cm L	unknown	small	nut/achene	small	unknown	<27°, 20 - 30	moderate to high	tolerant	5.0 - 7.0	nutrient rich	M	APC, 2009; Aquascapingworld, n.d.; Tropica, n.d.
<i>Cyperus longus</i>	perennials	emergent	2	unknown	rhiz/runners	3	division [Cat. C], rhiz,runner [Cat. A], seed [Cat. E]	1	2	human, water	fast	1	2 - 3mm D	sheaths 20 - 30cm L, blade to c. 50cm L, 7mm W	spike: 5 - 15 x 1.5mm	nut/achene: c. 1 x 0.5mm	small	Flwr June to Oct, seed germin 2 - 6wks @18°	hardy to -15°, 10 - 30	moderate to high	tolerant	acid, alkaline, neutral, 6.0 - 8.0	nutrient rich	M	Cook, 1974; Beck, 2005; FAO, 2007; Efforas, 2008b; PFAF, 2010
<i>Cyperus papyrus</i>	perennials	emergent	2	unknown	rhiz (3 - 6cm thick)	2	rhiz, rhiz divsn [Cat. A], seed (not rcmd) [Cat. E]	1	3	human, wind, water	fast	1	culm: 300 - 500cm x 15 - 45mm	bladeless	spikes: 10 - 20 x 6 - 10mm, spikelets: 6 - 10 x 0.8 - 1mm	nut/achene: 0.8 - 1 x 0.4mm	small	Fruit in summer, Flwr thruout year in Egypt except winter	20 - 30	very high	tolerant	6.0 - 8.5	nutrient rich	M	Cook, 1974; Purdue, 1988; FONA, 1993; Archer, 2004
<i>Cyperus</i> spp.	annual or perennial	emergent	2	unknown	rhiz	2	rhiz or stolons [Cat. A], seed [Cat. E]	1	4	human, water, wind, animal	fast	1	to 5m L	sheath-like, blade: 1 - 140cm L	inflor: to 20cm L, spikelet: 2 - 40mm L, 0.7 - 5mm W	achene, 0.6 - 2.7mm L, 0.3 - 1.3mm W	small	Flwr June to August	20 - 30	moderate to very high	tolerant	5.6 - 8.5	nutrient rich	M	Cook, 1974; Lunkai <i>et al.</i> , 2010
<i>Dichromena colorata</i> (syn. <i>Rhynchospora colorata</i>)	perennial	emergent, can be submerged	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, wind, animal	moderate	1	10.2cm - 61cm L, rhiz, 2m D	10.2 - 40.6cm L, 0.5 - 3 - 6.4mm W (blade)	spikelet: 5 - 7mm L	achene, 1.5 - 1.7 (- 2)mm L, 1 x 0.5 - 0.7mm (midpt), tubercle 0.5 - 0.6mm	seed bracts 5cm W	Fruit May to August, Flwr June to August	winter (-4 to -1), 15 - 31	moderate to high	tolerates 0.5 - 30‰	4.6 - 7.8	likes additions of nutrients	M	FONA, 1993; Darke, 1999; SMG, 2001; Speichert & Speichert, 2004; Dave's Garden, 2011; LBJWC, 2011; UFLIFAS, 2011

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Didiplis diandra</i>	annual or shortlived perennial	submerged or emergent	2	unknown	frag	3	cuttings, stem frag [Cat. C], side shoots [Cat. C], seed [Cat. E]	many	2	human, water	moderate to fast	1	25 - 38cm L, 2 - 4cm W	7 - 25mm L x 2 - 4.5mm W	1mm D	capsule, 0.5mm D	tiny or upto 4mm L	Flwr late June to early Sept	24 - 28/20 - 26/18 - 25 (opt 22 - 26)	moderate to very high	<0.5‰	5 - 8 (TROPICA)	nutrient rich	M	Cook, 1974; Hiscock, 2003; Thierry & Piednor, 2005; Winterton & Scher, 2007; The Planted Tank, 2008; APC, 2009; Diszhalak, 2009
<i>Dracaena fragrans</i>	perennial	emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	1	2	human, animal	slow	1	1 - 15m or more L, 30cm D	(12-) 20 - (30 - 40) - 125 - 150cm L, (1-) 2 - (3 - 4) - 10 (- 12)cm W	(15-) 18 - 22 (- 25)mm L	berry, 11 - 18mm L, 13 - 19mm D	6 - 14mm L x 5 - 9mm W x 4 - 7mm D	Flwr late fall early winter	16 - 24, not less than 13, some say min is 4	moderate to very high	low	6.1 - 6.5	low	M	Bos, 1984; Bos, 1992; USFS,PIER, 2007; Dave's Garden, 2011; Sagebud, 2011; USDA, NRCS, 2011
<i>Dracaena sanderiana</i>	perennial	emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	1	1	human	slow	1	to 1.5m L	15 - 25cm L, 1.5 - 4cm W	unknown	berry	unknown	Flwr autumn, winter, early spring	15 - 25	moderate to high indirect light	non-tolerant	6.1 - 6.5	low	M	Bos, 1984; Dave's Garden, 2011
<i>Dracaena</i> spp.	perennial	emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	ovary 3-locular, each with 1	2	human, animal	slow	1	<10cm to >40m L	>1m L	perianth: <1cm to >5cm L	berry, <0.5cm to >2.5cm D	unknown	unknown	22 - 28/18 - 32, min 10	moderate	non-tolerant to low	6.0 - 6.5	low	M	Brown, 1914; Bos, 1984; Pooleet al., n.d.
<i>Drosera</i> spp.	perennial or annual	emergent	2	unknown	bud	2	seed [Cat. E], budding [Cat. C]	3 - ∞	4	human, wind, water, animal	slow	1	1cm - 1m L	1m L, 1.5cm D	unknown	capsule	unknown	unknown	temp varies depends on type, germn 14 - 32, 10 - 35, dormant 3 - 7	moderate to very high	0.5 - 30‰	3 to 7	nutrient poor	M	Crowder et al., 1990; Franco, 2000; Schnell, 2002; Willis & Shaw, 1919
<i>Dulichium arundinaceum</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, animal, water	moderate	1	30 - 91.4 - 100cm L	2.5 - 7.6cm L x 0.4 - 0.8cm W	1.5 - 2.5cm L	nut or achene, 2.5 - 4mm L	2 - 4 x 0.8 - 1.1mm	Flwr July to Sept (AON), Fruit in August	min -38°, 40 - 41	high to very high	<0.5‰ (non-tolerant)	4.7 - 7.5	moderate nutrient	M	FONA, 1993; Rook, 2002; Sagebud, 2011; USDA, NRCS, 2011
<i>Echinodorus argentinensis</i>	short-lived perennial	emergent	2	unknown	rhiz (8cm L, 4cm D)	3	adven plts [Cat. D], rhiz divsn [Cat. A], seed [Cat. E]	1	1	human	fast	1	90 - 150cm L	80 - 120cm L (emergl)/ 27 - 44.5cm L, 21 - 39cm W (blade)	to 4cm L, 0.8 - 3 - 4cm D, 6 - 10.3mm L, to 5.5mm W (petals)	achene, 2.2 - 3mm L, 0.7 - 1mm W, beak 0.4 - 0.5 - 1mm L	fruitlet, 1.4mm	Fruit & flwr Oct to May	22 - 28	high	<0.5‰	6.0 - 7.5	nutrient rich	M	Fassett, 1955; Riehl & Raenoch, 1993; Haynes & Holm-Nielsen, 1994; Aquapage.eu, 2010
<i>Echinodorus bleherae</i> (syn. <i>Echinodorus paniculatus</i>)	annual or short-lived perennial	submerged or emergent (amphibious)	2	unknown	bud, rhiz (3cm L, 4cm D)	4	adventitious plantlets [Cat. D], budding in the wild [Cat. C], seed [Cat. E]	1	1	human	slow to moderate	3 (terres, intermediate, amphib)	40 - 150 (-200 to 350)cm L, 0.3 - 1.5cm W	30 - 50cm L, 4 - 8cm W/12.5 - 27cm L, 1.4 - 15cm W (blade)	16mm W, 0.7 - 1.3 - 2.3cm L, ca. 6mm W (petals), crwn: 3 - 4.5cm D	aggregate fruit (globular) 0.6 - 0.9cm D	nutlet/achene, 1.5 - 2 - 2.5 - 3mm L, 0.4 - 0.8mm W, beak 0.5 - 0.7mm L	Flwr & fruit year round	24 - 28/20 - 30	moderate to high	<0.5‰	6.5 - 7.5/5.5 - 8	nutrient rich	M	Fassett, 1955; Rataj, 1968; Rataj, 1970; Cook, 1974; Haynes & Holm-Nielsen, 1994; Hiscock, 2003; Hargreaves, 2006; Tropica, n.d.
<i>Echinodorus bolivianus</i> (syn. <i>Echinodorus latifolius</i> , <i>Echinodorus angustifolius</i> , <i>Echinodorus quadricostatus</i>)	annual	submerged or emergent (amphibious)	2	unknown	rhiz/runners	1	rhiz/runner [Cat. A]	1	1	human	fast	2 leaf forms	to 45cm L	1 - 7.4cm L, 0.2 - 1.8cm W (emerg), 3.8 - 6.5cm L, 1 - 1.5cm W (subm)	8 - 15mm W/2.5 - 4.1mm L, 0.8 - 3mm W (petals)	achene/nutlet, 0.8 - 1.8mm L, 0.8 - 1.3mm W, beak 0.1 - 0.3mm L	small	Flwr & fruit year round in tropics	15 - 30, opt 24 - 28	high (bright)	<0.5‰	6.0 - 8.0 (TROPICA)	nutrient rich	M	Fassett, 1955; Haynes & Holm-Nielsen, 1994; Hargreaves, 2006; Aqua-fish.net, 2011; Tropica, n.d.
<i>Echinodorus cordifolius</i>	perennial (short-lived)	emergent	2	unknown	rhiz (6cm L)	3	adventitious shoots [Cat. C], seed [Cat. E], rhiz [Cat.A]	1	1	human	moderate	1 leaf forms, subm not seen	to 100cm L	6.5 - 32cm L, 2.5 - 19.1 cm W (emerg blade)	12mm L, to 25mm W, 8 - 10.5mm L, ca. 7.5mm W (petals)	nutlet/achene, 2 - 3.5mm L, 0.9 - 1.5 mm W, beak 1 - 1.3mm L	small	Flwr late summer to early fall	19 - 22 - 28	undemanding but does better in good lighting	<0.5‰	6.5 - 7.5	nutrient rich	M	Fassett, 1955; Cook, 1974; Haynes & Holm-Nielsen, 1994; Hiscock, 2003; LEJWC, 2011; Liveaquaria.com, 2011
<i>Echinodorus gabrieli</i>	annual or perennial	submerged or emergent (amphibious)	2	unknown	rhiz	3	adven plts [Cat. D], rhiz divsn [Cat. A], seed [Cat. E]	1	1	human	slow	1	10 - 20cm L	unknown	unknown	achene/nutlet	small	unknown	22 - 28	moderate	<0.5‰	6.5 - 7.5	nutrient rich	M	Fassett, 1955; Haynes & Holm-Nielsen, 1994; The Planted Tank, 2008
<i>Echinodorus grandiflorus</i> (syn. <i>Echinodorus muricatus</i>)	short-lived perennial	emergent	2	unknown	rhiz (8cm L, 4cm D)	3	adven plts [Cat. D], rhiz divsn [Cat. A], seed [Cat. E]	1	1	human	fast	1	90 - 150cm L	80 - 120cm L (emergl)/ 27 - 44.5cm L, 21 - 39cm W (blade)	to 4cm L, 0.8 - 3 - 4cm D, 6 - 10.3mm L, to 5.5mm W (petals)	achene, 2.2 - 3mm L, 0.7 - 1mm W, beak 0.4 - 0.5 - 1mm L	small	Fruit & flwr Oct to May	22 - 28	high	<0.5‰	5.5/6.0 - 7.5	nutrient rich	M	Fassett, 1955; Rataj, 1969; Haynes & Holm-Nielsen, 1994; Aquapage.eu, 2010
<i>Echinodorus grisebachii</i>	short-lived perennial	submerged or emergent (amphibious)	2	unknown	rhiz (2cm W)	3	seed [Cat. E], adven plts [Cat. D], roots/runner [Cat. A]	1	1	human	slow to moderate	1	to 100cm L	6 - 22.5cm L, 1.5 - 4cm W (emerg), 7.5 - 22.5cm L, 0.3 - 1.7cm W	to 1cm W, ca. 5mm L, 3mm W (petals)	achene/nutlet, 1.8 - 2.3mm L, 0.8 - 1mm W, beak 0.5mm L	small	Flwr & fruit year round	22 - 28	moderate to high	<0.5‰	6.0 - 7.3	nutrient rich	M	Fassett, 1955; Haynes & Holm-Nielsen, 1994; Diszhalak, 2009
<i>Echinodorus martii</i> (syn. <i>Echinodorus major</i>)	short-lived perennial	submerged or emergent (amphibious)	2	unknown	rhiz (2cm W)	3	rhiz [Cat. A], adven plantlets [Cat. D], seed [Cat. E]	1	1	human	moderate	2 leaf forms	to 80cm L	6 - 34cm L, 1.5 - 6.1cm W (emerg), 12cm L, ca. 2cm W (subm)	ca. 1.5cm W, ca.6.3mm L, ca. 4.2mm W (petals)	nutlet/achene, 1 - 2.1mm L, 0.5 - 1.5mm W, beak 0.2 - 0.3mm L	small	unknown	18 - 22 - 28 - 30 (opt 23 - 25)	moderate to very high	<0.5‰	slight acidic (6.5 to 7.5)	nutrient rich	M	Fassett, 1955; Cook, 1974; Haynes & Holm-Nielsen, 1994; Hargreaves, 2006; Liveaquaria.com, 2011
<i>Echinodorus palaefolius</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	adven plttts [Cat. D]	1	1	human	moderate	1	to 100cm L	7.5 - 22.5cm L, 5.5 - 19cm W (emerg blade), leaves 10 - 100cm L	ca. 20mm W, ca. 8mm L, ca. 6mm W (petals)	nutlet/achene, ca. 2.2mm L, ca. 1mm W, beak 1 - 1.5mm L	small	Flwr Jan to June	20 - 28	moderate to very high	<0.5‰	5.5 - 8	nutrient rich	M	Fassett, 1955; Haynes & Holm-Nielsen, 1994; The Planted Tank, 2008
<i>Echinodorus</i> spp.	annual or perennial	submerged or emergent (amphibious)	2	unknown	rhiz/runners	3	rhiz/runner [Cat. A], seed [Cat. E], adven plttts [Cat. D]	1	1	human	slow to moderate to fast	1	10.2 - 61cm L	unknown	unknown	achene/nutlet	unknown	Flwr July thru Sept	18 - 25	moderate to very high	tolerant to 2.6 - 4‰	5.0 - 8.0	nutrient rich	M	Fassett, 1955; Haynes & Holm-Nielsen, 1994; Tropica, n.d.
<i>Echinodorus tenellus</i> (syn. <i>Helanthium tenellum</i>)	annual	submerged or emergent (amphibious)	2	2 rhiz/week	rhiz/runners	3	runners, rhiz [Cat. A], seed [Cat. E], adven plttts [Cat. D]	1	1	human	variable depending on conditions, fast	1	3 - 20 - 25cm L	1 - 7.4 x 0.2 - 0.5cm (emerg), 5cm L, ca. 0.2mm W (subm)	6 - 8mm W/2.5 - 4.1mm L, 1.5 - 3mm W (petals)	nutlet (flattened), 0.8 - 1.5 x 0.8 - 1mm, beak 0.1 - 0.2mm L	small	Flwr summer to fall, Flwr & fruit thru year in tropics	22 - 30/17 - 27/19 - 30	moderate to high	0.5 - 30‰	prefer neutral or slight acidic (6.2 to 7.5)	nutrient rich	M	Fassett, 1955; Cook, 1974; FONA, 1993; Haynes & Holm-Nielsen, 1994; Hiscock, 2003; Hargreaves, 2006; Liveaquaria.com, 2011; Tropica, n.d.
<i>Echinodorus uruguayensis</i> (syn. <i>Echinodorus osiris</i> , <i>Echinodorus barthii</i>)	perennial	submerged & emergent (amphibious)	2	unknown	rhiz (1cm L)/runners	3	side shoots from rhiz/runner [Cat. C], adven plantlets [Cat. D], rhiz [Cat. A]	1	1	human	moderate	2 leaf forms	(20)-30-(45) - 85cm L	7 - 17cm L, 2.1 - 4.7cm W (float), 3.2 - 34.1cm L, 0.9 - 3.9cm W (subm)	1 - 1.5cm D or ca. 2.8cm W/1.3mm L, 9mm W (petals)	nutlet, 1 - 1.5 - 2mm L, 0.5 - 0.7mm W, beak 0.1 - 0.7mm L	small	Flwr & fruit August to May	10 - 27 (opt 20 - 25)	undemanding but some say moderate to high	tolerant to 0.4‰	slight acidic, 5 - 8	nutrient rich	M	Fassett, 1955; Cook, 1974; Haynes & Holm-Nielsen, 1994; Rataj, 1970; Hiscock, 2003; APC, 2009; Tropica, n.d.
<i>Egeria densa</i> (<i>Elodea densa</i>)	perennial	submerged	2	unknown	stolon, frag, branches, root crown	4	cuttings/frag [Cat. D], side shoots/branches/stem [Cat.C], root crowns/runner [Cat. E]	6 to 7	2	human, water	fast [1.3cm/day]	1	3 - 4m L, 1 - 2 - 3mm D	1 - 3cm/4cm L, 2 - 5mm W	male 4.9 - 10.5mm L x 3.3 - 8mm W; female 4 - 8.5mm L x 4 - 7mm W	11.5 - 14.5mm L x 4 - 5.5mm W	5.5 - 7.2mm L x 2mm W, beak 3 - 3.7mmL	Flwr June to Oct	18 - 26/16 - 20/4 - 40	moderate to high	<0.5‰	slight alkaline, 5 to 8 (TROPICA)	nutrient rich	D	Cook & Urmi-König, 1984; Catling & Wojtas, 1986; Hiscock, 2003; Pennington, 2009; CIPA, 2011; GSD, n.d.d; WSD, n.d
<i>Egeria</i> (<i>Elodea</i>) <i>najas</i>	perennial	submerged	2	unknown	frag, branches, root crown	3	seed [Cat. E], side shoots/branches/stem [Cat. C], root crowns [Cat. A],	6 to 9	2	human, water	fast to very fast	1	0.8 - 1.5mm D	7.5 - 25mm L (14.5+/-4.8), 0.8 - 2.5mm W (1.54+/-0.44)	male 3.5 - 9mm L x 2.6 - 7.5mm W; female 2.8 - 5.7mm L x 2.5 - 5.1mm W	7.5 - 8.0mm L x 2.6 - 3.5mm W	2.8 - 4.2mm L, beak 1.6 - 2.1mm L	Flwr June to Oct	19 - 27/20 - 32/16 - 28	low to high	<0.5‰	6.0 - 7.2 - 8	nutrient rich	D	Cook & Urmi-König, 1984; The Planted Tank, 2008; APC, 2009; Aquapage.eu, 2010
<i>Eichhornia azurea</i>	perennial	rooted species: floating-leaved (submerged/e mergent)	2	unknown	stem fragm.	3	cuttings [Cat. D], seed [Cat. E], stem frag [Cat. C]	10 to 13	3	human, water, wind	moderate	3 (FONA)	8 - 12 - 20.3cm L	7-16 x 2.3-16cm (blade), 7.6 - 25.4cm L x 1.3cm W	1.3 - 5.1cm L	capsule, 1cm L	1 - 1.8 x 0.8 - 1.1mm/1.5-2.6mm L x 0.3 - 0.9mm W	Flwr June to Oct	24 - 28/20 - 26	very high	<0.5‰	6.0 - 7.0	nutrient rich	M	Barrett, 1988; Haynes, 1988; Hiscock, 2003; Winterton & Scher, 2007

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Eichhornia crassipes</i>	annual (temperate) perennial (trop)	floating	2	unknown	offsets from stolons	2	seeds [Cat. E], daughter plants from offshoots [Cat. C]	450-500/capsule (mature), few - 5000/inflores, 10 - 60 (winged)	4	human, water, animal, wind	fast [doubles every 6 - 18 dys]	3 (FONA)	10 - 50cm L	0.91m L, 10 - 20cm Diam	7.6cm L, 4 - 6cm W	3-celled capsule, 1.5cm L	4 x 1 mm [1.1 - 2.1 L x 0.6 - 0.9mm W]	60 days (seed to young plant), 14 dy flowering cycle; July to October	20 - 26/15 - 30/5 - 40	high to very high	<0.5‰ (<15% seawater)	6.5 - 9.5	high nutrient	M	Penfound & Earle, 1948; Holmet <i>et al.</i> , 1969; Mondadori, 1976; Barrett, 1988; Haynes, 1988; FONA, 1993; Hiscock, 2003; GSD, n.d.; WSDE, n.d.
<i>Eichhornia diversifolia</i>	annual or perennial	rooted species: floating-leaved (submerged/emergent)	2	unknown	fragm., runner	3	frag/cuttings [Cat. D], seeds [Cat. E], runner [Cat. A]	numerous/<50/capsule, inflores prod >3K/ 20 - 60	2	human, water	moderate to fast	2	10 - 30cm L, 8 - 15cm W	4 - 10cm L/1.5 - 4cm L (blade)	perianth: 2cm L	capsule, 1cm L	0.8 - 1mm L, 0.4mm W	14dy flwr cycle, Flwr 10 - 15wks after germin; July to October	20 - 22 - 28	high to very high	<0.5‰	5.5 - 6.5/ 5 - 8	nutrient rich	M	NYBG, 1937; Barrett, 1988; Simpson & Burton, 2006; Winterton & Scher, 2007; APC, 2009; Invasive.org, 2011
<i>Eleocharis acicularis</i>	perennial	emergent or submerged (amphibious)	2	unknown	runners/rhiz (0.25 - 0.55m D)	3	seed [cat. E], runners/rhiz [Cat. A], offshoots [Cat. C]	1/achene	2	animal, human	slow to moderate/moderate	2 (submerged & aquatic form)	2 - 15.2cm L/ culm: 1 - 60cm x 0.2 - 0.5 - 0.7mm	absent - sheath/like	<5mm D, 0.2 - 0.64cm L, spikelet: 2 - 8 x 1 - 2mm	achenes, 0.7 - 1.1 - 1.6mm L, 0.35 - 0.6mm W	unknown	Flwr June to Oct (AON)	18 - 28/10 - 25, not below -30	high to very high	<0.5‰, moderate	slight acidic (6.5 to 7.5) or 4.5 - 7	high nutrient	M/D	Cook, 1974; Mondadori, 1976; FONA, 1993; Hiscock, 2003; Thierry & Piednor, 2005; Liveaquaria.com, 2011; WSDE, n.d.
<i>Eleocharis montevidensis</i>	perennial	emergent or submerged (amphibious)	2	unknown	runner, rhiz (0.7 - 2mm D), tuber, corn	2	runner/rhiz [Cat. A], seed [Cat. E]	1/achene	2	human, animal	moderate	1	culm: 25 - 50cm x 0.5 - 1.2mm	to 0.9mm L (sheath-like)	spikelets: 4 - 12 x (1.5) - 2 - 3mm	achene, 0.7 - 1 x 0.65 - 0.8mm	unknown	fruit spring to fall	15 - 25	very high	<0.5‰	6.3 - 7.0	nutrient rich	M	FONA, 1993; RUC, 2010; SMG, 2001
<i>Eleocharis parvula</i>	perennial	emergent or submerged (amphibious)	2	unknown	runners/rhiz, tuber (4 - 5mmL)	2	runners/rhiz/root [Cat. A], seeds [Cat. E]	1/achene	2	animal, human	moderate	1	1 - 10 - 15cm L	absent - sheath/like	spikelet: 2 - 4 x 1 - 2mm	achenes, 0.9 - 1.2mm L, 0.55 - 0.75mm W	unknown	Fruit summer to fall (north), late winter to fall (far south)	10 to 20 - 28	very high	0.5 - 30‰	5.5 - 8	nutrient rich	M	Cook, 1974; FONA, 1993; Hiscock, 2003; USDA, NRCS, 2011; Tropica, n.d.; WSDE, n.d.
<i>Eleocharis vivipara</i>	perennial	emergent or submerged (amphibious)	2	unknown	rhiz (0.5mm D)	2	adventitious plantlets [Cat. D], rhiz [Cat. A]	1/achene	2	human, animal	fast	1	culm: (4-)7-38(-45) cm x (0.1-)0.3-0.7 mm	sheath-like absent or persisting	spikelet: 3.3-9.6 x 1.2-2.3 mm	achene, 0.6-0.9 x 0.55-0.8 mm	unknown	fruit spring to fall	22 - 28	high	<0.5‰	6.5 - 7.2	nutrient rich	M	Cook, 1974; FONA, 1993; Hiscock, 2003; Aqua-fish.net, 2011
<i>Elodea canadensis</i>	perennial	submerged	2	unknown	turions, frag, swollen apices	2	seeds [Cat. E], cuttings/shoot/stem frag [Cat. D]	1 to 5	4	human, water, animal, wind	moderate to fast	1	20 - 30 - 102cm L	6 - 17mm L, 1 - 5mm W	male 3 - 20cm L; female 2 - 28cm L	5 - 6.5mm L x 2 - 3.2mm W/2 - 2.5mm D, capsules	4 - 4.5 - 5.7mm L, 1mm W	AON: flowers June to August, repro by seed rarely successful	10 - 20°, opt. 10 - 25	moderate to high	<3.5‰	6.0 - 10 (neutral, alkaline)	nutrient rich	D, rarely M, but can switch btwn 2	Cook, 1974; Cook & Urmí-König, 1985; Spicer & Catling, 1988; Bowmer <i>et al.</i> , 1995; Rook, 2002; Hiscock, 2003; Cdfa, 2011; WSDE, n.d.
<i>Equisetum hyemale</i>	perennial	emergent	2	unknown	rhiz	3	division [Cat. C], rhiz [Cat. A], spore [Cat. E]	numerous	2	human, animal	fast	1	0.6 - 1.3cm W	sheath 0.64cm L	non-flowering	cone, 2.5cm L	no seed, microscopic spores	none	18 - 27, min -15	moderate to high	0.5 - 30‰	6.1 - 6.5 - 7.5	low	M	Cook, 1974; FONA, 1993; Rook, 2002; Beck, 2005; Floridata, 2010; MBG, 2010; Dave's Garden, 2011; Liveaquaria.com, 2011; Texas AgLife, 2011
<i>Equisetum hyemale</i> var. <i>robustum</i>	perennial	emergent	2	unknown	rhiz	2	spore [Cat. E], rhiz, rhiz divsn [Cat. A]	numerous	2	human, animal	fast	1	18 - 220cm L (aerial)	sheaths 4.5 - 17 x 3.5 - 18mm	non-flowering	cone, 5.1cm L	spore	cone mature in summer	min low 30's, can bear harsh temps, 5 - 34, opt 15 - 30	moderate to high	non-tolerant, <0.5‰	6.1 - 7.5	low	M	FONA, 1993; Hilby, 2011; LBWC, 2011
<i>Equisetum palustre</i>	perennial	emergent	2	unknown	rhiz	3	division, sprig [Cat. C], rhiz, tuber [Cat. A], spore [Cat. E]	numerous	3	human, animal, water	fast	1	20 - 80cm L, 1 - 3mm W	4 - 9 x 2 - 5mm (sheaths)	non-flowering	cone, 2.5cm L	microscopic spore, 30-45 µm D	Flwr spring	<32, -2 to 18	moderate to high	non-tolerant, <0.5‰	4.0 - 7.0	low	M	Cook, 1974; FONA, 1993; Rook, 2002; FDC, n.d.
<i>Equisetum scirpoides</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], spore [Cat. E]	numerous	2	human, animal	slow	1	2.5 - 28cm L (aerial)	1 - 2.5 x 0.75 - 1.5mm (sheath)	non-flowering	cone, 2.5cm L	microscopic spore	cones mature in summer	winter hardy <(-9), -40 to 30	moderate to high	non-tolerant, <0.5‰	5.6 - 6.5	low	M	Aiken <i>et al.</i> , 1999; Hoshizaki & Mora, 2001; Rook, 2002; SMG, 2001; Dave's Garden, 2011
<i>Eriocaulon cinereum</i>	annual or short-lived perennial	emergent or submerged (amphibious)	2	unknown	stem cuttings	1	cuttings [Cat. C]	3	3	human, animal, water	slow to moderate	1	15 - 30cm L	2 - 5 - 8cm L, 0.8 - 1 - 1.7mm W	male: 2mm W; female: petals absent	capsule	0.25 - 0.4 - 0.5mm L	Flwr summer to fall, Flwr & fruit June to Oct	19 - 29/ 12 - 25	high to very high	<0.5‰	5.0 - 6.5 - 7/5.5 - 8	nutrient rich	D/M	Fona, 1993; Efforas, 2008a; The Planted Tank, 2008
<i>Eriophorum angustifolium</i>	perennial	emergent	2	unknown	rhiz	3	division [Cat. C], rhiz [Cat. A], seed [Cat. E]	numerous	2	human, wind	moderate	1	culm: 90 - 100cm L (0.8-) 1 - 1.2mm W	40cm L, 1.5 - 8mm W	spikelet: 10 - 20mm (in flwr), 20 - 50mm (in fruit), perianth 15 - 30mm L	nut/achene, 2 - 5mm	2.5 - 3 x 1 - 1.3mm	Flwr May to June, seeds ripen July to August	winter (-14.9) to (-34.4), germin @15, 7 - 27	high to very high	<0.5‰	acidic, 3.7 - 6.2	nutrient rich	M	Cook, 1974; Beck, 2005; FONA, 1993; PFAF, 2010; Dave's Garden, 2011; USDA, NRCS, 2011
<i>Eupatorium purpureum</i> (syn. <i>Eutrochium purpureum</i>)	perennial	emergent	2	none	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	1/fruit	1	human	moderate to fast	morpholy variable - 2 types	2m L	20 - 30cm L, 8 - 10cm W [blade:(7-)9-26(-30) x (2.5-)3-15(-18)cm]	30cm L, +/- 20cm D	cypselae, 3 - 4.5mm	unknown	Flwr May to Sept	tolerant to (-1°), 6 - 21	moderate to very high	tolerant	6.1 - 7.8	nutrient rich	M	FONA, 1993; MBG, 2010
<i>Fontinalis antipyretica</i>	perennial	submerged or floating, amphibious	2	unknown	stolons, pl. frag	4	from shoots [Cat. C], runner/stolon [Cat. A], frag [Cat. D], spores [Cat. E]	numerous	3	human, animal, water	moderate	1	20 - 30 - 50 - 60 - 90cm or > L, 0.2 - 0.5mm D	(2 - 4 - 9 - 10mm L) 1cm L x 0.5cm W (0.35 - 6.5 - 8.5mm W)	minute	capsule, 2 - 2.6mm L	microscopic spore	none	15 - 22/5 - 22/10 - 15	moderate to high to very high	<0.5‰	neutral, slight acidic (prefers pH <8.4, say 6 - 7)	nutrient poor, oligo-mesotrophic sps	D (bryophyte)	Cook, 1974; Mondadori, 1976; Hiscock, 2003; Dtschalak, 2009; Preston, n.d.; WSDE, n.d.
<i>Glossostigma elatinoides</i>	annuals or shortlived perennials	submerged (in shallow water)	2	unknown	rhiz/frag	3	shoots [Cat. C], rhizome plants [Cat. A], seed [Cat. E]	many	2	human, water	moderate to fast	1	1.9 - 3.1cm L	0.6 - 2 - 3.1cm L	0.95cm D, 2 - 3.5mm L	capsule, 1 - 2mm L	unknown	Flwr Dec to May	15 - 26/22 - 28	moderate high to very high	to 6.6‰ or lower	5.0 - 7.0/7.5	nutrient rich	M	Curtis, 1967; Cook, 1974; Hiscock, 2003; APC, 2009; Aqua-fish.net, 2011; RBG, 2011; Tropica, n.d.
<i>Glyceria</i> spp.	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	many	3	human, animal, water	fast	1	90 - 250cm L	14.6 - 25.4 - 30 - 60cm L, 7 - 20mm W	inflor: 15 - 45cm L, spikelet: 5 - 12mm L	caryopsis	1.5 - 2mm L	seeds prodd summer & autumn	hardy to <(-9), 15 - 20	moderate	<0.5‰	acid, neutral, alkaline	nutrient rich	M	Larson, 1993; DPIPWE, 2002; Carpenedo & Saul, 2010; SMG, 2001
<i>Gymnocoronis spilanthoides</i>	perennial	emergent	2	unknown	stem fragm. (hollow stems)	3	cuttings, frag [Cat. D], side shoots [Cat. C], seed [Cat. E]	1/fruit	3	human, water, animal	moderate to very fast (15cm/wk)	1	5 - 10 (young) - 20 (mature)mm D, 1 - 1.5m L, incr 1-2cm with age	5 - 20cm L x 2.5 - 5cm W	1.5 - 2cm D	cypsela	0.8 - 1.2 - 2 - 5mm D	Flwr late spring to late autumn, seed formn 1 mth after flwg	18 - 26/15 - 30	moderate to very high	<0.5‰ or 30 - 50‰	5.5 - 8	nutrient rich	M	Hiscock, 2003; EPPO, 2009; GSD, n.d.
<i>Hemianthus callitrichoides</i> (syn. <i>Micranthemum umbrosum</i>)	annual or perennial	submerged that can grow emergent	2	unknown	runners	3	runners [Cat. A], cuttings [Cat. D], side shoots [Cat. C]	several to many	1	human	moderate to slow/fast	1	0.5cm W, 3 - 5/10 - 20cm L	2cm L, 2cm W, 1 - 3mm L, 0.8 - 2.3cm W	tiny, 2mm L	capsule, 1mm L	minute or rarely conspicuous	Late spring to early fall	20 - 28	high	<0.5‰	5.0 - 7.5	nutrient rich	M	Liogier, 1994; Hiscock, 2003; APC, 2009; Dave's Garden, 2011; Liveaquaria.com, 2011; Aquascapingworld, n.d.
<i>Hemianthus micranthemoides</i> (syn. <i>Micranthemum micranthemoides</i>)	annual or perennial	submerged that can grow emergent	2	unknown	runners	3	cuttings [Cat. D], runners [Cat. A], side shoots [Cat. C]	several to many	1	human	moderate to fast	1	5 - 20 - 76.2cm L, 0.5 - 1cm W	2.5 - 6.35cm L	tiny, 1.3cm L	capsule, 1.3cm D	minute or rarely conspicuous	Flwr Aug to Oct	22 - 28/20 - 28	moderate to high to very high	<0.5‰	5 - 7.5 (TROPICA)	moderate to high nutrients	M	Cook, 1974; Pennell, 1923; Hiscock, 2003; Hargreaves, 2006; APC, 2009; Dtschalak, 2009; Aquascapingworld, n.d.
<i>Hemianthus</i> spp.	annual or perennial	amphibious	2	unknown	frag	2	seed [Cat. E], stem frag [Cat. D]	several to many	1	human	slow to moderate	1	0.5cm W	unknown	minute nearly invisible, petal 1 - 2mm L	capsule, 1mm L	minute or rarely conspicuous	unknown	18 - 28	very high	<0.5‰	5.0 - 8.0	nutrient rich	M	Don, 1831; Pennell, 1923; Baker, 1926; Winterton & Scher, 2007

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Hemigraphis exotica</i>	perennial	emergent (prostrate or trailing)	2	unknown	rhiz	2	cuttings [Cat. D]	6 - 20 (genus)	1	human	moderate	1	15 - 30cm L	8.89cm L	small	capsule	unknown	Late spring to summer	16 - 29	moderate to high	tolerant	6.1 - 7.5	low to moderate	M	Long, 1970; Burch & Demmy, 1986; MBG, 2010; Dave's Garden, 2011
<i>Hemigraphis repanda</i> (syn. <i>Ruellia repanda</i>)	annual or perennial	emergent	2	unknown	rhiz	1	rhiz divn [Cat. A]	6 - 20 (genus)	1	human	moderate	1	to 15.2cm L	5.08cm L	3.81cm L	capsule	unknown	Mid spring to early fall	18 - 22	moderate to very high	low	6.1 - 7.5	low to moderate	M	Long, 1970; Rauch, 1997; Dave's Garden, 2011
<i>Hesperantha coccinea</i>	perennial	emergent	2	unknown	rhiz, cormlets (sometimes)	2	rhiz, cormlet [Cat. A], seed [Cat. E]	few to many	2	human, water	fast	2 colour morphs - red & pink	to 60cm L	to 40cm L, 1cm W	30 - 35mm L	capsule, 1.5cm L	2 x 1.2cm	Flwr Dec to April, also late summer to autumn	frost hardy (-5 to -10), 7 - 9 - 20, >10	moderate to very high	tolerant	6.1 - 7.8	nutrient rich	M	Murshinyala, 2000; Goldblatt, 2003; Dave's Garden, 2011
<i>Heteranthera zosterifolia</i>	annual or perennial	emergent	2	unknown	frag	3	cuttings [Cat. D], seed [Cat. E], side shoots [Cat. C]	numerous, 10 - 200 (NAM)	3	human, water, animal	moderate to fast	2 leaf forms	5 - 12cm/30 - 50cm L	45 - 60mm L (subm or floating), 10 - 30mm L (emerg)	tiny	capsule	unknown	unknown	24 - 28/18 - 30	moderate to high to very high	<0.5‰	6.0 - 7.5	nutrient rich	M	Cook, 1974; Horn, 1988; FONA, 1993; Hiscock, 2003; Hargreaves, 2006; Winterton & Scher, 2007; APC, 2009; Tropica, n.d.
<i>Hibiscus acetosella</i>	annual or perennial (US zones)	emergent	2	unknown	frag	2	seed [Cat. E], cuttings [Cat. D]	100	3	human, water, animal	fast	1	1.8 - 2.4m L	10cm L, 10cm W (blade)	5.1 - 7.6 - 12.7cm L	capsule, 2.5cm L	3mml, 2.5mm W	Flwr fall & winter & summer	frost hardy (-12.2 to 4.5), -4 to 21	moderate to very high	low	acid, neutral, alkaline/6.0 - 6.5	nutrient rich	M	Wong, 2008; PFAF, 2010; USDA, NRCS, 2011
<i>Hibiscus coccineus</i>	perennial	emergent	2	unknown	frag	3	division [Cat. C], seed [Cat. E]	many	3	human, water, animal	fast	1	to 2.1m L	12.7 - 15.2cm L, 12 - 15cm W [blade: 10.2 - 20.3cm L]	2.4 - 3.2cm W, 7.6 - 12cm D	capsule, 1.3 - 2.5cm L	~1cm D	Flwr June to Sept	frost hardy, seeds germ @21, 21 - 23	moderate to high	<0.5‰, low	5.6 - 7.5	nutrient rich	M	Gilman, 2009e; Floridata, 2010; MBG, 2010; Dave's Garden, 2011
<i>Hibiscus moscheutos</i>	perennial	emergent	2	unknown	frag	3	division [Cat. C], seed [Cat. E], frag [Cat. D]	120/capsule	4	human, animal, water, wind	moderate to fast	1	1 - 2.5m L	8 - 22cm L	10.2 - 17.8cm W [petal: 6 - 10cm L]	capsule, 2.5 - 3cm L	2 - 3mm D	Flwr July to Sept, fruit set July to August	frost hardy (-28 to 1), opt 15 - 27 - 30	high	low, brackish, saltwater coastlines	4.0 - 7.5	nutrient rich	M	Meades <i>et al.</i> , 2004; COSEWIC, 2004; Beck, 2005; Dave's Garden, 2011; Glen <i>et al.</i> , n.d.; USDAFS, n.d.
<i>Hibiscus</i> spp.	annual or perennial	emergent	2	unknown	frag	2	seed [Cat. E], frag [Cat. D]	many	3	human, water, animal	moderate	1	1 - 2.5m L	shape & leaf varies/spp	4 - 18cm W	capsule	unknown	Flwr starting March	min 17 - 18, prefer warm, -18 to 20	moderate to high	low	5.5 - 6.5 (prefer alk)	nutrient rich	M	Ingram & Rabinowitz, 2004; Anderson, 2006
<i>Hippurus vulgaris</i>	perennial	emergent or submerged	2	unknown	rhiz	3	seed [Cat. E], rhiz [Cat. A], cuttings [Cat. D]	1	3	animal, human, wind	fast	2 leaf forms	0.61 - 1m L or 20.3 - 30.5cm L or 10 - 50cm	5.1 - 7.6cm L x 3mm W (subm), 0.64 - 2.5cm L x 0.5 - 3mm W (emerg)	inconspic (1mm L)	nut-like, 1.7 - 2 - 2.5mm D x 0.8 - 1 - 1.5mm W	1.8 - 2mm L	Flwr June to Sept (AON!), fruit mid to late summer	winter hardy <(-17), -18 to 20	high to very high	to 5‰	non-acidic (4.8 - 7.0)	nutrient rich/moderate (meso to eutro)	M	Cook, 1974; Aiken <i>et al.</i> , 1999; Rook, 2002; EBH, 2004; SMG, 2001; WSE, n.d.
<i>Hottonia palustris</i>	perennial or annual	submerged or floating	2	unknown	frag	2	side shoots [Cat. C]	49 - 93	3	human, animal, water	moderate to fast	2 forms - emerg & subm	to 30cm L, 2 - 5cm W	2 - 13cm L, 6 - 10mm W	2 - 2.5cm W	capsule, 1.5 - 3mm	0.4 - 0.6mm	Flwr May to June	16 - 26 (<27)	low to high to very high	<0.5‰	5.0 - 7.0	nutrient rich	M	Cook, 1974; Brocke <i>et al.</i> , 1989; The Planted Press Ltd (2006); The Planted Tank, 2008; APC, 2009; PFAF, 2010; Aquascapingworld, n.d.
<i>Houttuynia</i> spp.	perennial	emergent	2	unknown	runners/rhiz	3	division [Cat. C], seed [Cat. E]	6 to 9	3	human, animal, water	fast	1	15 - 23 - 40cm L	to 7.6cm L	spikes: 2.5 - 3.8cm L	capsule, 2 - 3mml	unknown	Flwr mid to late summer/May to June	hardy to -34°, >10	moderate to bright	<0.5‰	neutral, alkaline, acid/6.1 - 6.5	moderate to rich	M/D	MBG, 2010; Dave's Garden, 2011
<i>Hydrilla verticillata</i>	annual or perennial	submerged	2	1 tuber = 6000 turions/m ³ , 2,803 axillary turions/m2	hibernacula: axillary turions, subterranean turions (tubers)	3	frag [Cat. C], rhiz (tubers, turions) [Cat. A], seed [Cat. E]	rarely >5	3	water, human, animal	fast (2.5cm/dy)	highly polymorphic	2m or > L	2 - 4mm W, 6 - 20mm L	male 3mm L, 2mm W; female 10 - 50mm L, 4 - 8mm W	5 - 10 - 15mm L with linear process 3mm L (cylindrical)	2.5mm L	Flwr June to Oct	14 - 28 [opt growth 20 - 27, max temp 30]	low	7% of seawater or higher	best @7 but tolerates wide range (acidic to strong alkaline)	low to high nutrients	M or occasionally D	Cook & Lönnd, 1982b; Lal & Gopal, 1993; Langealand, 1996; Gatling <i>et al.</i> , 2003; Aquaspage.eu, 2010; CDFA, 2011; UFL/IFAS, 2011; GSD, n.d.
<i>Hydrocleys nymphoides</i> (syn. <i>Limncharis humboldtii</i>)	perennial	floating	2	unknown	rhiz, tubers, corms, bulbs	2	seed [Cat. E], runner/stolons [Cat. A]	50 to more (genus)	3	human, water, animal	fast	1	50cm L	5 - 10cm W [blade: 1.4-11.9 x 0.9-10.6cm]	6.5cm W/5 - 8cm D	10 - 14.5mm L, 2 - 3.5mm D, beak 3.5 to 5.5mm, follicle	1mm	Flwr June to August	18 to 21 - 27	moderate to high	<0.5‰	6.5 - 7.5	nutrient rich	M	Haynes & Holm-Nielsen, 1992; FONA, 1993; Beck, 2005; Liveaquaria.com, 2011
<i>Hydrocotyle bonariensis</i>	perennial	emergent (creeping)	2	unknown	runner/rhiz	2	runner, rhiz [Cat. A], seed [Cat. E]	2	3	human, animal, water	fast	1	10.2 - 15.2cm L	1.2 - 12cm D (lamina 30 - 120mm D)	umbel: 1 - 6cm D	schizocarp, 1 - 2mm L x 2 - 4mm W	unknown	Flwr April to Sept, Fruit Feb to June	should be able to tolerate high temps since found on beaches, 8 - 24	high to very high	30 - 50‰	7.0 - 9.0	low nutrients	M	Mathias, 1936; Knight & Miller, 2004; USFS,PIER, 2007; LEJWC, 2011; RBG, 2011
<i>Hydrocotyle sibthorpioides</i> (syn. <i>Hydrocotyle maritima</i> , <i>Hydrocotyle rotundifolia</i>)	perennial	emergent (creeping)	2	unknown	frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	2 (genus)	3	human, animal, water	moderate to fast	1	<25cm L	0.5 - 2cm W (blade: 0.5 - 1.5 x 0.8 - 2.5cm)	ca. 1.2mm (petal)	schizocarp, 0.7 - 1.5 x 1 - 1.5mm W	1mm W	Flwr & fruit April to Sept, flwr Nov & June	20 - 28	high to very high	low tolerant	6 - 8 (TROPICA)	undemanding in nutrients	M	Mathias, 1936; Cook, 1974; Keng & Keng, 1990; Hiscock, 2003; Efloras, 2008a; Texas AgriLife, 2011; USDA, NRCS, 2011
<i>Hydrocotyle</i> spp.	perennial	emergent (creeping) or floating	2	unknown	rootstock	1	rootstock [Cat. A]	2	3	human, animal, water	slow to fast	1	none reported	1 - 6.4cm D	small & inconspic	schizocarp	unknown	unknown	18 - 24 (aquatic)	low to high (condition dependent)	tolerant	6.0 - 7.5	undemanding	M/D	Mathias, 1936; Rowell, 1985; Baldwin <i>et al.</i> , 1996; Winterton & Scher, 2007; RBG, 2011
<i>Hydrocotyle umbellata</i>	perennial	floating	2	unknown	frag	2	seed [Cat. E], underground shoots [Cat. A]	2 (genus)	3	human, animal, water	fast	1	0.64cm D	5 - 75mmD/1.3 - 5cm W	0.32cm W, umbel: 1.3cm W	schizocarp, 1 - 2mm L, 2 - 3mm W	3 x 3 x 0.5mm	Flwr late July to early Sept, Fruit Aug to Nov	min (-26.2 to -28.8°C), 22 - 29	high to very high	tolerant	7.0	low nutrients	M	Mathias, 1936; Martin & Barkley, 1961; Cook, 1974; Howard & Mendelsohn, 2000; Dave's Garden, 2011; Texas AgriLife, 2011
<i>Hydrotiche hottoniiflora</i>	perennial or annual	submerged	2	unknown	frag	2	cuttings [Cat. D], lateral shoots [Cat. C]	numerous	2	human, water	fast	1	to 10.2cm L	to 70cm L	3mm L	capsule	minute or rarely conspicuous	unknown	20 - 30	moderate to high	<0.5‰	5.0 - 8.0	moderate to high nutrients	M	Winterton & Scher, 2007; APC, 2009
<i>Hygrophila angustifolia</i> (syn. <i>Hygrophila salicifolia</i>)	perennial	submerged or emergent (amphibious)	2	unknown	stem frag	2	shoots [Cat. C], cuttings [Cat. D]	12 to 18	1	human	fast	1	to 100cm L	15 - 20cm L, 1cm W or 4 - 12cm L, 0.8 - 2cm W	3mm L, petal: 1.2cm L, tube 7mm L, 2mm D	capsule, 8 - 10mm L, 1.5mm D	1mm L	Flwr Sept to Oct	22 - 28	moderate to high	<0.5‰	6.0 - 7.5	nutrient rich	M	Efloras, 2008a; APC, 2009; Aqua-fish.net, 2011
<i>Hygrophila balsamica</i>	perennial	emergent or submerged (amphibious)	2	unknown	stem frag	2	shoots [Cat. C]	6 to many/loculus	2	human, animal	fast	2 (aquatic & emergent)	3 - 7mm L, 5 - 20cm W	7cm L, 1.5cm W (subm)	small	capsule, 12 x 5mm	1.3 x 1.2mm	unknown	20 - 30	moderate to high	tolerant	6.0 - 8.0/5 - 7	nutrient rich	M	Trimen & Dassanayake, 1988; APC, 2009
<i>Hygrophila corymbosa</i>	perennials or annuals	emergent or submerged (amphibious)	2	unknown	stem frag	2	cuttings [Cat. D], side shoots [Cat. C]	6 to many/loculus	2	human, animal	moderate to fast	1	none reported	8 - 13cm L, 3 - 5cm W	unknown	capsule	unknown	Flwr June to Sept	20 - 28	moderate to high	tolerant	6.5 - 7.5/5.5 - 8	nutrient rich	M	Cook, 1974; Riehl & Baensch, 1982; Hiscock, 2003; Disshalak, 2009; Liveaquaria.com, 2011; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Hygrophila costata</i> (syn. <i>Hygrophila lacustris</i>)	perennial	submerged or emergent (amphibious)	2	unknown	stem frag	3	cuttings [Cat. D], root [Cat. A], seed [Cat. E]	12 to 18 to 20	2	human, animal	moderate to fast	1	0.5 - 1m L	3 - 18cm L, 1 - 5cm W	7 - 10mm L, 9 - 11mm W	capsule, 14 - 17mm L/6 - 8mm L	0.3 - 1mm L, 0.3mm W	Flwr & fruit December to March	22 - 28	moderate to high	tolerant	5.0 - 7.0	nutrient rich	M	Csurhes, 2008; AWC, n.d.
<i>Hygrophila difformis</i> (syn. <i>Synnema triflorum</i>)	perennials or annuals	submergent	2	unknown	stem frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	6 to many/loculus	2	human, animal	moderate to fast	1	5 - 30cm W	1 - 4cm L	1cm L	capsule, 8mm L	unknown	Flwr in summer	23 - 24 - 28/20 - 30, winter hardy -1 to -4	low to high to very high	tolerant	neutral, 6.5 - 7.5/5 - 9	nutrient rich	M	Cook, 1974; Mondadori, 1976; SMG, 2001; Hiscock, 2003; APC, 2009; Liveaquaria.com, 2011; Tropica, n.d.
<i>Hygrophila polysperma</i>	perennial	emergent or submerged (amphibious)	2	unknown	frag (stem & shoot)	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	15 - 20 - 30	3	human, water, animal	moderate to fast	2 (aquatic & emergent)	8 - 15cm W	1 - 3.5cm L x 4 - 10mm W [aquatic 8cm L x 2cm W]	8mm L	capsule, 5 - 9mm L	1 x 0.5mm	Flwr Sept to Nov, fruit Oct to Jan	10/18/20 - 30	low to high	<0.5 or 0 - 4‰	neutral/6.5 - 7.8/5 - 7 - 8 - 9	nutrient rich	M	Cook, 1974; Mondadori, 1976; Spencer & Bowes, 1985; Hiscock, 2003; USFS, PIER, 2007; APC, 2009; Diszhalak, 2009; EPPO, 2010; GISD, n.d.; Tropica, n.d.
<i>Hygrophila</i> spp.	perennials or annuals	emergent or submerged (amphibious)	2	unknown	stem frag	1	cuttings [Cat. D]	6 - 8 (or rarely 2 up to 18) in each locule, seeds 12 - 18 (rarely 4, up to 36)	2	human, animal	fast	1	0.64 - 0.95cm L	1.3 - 2.5cm L	small	capsule	unknown	unknown	16 - 27	any	tolerant	5.5 - 8.0	any	M	Long, 1970; APC, 2009; Aquapage.eu, 2010
<i>Hygrophila stricta</i> (syn. <i>Nomaphylla stricta</i>)	perennials	emergent or submerged (amphibious)	2	unknown	rhiz/stolon	2	cuttings [Cat. D]	6 to many/loculus	2	human, animal	moderate to fast	1	to 1m L	to 12cm L, 4cm W (blade: 6 - 15cm L, 2 - 7cm W)	corolla tube: 5mm L, lips ca. 12mm L, 8mm W	capsule	unknown	unknown	24 - 28/18 - 28/22 - 29	high to very high	0 - 4‰	6.3 - 7.5/5.0 - 7.0	nutrient rich	M	Cook, 1974; Ramamoorthy & Turner, 1992; Hiscock, 2003; The Planted Tank, 2008; Diszhalak, 2009
<i>Hymenocallis lirisome</i>	perennial	emergent	2	1 (genus)	bulb	2	seed [Cat. E], divsn of runners [Cat. A], bulb [Cat. A]	2 - 3/locule	1	human	fast	1	bulb, 4.5 - 6 x 5 - 6cm, neck 3 - 5cm	46cm L, 3.2 - 8.5 - 10.6dm x 1.7 - 3.6cm	4.5 - 8 (-10.5)cm L, tepal: 6 - 9cm x 4 - 8mm	capsule, 2 x 2cm	2 x 1.5cm	Flwr early to mid spring, Fruit spring to summer	16 - 27, min -3	moderate to high	tolerant	6.1 - 7.8/5.5 - 9	moderate	M	Sealy, 1954; FONA, 1993; Liveaquaria.com, 2011
<i>Hymenocallis</i> spp.	perennial	emergent	2	1 (genus)	bulb	2	bulb [Cat. A], seed [Cat. E]	2 - 10/locule	1	human	fast	1	none reported	varies (15) - 20 - 46 -(60)cm L, 6.2 - 15cm W	tube: 4 - 22.5cm L, segments: 8 - 14.5cm L (taxonomy a prob)	capsule, varies, 1 - 3.5cm L	unknown	germn few wks to 3 to 4 mths & sometimes years	prefer tropical temps, 10 - 24	moderate to very high	tolerant	5.6 - 9	moderate	M	Sealy, 1954; FONA, 1993; Speichert & Speichert, 2004; PBS, 2011
<i>Impatiens capensis</i>	annual	emergent	1	none	none	1	seed [Cat. E]	numerous	2	human, animal	fast	1	0.5 - 1.5m L	12.7cm L, 0.3 - 6.35cm W	1.9 - 3.2cm L	capsule, 1.5 - 2 - 3cm L x 1cm W	~2 x 1cm, 5 - 5.6 x 2.7 - 3.1mm	Flwr June to Sept/lasts 2mths, fruitmid-summer to early autumn	min 0°, 12 - 19	moderate to very high	<0.5‰	6.4 - 7.4	moderate	M	MBG, 2010; Hilty, 2011; Sagebud, 2011; USDA, NRCS, 2011
<i>Imperata cylindrica</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	3000/plant	3	human, wind, animal	fast	1	(10) - 30 - 95 - (217)cm L	150cm L, (1) - 3 - 11 (28)mm W	2.5 - 40.6cm L, 0.6 - 2.5cm D	caryopsis, 0.9 - 1.3mm L	small	Flwr & fruit April to August	don't tolerate cool temps well, >subfreezing, seeds germn @30, 20 - 40, opt 30	moderate to very high	high tolerance	4.5 - 7.8	nutrient rich	M	Bryson & Carter, 1993; Shillinget <i>et al.</i> , 1997; Masterson, 2007; Efforas, 2008a; Floridata, 2010; GISD, n.d.d.
<i>Iris kaempferi</i> (syn. <i>Iris ensata</i>)	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	numerous	1	human	moderate	1	60 - 70 - 90cm L	30 - 80cm x 5 - 12mm W	9 - 10 - 15cm D	capsule, 4.5 - 5.5 x 1.5 - 1.8mm	flat	Flwr June to July, fruit Aug to Sept, germn 1mth to 1.5 yr	thrives in hot climates, 18 - 23	moderate to high	tolerant threshold 0.4%, survival to 0.8%	5.5 - 6.5	nutrient rich	M	Cook, 1974; Dave's Garden, 2001
<i>Iris pseudacorus</i>	perennial	emergent	2	unknown	frag, rhiz, tubers	3	seed [Cat. E], frag [Cat. D], rhiz [Cat. A]	120 (40 fail)	3	human, water, animal	fast (aggressive)	2 floral forms	40 - 70 - 150cm L	40 - 100cm L x 1 - 3cm W	7 - 8 - 9 - 10cm W	capsule, 3.5 - 8.5cm, beak 5mm	6 - 7mm, 7.5 - 8.5 x 7.5 - 8.5mm	Flwr April to June, 2 years	18 - 27 - 30	high to very high	24‰	3.6 to 7.7 (mean 6)	nutrient rich	M	Cook, 1974; Sutherland, 1990; FONA, 1993; Liu <i>et al.</i> , 2008; Floridata, 2010
<i>Iris</i> spp.	perennial	emergent	2	unknown	rhiz, bulb	2	rhiz, bulb [Cat. A], seed [Cat. E]	4 to 20	3	human, water, animal	fast	1	from 10.2 - 15.2cm L to 122 - 152.4cm L	20 - 40cm L, 5 - 10mm W	4 - 18cm D	capsule, 3 - 5cm L	unknown	Flwr spring, summer & winter (depends on plant)	winter hardy & moderate to warm climates, 14 - 20 opt 18	moderate to very high	tolerant	4.5 - 7.7	nutrient rich	M	Winterton & Scher, 2007; APC, 2009
<i>Iris versicolor</i>	perennial	emergent	2	unknown	rhiz (1.0 - 2.5cm D)	3	division [Cat. C], rhiz [Cat. A], seed [Cat. E]	40 - 120	3	human, water, animal	fast	1	0.2 - 0.8 - 2m L, 1cm W	up to 1.2m L, 0.5 - 3cm W	1.2cm L, 6 - 8 - 15cm D, petal: 2.2 - 5.4 x 0.5 - 2.2cm	capsule, 1.5 - 6cm L, 1.9cm D	5 - 8mm W	Flwr May to July, capsules mature Aug to Sept	hardy to ~-25°, -4 to 20	high to very high	0.5 - 35‰	5 to 7	nutrient rich	M	Anderson, 1928; Cook, 1974; FONA, 1993; Roark, 2002; Meades <i>et al.</i> , 2004; PFAF, 2010; D'Aillon, 2011d
<i>Iris virginica</i>	perennial	emergent	2	unknown	rhiz (2 - 4cm D), bulb	2	rhiz [Cat. A], seed [Cat. E]	numerous, 4 - 20 (genus)	2	human, water	moderate	1	50 - 100cm L	60 - 80cm L, 2.5 - 3cm W	8.9cm W, petal: 3 - 7 x 1 - 3cm	capsule, 2 - 5.7 - 6cm L, 1.3 - 2cm W	5 - 8mm W	Flwr May to June	min temp -11°, germn 20 - 30	moderate to very high	<0.5‰	4.8 - 7.3	moderate nutrients	M	Anderson, 1928; FONA, 1993; Sagebud, 2011; USDA, NRCS, 2011
<i>Isolpis cernua</i> (syn. <i>Scirpus cernuus</i>)	annual or short-lived perennial	emergent	2	unknown	rhiz (1 - 19 x 0.3 - 1.5mm)	1	rhiz, rhiz divsn [Cat. A]	1/achene	2	human, water	moderate	1	culms: 1 - 4 - 40cm L, 0.2 - 0.5 - 1mm W	sheath: 4 - 20 - 30cm L, 0.2 - 1.8mm W, blade: 1 - 122 x 0.1 - 0.7mm	spikelet: 1.4 - 2 - 5 - 9 x 1 - 2.4mm	achene, 0.5 - 0.8 - 1.2 x 0.5 - 0.7 - 1mm	1mm L, 0.75mm W	Fruit late spring - winter (Pacific Coast), winter to spring (Texas), Bloom summer to	18 - 27 (don't tolerate frost)	moderate to very high	0.5 - 35‰	4.6 - 7.5	very poor	M	FONA, 1993; Musaya & Simpson, 2002; Dave's Garden, 2011; Humphrey & Colangeth, 2011
<i>Juncus effusus</i>	perennials	emergent	2	unknown	rhiz	3	division [Cat. C], seed [Cat. E], rhiz [Cat. A]	50 - 100	4	human, animal, water, wind	moderate	1	over 1m L, 1 - 3.5mm W (@base), culm: 1 - 2.5mm D	sheath: 5 - 15cm L (inconspic), blade absent	perianth: 1.8 - 4.2mm, tepal: 1.9 - 3.5mm L	capsule, 0.5 - 1.5 - 3.3mm L	(0.3) - 0.4 - 0.5mm L	Flwr in summer, fruit summer to fall	min -38.8°, opt 18 - 23	moderate to high	low	acidic, 5.5 - 8.8/3.5 - 7	prefer slightly enriched nutrients, tolerate of nutrient poor	M	Richards & Clapham, 1941a; Tweed & Woodhead, 1946; Cook, 1974; FONA, 1993; PFAF, 2010; RUC, 2010; Hilty, 2011; Texas AgriLife, 2011; USDA, NRCS, 2011
<i>Juncus glauucus</i> (syn. <i>Juncus inflexus</i>)	perennials	emergent	2	unknown	rhiz (3 - 5mm D)	3	seed [Cat. E], rhiz [Cat. A], division [Cat. C]	100/capsule (British Isle)	4	human, water, animal, wind	fast	1	1m L, 1 - 1.5 - 3mm W	basal: 4 - 10 - 15cm L, blade absent	2.5 - 3 - 4mm L	capsule, 3 - 4mm L	0.5mm L	Flwr & fruit in summer [Flwr June to Sept]	5 - 12 (germn), hardy to -28.9, 18 - 22 (sow)	moderate to high	tolerant, found in salt marsh	undemanding, 6.5 - 7.7	nutrient rich	M	Richards & Clapham, 1941b; Cook, 1974; FONA, 1993; Efforas, 2008b; Ashraf <i>et al.</i> , 2009; Evergreen, 2011
<i>Juncus repens</i>	perennial or annuals	submerged or emerged	2	unknown	rhiz, runner	3	rhiz, runner [Cat. A], side shoots [Cat. C], seed [Cat. E]	3 to many (genus)	1	human	moderate to fast	1	5 - 7cm W	0.5 - 1mm W, blade: 2 - 10 (- 15)cm x 1 - 3mm	0.63cm L, tepals: 5 - 9mmL	capsule, 3.5 - 5.5mm L x 0.8 - 1.2mm W	0.3 - 0.4mm L	Flwr June to August, Flwr & fruit summer to fall	15 - 30, min -11	low to very high	<0.5‰	5.0 - 8.0	low nutrients	M	FONA, 1993; APC, 2009; USDA, NRCS, 2011
<i>Juncus</i> spp.	perennials, rarely annuals	submerged or emergent (amphibious)	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	3 to many	4	animal, human, water, wind	moderate to fast	1	culm: 0.3 - 5dm L, <5mm thick	long, narrow or reduced to scales, <1 or 1 - 4.5mm W, blade: 2 - 12mm W	1.8 - 7mm L	capsules, 1 - 3 locular, 1 - 7mm L	minute, 0.3 - 0.8mm L	Flwr late spring to early fall	hardy from -34 to 1.7, 15 - 25 (germn)	moderate to high	tolerant	5.6 - 7.5	low to rich	M	Cook, 1974; FONA, 1993; Winterton & Scher, 2007; RUC, 2010; WSD, n.d.
<i>Jussiaea diffusa</i>	perennial	floating (creeping)	1	none	none	1	seed [Cat. E]	many	1	human	fast	1	30 - 40cm L	1 - 10cm L x 0.7 - 4cm W	petals: 7 - 24mm L, 4 - 10 or >mm W	capsule, 1.2 - 4cm L, 2.5 - 4mm W	1 - 1.5mm L, 0.5 - 0.7mm W	Flwr June to August/ May to Oct	opt. 15 - 25, range 8 - 30	very high or moderate	miohalophyte = salt tolerant	acid, alkaline, neutral (opt. 5.5 - 7.0), range 4.5 - 8.5	nutrient rich	M	Brenan, 1953; Hutchinsonson & Dalziel, 1968
<i>Jussiaea grandiflora</i>	perennial	floating (form mats) or emergent	2	unknown	stem frag	2	seed [Cat. E], frag [Cat. D]	many	3	human, water, animal	fast	2 (floating early stage & emergent after)	to 91.4cm L (emerg) or prostrate	to 12cm L	2 - 5cm D, petal: 15 - 30mm L	capsule, 13 - 25 - 30mm L, 3 - 4mm W	1.5mm L	Flwr in summer	winter hardy, 12 - 28, 10 - 25	moderate to very high	tolerant	acid, basic, neutral	low to high nutrients	M	Nesom & Kartesz, 2000; EPPO, 2004; USDA, NRCS, 2011; WSD, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Lagarosiphon madagascarensis</i>	perennial	submerged	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	8 to 14	3	human, water, animal	fast	1	0.3 - 1mm D	(4-) 6 - 18 (-32)mm L x 0.6 - 1.5 (-2.2)mm W	male 2.2 - 2.7mm L, 0.9 - 1.2mm W; female 2 - 4mm L, 0.6 - 1.5mm W	capsule, 2.1 - 4mm L x 0.9 - 2mm W	1 - 1.5mm L x 0.4 - 0.5mm W	Flwr June to August	18 - 25	moderate to high	<0.5‰	5.0 - 7.0	high nutrients	D	Symoens & Triest, 1983; APC, 2009
<i>Lagarosiphon major</i>	perennial	submerged	2	unknown	rhiz	3	cuttings [Cat. D], side shoots [Cat. C], rhiz [Cat.A], seed [Cat. E]	6 to 30	3	human, animal, water	fast	1	1 - 3m L x 3 - 5mm D	5 - 20 - 25mm L x 2 - 3 - 4mm W	male 3 - 5mm L, 1.9 - 2.7mm W; female 3.5 - 5.5mm L x 1.4 - 2.5mm W	capsule, 4.5mm L x 1mm W	2mm L x 0.7mm W	Flwr June to August	18 - 22 - 23 (max 25)	moderate to high	<0.5‰	alkaline (10)	high & low nutrients	D	Cook, 1974; Symoens & Triest, 1983; Hiscock, 2003; APC, 2009; GISD, n.d.d.
<i>Lemna minor</i>	perennial	floating	2	unknown	turions & buds	3	by division, budding [Cat. C], seed [Cat. E]	1	3	water, animal, human	fast [3 dys under high NO3]	1	none, root 0.5 - 15cm L, stalk 2 - 20mm L	frond/thallus, 1 - 2 - 5 - 10mm L, 0.16 - 0.32cm D	tiny, rarely seen 1mm D	utricle, 0.8 - 1mm L, 2 - 4mm x 1.5 - 3mm	uncommon, 0.7 - 1mm L, 0.4 - 0.6mm D	Flwrs (rare) late spring to summer (May to Sept)	5 - 7 - 10 - 30	undemanding, moderate to high	<0.5‰	neutral/<4/ wide range best btwn 4.5 - 7.5	nutrient moderate to rich	M	Cook, 1974; Mondadori, 1976; FONA, 1993; Rosh, 2002; Hiscock, 2003; APC, 2009; Hily, 2011; Texas Agrilife, 2011; WSDA, n.d.
<i>Leptodictyum riparium</i> (syn. <i>Amphystegium riparium</i>)	perennial	submerged	1	none	none	1	spore [Cat. E]	numerous	1	human	slow	1	prostrate, 5cm or > L	branch leaf smlr than stem leaf (2 - 3mm L), (0.8)2.5 - 4.5mm L	not known for mosses	capsule, 1 - 2 - 2.5mm L	9 - 10 - 15µm	unknown	18 - 28/10 - 25	low to high	0.5‰ (rarely in brackish)	6.0 - 8.0	moderate to rich	M (bryophyte)	Crum & Anderson, 1981; Carroll, 2003; MBG, 2010; BBS, 2011
<i>Leucocjum aestivum</i>	perennial	emergent	2	unknown	bulb 2-4 × 2-3(-4) cm	2	bulb divsn (inclgd offset) [Cat. A], offshoot [Cat. C]	numerous	2	human, water	moderate	1	to 40cm L	sheaths: 3 - 6mm, blade: 30-50(-70) × 0.5-2 cm, leaf: 0.3 - 0.6m L, 2.5cm W	tepals: (10) - 13 - 22mm L, 10 - 12mm W, flwr 2.5cm W	capsule	5 - 7 - 8mm L, 4.5 - 5.5mm W	Flwr spring to early summer/Flwr April to May, fruit July to Aug	bulbs hardy to -5°; 10 - 18 - 22	moderate to very high	<0.5‰, tolerant	neutral, alkaline, 5.5 - 8.0	high nutrients	M	FONA, 1993; Florida, 2010; PFAF, 2010; Dyatlov & Vasilieva, n.d.
<i>Lilaeopsis brasiliensis</i>	perennial	partially or entirely submerged	2	unknown	rhiz (0.2 - 1 (-1.7)mmL), runner	1	rhiz [Cat. A]	1	3	human, water, animal	slow	1	none reported	1 - 7 (-12)cm L, 0.5 - 5mm W	minute	schizocarp, 1.0 - 1.9mm L, 1.1 - 1.9mm W	unknown	Flwr Oct to Feb, mature fruit Nov to March	15 - 26 (TROPICA)	high to very high	low salt in brackish, salt tolerant (730‰)	6 - 8 (TROPICA)	nutrient rich	M	Affolter, 1985; Hargreaves, 2006; The Planted Tank, 2008; APC, 2009
<i>Lilaeopsis carolinensis</i>	perennial	submerged	2	unknown	rhiz (0.3 - 5.5mm D)	1	rhiz [Cat. A]	1	2	human, water	slow	1	none reported	(2.2-) 8 - 30 (-52)cm L, 1.4 - 16mm W	minute	(1.5-) 1.9 - 2.8mm L, 1.5 - 2.7mm W	unknown	Flwr & fruit April to August	22 - 26	high to very high	<0.5, 0.5 - 30‰	6.2 - 7.8	nutrient rich	M	Affolter, 1985; The Planted Tank, 2008
<i>Lilaeopsis mauritiana</i>	perennial	submerged	2	unknown	rhiz (0.5 - 1.2mm D), runner	1	rhiz [Cat. A]	1	2	human, water	moderate	1	none reported	2.8 - 13cm L, 0.4 - 1.3mm W	minute	schizocarp, 1.9 - 2.5mm L, 1.7 - 2mm W	unknown	unknown	18 - 33/15 - 28	low to high	tolerant	5.5 - 8.0	nutrient rich	M	Petersen & Affolter, 1999; Aquascapingworld, n.d.; Tropica, n.d.
<i>Lilaeopsis novae-zelandiae</i>	perennial	partially or entirely submerged	2	unknown	rhiz (0.6 - 3.5mm D), runner	1	rhiz [Cat. A]	1	3	human, water, animal	moderate to fast	1	none reported	0.7 - 20 (-51)cm L, 0.3 - 2.5mm W	minute	schizocarp, 1 - 2.1 (-2.6)mm L, 1 - 2.2mm W	unknown	Flwr Nov thru May, mature fruit Nov thru June	18 - 20 - 28	moderate to very high	tolerant	6.8 - 7.5	nutrient rich	M	Affolter, 1985; Hiscock, 2003; Liveaquaria.com, 2011
<i>Limnobiium laevigatum</i>	perennial	floating	2	unknown	runner	2	runners [Cat. A], seed [Cat. E]	100	3	human, water, animal	moderate to fast	1 (2 flower forms)	20cm L, 2mm D	(5-) 20 - 50 (-68)mm L, (3-) 8 - 40 (-64)mm W	male (5-) 6.5 +/- 1.3(-8.6)mm L, (0.9) 1.5 +/- 0.5 (-2.5)mm W; female (1-) 3.4 +/- 1.3(-5.5)mm L, 0.5 +/- 0.3mm W	(4-) 8.7 +/- 2.9 (-13)mm L, (1.7-) 3.7 +/- 1(-5)mm W (berry-like capsule)	0.8 - 1.2mm L, 0.6 - 0.8mm W	Late spring to early fall	22 - 24/18 - 28	high	<0.5‰	5.0 - 8.0	nutrient rich	D	Cook, 1974; Cook & Urmli-König, 1983b; FONA, 1993; Hiscock, 2003; APC, 2009; Tropica, n.d.
<i>Limnobiium spongia</i>	perennial	floating	2	unknown	stolon buds (hibernacula)	2	stolon buds [Cat. C], seed [Cat. E]	200 or more	3	human, water, animal	moderate	1 (2 leaf forms)	none reported	1 - 10cm L x 0.9 - 7.8cm W	male (5-) 9.4 +/- 2(-13)mm L, (0.6-) 1.6 +/- 0.5 (-2.2)mm W; female (4-) 9.9 +/- 3.7(-14)mm L, (0.9) 1.6 +/- 0.5 (-2.2)mm W	(4-) 9.2 +/- 3.4 (-18)mm L, (4.5-) 8.1 +/- 2 (-11.8)mm W (berry-like capsule)	0.9 - 2.3mm L, 0.6 - 1.5mm W	Flwr summer to fall	18 - 28	moderate to very high	<0.5‰	5.0 - 5.9	nutrient rich	D	Cook & Urmli-König, 1983b; FONA, 1993
<i>Limnophila aquatica</i>	annual	emergent (semi-aquatic)	2	unknown	stem frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	numerous (150 for the genus)	2	human, water	fast	1	to 25 - 50cm L	35 - 45 (-55)mm L x 6 - 11 (-20)mm W	8 - 13 (-20)mm L (petal)	capsule, 3.5 - 4mm L	small	Flwr April to Nov	22 - 26/20 - 28	high to very high	<0.5‰	slight acidic, 6.2 - 7.1	high nutrient	M	Philcox, 1970; Cook, 1974; Yang & Yen, 1997; Hiscock, 2003; Thierry & Piedra, 2005; Tropica, n.d.
<i>Limnophila aromatica</i>	annual or perennial	submerged	2	unknown	stem frag	3	side shoots [Cat. C], cuttings [Cat. D], seed [Cat. E]	numerous (150 for the genus)	2	human, water	fast	1	5 - 8cm W, 25 - 50cm L	1 - 2.5 - 5.5cm L, 0.3 - 1.5 - 2.2cm W	10.5 - 13.5mm L (petal)	capsule, 5 - 6mm L	small, 0.3mm L	Flwr & fruit March to Sept	22 - 26	high	<0.5‰	5.0 - 7.0	nutrient rich	M	Philcox, 1970; Yang & Yen, 1997; Brahmachari, 2008; APC, 2009; Aquascapingworld, n.d.
<i>Limnophila hippuroides</i>	annual	submerged	2	unknown	stem frag	2	cuttings [Cat. D], seed [Cat. E]	numerous (150 for the genus)	2	human, water	fast	1	to 60cm L	2 - 4cm L, 0.3 - 0.7cm W	7.5 - 10mm L (petal)	capsule, 3 - 3.5mm L	small	unknown	20 - 28	moderate to high	<0.5‰	5.8 - 7.2	nutrient rich	M	Philcox, 1970; Yang & Yen, 1997; APC, 2009
<i>Limnophila indica</i>	perennial	submerged or emergent (amphibious)	2	unknown	stem frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	numerous (150 for the genus)	2	human, water	moderate to fast	1	2.5 - 15cm L (aerial stem), 1m L (subm)	1.5 - 2.5 - 3cm L (subm), 0.25 - 0.4 - 1.2 - 2.2cm L (aerial)	6 - 8 - 12mm L (petal)	capsule, 3.5mm L	small, 0.3 - 0.5 - 0.7mm L, (+/-) 2.5mm D	Flwr & fruit March to November	22 - 28	high to very high	<0.5‰	7	nutrient rich	M	Obwi, 1953; Philcox, 1970; Cook, 1974; Yang & Yen, 1997; Hiscock, 2003
<i>Limnophila sessiliflora</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner	4	frag, cuttings [Cat. D], side shoots [Cat. C], runners [Cat. A], seed [Cat. E]	150 - 160/capsule [200 - 300]	2	human, water	moderate to fast	1	4 - 7cm W, 2 - 15cm L (aerial)/0.5 - 3.7m L (subm)	4 - 12 - 20mm L x 3mm W (emerg), 5 - 40mm L (subm)	5 - 8 - 10.5mm L (petals)	capsule, 3.5 - 5.5mm L	450µm L x 300µm D	Flwr July - November	15 - 22 - 28 (opt. 20 - 26)	high to very high	<0.5‰	5.5 - 8	nutrient rich	M	Philcox, 1970; Cook, 1974; Yang & Yen, 1977; Spencer & Bowes, 1985; Hiscock, 2003; APC, 2009; UFL, IFAS, 2011; GISD, n.d.d.
<i>Lindernia rotundiflora</i> (syn. <i>Lindernia microcalyx</i>)	annual	emergent	2	unknown	stem cuttings	1	lateral shoots [Cat. C]	numerous	1	human	fast	1	2.5 - 36 (-56)cm L	lamina: 2 - 16mm L, 1 - 12mm W	petal: 4 - 9mm L	capsule, 1.2 - 3.7mm L, 1 - 2.8mm D	0.22 - 0.43mm L, 0.11 - 0.3mm D	unknown	18 - 28	moderate	tolerant	5.0 - 8.0	nutrient rich	M	Lewis, 2002; The Planted Tank, 2008
<i>Lobelia cardinalis</i>	perennial	emergent	2	unknown	stem cuttings	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	578+/-241 per plant	1	human	slow to moderate	1	60 - 120cm L, 7 - 15cm W	2.5 - 4 - 12.7 - 17.8cm L, 2 - 9cm W	2.5 - 5cm L	capsule, 1.3cm W	0.9 - 1.3mm L, 0.4 - 0.5mm W	Flwr July - Sept, fruit late summer to early autumn	15 - 22 - 26/ 5 - 26	low to high	<0.5‰	6 - 8 (TROPICA)/5 - 6	nutrient rich	M	Cook, 1974; Devlin, 1989; Hiscock, 2003; Beck, 2005; The Planted Tank, 2008; APC, 2009; Florida, 2010; O'Neil, 2011c; USDA, NRCS, 2011
<i>Lobelia sessilifolia</i>	perennial	emergent	2	unknown	stem cuttings	2	cuttings [Cat. D], seed [Cat. E]	numerous	2	human, wind	moderate	1	to 90cm L	blade: 1.8 - 9 x 0.2 - 2.2cm	petals: 2.5 - 3.7cm L	capsule, 7 - 15 x 5 - 11.5mm	1.3 - 2mm	Flwr & fruit Jul to Oct	heat tolerant, 6.6 - 25.3	moderate to very high	moderately salt tolerant	6.1 - 7.8	nutrient poor	M	Cook, 1974; Koyama & Tsuyuzaki, 2010; Dave's Garden, 2011
<i>Lobelia siphilitica</i>	annual or perennial	emergent	2	unknown	stem cuttings	2	divsn or cuttings [Cat. D], seed [Cat. E]	~1000/plant	2	human, wind or water	moderate	1	1 - 1.5m L	5 - 15cm L, 2 - 6cm W	1.9 - 2.5 - 5cm L	capsule, 2.5 - 3.8cm L	0.7 - 0.8 x 0.3 - 0.4mm	Flwr July to Sept	annual: 14.1 - 1.5, warm: 32.7 - 24.7, cold: -4.7 to -24.6	moderate to very high	<0.5‰	6.1 - 7.5 - 8	nutrient rich	M	Cook, 1974; Proell, 2009; Dave's Garden, 2011; Evergree, 2011; UWSFP, n.d.
<i>Lobelia</i> spp.	annual or perennial	emergent	2	unknown	stem cuttings	2	seed [Cat. E], cuttings [Cat. D]	numerous	2	human, water	moderate	1	pl varies between 30.5 - 152.4cm L	7.6cm L, 2.5cm W	0.6 - 1.2m L	capsule	0.7mm L, 0.29mm W	Flwr late summer thru fall (June to Oct)	cold tolerant, 13 - 27, 16 - 18	low to bright	tolerant	6.1 - 7.5	nutrient rich	M	Cook, 1974; Speichert & Speichert, 2004

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Ludwigia arcuata</i>	perennial	emergent	2	unknown	frag, runner (genus)	3	rhiz divsn [Cat. A], shoot [Cat. C]	253	1	human	moderate to fast (1cm/dy)	1 (2 leaf forms)	3 - 5cm W, 15 - 30cm L	8 - 20mm L	5 - 10mm L	capsule, 15 - 35mm L	0.5 - 0.8mm L	Flwr June to November	20 - 28	high to very high	tolerant	5.5 - 8.0	undemanding but will take approp. nutrients	M	Peng, 1988; Peng <i>et al.</i> , 2005; APC, 2009; Aquascapingworld, n.d.
<i>Ludwigia brevipes</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner (genus)	2	cuttings [Cat. D], side shoots [Cat. C]	152	3	human, animal, water	moderate to fast (3cm/wk)	1	4 - 6cm W, 15 - 30cm L	3cm L, 4mm W (aq), 2.5cm L, 8mm W (aerial)	petal: 4 - 5mm L	capsule, 5 - 15mm L	unknown	Flwr July to August	18 - 23/15 - 25	high to very high	tolerant	neutral, 5 - 7	low nutrients	M	Cook, 1974; Peng, 1988; Riehl & Baensch, 1993; Hiscock, 2003; Peng <i>et al.</i> , 2005; The Planted Tank, 2008; APC, 2009; Aquascapingworld, n.d.
<i>Ludwigia glandulosa</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner (genus)	4	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	many	3	human, animal, water	moderate to fast	1	5 - 12cm W	to 5cm L	lacks petals	capsule, 2.5 - 5mm L, 2.5 - 5mm W	0.55 - 0.75mm L	Flwr in summer, fruits mature autumn	15/22 - 28	very high	~1% salt	neutral, 6.5 - 7.5	undemanding but will take approp. nutrients	M	Cook, 1974; Peng, 1988; Hiscock, 2003; Peng <i>et al.</i> , 2005; APC, 2009; Diszhalak, 2009; Liveaquaria.com, 2011; Tropica, n.d.
<i>Ludwigia inclinata</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner (genus)	3	cuttings [Cat. D], shoot [Cat. C]	many	1	human	fast	1	20 - 40cm L, 3 - 5cm W	3 - 5cm W	3cm L (flower stalk)	capsule	unknown	unknown	18 - 26	moderate to high	<0.5‰	6.5 - 7.4/5 - 7	undemanding but for best colours nutrient rich	M	Peng, 1988; Peng <i>et al.</i> , 2005; APC, 2009; Aqua-fish.net, 2011; Aquascapingworld, n.d.
<i>Ludwigia octovalvis</i>	bi-annual or perennial	emergent	2	unknown	frag, runner (genus)	4	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	many	4	human, water, wind, animal	fast	1	0.25 - 4m L, 1cm D	blade: 1 - 1.3 - 14 - 16.2 x 0.3 - 4cm, 6 - 15cm L, 0.4 - 4cm W	petal: 1 - 2 - 6 - 17 x 5 - 17mm	capsule, 1.5 - 1.7 - 4.5 - 5cm L, 2 - 8mm W	0.6 - 0.75mm L	Flwr & fruit Jan to Dec	25 - 30	low to very high	<0.5‰	acid, alkaline 7.35	nutrient rich	M	Peng, 1988; Chaulya <i>et al.</i> , 2003; Peng <i>et al.</i> , 2005; USFSPIER, 2007; Efforas, 2008; FAO, 2011; Francis, n.d.
<i>Ludwigia palustris</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner (genus)	3	cuttings/frag [Cat. D], side shoots [Cat. C]	108	3	human, animal, water	moderate to fast	1	50cm L, 4 - 7cm W	3.8cm L x 1.9cm W	petals can be absent or insign. 1.1 - 2mm	capsule, 5mm L	<1mm	Flwr May to Sept	18 - 26/15 - 25	high to very high	<0.5‰	neutral (6.5 - 7.5)	high nutrient	M	Clapham <i>et al.</i> , 1952; Cook, 1974; Peng, 1988; Hiscock, 2003; Peng <i>et al.</i> , 2005; APC, 2009; Hilty, 2011; Texas AgriLife, 2011; WSDR, n.d.
<i>Ludwigia repens</i>	perennial	submerged or emergent (amphibious)	2	unknown	frag, runner (genus)	4	cuttings, stem frag [Cat. D], side shoots [Cat. C]	10 - 60 (depend on condition)	3	human, animal, water	fast	2 leaf forms - emrg & subm	5 - 8cm W, 51cm L	0.32 - 3.8cm L	4 petals 3mm L	capsule, 2.5 - 3 x 2mm	<1mm	Flwr My thru Sept, seed capsules July thru Nov	15 - 20 - 28 (opt 24 - 26)	moderate to high	<0.5‰	neutral (6.5 - 7.5)	nutrient rich	M	Cook, 1974; Peng, 1988; Hiscock, 2003; Lytle, 2003; Peng <i>et al.</i> , 2005; APC, 2009; Liveaquaria.com, 2011; UFLIFAS, 2011
<i>Ludwigia sedioides</i>	annual (in colder zone), perennial	floating	2	unknown	frag, runner (genus)	3	seed [Cat. E], stem cuttings [Cat. D]	many	1	human	moderate	1	1 - 9cm L	7.6 - 17.8cm W (rosettes 10 - 15cm)	5cm L	capsule, 10 - 13mm L, 3mm W	0.6mm L	Flwr June to August/late summer early winter	frost tender, 24 - 36	moderate to very high	<0.5‰	<7.5 (prefer acid water, die in neutral or alkaline)	nutrient rich	M	Munz, 1959; Peng, 1988; Nashet <i>et al.</i> , 2003; Speichert & Speichert, 2004; Peng <i>et al.</i> , 2005; Aquascapingworld, n.d.
<i>Ludwigia</i> spp.	annual or perennial	emergent	2	unknown	frag, runner	3	seed [Cat. E], cuttings [Cat. D]	many	2	human, animal	moderate to fast	1	2.3m L x 5.1cm W	5.1cm L x 1.3 - 2.5cm W	2.5 - 5.1cm W	capsule, 1 - 12mm L up to 35 or 50mm L (depend on sps)	0.4 - 0.7mm but varies	Flwr June to Sept	22 - 28	low to very high	<0.5‰	6.0 - 8.0	nutrient rich	M	Peng, 1988; Peng <i>et al.</i> , 2005; Texas AgriLife, 2011
<i>Lycoris radiata</i>	perennial	emergent	2	unknown	bulb (1 - 3cm D)	1	bulb [Cat. A]	few	1	human	slow	1	30cm L	7 - 15cm L, 4 - 7mm W	3.8 - 5cm L (umbel 16.5cm W)	capsule	round	Flwr August to Sept, fruit Oct	min (<2 to -2), 16 - 21, 0 - 4	moderate to very high	NaCl stress<0.5mol/L, best @0.1mol/L	7.6 - 7.8	use nutrients for growing, >better	M	NCSU, 2005; Efforas, 2008a; Floridata, 2010; PFAF, 2010; Dave's Garden, 2011
<i>Lysimachia nummularia</i>	perennial	emergent (prostrate or trailing)	2	unknown	rhiz, stem frag	3	cuttings [Cat. D], rhiz [Cat.A], seeds [Cat. E]	unknown for this species, 1 - 5 - >10	3	human, water, animal	moderate to fast	1	1 - 5dm or 91cm L or 0.2 - 1m L	1 - 3.5 x 0.5 - 3.5cm (blade), 0.6 - 3.8cm L	1 - 1.5cm L, 5 - 8mm W (petal), 1.9 - 2.5cm W	capsule, 5 - 9mm L	1 - 1.5mm L, 0.6 - 1mm W	Fwrs in summer (FONA), June to August	15 - 22 - 27/10 - 22	low, moderate, very high	tolerant	6 - 7.5/ 4 - 7.2	nutrient rich	M	Ray, 1956; Cook, 1974; Coffey & Jones, 1980; FONA, 1993; Hiscock, 2003; Thierry & Piednot, 2005; Evergreen, 2011; Hilty, 2011; USDAFS, n.d.
<i>Lysimachia quadrifolia</i>	perennial	emergent	2	unknown	rhiz, runner	3	rhiz, runner [Cat. A], seed [Cat. E]	30 - 40	3	human, water, animal	moderate	1	1.2 - 2 - 10dm L	2 - 3.4 - 8 - 9cm L, 2 - 3 - 5 - 10mm W	7 - 12.5mm L, 5.5 - 9mm W	capsule, 3.5 - 6mm D, 3 - 3.5mm L	1.2 - 1.5 - 2.5mm L	Flwr July to Sept, fruit August to Oct	min -34°, needs high heat, min annual 13, monthly 27	moderate to very high	<0.5‰ (intolerant)	neutral, 4.8 - 5	nutrient rich	M	Ray, 1956; Coffey & Jones, 1980; Gargullo, 2007; Muma, 2011
<i>Lysimachia</i> spp.	perennial	emergent	2	unknown	stem frag, rhiz	3	rhiz [Cat. A], seed [Cat. E]	1 - 20+/14 - 48 per capsule	3	human, water, animal	moderate to fast	1	none reported	up to 15.24cm L	petals: < or = to 5 - 12mm L, family 2 - 3 - 20mm L	capsule, 1.3 - 7mm L	0.4 - 2 x 0.3 - 1.8 x 0.3 - 1.5mm (L, W, D)	Flwr mainly in summer	hardy from -40 to 1.7, 13 - 26	moderate to high	<0.5‰	5.6 - 7.5	nutrient rich	M	Ray, 1956; Coffey & Jones, 1980; Natic, 1983; Simpson & Heff, 1983; FONA, 1993; Oh <i>et al.</i> , 2008
<i>Lysimachia terrestris</i>	perennial	emergent	2	unknown	bulblet/bulbil (4 - 15mm L, 2 - 3mm W), rhiz	2	bulbil [Cat. D], rhiz [Cat. A]	several	2	human, water	moderate	1	25 - 40 - 80 - 100cm L	3 - 5 - 7.6 - 10cm L, 0.5 - 1.9cm W	0.8 - 1.3 - 2cm W, 10 - 30cm L, petal: 4 - 6mm L, 1.4 - 2.5mm W	capsule, 3 - 3.5mm L	1.3mm L	Flwr June to Sept, fruit Aug to Oct	min -28.9 to -31.6, 24 - 29	moderate to high to very high	<0.5‰	acidic ~3.6 - 4.2	nutrient rich	M	MacDougal, 1901; Ray, 1956; Coffey & Jones, 1980; FONA, 1993; CBS, 2005; UWSFP, n.d.
<i>Marsilea angustifolia</i>	perennial	emergent or submerged (amphibious)	2	unknown	rhiz	2	spore [Cat. E], rhiz [Cat. A]	20 - 64 (microspores), 1 megaspore [family]	3	human, water, animal	slow/fast	1	5 - 10cm L, 2 - 5cm W/0.03 - 0.2m L (frond)	5 - 7 - 20mm L, 3 - 5mm W (leaflet)	no flowers	sporocarp, 1 - 3mm L (stalk)	unknown	Flwr May to August	22 - 28	moderate to high	<0.5‰	5.5 - 6.5	nutrient rich	D (heterosporous: fern)	Johnson, 1986; RBG, 2011; Jones, n.d.
<i>Marsilea crenata</i> (syn. <i>Marsilea crenulata</i>)	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	rhiz [Cat. A], spore [Cat. E]	20 - 64 (microspores), 1 megaspore [family]	3	human, water, animal	slow/fast	1	1 - 20cm L (frond)	10 - 25mm L, 3 - 8mm W (leaflet)	doesn't flower	sporocarp, 1 - 3mm L (stalk)	unknown	sporocarp prod July to Oct	22 - 28	moderate to high	<0.5‰	5.5 - 7.5	nutrient rich	D (heterosporous: fern)	Johnson, 1986; Soerjaniet <i>al.</i> , 1987; Jones, n.d.
<i>Marsilea hirsuta</i>	perennial	submerged or emergent (amphibious)	2	unknown	runners	2	runners [Cat. A], spore [Cat. E]	20 - 64 (microspores), 1 megaspore [family]	3	human, water, animal	moderate to fast	1	1 - 20cm L (frond)	10 - 20cm L, 3 - 12mm W (leaflet)	no flowers	sporocarp, 3 - 6mm L (stalk)	unknown	Flwr April to August & Dec	18/22 - 28	high	tolerant of hypersaline conditions	5 - 7.5 (TROPICA)	nutrient rich	D (heterosporous: fern)	Cook, 1974; Johnson, 1986; Hiscock, 2003; Jones, n.d.; DECWAH, n.d.; Tropica, n.d.
<i>Marsilea quadrifolia</i> (syn. <i>Marsilea polycarpa</i>)	perennial	submerged or emergent (amphibious)	2	unknown	runners, rhiz	2	runners, rhiz [Cat. A], spore [Cat. E]	43 microspores, 1 megaspore	3	human, water, animal	very slow to fast	1	rhiz: 0.5 - 1.3mm D, in water 0.9 - 2mm D	7 - 21 x 6 - 19mm (pinnae)	no flowers	4 - 5.6 x 3 - 4mm, 2.3 - 2.8mm thick (sporocarp)	56 - 61µm (microsp), 560 - 610µm L, 355µm W (megasp)	Sporocarps prod mid-June to mid-Oct	16 - 29	moderate to high	<0.5‰	neutral to alkaline, 6.3 - 7.3	nutrient rich	D (heterosporous: fern)	Cook, 1974; Johnson, 1986; FONA, 1993; Evergreen, 2011; Aqua-fish.net, 2011; Aquascapingworld, n.d.
<i>Marsilea schelpeana</i>	perennial	submerged or emergent (amphibious)	2	unknown	runners	2	runners [Cat. A], spore [Cat. E]	20 - 64 (microspores), 1 megaspore [family]	3	human, water, animal	fast	1	rhiz: 5cm L, stipe: (4) 7 - 20 (25)cm L	4 - 7mm L x 3 - 4mm W [leaflet]	non-flowering	sporocarp: (4.5) 6 - 7mm L, 4 - 5mm high, 0.6 - 1.5mm thick	unknown	unknown	low (-6 to -4), + 29	moderate to high	<0.5‰	6.0 - 7.5	nutrient rich	D (heterosporous: fern)	Launert, 1969; Cook, 1974; Walter & Gillett, 1998; SMG, 2001; Darwall <i>et al.</i> , 2009
<i>Mayaca fluviatilis</i>	perennial	submerged, floating or emergent (prostrate)	2	unknown	stem cuttings	2	cuttings [Cat. D], shoot [Cat. C]	2-25/capsule	2	human, water	fast to very fast	2 (submerged & terrestrial form)	60cm L	2 - (20) - 30cm L, 0.5mm W	1cm W	capsule, 3.4 - 5mm L	0.9mm L	Flwr (March) - May to Oct (Nov)	20 - 30	moderate to high	tolerant	5.0 - 8.0	nutrient rich	M	Thieret, 1975; FONA, 1993; The Planted Tank, 2008; Aqua-fish.net, 2011
<i>Mentha aquatica</i>	perennial	emergent	2	unknown	rhiz	3	offsets/new pls from shoots [Cat. C], rhiz [Cat. A], seed [Cat. E]	1 to 4	2	human, water	fast	1	3 - 14dm L	2 - 5 - (9)cm L	3 - 4mm L, flwr head 18 - 25cm W	4 nutlet, 0.9 - 1 x 0.6 - 0.8mm ea	unknown	Flwr Jul to Oct, seeds ripen Sept to Oct	min -34°, 20 - 40 (opt 25)	moderate to high light	<0.5‰ (not tolerant)	acid, neutral, alkaline soils, 5.5 - 6.5	nutrient rich to moderate nutrient rich	M	Cook, 1974; Beck, 2005; Winterton & Scher, 2007; RUC, 2010; PFAF, 2010; UWSFP, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Menyanthes trifoliata</i>	perennial	emergent	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	23	3	human, water, animal	moderate	1	5 - 10 - 30cm L	2 - 12cm L x 1 - 5.1-6cm W, leaflets 7.5 - 10cm L	1.2 - 1.9cm W, 15.2 - 45.7cm L (spike), flwr cluster 10 - 30cm L	capsule, 0.64 - 0.95 - 1.5cm L	2 - 2.5mm L x 1 - 1.5mm W	flowers May to July, fruit ripens June/August (AON)	hardy to -25/-36° to 32	high to very high	<0.5‰	neutral to acidic, 4.8 - 6.5	moderate, nutrient rich	M	Hewett, 1964; Rook, 2002; Beck, 2005; PFAF, 2010; Sagebud, 2011; Evergreen 2011; USDA, NRCS, 2011; WSD, n.d.
<i>Microcarpaea minima</i>	annual	emergent	2	unknown	rhiz	2	rhiz [Cat.], seed [Cat. E]	few	2	human, water	fast	1	10 - 25cm L, 1 - 3cm W	2 - 4mm L, 1 - 2mm W	2.5mm L	capsule, 2mm L	0.3mm L	Flwr July to Oct	24 - 28	moderate to high	<0.5‰	6.0 - 8.0	nutrient poor	M	Matthew, 1995; Eforas, 2008a; Winterton & Scher, 2007; Romanowski, 2009
<i>Micromeria brownei</i> (syn. <i>Clinopodium brownei</i>)	perennial	emergent	1	none	none	1	seed [Cat. E]	4	1	human	moderate to fast	1	7 - 20 - 30 - 40cm L	blade: 4 - 20 - 25 x 3 - 18 - 20mm	petal: 7 - 9mm L	dry fruit/schizocarp, 1.5 - 2.5mm L	<1mm D	Blooms all year (spring & fall), fruit Feb - Mar, July - Aug	min >15° to 27	moderate to very high	<0.5‰	neutral, 7	high nutrient	M	Correll & Johnson, 1970; Adams, 1972; Hargreaves, 2006; USDA, NRCS, 2011
<i>Microsorium pteropus</i> (syn. <i>Cyrtis pteropus</i>)	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (0.5 - 5mm W), adven plts	3	advent plantlets [Cat. D], divn rhiz [Cat. A], spore [Cat. E]	many	1	human	slow to moderate	2 (simple & pinnatifid fronds)	15 - 30cm L	5.5 - 20 - 35 - 40cm L, 1 - 2.5cm W, lamina 3.5 - 30 x 0.2 - 5.5cm, pinnatifid: 15 -	no flowers	1 - 2.5mm D or 2 - 7mm L (sori)	40 - 50 x 20 - 30µm	unknown	18 - 28 - 30	undemanding, sheltered in high light	0.5 - 30‰ (to 17.3‰)	alkaline (6 - 7.5)/5 - 8/5.5 - 7.5	undemanding in nutrients even thou some say nutrient rich	M (homosporous ferns)	Nayar & Kaur, 1971; Bosman, 1991; Hiscock, 2003; Thilery & Piednor, 2005; Aquatic Plant Central, 2009; Diszhalak, 2009; Aquascaptingworld, n.d.; Tropica, n.d.
<i>Microsorium</i> spp.	perennial	submerged or emergent (amphibious)	2	unknown	rhiz (1-10mm W), adven plts (veg struc)	3	rhiz [Cat. A], spore [Cat. E], adven plits [Cat. D]	64/sporangium	2	human, water	slow	2 (subm & emerg fronds)	10 - 20cm L	to 30cm L	no flowers	capsule, 0.25 - 0.6mm L	75(-105) x 45(-60)µm	unknown	15 - 30	moderate or very high	tolerant	5.0 - 8.0	added nutrients needed	M (homosporous ferns)	Nayar & Kaur, 1971; Bosman, 1991; The Planted Tank, 2008; Tropica, n.d.
<i>Mimulus guttatus</i>	annual or perennial	emergent or floating in mats	2	unknown	rhiz	3	rhiz [Cat. A], cuttings [Cat. D], seed [Cat. E]	50 - 250/capsule	4	human, wind, water, animal	fast	1	60 - 91cm L/15 - 65	0.4 - 12.5cm L, 4cm W	2.5 - 3cm W, 4cm L	capsule, 0.5 - 1.2 - 2cm L	0.4 - 0.5 - 0.7mm L, 0.2 - 0.4mm W	Flwr March to August, spring, summer, early fall	hardy to -23.3 to -3.8, opt 10 - 24	moderate to high	<0.5‰	6.0 - 8.0/5.6 - 7.5	nutrient rich	M	Grant, 1924; Cook, 1974; RUC, 2010; Tokarska-Guzik & Dajdok, 2010; Humphrey & Colangelo, 2011; LBWC, 2011; USDA, NRCS, 2011; Montana PlantLife, n.d.b.
<i>Mimulus luteus</i>	annual or perennial	emergent	2	unknown	rhiz	3	cuttings [Cat. D], seed [Cat. E]	numerous	1	human	fast	1	10 - 30 - 40cm L	2.5 - 3cm L as W	petal: 2.5 - 4.5cm, 2.5 - 5.1cm L	capsule	0.6 - 0.8 x 0.35 - 0.45mm	Flwr in summer (July to August)	tolerant to (-8°), 10 - 20, (opt 20 - 24), max 38	high	<0.5‰	acid, neutral, alkaline soils, 5.5 - 6.5	nutrient rich	M	Grant, 1924; Cook, 1974; PFAF, 2010; Dave's Garden, 2011; USDA, NRCS, 2011; Stace <i>et al.</i> , n.d.
<i>Mimulus ringens</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	numerous, 1600 - 2300/capsule	2	human, wind or water	moderate	1	20 - 130cm L	2.5 - 5 - 10cm L, 25 - 80mm W or 1 - 2cm W	1.9 - 2.5 - 4cm L, 2.2cm W, petal: 2.5 - 3.5cm L	capsule, 10 - 20mm L	minute	Flwr June to Sept	tolerate annual min -37.3 to -39.9, 10 - 25 - 32 (opt 10 - 25)	moderate to high	<0.5‰	5.6 - 7.5	nutrient rich	M	Grant, 1924; Cook, 1974; Dickinson <i>et al.</i> , 2004; Karron <i>et al.</i> , 2009; MBG, 2010; RUC, 2010; D'Aillon, 2011b; Hilty, 2011; USDA, NRCS, 2011
<i>Musa</i> spp.	perennial	emergent	2	unknown	rhiz, corm	1	rhiz [Cat. A]	10 - many (rarely fertile)	1	human	fast until flowering	1	psuedostem (foliage hgt 2 - 2.7m L, 0.6mW)	3m L, 0.6m W/3 - 40cm L, 2 - 8cm D	varies with location, to 80cm L	berry, 3 - 40cm L, 2 - 8cm W	1 - 4mm L	Flwr year round	12 - 27/26 - 30	high	<0.5‰	5.5 - 7.5	nutrient rich	M	CRFG, 1997; Nelson <i>et al.</i> , 2006
<i>Myosotis scorpioides</i> (syn. <i>Myosotis palustris</i>)	perennial	emergent	2	unknown	rhiz, runner	3	rhiz, runner [Cat. A], seed [Cat. E], shoot [Cat. C]	many	2	human, water	moderate	1	2 - 6dm L	2.5 - 8cm L, 7 - 20mm W	0.61 - 0.95cm W	nutlet, 1.5 - 2 - 2.5mm L, 0.9 - 1.1mm W (4 parted schizocarp)	69µm	Flwr May to Oct, seeds ripen July to Sept	hardy to -20 or -33°, germin 2 - 4 wks @20, 8 - 26	moderate	<0.5‰	5.5 - 7.5	poor to average nutrients	M	Beck, 2005; CBS, 2005; PFAF, 2010; RUC, 2010; D'Hondt & Hoffman, 2011; Sagebud, 2011; USDA, NRCS, 2011; UWSPF, n.d.
<i>Myosotis</i> spp.	annual or perennial or biannual	emergent	2	unknown	rhiz	3	seed [Cat. E], shoot/sprig [Cat. C], rhiz [Cat. A]	many	1	human	moderate	1	30 - 45cm L	5.08 - 7.62cm L	0.64cm W	4 nutlets, 1 - 1.5mm L, 0.5 - 1mm W	unknown	Flwr mid summer to early fall	frost tolerant, 10 - 24	moderate or high	<0.5‰	neutral, 5 - 7	nutrient rich	M	van Royzen, 1975; Eforas, 2008b; Botany.com, 2010; Dave's Garden, 2011
<i>Myriophyllum aquaticum</i> (syn. <i>Myriophyllum proserpinacoides</i> , <i>Myriophyllum brasiliense</i>)	perennial	submerged	2	unknown	rhizomes, frag (turions not developed)	3	cuttings [Cat. D], side shoots [Cat. C], rhiz [Cat. A]	2 - 4 (genus)	3	water, human, animal	moderate to fast	2 leaf forms	2m L x 5mm D (51 - 152cm L; Liveaquaria)	1.5 - 3.5 - 7.6cm L (subm), 2 - 5cm L (emerg)	male: 4mm L, petal: (2.3-)2.7 - 3.1mm L x 0.8 - 1.1mm W; female: 0.5 - 2mm	No fruits in North America, 0.7 - 0.8mm L, 1.7mm L x 1.3 - 1.4(-1.7)mm D	No seed set known to occur in N. Am., mericarp 1.7mm L, 0.6 - 0.7mm D	Flwr July to August	22 - 30/16 - 23, tolerate freezing temps, hardy to -23°/10 - 29°	high to very high	<0.5‰	alkaline: 6.8 - 8	high nutrient	D	Cook, 1974; Orchard, 1979, 1981; Dan <i>et al.</i> , 2002; Hiscock, 2003; Liu <i>et al.</i> , 2008; MBG, 2010; Liveaquaria.com, 2011; GUSD, n.d.d.
<i>Myriophyllum mattogrossensis</i>	perennial	submerged	2	unknown	rhiz	3	cuttings [Cat. D], side shoot [Cat. C]	4	1	human	fast to very fast	1	5 - 8cm W, 50 - 60cm L, 2mm D	2 - 2.5mm L, 1 - 1.3cm W	petal: c. 0.5mm L	0.7 - 0.8mm L, 0.7mm W	mericarp 0.7 - 0.8mm L, 0.4mm D	Flwr & fruit March & Nov	22 - 27/20 - 28	moderate to high	<0.5‰	6.0 - 7.2/5.5 - 8	nutrient rich	M	Orchard, 1979, 1981; Dan <i>et al.</i> , 2002; The Planted Tank, 2008; Aquatic Plant Central, 2009; Tropica, n.d.
<i>Myriophyllum</i> spp.	annual or perennial	submerged or littoral (emergent)	2	unknown	rhiz, frag	3	cuttings [Cat. D], side shoots [Cat. C]	2 to 4	3	human, animal, water	fast	leaves heterophyllous	to 40cm L, 5 - 8cm W	considerable leaf variation, 1 - 40mm L	small & inconspic	dry fruit (schizocarp) split into 1 seeded mericarps, < or > 1.5 - 2mm L	unknown	Flwr May to Sept	18 - 29	very high	<0.5‰	5.0 - 7.0	nutrient rich	M or D	Orchard, 1979, 1981; Aiken, 1981; Gerber & Les, 1994
<i>Myriophyllum tuberculatum</i>	perennial	submerged	2	unknown	rhiz	3	cuttings [Cat. D], side shoots [Cat. C]	2 - 4 (genus)	2	human, animal	moderate to fast	leaves heterophyllous	to 150cm L, 5 - 10cm W	subm: 2.5 - 4cm L, 1 - 1.5cm W, emerg: 5 - 20mm L	petals: 0.5 - 1.5mm L	dry fruit (schizocarp) 2 - 2.5 - 3.5mm L	L/D: > or = 0.25cm <0.5cm	Flwr & fruit May to Sept	22 - 28/18 - 29	very high	<0.5‰	5.0 - 7.0	nutrient rich	M	Cook, 1974; Orchard, 1979, 1981; Dan <i>et al.</i> , 2002; Hiscock, 2003; Eforas, 2008aa; The Planted Tank, 2008; Diszhalak, 2009; Aquatic Plant Central, 2009; ENVIS, n.d.
<i>Najas indica</i>	annual, rarely perennial	submerged	2	unknown	stem frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	1	2	human, water	moderate to fast to very fast	1	8 - 20cm L, 0.3 - 0.5mm D	sheath: 20 - 26mm L	male: ca. 3.5mm L; female: 2 - 3mm L (conspic)	achene-like/nutlet, 2 - 3mm L, 0.5mm W	1.5 - 2 x 0.5 - 0.75mm	Flwr & fruit June to August	24 - 28/22 - 26	high	0.5 - 30‰	highly alkaline waters, 6.5 - 7	nutrient rich	M or D	Cook, 1974; de Wilde, 1960; Lowden 1986; FONA, 1993; Hiscock, 2003; Eforas, 2008aa
<i>Nasturtium officinale</i> (syn. <i>Rorippa nasturtium aquaticum</i> , <i>Radicula nasturtium aquaticum</i>)	perennial	emergent	2	unknown	frag, rhiz	3	seed [Cat. E], frag [D], rhiz [Cat. A]	28 - 36 - 60/ovary	4	animal, human, water, wind	fast	1	10 - 60cm L or 1 - 11 - 20dm	4 - 12cm L/2 - 15 - 20cm L	3 - 5mm L, 0.5cm W	Pods, 10 - 25mm L x 2mm W	0.8 - 0.9 - 1.1 - 1.3 x 0.6 - 0.7 - 0.9 - 1mm	Flwr Feb to Sept, seeds ripen Jul to Oct	hardy to -15°, 6 - 27	low to high	<0.5‰	acid, neutral, alkaline, 4.3 - 8.3, opt. 7.2	low	M	Purdue, 1988; FONA, 1993; Beck, 2005; PFAF, 2010; RUC, 2010; WSD, n.d.
<i>Nelumbo lutea</i>	perennial	emergent/floating	2	unknown	2 types rhiz (6 - 8mm & 8 - 20mm), tuber	2	rhiz [Cat. A], seed [Cat. E]	1	2	human, water	fast	1 (dimorphic leaves)	none	blade: to 6dm or more	tepals: 1 - 13cm, mature flwr 5.1 - 22.86 - 25.4cm W	globose fruit, 10 - 16 x 8 - 13mm	nut	Flwr late spring to summer (July to Sept)	hardy to -38°, 10 - 24	high	<0.5‰	4.6 - 6.1 - 7.5	nutrient rich/moderate	M	Hall & Penfound, 1944; PFAF, 2010; Sagebud, 2011; UWSPF, n.d.
<i>Nelumbo</i> spp.	perennial	floating or emergent	2	unknown	runner/rhiz	2	runner, rhiz [Cat. A], seed [Cat. E]	1 or 2	2	human, water	fast	dimporhic stems	none	blade: up to 1m D, 30.5 - 76.2cm W	10 - 20 - 35cm W, 76.2 - 183cm L	globose fruit	nut	Flwr July to August	23 - 27	very high	<0.5‰	9.0 - 9.3	nutrient rich	M	Tutin <i>et al.</i> , 1993; Masuda <i>et al.</i> , 2006; Winterton & Scher, 2007; PFAF, 2010; Botany.com, 2010
<i>Nesaea crassicaulis</i> (syn. <i>Ammannia crassicaulis</i> , <i>Nesaea polyantha</i>)	annual or perennial	submerged or emergent	2	unknown	stem frag	3	cuttings [Cat. D], side shoots [Cat. C], seed [Cat. E]	many	2	human, water	moderate to fast	1	8 - 12cm W	blade: 0.5 - 6cm L, 0.3 - 2cm W	petals: 1 - 1.5mm L	capsule, (+/-) 2mm L	(+/-) 5mm L	unknown	22 - 28	very high	<0.5‰	5.5 - 8.5 (TROPICA)	nutrient rich	M	Cook, 1974; Hiscock, 2003; Cook, 2004; Aquatic Plant Central, 2009
<i>Nesaea pedicellata</i>	annual or perennial	submerged or emergent	2	unknown	stem frag	2	side shoots [Cat. C]	many	2	human, water	moderate	1	3 - 20cm L	unknown	unknown	capsule	unknown	unknown	22 - 28	high	tolerant	5.5 - 7.0	nutrient rich	M	Winterton & Scher, 2007; APC, 2009; Graham <i>et al.</i> , 2011; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Nesaea</i> spp.	annual or perennial	submerged or emergent	2	unknown	stem frag	2	side shoots [Cat. C]	many	2	human, water	moderate	1	none reported	blade: 15 - 30mm L	petal: 4mm L, 1 - 4.7mm L	capsule, 4mm D	3mm L (family), 0.3 - 1mm L, 0.2 - 0.5mm W	Flwr April to Aug	22 - 28	high to very high	<0.5‰	5.0 - 8.0	nutrient rich	M	Graham, 1964; Kubitzki <i>et al.</i> , 2007; Graham <i>et al.</i> , 2011
<i>Nuphar lutea</i>	perennial	submerged or floating	2	unknown	winter buds on rhiz (3 - 8cm D)	2	rhiz [Cat. A], cuttings [Cat. D]	76 - 418/fruit	2	human, water	fast	2 leaf forms: floating & subm	none	20 - 30cm L or 1 - 4dm L, to 30cm W	4 - 5 - 7cm L, 3 - 4 - 5 - 6.5cm D; petals: 20 - 43mm L, 15 - 43mm W	berry-like, 3.5 - 6cm L	3 - 5 - 5.5 - 6mm L, 3.4 - 3.8mm W	Flwr May to Oct (June to August, seeds ripen late Sept to Oct)	cold tolerant, 12 - 35	moderate to high	to 1.0‰ (oligohaline & 'acidotrophic' waters)	acid, neutral, alkaline soils, 6.5 - 7 & 8 - 8.5	nutrient rich	M	Heslop-Harrison, 1955; Beal, 1956; MBG, 2010; PFAF, 2010; RUC, 2010; LBJWC, 2011
<i>Nuphar stellata</i>	perennial	submerged or floating	2	unknown	bulb	2	bulb, stolon [Cat. A], seed [Cat. E]	many (genus)	2	human, water	slow	2 leaf forms	none	to 30.5cm D (emerg), 10.2cm D (subm)	unknown	berry-like, 0.5 - 5cm D (genus)	3 - 6.5mm L, 1.5 - 5mm W (genus)	Flwr mid spring to early autumn (genus)	22 - 28	low	<0.5‰	5.0 - 8.0	nutrient rich	M	Heslop-Harrison, 1955; Beal, 1956
<i>Nymphaea lotus</i>	perennial	submerged or floating	2	unknown	rhiz, runner (2.5cm L, 0.08 - 0.16cm D)	2	from daughter plants on runners [Cat. A], seed [Cat. E]	1000's	3	animal, water, human	moderate to fast	1	none	3 x 3dm (blade)	12 - 25cm D	berry, 4 - 6 - 9cm D	1.4 - 1.8 x 0.9 - 1.2mm, 1.09 thick	Flwr spring to summer	22 - 28 - 30	high to very high	<0.5‰	5 - 8 (TROPICA)/5.5 - 7.5	nutrient rich	M	Conard, 1905; Cook, 1974; FONA, 1993; Hiscock, 2003; Diszhalak, 2009; Texas AgrLife, 2011; Tropica, n.d.
<i>Nymphaea mexicana</i>	perennial	floating or emergent	2	unknown	rhiz, runner	1	rhiz, root, runner [Cat. A]	4 to 56	2	human, animal	moderate	1 (flwr floating or emergt)	none	7 - 18 - (27)cm L, 7 - 14 - (18)cm W	6 - 11 - 12 - 13cm D	berry, 2 - 2.5cm L, 3mm D	4 - 5 - 6 x 3 - 5mm	Flwr spring to fall, mainly summer farther north	min - 19°, 25 - 30 (genus)	high to very high	low	5.0 - 9.0	moderate to nutrient rich	M	Conard, 1905; Capperino & Schneider, 1985; FONA, 1993; RUC, 2010; Sagebud, 2011; USDA, NRCS, 2011; USGS, 2011a; AWC, n.d.
<i>Nymphaea micrantha</i>	perennial	floating or emergent	2	unknown	bulb	3	advent plts [Cat. D], seed [Cat. E] (rare)	very numerous	1	human	moderate	floating & subm leaves	none	8cm L x 5cm W	2.5 - 10cm L	berry, 8 - 12cm W	0.34mm L (with embryo)	Flwr mid summer to early fall	24 - 28	high to very high	tolerant	acidic lakes, 6.5 - 8	nutrient rich	M	Conard, 1905; Slocum, 2005; Baskin & Baskin, 2007; Aquatic Plant Central, 2009
<i>Nymphaea odorata</i>	perennial	floating	2	unknown	rhiz, tubers	3	rhiz [Cat. A], seed [Cat. E], bulb [Cat. C]	many	3	animal, water, human	moderate	2 (Great Lakes)	none	7 - 30cm L, 15.2 - 25 - 30.5cm across	6 - 12 - 25cm across	berry, 1 - 2 - 3cm D	2 - 3mmL or 1.5 - 4.5 x 0.9 - 3mm	Flwr June to Oct, Fruit mid to late summer	7 to 24	high	poor tolerance	acid, alkaline (6.1 - 7.5), 4 - 5	nutrient rich	M	Conard, 1905; Cook, 1974; FONA, 1993; Gilman, 2009a; Floridata, 2010; Liveaquaria.com, 2011; Texas AgrLife, 2011; GISD, n.d.; WSDI, n.d.
<i>Nymphaea stellata</i> (syn. <i>Nymphaea nouchali</i>)	perennial	floating	2	unknown	rhiz (10cm L, 2cm thick)	3	daughter plants on shoots [Cat. C], rhiz [Cat. A], seed [Cat. E]	many	3	animal, water, human	moderate	1	none	blade: 7 - 15 - (45)cm D	3 - 15cm D, petals 4.5 - 5cm	berry, 1.5 - 4.5cm D	0.5 - 1.3mm	Flwr July to Dec	22 - 28	very high	<0.5‰	6.0 - 7.5	nutrient rich	M	Conard, 1905; Cook, 1974; Hiscock, 2003; Efloras, 2008a; Texas AgrLife, 2011; Aquaspage.eu, n.d.
<i>Nymphaea</i> spp.	perennial	floating	2	unknown	rhiz, runner	2	rhiz [Cat. A], seed [Cat. E]	~2000/fruit	3	human, animal, water	moderate	flwr floating or emergd	none	5 - 29 - 60cm D, 15.2 - 30.5cm W	7.6 - 12.7cm W, 2.5 - 30cm D	berry-like = bacate capsule	varies from large to moderate to small (1.1 - 16mm L (for family))	Flwr spring and summer	15.5 - 21 - 26.6	high to very high	<0.5‰ (best growth)	acid tolerant, 6.5 - 7.5	nutrient rich	M	Cook, 1974; Conard, 1905; Kubitzki <i>et al.</i> , 1993; Erier, 2005; USFS,PIER, 2007; Efloras, 2008a; Texas AgrLife, 2011; WSDI, n.d.
<i>Nymphaea zenkeri</i>	perennial	floating	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	many	1	human	moderate	1	none	to 15cm L, 9 - 13cm W	5 - 7cm D, petal 2cm L, 4mm W	berry-like, 4 - 9mm D	pea size, 1.4 - 1.8 x 0.9 - 1.2mm	unknown	22 - 30	moderate	0.5 - 30‰	5.0 - 8.0	nutrient rich	M	Conard, 1905; Vercourt, 1989
<i>Nymphoides aquatica</i>	perennials, sometimes annuals	submerged or emergent (amphibious)	2	unknown	frag, winter tubers resemble banana	3	advent plantlets [Cat. D], division of shoots [Cat. C]	numerous	2	human, animal	slow to moderate	2 leaf forms (aerial & subm)	>10mm D	8 - 10cm W or 5 - 15cm D, to 15cm L	1.3cm W	capsule, 10 - 14mm L	unknown	Flwr spring to fall, May to Sept	10 - 25/20 - 30/18 - 24	high to very high/low to moderate	non-tolerant, <0.5‰, 6.6‰	neutral (6 - 7.2)/ 6 - 8	nutrient rich	D	Cook, 1974; Mondadori, 1976; Godfrey & Wooten, 1981; Sivarajan & Joseph, 1993; Jacom, 2002; Hiscock, 2003; LBJWC, 2011; Texas AgrLife, 2011
<i>Nymphoides geminata</i>	perennials, sometimes annuals	floating or amphib	2	unknown	frag, runner	2	frag [Cat. D], runner [Cat. A], adven plts [Cat. D]	numerous	2	human, water	fast	1	to 2' m L	3 - 8cm L, 5 - 7.6cm W, blade 2 - 10cm L	1.9cm W, to 30cm L (inflor), petal 20 - 35mm D	capsule, 5 - 10mm L	1 - 1.5mm L	Flwr May to Sept/Nov to Feb, fruit Feb to March	tolerates wide range, tol to -4 & - 1, 20 - 25 - 29	moderate to high	non-tolerant, <0.5‰	mild acid, mild alkaline, 4.5 - 7.8	nutrient rich	M	Cook, 1974; Sivarajan & Joseph, 1993; SMG, 2001; Gray, 2009; ARC, 2010
<i>Nymphoides hydrocharioides</i> (syn. <i>Nymphoides aurantiaca</i>)	perennial	floating	2	unknown	runner, rhiz	1	runner [Cat. A]	10 to 15	1	human	slow to moderate	1	elongated, none reported	blade: ca. 4.5cm D	petal: 8 - 10mm	capsule, ca. 6mm D	ca. 1.5mm D	Flwr April to Sept	12 to 31	moderate	non-tolerant, <0.5‰	5.9 - 9.4	nutrient rich	M	Sivarajan & Joseph, 1993; Efloras, 2008a; DECWAH, n.d.
<i>Nymphoides peltata</i>	perennial	floating	2	unknown	frag, rhiz, runner/stolons	3	seed [Cat. E], frag [Cat. D], rhiz [Cat. A]	20 - 25/capsule, avg 26.5	3	human, water, animal	fast	1 (has dimorphic flowers)	1.6 - 3m L	3 - 10cm W (vegve), 3.5 (11) cm L, (2) 3.5 (10) cm W (floating leaves)	2 - 4cm D, petals: 2.5 - 4 (4.6)cm W	capsule, 1.2 - (1.5) 1.7 - 2.6 x 0.8 - 1.1 cm	3 - 3.8 - 5 (6)mm L, 2.7 - 3.5mm W, 0.4mm thick, beak 0.07 - 0.35mm L, 0.02 - 0.06mm	Flwr late June to Sept/Oct	tolerate moderately cold climates, 18 - 29	high	non-tolerant, <0.5‰	neutral to alkaline but found in 6.5 - 7.6	nutrient rich (found in oligo also)	M	Cook, 1974; van der Velde, 1981; Sivarajan & Joseph, 1993; Darbyshire & Francis, 2008; Liu <i>et al.</i> , 2008; RUC, 2010; GISD, n.d.
<i>Oenanthe aquatica</i>	annual or biannual, perennial (USDA)	submerged, mainly emergent	2	unknown	offsets from stolons	2	seed [Cat. E], offsets [Cat. C]	2	3	human, water, animal	moderate	1	120 - 150cm L	3 - 10cm W (vegve), 3.5 (11) cm L, (2) 3.5 (10) cm W (floating leaves)	2 - 4cm D, petals: 2.5 - 4 (4.6)cm W	capsule, 1.2 - (1.5) 1.7 - 2.6 x 0.8 - 1.1 cm	3 - 3.8 - 5 (6)mm L, 2.7 - 3.5mm W, 0.4mm thick, beak 0.07 - 0.35mm L, 0.02 - 0.06mm	Flwr June to Sept	5 - 40, opt 20 - 25	high	<0.5‰, to 3.3‰	acid, alkaline, neutral, 4.5 - 7.3	nutrient rich	M	Cook, 1974; Hroudová <i>et al.</i> , 1992; PFAF, 2010; USDA, NRCS, 2011; Stace <i>et al.</i> , n.d.
<i>Oenanthe</i> spp.	perennial, biennial, annual	emergent	2	unknown	stolon	2	stolon [Cat. A], seed [Cat. E]	2	2	human, water or animal	fast	1	10 - 15cm L	7 - 15cm L	tiny	schizocarp, 4mm L	larger than minute (family)	Flwr summer (July to Sept)	20 - 21, germn 24 - 29	moderate to high	<0.5‰	alkaline, neutral, acid, 5.5 - 6.5	nutrient rich	M	Kirkbride <i>et al.</i> , 2006; Winterton & Scher, 2007; MBG, 2010
<i>Ophiopogon japonicus</i>	perennial	emergent	2	unknown	rhiz, runner, tubers	2	sh. division [Cat. C], rhiz divsn [Cat. A],	2 - 6/locule (genus)	1	human	moderate	1	none	5 - 30.5cm L, 0.3cm W/ 10 - 50cm x 2 - 4mm	tepals: 5 x 2mm	berry, 0.318cm W	7 - 8mm D	Flwr May to Aug, fruit Aug to Sept	15 - 24	moderate to high	tolerant	6.1 - 6.5 - 7.5	nutrient rich	M	Black, 1985; Efloras, 2008a; Floridata, 2010; Animal World, 2011; Dave's Garden, 2011
<i>Orontium aquaticum</i>	perennial	emergent	2	unknown	rhiz (1.5 - 3cm D)	3	division [Cat. C], seed [Cat. E], rhiz [Cat. A]	1 (FONA)/5 to 9 (Cook)	1	human	slow	1	46cm L	blade: 6 - 10 - 30 (45)cm L x 0.85 - 3cm W	spadix: 2 - 10cm x 5 - 10mm	berry, 1 - 2cm D	1 - 1.5cm D	Flwr April to June/late winter to spring, seeds ripen early summer	hardy to -15 & - 20°, 0 - 25 (opt 10 - 25)	all light (prefer very high)	low tolerance	acid, alkaline, neutral, 6.6 - 7.8	nutrient rich	M	Cook, 1974; FONA, 1993; Beck, 2005; Floridata, 2010; MBG, 2010; PFAF, 2010
<i>Phalaris</i> spp.	annual or perennial	emergent	2	unknown	rhiz	3	rhiz [Cat. A], seed [Cat. E], division [Cat. C]	600	4	human, water, animal, wind?	fast	1	61 - 91cm L, culm: 10 - 100cm L	60 - 80cm L, 1.7cm W, blade: 2 - 20mm W	80 - 100cm L, spikelet: 3.5 - 9.5mm L	caryopsis	1.3 - 2.2mm L	Flwr June to August	cold tolerant +/- 2 to 5 - 21	moderate to very high	tolerant of salt spray & wind	neutral, acid, alkaline, 5.8 - 6.2	nutrient rich	M	Watson & Dallwitz, 1992; Cizer, 2006; MBG, 2010
<i>Phragmites australis</i>	perennial	emergent	2	unknown	stolon/runner, rhiz	3	clones [Cat. C], rhizomes [Cat. A], seeds [Cat. E]	2000	4	wind, water, human, animal	fast	1	10mmD, 2 - 4m L	5 - 10.2 - 51 - 60cm L, 1.0 - 5.1/0.3 - 6cm W	flwr spike 15 - 30 - 40cm L, spikelet 12 - 15mm L	seed-like grains, rarely produced, caryopsis	1.5mm L	Flwr August to Sept/ Jul - Oct	germn 16 - 25, opt growth 30 - 35	high to very high	0.5 - 30‰ even 40ppt seen	4.5 - 8.7	undemanding as competes for nutrients	D but only M seen	Alex, 1998; Texas AgrLife, 2009; Whetstone, 2009; OFAH, 2010; GISD, n.d.
<i>Phragmites</i> spp.	perennial	emergent	2	unknown	stolon &/or rhiz	1	stolon, rhiz [Cat. A]	numerous	4	human, animal, water, wind	fast	1	culms: 0.6 - 40m L	blades: 20 - 60cm L, 0.8 - 4cm W	spikelets: 10 - 15mm L	caryopsis	small	Flwr summer to fall	cold tolerant, 10 - 35 (opt 30)	moderate to very high	tolerant, 0.5 - 30‰	mild acid, mild alkaline, 4.5 - 8.7	nutrient rich	M or D	Cook, 1974; Botany.com, 2010

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Pilea cadierei</i>	perennial	emergent	2	unknown	rhiz	2	cuttings [Cat. D], division [Cat. C]	1	1	human	moderate	1	15 - 30.5 - 40cm L	7.6cm L or 8 x 5cm; blade: 2.5-6 × 1.5-3 cm	male: capitulum, 5-8mm D (glomerules), in bud ca 2.5mm; female: perianth 0.5 - 0.7mm L	achene, ca. 1.5mm	small	Flwr Sept to Nov, fruit Nov to Dec	15 - 21, min 12	moderate	poor tolerance	6.1 - 7.8	nutrient rich	D	Cullen <i>et al.</i> , 2011; Gilman, 1999; Efloras, 2008a; Texas AgriLife, 2009; MBG, 2010; Dave's Garden, 2011
<i>Pistia stratiotes</i>	perennial or annual (temperate)	floating	2	unknown	seed overwinter, runners, offsets	3	from runners [Cat. A], seed [Cat. E], offshoots on stolon [Cat. C]	4 to 5 to 15 to 20	3	human, water, animal	moderate to fast	1	no stem	2 - 20 - 25cm L x 10cm W	inconspic	raphidian berry	2 x 1mm L	Flwr May to Oct	22 - 25, 15 - 35, germin 20 - 25, seed seen to survive 4 & - 5	high	<0.5‰	slight acidic (6.5 - 7.2), best @pH 4	undemanding as competes for nutrients	M	Kulkarni <i>et al.</i> , 1990; FONA, 1993; Hiscock, 2003; Liu <i>et al.</i> , 2008; Liveaquaria.com, 2011; GISD, n.d.; Tropica, n.d.d.
<i>Pogostemon helferi</i> (syn. <i>Dysophylla/Eusteralis helferi</i>)	annual or perennial	emergent	2	unknown	frag	2	side shoots/offshoots [Cat. C], seed [Cat. E], stem frag [Cat. D]	4	2	human, water	moderate to fast (light dependent)	1	2 - 5 - 10cm L, 5 - 10cm W	2.5 - 5cm L, 3 - 6mm W	inflor: 15 - 30mm L	nutlet, very minute, <1cm to/fr 1 - 5cm L, 0.5 - 3.5cm L (family)	larger than minute	Flwr & fruit year round	20 - 30	low to moderate to high	<0.5‰	5.0 - 7.0	nutrient rich	M	Kirkbride <i>et al.</i> , 2006; Winterton & Scher, 2007; The Planted Tank, 2008; Aquascapingworld, n.d., Tropica, n.d.
<i>Pogostemon stellatus</i> (syn. <i>Dysophylla/Eusteralis stellata</i>)	annual	emergent	2	unknown	frag	3	shoot [Cat. C], seed [Cat. A], stem frag [Cat. D]	4	2	human, water	moderate to fast	1	6 - 14 - 15 - 40cm L, 1cm D	2 - 7cm x 1.5 - 4 - (7.5)mm	spikes: 0.5-7(-9) cm x 4-6.5(-8) mm, petals: 1.8 - 2mm	nutlet, very minute, <1cm to/fr 1 - 5cm L, 0.5 - 3.5cm L (family)	larger than minute	Flwr & fruit year round	22 - 25	high to very high	tolerant	5.0 - 7.0	nutrient rich	M	Hooker, 1997; Winterton & Scher, 2007; Efloras, 2008a; Aquatic Plant Central, 2009
<i>Polygonum amphibium</i>	perennial	emergent or submerged (amphibious)	2	unknown	rhiz or stolons	2	seeds [Cat. E], rhiz [Cat. A]	1 (0 - 75 in British Isles)	2	animal, human	fast	2 (terres & aquatic)	1 - 2m L x 1cm across	35cm L x 6cm W / 2 - 15cm L (aqua), 6 - 12cm L (teres)	flwr cluster: 1 - 15cm L, 0.4 - 1 - 1.7 - 2cm W, flwr 5mm L, 0.32cm W	achene, 2.5 - 3mm L & W	0.2mm D	Flwr June to September, fruit late summer to early autumn	hardy to -25°, 4 - 20 (germin), 25 - 35 (opt)	moderate or very high	0.5 - 30‰	3.0 - 8.0	nutrient rich/moderate (meso to eutro)	M	Cook, 1974; Alex, 1998; Partridge 2001; CBS, 2005; PFAF, 2010; WSDE, n.d.
<i>Pontederia cordata</i>	perennial	emergent	2	unknown	rhiz, stolons	2	rhiz division [Cat. A], stolons, seed [Cat. E]	1	4	human, animal, water, wind	moderate	3	0.9 - 1.3cm L/30 - 120cm L (FONA)	5 - 25cm L, 2 - 15cm W	8mm L	utricle, 4 - 6 x 2 - 3mm	large	Flwr July to Sept	18 - 27, hardy to - 25°	moderate to high	low	6.5 - 7.5	nutrient rich	M	Cook, 1974; FONA, 1993; Beck, 2005; Floridata, 2010; PFAF, 2010; Texas AgriLife, 2011; Hiby, 2011; Liveaquaria.com, 2011; USDA, NRCS, 2011
<i>Pontederia</i> spp.	perennial	emergent	2	unknown	rhiz	1	rhiz [Cat. A]	1	3	human, water, animal	moderate	1	to 76.2cm L	15.2cm L, 5 - 10cm W	1.3cm W, flwr spike: 15.2cm L	utricle	large	Flwr July to Sept	frost tolerant, 18 - 28 (opt 22 - 25)	moderate to high	low	6.5 - 7.5	nutrient rich	M	Cook, 1974; Hiby, 2011
<i>Potamogeton malaianus</i> (syn. <i>Potamogeton nodosus</i>)	usu perennial, rarely annual	submerged (floating leaves)	2	unknown	turions (dominant ones not develop), rhiz/runner, apical winter buds	2	rhiz [Cat. A], seed [Cat. E]	1	3	human, animal, water	fast	2 leaf forms but floating leaf present rarely absent, most	30 - 100cm L, 1.5 - 2mm D	subm lamina: (47-116)-280(-350)mm L, (1 -)22-38mm W, 5-9 times as long as wide.	25 - 80mm L (in fruit)	achene, 2.7 - 2.9 - 3.7 - 4.1 - 4.3mm L	2.5 x 1.9mm	Flwr & fruit July to Sept	18 - 28	moderate to high	<0.5‰	6.5 - 8.0	undemanding	M	Cook, 1974; Wiegleb & Kaplan, 1998; Huang <i>et al.</i> , 2002; Efloras, 2008a
<i>Potamogeton octandrus</i>	perennial or annual	submerged (floating leaves)	2	unknown	rhiz, turion (develop)	2	rhiz, rhiz divsn [Cat. A], seed [Cat. E]	1	1	human	fast	2 leaf forms but floating leaf absent or present	ca. 0.5mm D	submg: 2.5 - 5.5 (-7.9)cm L, 0.5 - 1.2 (-1.9)mm W (30 - 75 times long as wide)	spike: 5 - 16mm L (in fruit)	nutlet/achene, 1.5 - 2.5mm L, 1.5mm W, beak 0.3mm L	unknown	Flwr & fruit May to Oct	18 - 27	moderate to high	<0.5‰	6.5 - 7.0	undemanding	M	Wiegleb & Kaplan, 1998; Harper <i>et al.</i> , 2002; Efloras, 2008a; RBG, 2011; Hyde & Wursten, 2011
<i>Potamogeton perfoliatus</i>	perennial or annual	submerged	2	unknown	rhiz, turion (dominant ones not develop), apical winter buds, stem frag	2	rhiz [Cat. A], seed [Cat. E]	1 (20 - 46/inflor)	3	human, water, wind	fast	2 leaf forms but floating leaf always absent	30.5 - 250 - 305cm L, 0.5 - 2.5mm D	submg: 1.6 - 11.5cm L, 0.7 - 4.2cm W, ((1) - 1.3 - 7 (-10) times long as wide)	13 - 25mm L (spike in fruit)	nutlet/achene, 2.5 - 4.5mm L, 1.5 - 2 - 2.5mm W, beak 0.4 - 0.6mm	2.45 - 2.55mm L, 1.82 - 1.9mm W, 1.07 - 1.12mm thick (D)	Flwr & fruit May to Oct	18 - 26	moderate to high	0.5 - 30‰	6.0 - 8.5	tolerant of a wide range of nutrients	M	Wiegleb & Kaplan, 1998; Efloras, 2008a; Koch <i>et al.</i> , 2010; MDNR, 2010; USDA, NRCS, 2011; UFLIFAS, 2011; GISD, n.d.d.
<i>Primula japonica</i>	short-lived perennial	emergent	2	none	rootstock	2	root divsn [Cat. A], seed [Cat. E]	numerous	1	human	moderate	1	to 45cm L	30.5cm L, 12.7cm W	petal: 20mm D, flwr stalk 91.4cm L	capsule, 5mm D	0.3 - 2.5mm L (genus)	Flwr May to June	annual low -29°, 4 - 21	moderate	<0.5‰	5.6 - 7.5	nutrient rich	M	Richards, 2003; Dave's Garden, 2011
<i>Primula</i> spp.	short-lived perennial	emergent	2	none	rootstock	2	root divsn [Cat. A], seed [Cat. E]	10 - 100 - 150	1	human	moderate	1	20.3 - 61cm L	0.8 - 25cm L, 0.4 - 9cm W	15 - 40mm L (in sect.)	capsule, 0.084cm L or 5 - 20mm L	0.3 - 2.5 - 3mm L	Flwr March to mid-summer, prinp. Dec to April	13 to 15, <26	moderate to very high	<0.5‰	5.0 - 7.0	nutrient rich	M	FONA, 1993; Richards, 2003; Diaz <i>et al.</i> , n.d.
<i>Proserpinaca palustris</i>	perennial	emergent	2	unknown	rhiz, stem frag	3	division, lateral shoots [Cat. C], seed [Cat. E], rhiz [Cat. A]	3	2	human, animal	moderate	1 (terrestrial and subm forms)	10 - 40cm L, 5 - 15cm W	subm: 5 - 10cm L, emrg: 8.5cm L, 1.5cm W	2cm W	nutlets, 5.1cm L, 2.5 - 4mm W	3.5mm L (mean)	Flwrs mid-summer (Jan - Feb, May - July, Oct - Dec)	10 to 28	moderate to very high	<0.5‰	5.0 - 7.5	low nutrients	M	Stutzenbaker, 1996; Mossman, 2009; Aquascapingworld, n.d., UWSPF, n.d.
<i>Ranunculus flammula</i> (syn. <i>Ranunculus reptans</i>)	annual or perennial	emergent (amphibious)	2	unknown	runner	3	stolon/runner [Cat. A], seed [Cat. E], shoot [Cat. C]	1/ovary	2	human, animal	moderate	1	to 50cm L	blade: 0.7-6.5 × 0.04-1 cm, 2cm W, 6 - 25mm L	0.64 - 1.3cm W, petals: 2.5-7 × 1-4 mm	achene, 1.2 - 1.6mm L x 1 - 1.4mm W, beak 0.1 - 0.6mm	tiny	Flwr May/July to Sept	min -36°, 4.4 - 29.4	moderate to high	<0.5‰	6.0 - 7.5	moderate nutrients	M	Cook, 1974; PFAF, 2010; Saghead, 2011; USDA, NRCS, 2011; UWSPF, n. d.; Montana Plant Life, n.d.a.
<i>Ranunculus lingua</i>	perennial	emergent	1	none	none	1	seed [Cat. E]	1/carpel (numerous carpels)	1	human	moderate	1	ca 75cm L, 10cm W	blade: 10-15 × 0.7-2 cm	2.7 - 3.8cm D, petals: 17-20 × 14-17 mm	aggregate fruit: ca. 9mm D	achene, 2 - 3 x 1.5 - 1.8mm	Flwr June to Sept	tolerant of cold temperate temps, 6 - 8 - 20	moderate to very high	tolerant	5.5 - 8.0	low nutrients	M	The Plant Press Ltd., 2006; Efloras, 2008a
<i>Ranunculus papulentus</i>	perennial	emergent	2	unknown	runner	1	stolon/runner, rhiz [Cat. A]	12 to 36	1	human	moderate	1	3 - 30cm L	2 - 4cm L	petals: 7 - 12mm L, 2 - 4 mm W	achene, 1.7 - 3.6mm L	tiny	Flwr July to Sept, spring to autumn	20 - 28	moderate to very high	<0.5‰ but also slightly saline	6.0 - 6.8	nutrient rich	M	SVDOI, 2011c; RBG, 2011
<i>Riccia fluitans</i>	annual or short-lived perennial	submerged/floating	2	unknown	budding, thallus frag	3	by division, budding [Cat. C], spores [Cat. E]	numerous	2	animal, human	moderate	1	segment <1mm W	2 - 3 - 6cm L, 0.5 - 1mm W (thallus)	none	none, microscopic spores prodd within thallus	microscopic	none	15 - 30/10 - 18 - 25	moderate to high	slightly brackish (500 - 2000 micromhos/cm @25°)	neutral, 6 - 8	nutrient rich (not in aqms thou)	M/D (but most say D (liverwort))	Stewart & Kantrud, 1972; Mondadori, 1976; Selkirk, 1979; Hiscock, 2003; Winterton & Scher, 2007; WSDE, n.d.
<i>Rorippa aquatica</i> (syn. <i>Neobeckia aquatica</i> , <i>Armoracia lacustris</i>)	perennial	submerged, emergent	2	unknown	rhiz, frag, gemmipary, rootstalk	4	rhiz [Cat. A], budding [Cat. C], frag [Cat. D], seed [Cat. E]	1 to few, 48 - 80/ovary	2	human, water	slow	1	3 - 8.5 - (11)dm L	3 - 7cm L (emerg), 5 - 15cm L (subm)	6 - 8mm L, petals: 4 - 8 × 2-3.5 mm	silicle, 4 - 5 - 8mm L, 2 - 2.5 - 3.5mm W	0.7 - 0.8mm L, 0.5 - 0.6mm D	Flwr April to August	20 - 26	moderate to high	<0.5‰	7.0 - 7.5	nutrient rich	M	USDAFS, 2005; USDA, NRCS, 2011; UWSPF, n.d.
<i>Rotala indica</i>	summer annual to perennial	emergent (amphibious)	2	unknown	stem frag	1	cuttings [Cat. D]	numerous	3	human, water, animal	fast	amphib & terres forms	to 40cm L, 1.3cm W	5 - 17 x 3 - 8mm	tiny, inconspic	capsule, ca. 1mm D, (+/-) 2mm L	0.4mm L	Flwr Sept to Oct, fruit Oct to April	22 - 28	moderate to high	<0.5‰	6.5 - 7.5/5.8 - 7.1	nutrient rich for good growth	M	Liveaquaria.com, 2011; Aquatic Plant Central, 2009; USFS/PIER, 2007; Efloras, 2008a
<i>Rotala macrandra</i>	annual, rarely perennial	emergent	2	unknown	stem frag	1	from cuttings [Cat. D]	numerous	1	human	moderate to fast	1	2 - 7cm W	0.32 - 2.5cm L	tiny, inconspic	capsule, 1mm D	tiny	unknown	22 - 25 - 30	high to very high	<0.5‰	slight acidic (6.5 - 7.5)	low (~10ppm or >)	M	Cook, 1974; Liveaquaria.com, 2011; Hiscock, 2003; Thierry & Piednor, 2005; Aquatic Plant Central, 2009; Hargreaves, 2006
<i>Rotala rotundifolia</i>	perennial, possibly annual	floating or emergent	2	unknown	stem frag	2	cuttings [Cat. D], side shoots [Cat. C]	numerous	1	human	moderate to fast	1	1.5 - 2cm W, to 30cm L	0.64cm L, 5-13 × 3.5-15 mm	spikes: 1-4(-8) cm (lax in fruit)	capsule, ca. 1.5mm D	ca. 0.5mm L	Flwr & fruit Nov to June, 1mth germin	18 - 20 - 28 - 30	high to very high	<0.5‰	6.5 - 7.5	low (~5ppm)	M	Cook, 1974; Hiscock, 2003; Thierry & Piednor, 2005; Aquatic Plant Central, 2009; Efloras, 2008a; UFLIFAS, 2011; Tropica, n.d.

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Rotala</i> spp.	annual, rarely perennial	emergent or floating	2	unknown	stem frag	2	cuttings [Cat. D], side shoots [Cat. C]	many	1	human	fast	1	3cm W, 40 - 50cm L	0.64 - 0.95cm L [range 0.32 - 2.5cm L, 0.3 - 1.5mm W]	tiny	capsule, 1mm D	tiny	unknown	18 - 30/10 - 26	moderate to very high	<0.5‰	5.0 - 8.0	low	M	Graham, 1964; Graham <i>et al.</i> , 2011
<i>Rotala wallichii</i>	perennial	submerged, emergent inflor, or amphibious	2	unknown	stem frag	2	cuttings [Cat. D], side shoots [Cat. C]	numerous	1	human	moderate to fast	amphib & terres forms	2 - 5cm W	subm: 1.5 - 2.5mm	tiny, produces flwr in wild but not in aqns	capsule, ca. 1mm D	ca. 0.7mm	Flwr & fruit autumn & winter	22 - 30/18 - 28	high	<0.5‰	acidic, 5.0 - 7.0	low (20 - 25ppm)	M	Cook, 1974; Hiscock, 2003; Aqua-fish.net, 2011; Aquatic Plant Central, 2009; Hargreaves, 2006; Efforas, 2008a; Tropica, n.d.
<i>Ruellia</i> spp.	perennial	emergent	2	unknown	rhiz	3	rhiz [Cat. A], seed [Cat. E], cuttings [Cat. C]	4 to 20	2	human, wind	moderate to fast	1	20.3 - 30.5cm L	11.4 - 12.7cm L, 1.3 - 1.8cm W	3.8 - 5.1cm W	capsule, 2.5cm L	2.5mm W	Flwr June to Sept	hardy to -9.4, 13 - 40	moderate to very high	tolerant	acid, neutral, alkaline, 6.1 - 7.8	moderate	M	Long, 1970; MBG, 2010; MSWN, 2002
<i>Rumex sanguineus</i>	perennial	emergent	2	unknown	rootstock	2	seed [Cat. E]	7 to 10	1	human	moderate	1	30 - 70 - (90)cm L	(5) - 10 - 30cm L, 2.5 - 6cm W	tepals: 2-3 × 0.8-1.3(-1.8) mm, ca. 2 times as long as wide	achene, 1.3 - 1.5-(1.8)mm L, 1 - 1.3mm W	1.4 - 1.6 x 1 - 1.2mm	Flwr June to July, 55 days, germn 2 - 3wks @20°	min -34 to -3.8, 2 - 40 (germ 18 - 23) (opt 40)	moderate to high	<0.5‰	5.8 - 6.8	moderate	M/D but mainly M	FONA, 1993; PFAF, 2010; Dave's Garden, 2011; UWSPF, n.d.
<i>Sagittaria latifolia</i>	perennial	emergent	2	unknown	corm (0.5 - 1cm L, 2cm D), stolon (30cm L, 0.3cm W), tubercles	2	seed [Cat. E], rhiz, runner/stolon, rootstock, tubers, tubercles [Cat. A]	1 (size 2.7mm L)	2	human, animal	moderate	2 leaf types	0.2 - 1.5m L	1.5 - 30.5 - 45cm L x 2 - 17cm W (blade)	male: 6 - 9mm L, 4.5 - 5mm W (2 - 4cm W); female: ca. 18mm L, ca. 12mm W	fruit aggregate 1 - 1.7cm D	achene, 2.5 - 3.5mm L, to 2mm W, beak 1 - 2mm L	Flwr summer to fall, fruit mid to late summer, germn 2 yrs	hardy to -36°, 15 - 37, germn 25 - 37	high to very high	<0.5‰	4.7 - 8.9	oligo to eutro	M/subD	Cook, 1974; FONA, 1993; Haynes & Holm-Nielsen, 1994; MBG, 2010; USDA, NRCS, 2011
<i>Sagittaria montevidensis</i>	perennial	submerged or emergent	2	unknown	rhiz (8cm L, 6cm D), corm	2	rhiz [Cat. A], seed [Cat. E]	1 (size 2 - 3mm L)	2	human, animal	moderate	2 leaf types	to 100cm L	5 - 17cm L, 2cm W (subm), 2.5 - 17.5cm W, 0.6 - 22cm L (emerg blade)	male: 1 - 2.5cm L, 0.5 - 2.5cm W; female: 0.6 - 1.25 - 2.5cm L, 0.5 - 3mm W	fruit aggregate 1.2 - 2.1cm D	achene, 2 - 4.3mm L, 0.7 - 1.5mm W, beak 0.4 - 1.5mm L	Flwr June to Sept	15 - 26	moderate to high	tolerant	6.5 - 7.5	nutrient rich	M	FONA, 1993; Haynes & Holm-Nielsen, 1994; Liveaquaria.com, 2011; RUC, 2010; UGPM, 2010; Australian Weeds Committee, n.d.
<i>Sagittaria platyphylla</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz frag, tubers, corm (0.8 - 2cm L, 0.8 - 3.1cm D), runner (16cm L, 1.2 - 4.1mm W)	2	runners/rhizome [Cat. A], seed [Cat. E]	1	3	human, water, animal	slow to moderate to fast	2 leaf forms	to 150cm L	26cm L, ca. 5mm W (subm), 4.6 - 16.4 x 0.7 - 6.1cm (emerg blade)	male: 8.5 - 9.1mm L, 4.5 - 6mm W; female: ca. 6mm L, ca. 5mm W	fruit aggregate 0.7 - 1.2cm D	achene, 1.2 - 2 x 0.8 - 1.2mm, beak 0.3 - 0.6mm	FONA: flower summer to fall	16/18 - 26, opt growth 24	high to very high	non-tolerant, <0.5‰ & tolerant (<i>depends on locale</i>)	6.5 - 7.5	nutrient rich	M	Cook, 1974; FONA, 1993; Haynes & Holm-Nielsen, 1994; SVDPL, 2011b; Liveaquaria.com, 2011; RBC, 2011; Hiscock, 2003; Thierry & Piedrot, 2005; GSD, n.d.
<i>Sagittaria</i> spp.	perennials, occ. annuals	emergent	2	unknown	rhiz, tubers, whole plant	3	rhiz [Cat. A], seed [Cat. E], division [Cat. C]	1	2	human, water	moderate	1	to 61cm L	<30.5cm - 122cm L	2.5 - 5.1 - 6.4cm W	achene, 2.5mm L, 1.5mm W	unknown	Flwr July to August	hardy to -10, 10 - 28 (opt 18 - 28)	moderate to very high	tolerant	7.0	nutrient rich	M	Haynes & Holm-Nielsen, 1994; PFAF, 2010; Texas AgriLife, 2011; Yensen, 2011
<i>Sagittaria subulata</i> (syn. <i>Sagittaria lorata</i> , <i>Sagittaria natans</i> , <i>Sagittaria pusilla</i>)	perennial	submerged or floating (rooted plant)	2	unknown	rhiz, corm (0.5cm L, 0.3cm D), runner (15cm L, 0.5 - 3mm W)	1	runners/rhizomes, corm, tuber [Cat. A]	1	2	human, animal	moderate	2 leaf forms	to 90cm L	5 - 30.5 - 60 - 90cm L, 0.1 - 0.3 - 0.5cm W (subm), 24 - 40cm L, 0.5 - 4mm W (float)	male: 2 - 6mm L, 0.15 - 0.4 - 1.2cm W; female: ca. 5mm L, ca. 4mm W	fruit aggregate 5.5 - 8mm D	nutlet/achene, ca. 2mm L, 0.2 - 0.6 - 0.8cm W, beak 0.2 - 0.4mm L	Flwr July to Oct	16 - 22 - 28/15 - 30	high	0.5 - 35‰	alkaline/6.0 - 8.0	nutrient rich	M	Cook, 1974; FONA, 1993; Haynes & Holm-Nielsen, 1994; Hiscock, 2003; APC, 2006; Tropica, n.d.
<i>Salvinia cucullata</i>	annual, perennial	floating	2	unknown	frag, rhiz	3	spore [Cat. E], frag [Cat. D], runner/rhiz [Cat. A]	many	3	human, water, animal	fast	floating & subm leaves	floating, none reported	to 1.2cm L	non-flowering	sporocarp	microsp. 24µm	unknown	15 - 30	moderate to high	<0.5‰	5.0 - 8.0	nutrient rich	D (heterosporous: fern)	Haig & Westoby, 1988; USFS,PIER, 2007; Tropica, n.d.
<i>Salvinia minima</i>	annual, perennial	floating	2	unknown	rhiz, frag, buds	4	frag [Cat. D], terminal or lateral buds [Cat. C], spores [Cat. E]	25 megasp, numerous micro	3	human, water, animal	fast (every 2 weeks)	floating & subm leaves	ca. 6 - 10cm L	0.4 - 2cm L, 1 - 1.5cm D	non-flowering	sporocarps: ~1mm W (5/node = fronds)	mega: 224 - 402µm (polar D), 179 - 378µm (equa D)/micro: 15 - 36µm D	unknown	24 - 29 (also 10 - 35)	high	low tolerance (5‰)/4 - 7‰	6 - 7.5	nutrient rich	D (heterosporous: fern)	Cook, 1974; FONA, 1993; USGS, 2005; TexasInvasives, 2007; Nielsen, 2009; Hargreaves, 2006; 2011; UF,IFAS, 2011; GSD, n.d.
<i>Salvinia natans</i> (syn. <i>Salvinia rotundifolia</i> , <i>Salvinia auriculata</i>)	annual	floating	2	unknown	frag, rhiz (20cm D)	4	daughter plants [Cat. C], spore [Cat. E], frag [Cat. D]	32 microsp.	2	human, water	moderate to fast	floating & subm leaves	ca. 2.5cm (mat) - floating stem	8 - 10 - 15mm W x 15 - 20mm L	non-flowering	sporocarp, ~1 - 3mm D	microsp. 16 - 20µm W, megasp. 70 - 75µm W	sporocarp prod in August, spore germn late Jan, fert by Feb, ripen Aug to Sept	14 - 28/12 - 30, >10	moderate to high	<0.5‰	5.5 - 8, 8.5 - 9.5	high nutrients	D (heterosporous: fern)	Schneller, 1981; Hiscock, 2003; USGA, 2011; Invasive.org, 2011; Dyatlov & Vasilieva, n.d.
<i>Salvinia oblongifolia</i>	annual, perennial	floating	2	unknown	rhiz	2	rhiz, rhiz divsn [Cat. A], spore [Cat. E]	many	2	human, water	fast	floating & subm leaves	floating, none reported	2.7 - 4.2 - 10cm L x 1 - 1.8cm W	non-flowering	sporocarp	mega: 224 - 402µm (polar D), 179 - 378µm (equa D)/micro: 15 - 36µm D	unknown	15 - 35, >10	moderate	<0.5‰	5.5 - 6.0	high nutrients	D (heterosporous: fern)	Cook, 1974; USGS, 2005; APC, 2009; Aqscape.eu, 2010
<i>Samolus parviflorus</i> (syn. <i>Samolus valerandi</i> ssp <i>parviflorus</i>)	perennial	emergent	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	20 - 50+ (genus)	3	human, water, animal	slow	1	30cm L, 1.5 - 4dm L	2 - 7.6cm L, 2.5 - 4cm W, blade: 1.5 - 15cm	0.32cm W, petal: 1.2 - 3mm	capsule, 2 - 3mm L x 3mm D	small	Flwr April to June to Sept (2 - 3mths flwg)	15 - 24	low to moderate	0.5 - 30‰	6.5 - 7.0	nutrient rich	M	FONA, 1993; Jitty, 2002; RUC, 2010
<i>Samolus valerandi</i>	perennials, biennials, rarely annuals	emergent	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	35 - 104/capsule	3	human, water, animal	slow to moderate	1	10 - 30 - (40)cm L, 3 - 4cm W	3.5 - 7 - 15.2 - 20cm L, 1 - 2 - 4cm W [basal leaves: 1.2 - 6.5 X 0.7~3 cm]	0.32cm W, petal: 2 - 3mm, 2 - 6cm D	capsule, 0.32cm W, 2 - 3mm D	0.5 - 0.6mm L	Flwr March to April	20 - 24/15 - 26	high	0.5 - 30‰ (to 13.3 - 15.9‰)	6.0 - 8.0/6.5 - 8.5	nutrient rich	M	Cook, 1974; FAO, 2007; Hiscock, 2003; Grubben & Denton, 2004; Aqua-fish.net, 2011; Efforas, 2008a
<i>Sarracenia purpurea</i>	perennial	emergent	2	unknown	rhiz frag	2	seed [Cat. E], rhiz frag [Cat. B]	400 - 1000 (genus)/300 - 600	3	human, water, animal	slow	1	none	10 - 20 - 43.2cm L	2.5 - 5.1cm L, 3 - 7cm W	capsule, 1 - 2cm D	1.7 - 2mm L	Flwr May to August, fruit mid to late summer	min to -40 & -26, 23 - 27	high	<0.5‰	4.5 - 5.5, can use alkaline as well	nutrient rich	M	FONA, 1993; Rook, 2002; Meades <i>et al.</i> , 2004; D'Allion, 2011a; USEPA, 2011; UWSPF, n.d.
<i>Sarracenia</i> spp.	perennial	emergent	2	unknown	rhiz frag	2	seed [Cat. E], rhiz [Cat. A]	400 - 1000 (genus)/300 - 600	3	human, water, animal	slow	1	stem apart of pitcher	pitcher (leaf): 10cm - 1m L	3 - 10cm D	capsule	1.5 - 2mm L	Flwr late spring to early summer	min to -28.8, 16 - 27	moderate to high to very high	<0.5‰	6.1 - 6.5	nutrient rich	M	Floridata, 2010; Schnell, 2002; D'Allion, 2011a
<i>Saururus cernuus</i>	perennial	emergent	2	unknown	rhiz/runner	3	cuttings [Cat. D], rhiz. Divn [Cat. A], seed [Cat. E]	2 to 4 seeds but only 1 develop	3	human, animal, water	slow	1	5 - 15cm W, 0.5 - 1.2m L	31 - 91cm L (5.1 - 13cm L x 2.5 - 7.6cm W)	15.2 - 20.3cm L (can be longer)	nutlet, schizocarp, 1.5 - 3mm L	1 - 1.3 x 0.7 - 1mm	FONA: flower spring to summer sometimes early fall	10 - 26 - 30°	moderate to high	<0.5‰, tolerant to 0.3‰	6.5 - 7.5	nutrient rich	M	Cook, 1974; FONA, 1993; Hiscock, 2003; Winterton & Scher, 2007; Texas AgriLife, 2011; UF,IFAS, 2011; UF,IFAS, n.d.
<i>Schoenoplectus tabernaemontani</i> (syn. <i>Scirpus validus</i> & <i>Scirpus lacustris</i>)	perennial	emergent	2	unknown	rhiz	3	rhiz [Cat. A], seed [Cat. E], offshoot [Cat. C]	1	2	human, animal	fast	1	culm: 0.5 - 3m L, 2 - 10mm W	2m L, 1 - 4mm W, blade: 2 - 200 x 1 - 4mm	spikelet: 1.3cm L, 3-17 × 2.5-4 mm	achene/nut, 1.5 - 2.8mm L, 1.2 - 1.7mm W, beak 0.2 - 0.4mm	2.5mm L	Flwr June to August, fruit ripen Aug to Sept	hardy to -39°, opt 25 - 35 (water), 30 - 40 (soil)	moderate to high	0.5 - 30‰ (low tol, 0.02>0.35>0.73)	5.4 - 7.5	nutrient rich	M	Cook, 1974; Latham <i>et al.</i> , 1991; FONA, 1993; RUC, 2010; USDA, NRCS, 2009; Humphrey & Cotagelli, 2011; Haddock, 2011
<i>Scirpus</i> spp.	perennial but called annuals at the cold temps	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	1	human	moderate	1	0.3 - 1.5 - 2.4m L	2m L, 11 - 80cm L, 3 - 23mm W	spikelet: 1.3 - 23cm L	achene vs nut, 0.6 - 1.8mm	small	Flwr August to Sept	hardy to -18°, 10 - 24	moderate to very high	tolerant	mild acid, mild alkaline, 6.0 - 7.5	undemanding as removes nutrients from water	M	Beetle, 1943; Cook, 1974
<i>Shinerisia rivalaris</i> (syn. <i>Trichocoronis rivalaris</i>)	perennial	emergent	2	unknown	rhiz	3	cuttings [Cat. D], side shoots [Cat. C]	1/fruit	1	human	fast	1	10 - 30cm L	2 - 4cm L, 1.9cm W, blade: 5cm L x 4cm W	petals ca. 2mm	cypselae, 2mm	pollen/microsp: 25µ D	FONA: flowering Dec - Mar - May - August	20 - 25/18 - 30	moderate to very high	<6.6‰	5.5 - 9.0	undemanding as removes nutrients from water	M	Robinson & King, 1970; FONA, 1993; Hiscock, 2003; Hargreaves, 2006

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propagule used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Sisyrinchium californicum</i>	perennial	emergent	2	unknown	rhiz	2	rhiz, rhiz divsn [Cat. A], seed [Cat. E]	many	2	human, animal	moderate to fast	1	2 - 6.8mm W	15.2 - 40.6cm L	11 - 18mm L (tepals)	capsule, 6 - 13mm L	0.7 - 1.5mm L	Flwr spring to late summer	min -18 & -12, 12 - 18	moderate to very high	<0.5‰	6.6 - 7.8	nutrient rich	M	FONA, 1993; RUC, 2010; Berkeley, 2011; Dave's Garden, 2011; LBJWC, 2011; Humprey & Colanelli, 2011
<i>Sparganium eurycarpum</i>	perennial	submerged or emergent	2	unknown	rhiz, tuber/corm	3	rhiz [Cat. A], shoot [Cat. C], seed [Cat. E]	1 to 2 to 3	3	human, water, animal	moderate	1	0.5 - 2.5m L	(0.2 - 0.8) - 2.5m L, 6 - 20mm W	male 1 - 2cm D; female 1.5 - 2.5 - 4cm D (flower head)	achene, 5 - 10mm L x 4 - 8mm W, beak 2 - 4mm	endocarp (seed) 7 - 10mm L	Flwr July to August, fruit late summer	min -36°, 8 - 23	high to very high	<0.5‰, somewhat brackish (0.5 - 30‰)	5.0 - 8.5	low nutrients	D/M	Cook & Nicholls, 1986; FONA, 1993; Larson, 1993; USDA, NRCS, 2011; Sagebud, 2011; WSDE, n.d.
<i>Spathiphyllum tasson</i>	perennial	submerged or emergent (amphibious)	2	unknown	rhiz	2	rhiz, rhiz divsn [Cat. A], seed [Cat. E]	(8-)>5 - 1 (genus)	1	human	slow	1	none reported	12 - 65cm L, 3 - 25cm W	unknown	berry-like	small	Flwr Jan to June	22 - 28	moderate to high	non-tolerant	6.5 - 7.0	nutrient rich	M	Liveaquaria.com, 2011; Henry, 1998
<i>Spathiphyllum wallisii</i> (syn. <i>Stenogrammatium popatense</i> var. <i>wallisii</i>)	perennial	emergent	2	unknown	rhiz	2	daughter plants/offshoots [Cat. C]	4 to 3(-2), total 6 - 12/ovary	1	human	slow to moderate	1	44cm L, 0.5cm W	37cm L, 17cm W, blade: (14-)24 - 36cm L, (3-)5 - 10cm W	spadix: 1.5 - 7 - 8cm L	berry-like, 0.4 - 1.3cm L	small	Flwr spring, summer, fall & winter, naturally Jan to Sept	18 - 28, min 10	undemanding will grow in low light	non-tolerant	5.0 - 7.5	nutrient rich	M	Bunting, 1960; Henry, 1988; Reslar, 1999; Hiscock, 2003; Gilman, 2009a
<i>Stratiotes aloides</i>	perennial	submerged mainly but floats later in cycle	2	unknown	overwinters as a rosette	3	plantlets [Cat. D], seed [Cat. E], runner/rosette [Cat. A]	24/ovary	3	human, water, animal	fast (aggressive)	1	1 - 1.8cm L, 2.5 - 3.7mm W	15 - 50cm L, 4cm W	male (15-) 18 - 24mm L, (14-) 16 - 22 (-24)mm W; female (14-) 16 - 21 (-23)mm L, (5-) 6 - 9 (-12)mm W	berry-like capsule, 12 - 34mm L, 9 - 15mm D	5.8 - 10.6mm L, 2.3 - 3mm W	seeds germinate 4 months after release, flowering May - Sept	15 - 24	moderate to high	<0.5‰	4.5 - 8.5	nutrient rich (also found in oligo, meso, eutrophic)	D	Cook, 1974; Cook & Urmli-König, 2003a; Beck, 2005; OFAH, 2010; Aquapage.eu, 2010
<i>Symplocarpus foetidus</i>	perennial	emergent	2	unknown	rhiz	2	rhiz, rhiz divsn [Cat. A], seed [Cat. E]	1	2	human, animal	moderate	1	never elongates & remains in the ground	10 - 60cm L, 7 - 40cm W	7.6 - 12.7cm L, spadix: 1 - 3cm L	berry, 8 - 10 - 12cm L x 7.6cm W	0.7 - 1.5cm W	Flwr March to April	15 - 35 (above air temp; floral thermogenesis)	moderate	<0.5‰	4.0 - 7.0	nutrient rich	M	FONA, 1993; Holdrege, 2000; Hilty, 2011; CBS, 2005; USEPA, 2009; Taiz & Zeiger, 2010
<i>Syngonium</i> spp.	perennial	epiphyte or hemiepiphyte	1	none	none	1	seed [Cat. E]	50 - 100	2	human, animal	moderate	1	1.7 - 2.3cm D, to 6cm D	7 - 14cm L, 12 - 27cm L (creeping)	spike: 7 - 48mm L, male: 4 - 7cm L, 7 - 15mm D; female: 1 - 2cm L, 6 - 9mm D	5 - 10mm L, 3 - 6mm D, 3 - 5.5 (-7)cm L, 1.5 - 3.5cm W	7 - 11mm L, 5 - 7mm W	Flwr & fruit year round	20 - 28/16 - 24	moderate to high	poor tolerance	5.0 - 8.0	moderate	D (evergreen vine)	Croat, 1981; Gilman, 2009b
<i>Taxiphyllum barbieri</i> (Java Moss)	perennial	floating (have seen submersed on rocks)	2	unknown	stem cuttings	3	by shoot division [Cat. C], spore [Cat. E]	numerous	2	human, water or wind	slow to moderate to fast	1	0 - 5cm L	10 - 14mm L	not known for mosses	capsule	7 - 28µm (genus)	unknown	18 - 30	undemanding	to 6.6 - 13.3‰	neutral [(6.5 - 7.2)/5.8 - 8]	low to rich	D (dioicous, rarely synoicous; Aquatic moss)	Mondadori, 1976; Hiscock, 2003; Aqua-fish.net, 2011; Aquatic Plant Central, 2009; Aquamoss, n.d.
<i>Taxiphyllum</i> spp.	perennial	floating	1	none	none	1	spore [Cat. E]	numerous	2	human, water or wind	very slow	1	none reported	unknown	not known for mosses	capsule	7 - 28µm (genus)	unknown	15 - 30	low to high	<0.5‰	5.0 - 9.0	low to rich	D (dioicous, rarely synoicous; Aquatic moss)	Aquamoss, n.d.; Aquascapingworld, n.d.
<i>Teucrium scorodonia</i>	perennial	emergent	2	unknown	rhiz (0.5cm D)	3	seed [Cat. E], rhiz [Cat. A], cuttings [Cat. D]	4 (400 to 48K/pl/yr in British Isles)	2	human, animal	slow to moderate	1	10 - 40cm L (flwg stem to 50cm)	blades: 2.5 - 7cm	12 - 15mm L	nutlet	1 - 1.5mm D	Flwr July to Sept, seeds ripen August to Sept	>15, 18 - 23	moderate to very high	tolerant	acid, alkaline, neutral, 3.6 - 8.2	nutrient rich	M	Horwood, 1919; PFAF, 2010; The Plant Press Ltd, 2006
<i>Thalia dealbata</i>	perennial	emergent	2	unknown	rhiz	2	rhiz division [Cat. A], seed [Cat. E]	8 to 10 (fruit 9 - 12>1 seeded)	2	human, water	fast	1	to 2m L	20 - 45.7cm L, 51cm W, 17 - 55 x 7 - 22cm (blade), 50 x 25cm	panicle: 20.3 - 30.2 - 45.7cm, flwr: 18mm W	capsule, 9 - 12mm L, 8 - 11mm W, 10.2cm D	1mm	Flwr May to Sept, Fruit Jun to Oct	hardy to -1, 2 - 10 - 21 - 30	high to very high	tolerant	5.5 - 6.5	nutrient rich	M	Britton & Brown, 1913; Cook, 1974; Hunter, 1984; Burkhill, 1985; FONA, 1993; NCSU, 2005; Beck, 2005; LBJWC, 2011
<i>Thalia geniculata</i>	perennial	emergent	2	unknown	rhiz	2	rhiz divsn [Cat. A], seed [Cat. E]	7 to 10 (fruit 9 - 12>1 seeded)	2	human, water	fast	1	to 2m L	20 - 61 - 76.2cm L, 4 - 20.3 - 26cm W	2cm L, inflor. 2.5m L	capsule, 9 - 12mm L, 6 - 7mm W (12 x 7mm)	9 - 12mm L, 5 - 6mm W (10 x 6mm)	Flwr late June to Dec, fruit August to Jan	hardy -17.7 to 1.7°, ideal 21 - 28	moderate to very high	<0.5‰ (not tolerant, low)	5.5 - 7.0	nutrient rich	M	Gann <i>et al.</i> , 2011; JCU, 2005; University of Florida, 2011; Australian Weeds Committee, n.d.
<i>Tonina fluviatilis</i> (syn. <i>Hyphydra amplexicaulis</i> , <i>Tonina fluviatilis</i> f. <i>parvifolia</i>)	perennial	submerged, floating or emergent (prostrate)	2	unknown	stem frag	3	side shoots [Cat. C], seed [Cat. E]	1	1	human	moderate	1	20 - 30 - 40 - 80cm L, 2 - 3cm W	5 - 9mm L, 2 - 3mm W, lamina: 0.8 - 1 - 1.5cm L x 1 - 2.5mm W	small	capsule	0.4 - 0.5mm L	Flwr & fruit March to August, flwr also Nov, fruit Jan to Oct	22 - 28	low to very high	<0.5‰	4.5 - 7.0/3.9 - 4.2 - 6	nutrient rich	D	Lindley, 1853; Moldenke, 1972; Moldenke, 1984; Aquatic Plant Central, 2009
<i>Tonina</i> spp.	perennial	submerged, floating or emergent (prostrate)	2	unknown	stem frag	3	side shoots [Cat. C], seed [Cat. E]	1	1	human	very slow to moderate	1	to 50cm L or more, 5 - 6cm W	8 - 15mm L, 1 - 2.5mm W	small	capsule	7 - 65 x 2 - 7µm	unknown	20 - 28	moderate to high to very high	<0.5‰	5.0 - 6.5	nutrient rich	D	Cook, 1974; The Planted Tank, 2008
<i>Trapa natans</i>	annual or shortlived perennial	floating	2	unknown	offshoots, runners	3	runners or rhizomes [Cat. A], offshoots [Cat. C], nuts (seed) [Cat. E]	15 - 20 seed/roset, ea nut = 10 - 15 rosette	3	human, water, animal	moderate to fast (aggressive)	1	1 - 5m L	10.2cm L (sub), 0.3m diam & 2 - 5cm W (floa)	8mm L (inconspic), petal 7 - 10mm L	nuts, 2.5cm with spines	2.5cm L x 2 - 4cm W	Flwr begins July til killed by frost, seed ripen in Aug (US), May to Oct, fruit Jul to Nov	18 - 26	high to very high	0.5 - 30‰	alk but tol all ranges, gen 6.7 - 8.3	nutrient rich (high nutrient)	M	Rhoads & Block, 2002; Hiscock, 2003; Hummel & Kiviat, 2004; Liu <i>et al.</i> , 2008; Efloras, 2008a; Krisbaugh, 2009; GISD, n.d.d.
<i>Tulbaghia</i> spp.	perennial	emergent	2	unknown	rhiz, bulb	2	rhiz divsn [Cat. A], seed [Cat. E]	2 to numerous	1	human	fast	1	to 30cmL	to 30cm L	perianth: 7 - 14mm L	capsule	flat	Flwr mid summer	hardy to -6, 15 - 30	very high	moderate	6.6 - 7.5	nutrient rich	M	Burbridge, 1978
<i>Tulbaghia violacea</i>	perennial	emergent	2	unknown	bulb, corm, rhiz	2	rhiz [Cat. A], seed [Cat. E]	2 to numerous	1	human	fast	1	30 - 40cm L	5 - 30.5cm L, 1.3 - 7cm W	1.9 - 2.54cm L, 2.54cm W	capsule, 0.5 - 1.1cm L	flat	Flwr July to Sept	>0 (min to -10 in Britain), heat tolerant, 10 - 24 - 40 (opt germn 23 - 27)	moderate to high	moderate	6.6 - 7.5	nutrient rich	M	Burbridge, 1978; PFAF, 2010; Floridata,2010; Kubitzki & Huber, 1998; Glen <i>et al.</i> , n.d.;
<i>Typha angustifolia</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	~20K - 70K, 117K to 268k/spike (AON)	4	human, wind, water, animal	fast	1	91.4 - 183cm L	3 - 8mm or 0.64 - 1.3cm W, 91.4 - 183cm L	male 4 - 6mm; female 2mm in flwr, 5 - 7mm in fruit	nutlet, 5.1 - 15.2cm L	1mm L (0.718 - 1.358mm)	Flwr May to June/late spring to summer, seeds germinate May to Sept	14 to -13	high to very high	0.5 - 30‰, FONA: 30 - 50‰	alkaline, 3.7 - 8.5	nutrient rich	D	Grace & Harrison, 1986; FONA, 1993; Rook, 2002
<i>Typha latifolia</i>	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	~20K - 70K, 117K to 268k/spike (AON)	4	human, wind, water, animal	fast	1	30.5cm L or 152.4 - 304.8cm L, 0.95 - 1.9cm D, 0.32 - 0.64cm D (near flwr)	8 - 15 - 25mm W or 0.76 - 1.9cm W, 91.4 - 304.8cm L	male >1.3cm L or 0.48 - 1.3cm L; female 2 - 3mm L in flwr, 10 - 15mm L in fruit	nutlet, 0.8 - 1.6mm L	1.5mm L (0.962 - 1.776mm)	Flwr May to June	all temps zones (7 - 24 & -23 to -34)/25 - 30	moderate to high	0.5 - 30‰ (prefer fresh)	acid, 5.5 - 7.5	nutrient moderate	D	Grace & Harrison, 1986; Rook, 2002; USDA, MNRCS, 2007; GISD, n.d.d.
<i>Typha laxmanii</i> (syn. <i>T. stenophylla</i>)	perennial	emergent	2	unknown	rhiz	2	rhiz [Cat. A], seed [Cat. E]	1	2	human, animal	fast	1	0.8 - 1.3m L	50 - 90cm x 2 - 4mm	male: 6 - 14cm L; female: 3 - 4 - 6 - 12cm L	nutlet	0.95 - 1.1mm	Flwr & fruit June to Sept	hardy to <-9, 7.4 - 19.8	moderate to high	0.5 - 30‰	6.0 - 8.0	nutrient rich	D/M	FONA, 1993; Efloras, 2008a; Invasive.org, 2011; Australian Gardening, n.d.
<i>Typha minima</i>	perennial	emergent	2	unknown	runners	3	runners [Cat. A], seed [Cat. E], shoot [Cat. C]	1	2	human, animal	fast	1	16 - 25cm L, 1 - 2 - 3mm W	blade: 15 - 40cm x 1 - 2mm	male: 3 - 8cm L; female: 1.6 - 4.5cm	nutlet	0.2mm L	Flwr May to August, seed ripes June to Sept	7 to 27	moderate to high	0.5 - 30‰	6.5 - 7.5	moderate	D	Liveaquaria.com, 2011; PFAF, 2010; Missouri Botanical Garden, 2001; Efloras, 2008a

Appendix 9: Biological information for aquatic plants sold by aquarium and ornamental pond industries

Species Name	Life cycle	Growth form	No. of reproductive strategies used	No. of vegetative propagules produced	Type of vegetative propague used	No. of propagation strategies	Type of propagation strategies used	No. of seeds produced	No. of dispersal mechanism used	Type of dispersal mechanism used	Growth rate	No. of phenotypic forms	Stem length & width	Leaf length & width	Flower length & width	Fruit length & width & type	Seed/Spore size	Time to flower	Temperature (°C)	Light	Salinity	pH	Nutrient content	Breeding system	References
<i>Typha</i> spp.	perennial	emergent	2	unknown	rhiz	2	seed [Cat. E], rhiz [Cat. A]	100's - 1000's - 200K (nutlets)	3	human, animal, water	fast	1	to 3m L	152 - 305 - 350cm L, 3 - 23mm W (blade: 1m L, 3cm W)	female: 5 - 30mm D, 5 - 30mm long as wide	nutlet, seed pods 7.6cm L	0.2mm L	Flwr May to August, seed ripens June to Sept	16 - 27	moderate to high	0.5 - 30‰	6.5 - 7.5	nutrient rich	D	Morton, 1975; Cook, 1980; Parsons & Cuthbertson, 2001; The University of Queensland, Australia, 2009; UCIPM, 2010
<i>Utricularia graminifolia</i>	perennial, sometimes annuals	emergent or submerged	2	unknown	rhiz (0.5 - 1.3mm), stolon (turions)	2	rhiz, rhiz divsn [Cat. A], seed [Cat. E]	few to many	3	human, water, animal	moderate	1	none reported	blade: 0.4-2 - 4 cm × 0.8-3 - 6 mm	inflor: 2.5 - 30cm, petal: 0.7 - 1.5cm L	capsule, 2 - 3mm L	0.3 - 0.4 - 0.6mm L	Flwr May to Dec, fruit Jun to Jan	16 - 28	moderate to high	tolerant	5.0 - 6.5	nutrient rich/poor	M	The Planted Tank, 2008; Tropica, n.d.
<i>Utricularia vulgaris</i> (syn. <i>Utricularia macrorhiza</i>)	perennial	floating	2	unknown	frag, winterbuds (tubers or turions), rhizoids (c. 0.5mm thick)	3	frag [Cat. D], seeds [Cat. E]	1 to numerous	3	water, animal, human	moderate	1	none reported	no true leaf: bladders (4 - 9cm L when floating), leaf 1.5 - 6cm L	1 - 2cm L, 25mm W, inflor: 10 - 25cm L, petal: 1.4 - 1.9cm L	capsule ca. 5 mm D	0.3-0.4 × 0.5-0.7 mm	Flwr summer, fruit: mid to late summer	hardy to 0, -23 to 30	moderate to high	moderately salt tolerant (2k - 5k micromhos/cm @25	slight acid, 4.5 - 6.0, 5 - 8	nutrient poor, meso-eutropic	M	Taylor, 1989; PFAF, 2010; Muma, 2011; FDC, n.d.; WSDE, n.d.
<i>Vallisneria americana</i>	perennial	submerged	2	20 stolon buds per season	turions, stolon buds/runners	2	daughter plants on runners [Cat. A], seed [Cat. E]	160 - 300/fruit	4	animal, water, human, sediment mvmt	moderate to fast	1	none reported	8-100-300cm L, 3 - 18mm W	male 1 - 1.5mm across; female 4 - 8mm across	3 - 15cm L x 3 - 5mm W, capsules	1.8 - 2.6mm L x 0.6 - 1mm W	Flwr summer to fall	22 - 30/ 15 - 18 - 28	high	3 - 5 - 7-10‰ (depends on locale)	6 - 7.7 - 8.5	moderate to high nutrients	D	Lowden, 1982; Catling et al., 1994
<i>Vallisneria rubra</i> (syn. <i>Maidenia rubra</i>)	annual	submerged	2	unknown	runners	2	runners [Cat. E], seed [Cat. E]	numerous	3	human, animal, water	fast	1	to 2mm thick	40 - 60cm L	3mm L	4mm L	minute	Flwr March to May	20 - 27	high	0 - 4‰	6.5 - 8	nutrient rich	D	Rendle, 1916; Aqua-fish.net, 2011; DECWAH, n.d.
<i>Vallisneria spiralis</i>	perennial	submerged	2	unknown	runner	3	runners [Cat. A] & daughter pls [Cat. C], seed [Cat. E]	numerous	3	human, water, animal	fast	1	none reported	20 - 90cm L, 0.5 - 1cm W	male 0.9 - 1.1mm W; female :0.5mm W	capsule, to 20cm L	1.5 - 3mm L	Flwr Oct to March	15 - 30	moderate, grows faster in high lighting	<0.5‰	neutral (6 to 9)	nutrient rich	D	Beck, 2005; Ditchlak, 2009; GISD, n.d.d.
<i>Vallisneria</i> spp.	perennial	submerged	2	unknown	runner	2	runner [Cat. A], seed [Cat. E]	numerous	3	human, water, animal	fast	1	none reported	to 214cm L	minute	9.5 - 10cm L	1.3 - 2cm L	unknown	18 - 30	moderate to high	<0.5 - 30‰ (fresh & brackish)	neutral to alkaline, 6 - 8.5	moderate to high	D	Lowden, 1982
<i>Veronica beccabunga</i>	perennial	emergent	2	unknown	stem cuttings	3	seed [Cat. E], division [Cat. C]	numerous	3	human, water, animal	moderate	1	10 - 70cm L	1 - 5 - 8cm L	5.1 - 10.2cm L, 5 - 10mm W	capsule, 3 - 4mm L	0.5mm L	Flower May to Sept	3.6 - 14.7	moderate to high	<0.5‰	acid, neutral, alkaline soils, 4.5 - 5.5	moderate to high	M	Horwood, 1919; Cook, 1974; Grieve, 1995; The Plant Press Ltd, 2006
<i>Vesicularia dubyana</i> (Singapore Moss)	perennial	floating, submerged when on a rock	1	none	none	1	spore [Cat. E]	numerous	2	human, water	slow	1	none reported	1.3mm L	no flowers (bryo)	capsule, seta 1.5 - 2cm L	unknown	unknown	18 - 30	high	<0.5‰, tolerant	6 - 7.5	low to rich	M (autoicous: bryophyte)	Aquamoss, n.d.; Aquapage.eu, 2010
<i>Vesicularia montagnei</i> (Xmas Moss)	perennial	floating	1	none	none	1	spore [Cat. E]	numerous	2	human, water	slow	1 (dimorphic leaves)	to 17cm L	1 - 1.5mm L, dorsal: 0.9 - 1 x 0.4 - 0.6mm, lateral: 1.2 - 1.5 x 0.9mm	not known for mosses	capsule, 1mm L	9 - 12µm D	unknown	21 - 24 & 29 - 32 & 15 - 28	low to high	<0.5‰	4 - 5 - 6.0 - 8.0	high nutrient	M (autoicous: bryophyte)	Tropicos.org, Missouri Botanical Garden, 2011; PlantedTanks, n.d.
<i>Zantedeschia aethiopica</i>	perennial	emergent	2	unknown	rhiz	3	rhiz [Cat. A], seed [Cat. E], cuttings [Cat. C]	18/fruit (40 - 50/spadix)	3	human, animal, water	fast	1	0.6 - 1.5m L	15 - 50cm L, 8 - 25cm W	10 - 25cm L; female 0.25 - 0.5 of basal portion, male top portion	1cm W, berry	3mm W	Flwr August to January	10 to 24	moderate to very high	<0.5‰	5.5 - 7.5	rich	D	SVDPL 2011a; Aubrey A, 2001; Zimer, 2008; Kew Botanic Gardens, n.d.; Australian Weeds Committee, n.d.
<i>Zephyranthes candida</i>	perennial	emergent	2	unknown	rhiz, corm, tuber, offsets	3	seed [Cat. E], division [Cat. C], rhiz [Cat. A]	numerous	2	human, water	slow	1	10.2 - 15.2 - 25 - 35cm L, 2 - 4mm W	5.1 - 10.2 - 20 - 35cm L, 10.2 - 20.3cm W	2.5 - 5.1 - 6.5cm L	capsule, 10mm D	6 - 7mm L x 3.5 - 4mm W	Flwr June to November, seed 3 - 4wks	22, 10 to 24	moderate to high	<0.5‰ (moderate)	6.1 - 6.5 - 7.5	nutrient poor	M	POW, 1998; MBG, 2010; SMG, 2001; Bojňanský & Fargašová, 2007; Gilman, 2009c; Dave's Garden, 2011

KEY
yellow = alien species
green = native species
red = invasive species
blue = cosmopolitan species

Appendix 10: Volume of sales of taxa sold/year by 20 aquarium and ornamental pond stores in the GTA

Species Name	Total of volume sales
<i>Eichhornia crassipes</i>	32633
<i>Pistia stratiotes</i>	16374
<i>Ceratophyllum demersum</i>	13204
<i>Vallisneria americana</i>	7595
<i>Iris versicolor</i>	7164
<i>Cabomba caroliniana</i>	6146
<i>Sagittaria latifolia</i>	6078
<i>Lobelia cardinalis</i>	5504
<i>Cyperus</i> spp.	5429
<i>Echinodorus bleherae</i>	5415
<i>Pontederia cordata</i>	5170
<i>Egeria densa</i>	5144
<i>Colocasia</i> spp.	5050
<i>Utricularia vulgaris</i>	5040
<i>Asclepias incarnata</i>	5030
<i>Acorus americanus</i>	5015
<i>Aster puniceus</i>	5005
<i>Lobelia sessilifolia</i>	5004
<i>Sarracenia purpurea</i>	5002
<i>Teucrium scorodonia</i>	5000
<i>Nymphaea odorata</i>	5000
<i>Nymphaea mexicana</i>	5000
<i>Lysimachia terrestris</i>	5000
<i>Lysimachia quadrifolia</i>	5000
<i>Iris virginica</i>	5000
<i>Impatiens capensis</i>	5000
<i>Eupatorium purpureum</i>	5000
<i>Drosera</i> spp.	5000
<i>Nymphaea</i> spp.	4336
<i>Myriophyllum aquaticum</i>	4107
<i>Hygrophila</i> spp.	3949
<i>Echinodorus</i> spp.	3757
<i>Anubias barteri</i> var. <i>nana</i>	3460
<i>Taxiphyllum barbieri</i>	3420
<i>Cryptocoryne</i> spp.	3107
<i>Lemna minor</i>	2967
<i>Iris pseudacorus</i>	2935
<i>Canna</i> spp.	2644
<i>Microsorium pteropus</i>	2626
<i>Echinodorus uruguayensis</i>	2519

Species Name	Total of volume sales
<i>Vallisneria rubra</i>	2056
<i>Hygrophila polysperma</i>	2017
<i>Cladophora aegropila</i>	1990
<i>Anubias barteri</i>	1974
<i>Alternanthera reineckii</i>	1966
<i>Typha laxmanii</i>	1953
<i>Cryptocoryne wendtii</i>	1871
<i>Acorus</i> spp.	1815
<i>Vallisneria</i> spp.	1792
<i>Ranunculus flammula</i>	1784
<i>Iris</i> spp.	1732
<i>Cyperus alternifolius</i>	1526
<i>Hygrophila corymbosa</i>	1516
<i>Caltha palustris</i>	1465
<i>Myosotis scorpioides</i>	1439
<i>Cyperus haspan</i>	1434
<i>Typha</i> spp.	1396
<i>Bacopa monnieri</i>	1389
<i>Nasturtium officinale</i>	1388
<i>Alternanthera</i> spp.	1371
<i>Juncus glaucus</i>	1360
<i>Butomus umbellatus</i>	1350
<i>Typha minima</i>	1345
<i>Hygrophila difformis</i>	1299
<i>Cabomba piauhyensis</i>	1285
<i>Mayaca fluviatilis</i>	1281
<i>Rotala</i> spp.	1214
<i>Zantedeschia aethiopica</i>	1155
<i>Ceratopteris thalictroides</i>	1093
<i>Cyperus papyrus</i>	1080
<i>Limnophila indica</i>	1060
<i>Vallisneria spiralis</i>	1053
<i>Rotala indica</i>	1001
<i>Rotala wallichii</i>	986
<i>Azolla caroliniana</i>	931
<i>Sagittaria subulata</i>	924
<i>Microsorium</i> spp.	918
<i>Glossostigma elatinoides</i>	877
<i>Hemianthus callitrichoides</i>	848
<i>Ludwigia repens</i>	843
<i>Nymphoides aquatica</i>	833
<i>Egeria najas</i>	832
<i>Limnophila sessiliflora</i>	766

Species Name	Total of volume sales
<i>Cardamine lyrata</i>	758
<i>Alternanthera ficoidea</i>	756
<i>Hemianthus micranthemoides</i>	737
<i>Hydrocotyle</i> spp.	735
<i>Eleocharis acicularis</i>	729
<i>Anubias</i> spp.	722
<i>Echinodorus tenellus</i>	708
<i>Didiplis diandra</i>	697
<i>Cryptocoryne undulata</i>	568
<i>Bacopa caroliniana</i>	561
<i>Salvinia natans</i>	546
<i>Cryptocoryne crispatula</i>	542
<i>Anubias congensis</i>	541
<i>Limnophila hippuroides</i>	531
<i>Hygrophila angustifolia</i>	523
<i>Ludwigia</i> spp.	517
<i>Bacopa myriophylloides</i>	516
<i>Cabomba aquatica</i>	491
<i>Ammania senegalensis</i>	482
<i>Ludwigia inclinata</i>	481
<i>Lilaeopsis novae-zelandiae</i>	476
<i>Hemigraphis repanda</i>	444
<i>Cabomba palaeformis</i>	441
<i>Eleocharis parvula</i>	435
<i>Spathiphyllum tassel</i>	428
<i>Aponogeton madagascariensis</i>	418
<i>Cryptocoryne parva</i>	416
<i>Lilaeopsis brasiliensis</i>	415
<i>Bacopa australis</i>	406
<i>Dracaena sanderiana</i>	398
<i>Echinodorus cordifolius</i>	389
<i>Cryptocoryne spiralis</i>	376
<i>Elodea canadensis</i>	370
<i>Trapa natans</i>	360
<i>Crinum calamistratum</i>	338
<i>Cryptocoryne beckettii</i>	337
<i>Nesaea</i> spp.	329
<i>Ranunculus lingua</i>	326
<i>Ludwigia glandulosa</i>	320
<i>Riccia fluitans</i>	312
<i>Crinum thaianum</i>	310
<i>Limnophila aquatica</i>	303
<i>Dracaena fragrans</i>	300

Species Name	Total of volume sales
<i>Taxiphyllum</i> spp.	299
<i>Rotala macrandra</i>	295
<i>Hygrophila balsamica</i>	288
<i>Rotala rotundifolia</i>	280
<i>Lilaeopsis mauritiana</i>	276
<i>Sagittaria platyphylla</i>	271
<i>Proserpinaca palustris</i>	270
<i>Juncus</i> spp.	266
<i>Schoenoplectus tabernaemontani</i>	265
<i>Nesaea pedicellata</i>	264
<i>Anubias barteri</i> var. <i>glabra</i>	260
<i>Pogostemon stellatus</i>	256
<i>Mimulus guttatus</i>	255
<i>Echinodorus martii</i>	254
<i>Limnobium spongia</i>	248
<i>Equisetum hyemale</i> var. <i>robustum</i>	245
<i>Eleocharis montevidensis</i>	232
<i>Heteranthera zosterifolia</i>	218
<i>Ludwigia arcuata</i>	210
<i>Vesicularia dubyana</i>	204
<i>Hemianthus</i> spp.	200
<i>Nymphaea lotus</i>	196
<i>Cryptocoryne ciliata</i>	194
<i>Zephyranthes candida</i>	192
<i>Myriophyllum</i> spp.	192
<i>Ludwigia octovalvis</i>	192
<i>Blyxa japonica</i>	190
<i>Cyperus helferi</i>	188
<i>Anubias barteri</i> var. <i>barteri</i>	187
<i>Crinum natans</i>	184
<i>Anubias afzeli</i>	183
<i>Rumex sanguineus</i>	182
<i>Hygrophila stricta</i>	180
<i>Bolbitis heudelotii</i>	179
<i>Oenanthe</i> spp.	174
<i>Marsilea hirsuta</i>	170
<i>Aponogeton crispus</i>	170
<i>Spathiphyllum wallisii</i>	162
<i>Gymnocoronis spilanthoides</i>	162
<i>Ludwigia palustris</i>	160
<i>Limnobium laevigatum</i>	158
<i>Cotula coronopifolia</i>	148
<i>Houttuynia</i> spp.	146

Species Name	Total of volume sales
<i>Syngonium</i> spp.	144
<i>Ophiopigon japonicus</i>	144
<i>Nesaea crassicaulis</i>	144
<i>Rorippa aquatica</i>	140
<i>Echinodorus grandiflorus</i>	140
<i>Anubias hastifolia</i>	139
<i>Bolbitis heteroclita</i>	128
<i>Pontederia</i> spp.	126
<i>Myriophyllum tuberculatum</i>	122
<i>Eleocharis vivipara</i>	121
<i>Pilea cadierei</i>	120
<i>Hippurus vulgaris</i>	120
<i>Lysimachia</i> spp.	119
<i>Mentha aquatica</i>	115
<i>Aponogeton ulvaceus</i>	114
<i>Anubias barteri</i> var. <i>caladifolia</i>	114
<i>Lycoris radiata</i>	113
<i>Echinodorus bolivianus</i>	113
<i>Salvinia cucullata</i>	112
<i>Shinnersia rivularis</i>	108
<i>Saururus cernuus</i>	107
<i>Hygrophila costata</i>	102
<i>Echinodorus palaefolius</i>	100
<i>Cryptocoryne affinis</i>	100
<i>Micromeria brownei</i>	98
<i>Vesicularia</i> spp.	96
<i>Aponogeton boivinianus</i>	96
<i>Jussiaea grandiflora</i>	91
<i>Utricularia graminifolia</i>	90
<i>Carex</i> spp.	89
<i>Isolepis cernua</i>	87
<i>Carex buchananii</i>	86
<i>Hemigraphis exotica</i>	85
<i>Juncus repens</i>	80
<i>Hibiscus coccineus</i>	80
<i>Aponogeton capuronii</i>	78
<i>Mimulus ringens</i>	75
<i>Cryptocoryne pontederiifolia</i>	73
<i>Cyperus longus</i>	72
<i>Aponogeton undulatus</i>	72
<i>Typha angustifolia</i>	71
<i>Imperata cylindrica</i>	70
<i>Hydrocleys nymphoides</i>	70

Species Name	Total of volume sales
<i>Echinodorus grisebachii</i>	68
<i>Nymphoides peltata</i>	66
<i>Alisma plantago-aquatica</i>	65
<i>Agapanthus</i> spp.	65
<i>Ludwigia sedioides</i>	64
<i>Carex albula</i>	63
<i>Limnophila aromatica</i>	62
<i>Hydrocotyle bonariensis</i>	62
<i>Cryptocoryne retrospiralis</i>	62
<i>Pogostemon helferi</i>	61
<i>Nymphaea stellata</i>	60
<i>Hydrilla verticillata</i>	60
<i>Phalaris</i> spp.	57
<i>Marsilea crenata</i>	57
<i>Sarracenia</i> spp.	56
<i>Calla palustris</i>	55
<i>Tulbaghia</i> spp.	54
<i>Glyceria</i> spp.	54
<i>Agapanthus africanus</i>	54
<i>Lobelia</i> spp.	53
<i>Ammania</i> spp.	52
<i>Stratiotes aloides</i>	50
<i>Jussiaea diffusa</i>	50
<i>Hibiscus moscheutos</i>	50
<i>Hydrotriche hottoniflora</i>	49
<i>Veronica beccabunga</i>	48
<i>Nymphaea zenkeri</i>	48
<i>Dracaena</i> spp.	48
<i>Cryptocoryne lingua</i>	48
<i>Thalia geniculata</i>	45
<i>Cryptocoryne griffithii</i>	44
<i>Arundo</i> spp.	43
<i>Myosotis</i> spp.	40
<i>Mimulus luteus</i>	40
<i>Anemopsis californica</i>	40
<i>Scirpus</i> spp.	39
<i>Nuphar lutea</i>	36
<i>Tulbaghia violacea</i>	34
<i>Dichromena colorata</i>	34
<i>Thalia dealbata</i>	32
<i>Phragmites</i> spp.	32
<i>Typha latifolia</i>	30
<i>Lysimachia nummularia</i>	30

Species Name	Total of volume sales
<i>Hesperantha coccinea</i>	30
<i>Aponogeton longiplumulosus</i>	30
<i>Acorus gramineus</i>	30
<i>Sagittaria montevidensis</i>	29
<i>Menyanthes trifoliata</i>	28
<i>Cryptocoryne cordata</i>	28
<i>Nelumbo</i> spp.	26
<i>Equisetum hyemale</i>	26
<i>Barclaya longifolia</i>	26
<i>Ruellia</i> spp.	25
<i>Aponogeton distachyos</i>	25
<i>Aeschynomene fluitans</i>	25
<i>Salvinia minima</i>	24
<i>Nymphoides hydrocharioides</i>	24
<i>Lilaeopsis caroliniana</i>	24
<i>Caladium</i> sp.	24
<i>Blyxa aubertii</i>	24
<i>Primula japonica</i>	23
<i>Hibiscus acetosella</i>	23
<i>Eichhornia azurea</i>	23
<i>Hymenocallis</i> spp.	21
<i>Sisyrinchium californicum</i>	20
<i>Phragmites australis</i>	20
<i>Oenanthe aquatica</i>	20
<i>Equisetum palustre</i>	20
<i>Crinum</i> spp.	20
<i>Colocasia esculenta</i>	20
<i>Bacopa rotundifolia</i>	20
<i>Eriophorum angustifolium</i>	18
<i>Marsilea schelpeana</i>	17
<i>Echinodorus argentinensis</i>	17
<i>Bletilla striata</i>	17
<i>Hibiscus</i> spp.	16
<i>Sparganium eurycarpum</i>	15
<i>Salvinia oblongifolia</i>	15
<i>Orontium aquaticum</i>	15
<i>Nymphoides geminata</i>	15
<i>Juncus effusus</i>	15
<i>Hydrocotyle umbellata</i>	15
<i>Leucojum aestivum</i>	14
<i>Hydrocotyle sibthorpioides</i>	14
<i>Equisetum scirpoides</i>	14
<i>Eichhornia diversifolia</i>	14

Species Name	Total of volume sales
<i>Marsilea angustifolia</i>	13
<i>Sagittaria</i> spp.	12
<i>Nuphar stellata</i>	12
<i>Carex glauca</i>	12
<i>Polygonum amphibium</i>	11
<i>Echinodorus gabrielli</i>	11
<i>Anubias barteri</i> var. <i>angustifolia</i>	11
<i>Samolus valerandi</i>	10
<i>Lobelia siphilitica</i>	10
<i>Dulichium arundinaceum</i>	10
<i>Potamogeton octandrus</i>	9
<i>Crassula helmsii</i>	8
<i>Samolus parviflorus</i>	7
<i>Primula</i> spp.	7
<i>Musa</i> spp.	7
<i>Hymenocallis liriosome</i>	7
<i>Tonina fluviatilis</i>	6
<i>Carex retrorsa</i>	6
<i>Symplocarpus foetidus</i>	5
<i>Ranunculus papulentus</i>	5
<i>Iris kaempferi</i> (ensata)	5
<i>Aponogeton natans</i>	5
<i>Andromeda polifolia</i>	5
<i>Tonina</i> spp.	4
<i>Nelumbo lutea</i>	4
<i>Leptodictyum riparium</i>	4
<i>Carex crinita</i>	4
<i>Anubias gracilis</i>	4
<i>Anubias gigantean</i>	4
<i>Myriophyllum mattogrossensis</i>	3
<i>Hottonia palustris</i>	3
<i>Cryptocoryne albida</i>	3
<i>Carex grayi</i>	3
<i>Potamogeton malaianus</i>	2
<i>Najas indica</i>	2
<i>Marsilea quadrifolia</i>	2
<i>Ludwigia brevipes</i>	2
<i>Lagarosiphon major</i>	2
<i>Fontinalis antipyretica</i>	2
<i>Caltha</i> spp.	2
<i>Potamogeton perfoliatus</i>	1
<i>Nymphaea micrantha</i>	1
<i>Microcarpaea minima</i>	1

Species Name	Total of volume sales
<i>Lindernia rotundifolia</i>	1
<i>Lagarosiphon madagascarensis</i>	1
<i>Eriocaulon cinereum</i>	1
<i>Cryptocoryne pygmaea</i>	1
<i>Cordyline</i> spp.	1
<i>Barclaya</i> spp.	1
<i>Aponogeton rigidifolius</i>	1
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Appendix 11: Invasive species sold by aquarium and ornamental pond stores

SCIENTIFIC NAME	COMMON NAME
<i>Alternanthera ficoidea</i>	Cherry hedge, Green hedge, Joseph's coat
<i>Aponogeton distachyos</i>	Water hawthorn, Cape pondweed
<i>Arundo</i> spp.	
<i>Azolla caroliniana</i>	Water velvet, Water fern, Fairy moss
<i>Bacopa monnieri</i>	Dwarf bacopa, Baby tears, Moneywort
<i>Butomus umbellatus</i>	Flowering rush
<i>Cabomba caroliniana</i> (syn. <i>Cabomba australis</i> , <i>Cabomba pulcherrima</i>)	Green cabomba, Fanwort
<i>Canna</i> spp.	African sunset canna
<i>Ceratophyllum demersum</i>	Hornwort, Common hornwort
<i>Ceratopteris thalictroides</i> (syn. <i>Ceratopteris siliquosa</i>)	Water sprite, Indian fern, Water horn fern, Floating antler fern
<i>Cotula coronopifolia</i>	Golden buttons, Brass buttons
<i>Crassula helmsii</i>	
<i>Cyperus haspan</i>	Dwarf papyrus
<i>Dichromena colorata</i> (syn. <i>Rhynchospora colorata</i>)	Star grass, Star rush white top
<i>Egeria densa</i> (syn. <i>Elodea densa</i>)	Elodea, Pondweed, Anacharis, Common waterweed, Brazilian elodea, Water thyme, Brazilian waterweed, South American waterweed
<i>Eichhornia azurea</i>	Blue water hyacinth, Anchored water hyacinth, Rooted water hyacinth
<i>Eichhornia crassipes</i>	Water hyacinth, Common water hyacinth, Floating water hyacinth
<i>Elodea canadensis</i>	Canadian pondweed, Pondweed, Water thyme, Canada waterweed, Canadian waterweed, Broad waterweed
<i>Gymnocoronis spilanthoides</i>	Spade leaf plant, Water daisy
<i>Hippurus vulgaris</i>	Mare's tail
<i>Hydrilla verticillata</i>	
<i>Hydrocleys nymphoides</i> (syn. <i>Limnocharis humboldtii</i> , <i>Stratiotes nymphoides</i>)	Water poppy
<i>Hydrocotyle bonariensis</i>	Giant pennywort, Large leaf pennywort
<i>Hydrocotyle umbellata</i>	Pennywort, May flower marsh pennywort, Umbrella penny royal
<i>Hygrophila costata</i> (syn. <i>Hygrophila lacustris</i>)	Sword leaf stricta, Gulf swamp weed
<i>Hygrophila polysperma</i>	Dwarf hygrophila, Green hygrophila, East Indian hygrophila, Indian swamp weed, Miramar weed

SCIENTIFIC NAME	COMMON NAME
<i>Imperata cylindrica</i>	Japanese blood grass, Blady grass, Cogon grass
<i>Iris pseudacorus</i>	Yellow flag iris, Yellow water iris, Pale yellow iris
<i>Juncus glaucus</i> (syn. <i>Juncus inflexus</i>)	Blue rush
<i>Jussiaea grandiflora</i> (syn. <i>Ludwigia uruguayensis</i> , <i>Ludwigia hexapetala</i>)	Large flowered primrose, Water primrose, Uruguay water primrose, Uruguayan primrose willow
<i>Lagarosiphon major</i>	African water weed, African elodea, Oxygen weed, South African oxygen weed
<i>Lemna minor</i>	Duckweed, Common duckweed, Least duckweed, Lesser duckweed
<i>Leucojum aestivum</i>	Snowflake, Loddon lily, Summer snowflake
<i>Limnobium laevigatum</i>	Amazon frogbit, Frogbit
<i>Limnobium spongia</i>	American frogbit, American sponge plant, Frogbit
<i>Limnophila sessiliflora</i>	Dwarf ambulia Asian ambulia, Asian marsh weed, Ambulia
<i>Ludwigia octovalvis</i>	Mexican primrose willow
<i>Lysimachia nummularia</i>	Creeping Jenny, Lloydella, Moneywort
<i>Marsilea quadrifolia</i>	Four leaf water clover, European water clover
<i>Mentha aquatica</i>	Water mint, Water spearmint
<i>Mimulus guttatus</i>	Monkey flower, Common monkey flower
<i>Myosotis scorpioides</i> (syn. <i>Myosotis palustris</i>)	Water forget-me-not
<i>Myriophyllum aquaticum</i> (syn. <i>Myriophyllum proserpinacoides</i> , <i>Myriophyllum brasiliense</i> , <i>Myriophyllum papillosum</i> var. <i>pulcherrima</i>)	Brazilian milfoil, Milfoil, Parrot feather, Parrot feather milfoil, Dwarf parrot feather, Red-stem parrot feather
<i>Nasturtium officinale</i> (syn. <i>Rorippa nasturtium aquaticum</i>)	Watercress
<i>Nelumbo lutea</i>	American lotus
<i>Nymphaea odorata</i>	Fragrant white water lily, American water lily, American white water lily, White water lily
<i>Nymphoides geminata</i>	Yellow snowflake
<i>Nymphoides peltata</i>	Yellow floating heart, Floating heart
<i>Ophiopogon japonicus</i>	Green mondo grass, Dwarf mondo grass, Kyoto grass, Dwarf lily turf
<i>Phalaris</i> spp.	
<i>Phragmites australis</i>	Common reed
<i>Pistia stratiotes</i>	Water lettuce

SCIENTIFIC NAME	COMMON NAME
<i>Potamogeton perfoliatus</i>	Clasping leaf pondweed
<i>Rotala indica</i>	Indian tooth cup
<i>Rotala rotundifolia</i>	Dwarf rotala, Round leaf rotala
<i>Rumex sanguineus</i>	Red veined spatterdock, Wood dock, Red vein spatterdock, Bloody water dock, Bloody dock, Bloody wood dock
<i>Sagittaria latifolia</i>	Duck potato, Broad leaf arrowhead, Common arrowhead
<i>Sagittaria montevidensis</i>	Ruby eyed arrowhead, California arrowhead, Giant arrowhead
<i>Sagittaria platyphylla</i>	Giant sagittaria, Chilensis sagittaria, Broad leaf sagittaria, Chilensis, Delta arrowhead
<i>Salvinia cucullata</i>	Floating plant, Asian water moss
<i>Salvinia minima</i>	Water fern, Water spangles
<i>Salvinia natans</i> (syn. <i>Salvinia rotundifolia</i> , <i>Salvinia auriculata</i>)	Salvinia, Floating fern, Floating water moss, Giant Salvinia, Eared water moss
<i>Schoenoplectus tabernaemontani</i> (syn. <i>Scirpus validus</i> , <i>Scirpus lacustris</i> , <i>Schoenoplectus lacustris</i>)	Soft stem bulrush, Great bulrush, Bulrush, Lakeshore bulrush
<i>Shinnersia rivularis</i>	Mexican oak leaf
<i>Stratiotes aloides</i>	Water Soldier
<i>Trapa natans</i>	Water chestnut
<i>Typha angustifolia</i>	Lesser reedmace, Narrow leaf cattail, Graceful cattail
<i>Typha latifolia</i>	Greater reedmace, Common cattail, Cattail, Broadleaf cattail
<i>Typha laxmanii</i> (syn. <i>Typha stenophylla</i>)	Small reedmace cattail, Dwarf cattail, Slender cattail
<i>Vallisneria americana</i> (syn. <i>Vallisneria asiatica</i> , <i>Vallisneria americana</i> var. <i>americana</i> , <i>Vallisneria neotropicalis</i> , <i>Vallisneria americana</i> var. <i>biwaensis</i> , <i>Vallisneria gigantea</i>)	Dwarf vallisneria, Corkscrew vallisneria, Jungle vallis, American eel grass, Water celery, Twisted vallis, Contortion vallis, Giant vallisneria, Giant vallis, Jungle vallisneria, Giant torta, Jungle Val, Eel grass
<i>Vallisneria spiralis</i>	Straight vallisneria, Italian vallis, Straight vallis, Straight Val, Straight torta, Italian Val
<i>Veronica beccabunga</i>	European brooklime, European speedwell
<i>Zantedeschia aethiopica</i>	Calla lily, White arum lily

Appendix 12: Other invasive taxa sold by aquarium and ornamental stores

SCIENTIFIC NAME	COMMON NAME
<i>Alternanthera sessilis</i>	Scarlet hygro, Beetroot hygro, Sessile joy weed
<i>Azolla filiculoides</i>	Azolla, Moss fern, Fairy moss, Water fern
<i>Cyperus involucratus</i>	Umbrella sedge, Umbrella plants, Galingale
<i>Gunnera manicata</i>	Gunnera, Giant rhubarb
<i>Hydrocharis morsus-ranae</i>	European frog-bit
<i>Nelumbo nucifera</i>	Sacred pink, sacred lotus
<i>Oenanthe javanica</i>	Water parsley, Variegated water celery, Java water dropwort
<i>Phalaris arundinacea</i>	Ribbon grass, Eel grass, Reed canary grass
<i>Ranunculus repens</i>	Golden creeping buttercup, Creeping buttercup
<i>Ruellia brittoniana</i>	Dwarf blue bell, Blue bell dwarf, Britton's wild petunia
<i>Terminalia catappa</i>	Indian almond leaves (used in aquarium with betta fish)
<i>Xanthosoma sagittifolium</i> (syn. <i>Xanthosoma atrovirens</i> , <i>Xanthosoma mafaffa</i>)	Dwarf green taro, Lemon lime taro, Arrow-leaf elephant's ear

Appendix 13: Weed risk assessment model (Pheloung *et al.*, 1999)

Questions forming the basis of the Weed Risk Assessment model (WRA)

Weed Risk Assessment system question sheet: Answer yes (y) or no (n), or don't know (leave blank), unless otherwise indicated

Botanical name:		Outcome:	
Common name:		Score:	
Family name		Your name:	
History/Biogeography			
A	1 <i>Domestication/</i>	1.01 Is the species highly domesticated? If answer is 'no' got to question 2.01	
C		1.02 Has the species become naturalised where grown?	
C		1.03 Does the species have weedy races?	
	2 <i>Climate and</i>	2.01 Species suited to Australian climates (0–low; 1–intermediate; 2–high)	2
	<i>Distribution</i>	2.02 Quality of climate match data (0–low; 1 intermediate; 2–high)	2
C		2.03 Broad climate suitability (environmental versatility)	
C		2.04 Native or naturalised in regions with extended dry periods	
		2.05 Does the species have a history of repeated introductions outside its natural range?	
C	3 <i>Weed</i>	3.01 Naturalised beyond native range	
E	<i>elsewhere</i>	3.02 Garden/amenity/disturbance weed	
A		3.03 Weed of agriculture/horticulture/forestry	
E		3.04 Environmental weed	
		3.05 Congeneric weed	
Biology/Ecology			
A	4 <i>Undesirable</i>	4.01 Produces spines, thorns or burrs	
C	<i>traits</i>	4.02 Allelopathic	
C		4.03 Parasitic	
A		4.04 Unpalatable to grazing animals	
C		4.05 Toxic to animals	
C		4.06 Host for recognised pests and pathogens	
C		4.07 Causes allergies or is otherwise toxic to humans	
E		4.08 Creates a fire hazard in natural ecosystems	
E		4.09 Is a shade tolerant plant at some stage of its life cycle	
E		4.10 Grows on infertile soils	
E		4.11 Climbing or smothering growth habit	
E		4.12 Forms dense thickets	
E	5 <i>Plant type</i>	5.01 Aquatic	
C		5.02 Grass	
E		5.03 Nitrogen fixing woody plant	
C		5.04 Geophyte	

C	6 <i>Reproduction</i>	6.01 Evidence of substantial reproductive failure in native habitat	
C		6.02 Produces viable seed.	
C		6.03 Hybridises naturally	
C		6.04 Self-fertilisation	
C		6.05 Requires specialist pollinators	
C		6.06 Reproduction by vegetative propagation	
C		6.07 Minimum generative time (years)	1
A	7 <i>Dispersal mechanisms</i>	7.01 Propagules likely to be dispersed unintentionally	
C		7.02 Propagules dispersed intentionally by people	
A		7.03 Propagules likely to disperse as a produce contaminant	
C		7.04 Propagules adapted to wind dispersal	
E		7.05 Propagules buoyant	
E		7.06 Propagules bird dispersed	
C		7.07 Propagules dispersed by other animals (externally)	
C		7.08 Propagules dispersed by other animals (internally)	
C	8 <i>Persistence attributes</i>	8.01 Prolific seed production	
A		8.02 Evidence that a persistent propagule bank is formed (>1 yr)	
A		8.03 Well controlled by herbicides	
C		8.04 Tolerates or benefits from mutilation, cultivation or fire	
E		8.05 Effective natural enemies present in Australia	

A = agricultural, E = environmental, C = combined.

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9.0 GLOSSARY

Achene	A simple, dry, one-celled, one-seeded, indehiscent fruit ^(a)
Adventitious	Plant organs produced in an unusual or irregular position, or at an unusual time of development, as in adventitious buds, roots or shoots ^(a)
Amphibious	Plants are able to survive both on land and in water ^(a)
Annual	Plants that complete their life cycle within one growing season ^(c)
Aquarist	A person who keeps an aquarium ^(b) ; a curator, collector, or ichthyologist associated with an aquarium ^(c)
Berry	A fruit developed from an ovary containing one to several carpels in which the ovary wall (or at least its inner portions) and the inner structures of the ovary become enlarged and juicy; seeds within have their own seed coat ^(a)
Biennial	Plants that use two growing seasons to complete their life cycle ^{(a)(d)}
Bud	An undeveloped shoot containing the embryonic meristems which develop into flowers, stems or leaves, and are enclosed in protective specialized leaves termed bud scales. Buds are often classified according to function or position, e.g. accessory, lateral, or axillary ^(a)

Budding	<p>The vegetative (asexual) reproduction of plants by grafting a stem bud of a desired species onto the root stock of another plant, often a different species or variety^(a)</p> <p>A type of sexual reproduction in which a small protuberance or outgrowth (bud) develops, and becomes separated from the parent cell^(a)</p>
Bulbil	Small secondary bulbs that are developed from unusual locations (e.g. inflorescence and leaf axil) ^(a)
Capsule	A dry, dehiscent fruit derived from a compound ovary of two or more carpels; also, a dry indehiscent fruit from a two or more loculed ovary ^(a)
Caryopsis	A one-seeded, dry, indehiscent fruit with the seed coat adnate to the fruit wall (pericarp), derived from a one-loculed superior ovary ^(a)
Cone	Ovules and seeds are borne on sterile scales ^(d)
Cormel	Small corms that arise vegetatively from the parent ^(a)
Cormlets	Small corms that grow at the base of the parent corm ^(e)
Cosmopolitan	An organism that is found worldwide or is pandemic ^{(a)(d)}
Cultivar	Any variety or strain of plant which has been produced by horticultural techniques and is not normally found in wild populations ^(d)

Cuttings	A part of a plant, such as a bud, leaf, or a portion of a root or shoot, that, when detached from the plant and inserted in soil, can take root and give rise to a new daughter plant ^(f)
Cypselae	a dry single-seeded fruit formed from a double ovary of which only one develops into a seed ^(e)
Dioecious	Plants have male and female flowers or organs on different plants ^(a)
Follicle	A dry, dehiscent fruit derived from one carpel that splits along one suture ^(a)
Hardiness zone	A geographically defined area in which certain kinds of plants are capable of growing, as determined by average climatic conditions as well as indicates the area the plant is most likely to survive ^(g)
Hibernaculum (<i>pl.</i> hibernacula)	A winter bud; develops into a new plant under proper growing conditions ^(a)
Hull fouling/Biofouling	The gradual accumulation of organisms such as algae, bacteria, barnacles, and protozoa on underwater equipment, pipes, and surfaces, corroding and impairing structures and systems ^(b)
Inoculum	The substance used to make an inoculation ^(b)
Loment	A modified legume fruit having constrictions between the seeds, which at maturity, separates at the constrictions into one-seeded segments ^(a)

Monoecious	Plants have separate male and female reproductive structures on the same plant ^(a)
Offsets	A short, lateral shoot or branch, which develops from the base of the main stem in certain plants, providing a means of asexual reproduction (<i>syn.</i> offshoot, slip, sucker, ratoon) ^(a)
Perennials	Plants that survive for more than two seasons or years and produces flowers yearly after the initial period ^{(a)(d)}
Phenotypic plasticity	The ability to which a given phenotype may vary phenotypically under different environments; the total variation (genotype and phenotype) of a species or population ^(a)
Pod	A general term applied to any dry, dehiscent fruit ^(a)
Propagule pressure	The number of individuals of a species introduced to a given area per unit time ^(h)
Rhizome	An underground, more or less horizontal stem ^(a)
Rootstock	A rhizome ^(a)
Runner	A specialized stem (stolon) which develops from the axil of a leaf at the crown of a plant, has long internodes and grows horizontally along the ground; it forms adventitious roots and shoots at some of the nodes ^(a)
Schizocarp	A dry, dehiscent fruit that splits into two or more separate one-seeded carpels (mericarps) at maturity ^(a)

Silicle	A dry, dehiscent fruit, that is as wide as or wider than long
Sorus (<i>pl.</i> sori)	A cluster of spores and/or sporangia, as in ferns ^(a)
Sporocarp	A hard, multicellular, nutlike receptacle which contains sporangia in heterosporous ferns, and in some fungi ^(a)
Sprig	A small shoot or twig ^(a)
Syncarp	A compound fruit of two or more fused carpels ^(d)
Tuber	The short, swollen, sometimes edible underground stem, modified for the storage of food, or as a swollen root. They enable the plant to survive an adverse season, providing food for the later development of new shoots and roots ^(a)
Tubercle	Small, tuber-like swellings, nodules or projections ^(a)
Turions	Perennating winter buds that can get separated from the parent plant and give rise to a new plant in spring ^(a)
Utricle	A small cell, sac, or bladder-like protuberance in a plant ^(e)

LEGEND

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