PHPD REQUEST: 2000-42b

WEED RISK ASSESSMENT

EUROPEAN WATER-CHESTNUT

TRAPA NATANS L.

CFIA ACIA
CANADIAN FOOD INSPECTION AGENCY
AGENCE CANADIENNE D'INSPECTION DES ALIMENTS

Plant Health Risk Assessment Unit
Science Division
Nepean, Ontario

Date: November 2, 2001

Preface

Pest risk analysis involves three processes, risk assessment, risk management and risk communication. **This document represents the risk assessment portion of the overall risk analysis.**

Pest risk assessment provides the scientific basis for the overall management of risk. It involves identifying hazards and characterizing the risks associated with those hazards by estimating their probability of introduction and establishment as well as the severity of their economic impact.

The risk assessment process does not, as a general rule, take into account trade considerations. However, trade considerations are recognized as being a very important factor in overall risk management. The Plant Health & Production Division of the Canadian Food Inspection Agency is responsible for the overall coordination of the pest risk analysis process, and takes into account the pest risk assessment, trade considerations and other **risk management** factors, as well as **risk communication** with stakeholders, prior to developing any new or altering existing regulatory policies.

Risk assessments are science-based evaluations. They are not scientific research nor are they scientific manuscripts. The risk assessment forms a link between scientific data and decision makers and expresses risk in terms appropriate for decision makers. Information provided in this assessment is considered necessary, but not sufficient on its own, to provide the basis for regulatory decisions.

This risk assessment follows the format and terminology used in the Food and Agriculture Organization (FAO) models for pest risk analysis. For further information on the FAO models for risk assessment, refer to the FAO International Standard for Phytosanitary Measures available at: http://www.fao.org/WAICENT/FaoInfo/Agricult/AGP/AGPP/PQ/Default.htm.

Methods for weed risk analysis are based on the Canadian Food Inspection Agency's format for Pest Risk Assessment, the United States Department of Agriculture's format for Weed Risk Assessment, and the Australian Quarantine Inspection Service's Weed Risk Assessment System.

If you have any comments concerning this assessment, or would like additional information on plant health risk assessment, please contact the Unit Chief at:

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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 northeastern 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 northeastern 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 southwestern 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 northeastern 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 southwestern 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 northeastern 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 populations 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.

Evaluated by: Approved by:

Claire Wilson, Weeds Program Biologist

Doreen Watler, Chief, PHRA Unit

Date:

STAGE 1: INITIATING THE PROCESS

1.1 REQUEST

1.1.1. Purpose of the PRA

The Plant Health Risk Assessment Unit of the Science Division, CFIA has undertaken this pest risk assessment at the request of the Plant Health and Production Division, CFIA. See Appendix 1 for more administrative details.

The purpose of this assessment is to evaluate the plant health risk of the European water-chestnut (*Trapa natans* L.), an aquatic weed. This document is the risk assessment portion of the pest risk analysis process. The method used by the CFIA to initiate and conduct this pest risk assessment is consistent with international guidelines (FAO, 1996).

1.1.2. Preliminary Risk Profile

Brief Description of the Pest: European water-chestnut, or simply water-chestnut, is a floating-leaved aquatic plant native to the Old World, that has become an invasive weed in the northeastern United States (US) since its introduction in New York and Massachusetts in the late 1800s.

Brief History and Background of Request: Water-chestnut is prohibited from Canada under the Plant Protection Act and Plant Quarantine Regulations, due to its potential to invade and disrupt aquatic habitats. Water-chestnut was considered absent from Canada until 1998, when a population was observed in Rivière du Sud, a tributary to the Richelieu River in southwestern Québec. The population has overwintered and continued to spread since 1998, and the politics of funding for an eradication program came to the attention of the Québec press in May, 2001 (*Le Devoir*, Les Actualités, Mercredi 30 Mai et Jeudi, 31 Mai, 2001). The newspaper reports feature the Québec Minister of the Environment pledging support and funding for a water-chestnut eradication plan proposed by Ducks Unlimited (Canards Illimités), along with la Societé de la faune et des parcs du Québec, and CIME (Centre d'Interpretation du milieu écologique du Haut-Richelieu). The program was initiated in June of this year (2001), and workers in canoes have been manually removing plants from the river. It is expected that intensive control will be necessary for at least 3-4 years, with progress being monitored through a seed bank survey (Ducks Unlimited, personal communication). In the CFIA, the request for a risk assessment on water-chestnut was submitted in November, 2000, just prior to the initiation of a Weed Risk Assessment Program. The request was made "fast-track" in June, 2001, as a result of the media attention focussed on the plant in Québec.

Delimitation of the PRA Area: All of Canada

Values Potentially at Risk and Potential Negative Consequences: Water-chestnut is an aquatic and environmental weed with the potential to quickly colonize and infest waterways. Natural aquatic ecosystems could be disrupted, and native aquatic vegetation and wildlife displaced, causing changes in biodiversity as well as in water levels and water quality. Water use, navigation and recreation could be disrupted, with economic losses to associated industries (e.g. tourism) and large costs incurred in control programs.

1.2 PREVIOUS PRA, CURRENT STATUS AND PERTINENT PEST INTERCEPTIONS

Familiarity and Substantial Equivalence

There has been no previous risk assessment for water-chestnut.

Relevant PRAs and/or Related Materials

All aquatic plants are subject to import requirements under the Plant Protection Act and Plant Quarantine Regulations. Water-chestnut is one of four taxa (*Elodea densa*, *Hydrilla verticillata*, *Myriophyllum* spp., and *Trapa* spp.) that are prohibited from Canada, although the edible parts of *Trapa* spp. can be imported for consumption. All other aquatic plant species are permitted, but must be named on an import permit and phytosanitary certificate, and shipments inspected at the port of entry upon arrival. Shipments that do not comply with the import requirements will be refused entry. The following directives, letters, and circulars provide more details:

D-94-27	The Plant Protection Import Requirements for True Aquatic Plants (Sept 8, 1994)
Directive 04-0	The entry of aquatic plants into Canada (Operational Directive 16-6-86)
D-84-29	Rooted Aquatic Plants Associated with Plant Debris or Contaminated with Soil or Soil-Like Materials (Aug 16, 1984)
D-83-2	Revision of Quarantine Directive and Memorandum for Plant Commodities Controlled under the Plant Quarantine Act (Jan 10, 1983)
Permit Letter 10	Notice to Importers of Aquatic Plants (01/10/81)
Circular No. 18C	Plant Quarantine Circular No. 18C (Feb. 22, 1978)

Available Pest Facts Sheets/Pest Alerts etc.:

There has been no previous facts sheet prepared for water-chestnut. Pest facts sheets for other regulated pests may be viewed at the PHRA site on the CFIA network site, at O :/APHD/PHRA/FACTSHEETS/aa-list.htm)

STAGE 2: WEED FACTS SHEET

IDENTITY

Name: *Trapa natans* L.

Taxonomic position: (after Cronquist, 1981)
Division: Spermatophyta (Seed plants)
Subdivision: Angiospermae (Flowering Plants)
Class: Magnoliopsida (Dicots)
Subclass: Rosidae
Order: Myrtales
Family: Trapaceae

(Photo from VDEC, 2001b)

Common name(s): European water-chestnut, water-chestnut, water-nut, water caltrop, bull nut, Jesuit nut (Kiviat, 1987; Haber, 1999).

Note: The fruits of *Trapa* sp. are edible and are cultivated in parts of Asia, but are not the same as the more familiar and commercially available water-chestnut that is popular in Chinese cooking. The Chinese water-chestnut is derived from a different and unrelated plant, a spikerush called *Eleocharis dulcis* (Kiviat, 1987; Haber, 1999).

Etymology: *Trapa* is derived from the Latin "calcitrapa" which refers to a caltrop (or caltrap), an iron ball with four spikes used in Roman warfare to injure the feet of the enemy's cavalry horses (Mills *et al.*, 1993; Haber, 1999). The word *natans* means floating (Haber, 1999).

Notes: The family Trapaceae is closely allied to the Onagraceae (evening primrose) family (Cook, 1978). The genus *Trapa* was originally included in the Onagraceae, but is now considered distinct enough to warrant its own single-genus family (Hutchinson, 1969; Haber, 1999). The number of species in the genus *Trapa* is not well established, and is considered to be one, three, or up to 30, depending on the source (Cook, 1978). *Trapa* species are determined by fruit (nut) morphology, and variation in nut size and form among populations has led some authors to differentiate many varieties and species. For example, plants with four horns or spikes on the nut have been commonly called *T. natans* (Pemberton, 1999), while cultivated plants in India with two slender spines on the nut are often referred to as *T. bispinosa*. However, there are also many overlapping characteristics among populations, and it has been more recently proposed that *Trapa* may contain only one highly variable and widespread species, *T. natans*, with allopatric races (Daniel *et al.*, 1983). *T. natans* is now generally considered to be the only species to occur in Europe (Pemberton, 1999) although some East European authors have treated up to 25-31 different varieties as species in the past (Vuorela and Aalto,1982). *T. natans* is used to refer to species in Africa (e.g. var. *africana*) (Daniel *et al.*, 1983), and is also the species that has been introduced in the US The most confusion remains in Asia, where different forms are treated as species by some (e.g. *T. japonica*, *T. bispinosa*, *T. bicornis*) (e.g. Kumar *et al.*, 1985; Kunii, 1988a, 1988b; Arima et al., 1999), and as varieties by others (e.g. *T. natans* var. *bispinosa*, etc) (e.g. Brezny *et al.*, 1973; Daniel *et al.*, 1983; Kurihara and Ikusima, 1991; Dixit and Banerji, 1994).

HABITAT

European water-chestnut (*T. natans*, referred to simply as water-chestnut throughout the rest of this document) is a floating aquatic plant that occurs in lakes and ponds, slow-moving rivers and streams, wetlands, and freshwater regions of estuaries (Cook, 1978; Methé *et al.*, 1993; Haber, 1999; NHDES, 1999). Although it can survive on wet mudflats or in water up to 5m deep, it prefers calm, shallow water, ranging in depth from several cm to 2m (Smith, 1955; Kiviat, 1987). It has distinct preference for nutrient rich waters (Kiviat, 1987, Groth *et al.*, 1996), and one US report from the 1950s observed that it was often found growing best in waters polluted with raw sewage (Smith, 1955). This is consistent with reports from Asia, where water-chestnut in Japan is found in eutrophic waters high in organic content (Tsuchiya and Iwaka, 1983; Kunii, 1988b; Kurihara and Ikusima, 1991; Pemberton, 1999) and cultivated varieties in India yield fruit of greater size and quality when water is fertilized with urea, phosphate, and potash (Mazumdar, 1985; Ahmad and Singh, 1998). Water-chestnut is considered a warmth-demanding plant (Hultén and Fries, 1986) that requires full sunlight and grows best on a soft mud substrate (Kiviat, 1987). In North America, it is generally found in neutral to alkaline waters with pH ranging between 6.7-8.2 and an alkalinity of 12-128 mg/l of calcium carbonate (Haber, 1999).

This corresponds with data from Europe (Lithuania), where water-chestnut is reported growing in nutrient-rich brown-water lakes up to 1.5m deep and with a pH between 6.7-7.3 (Vuorela and Aalto, 1982). It is further reported from Lithuania that water temperature must be at least 12^{o}C in May for germination to occur, and high temperatures are required in July for nuts to ripen, suggesting the plant has a preference for a continental climate (Incidentally, reports from Japan set the threshold temperature for germination slightly lower, at 8-10^{o}C (Kunii, 1988a; Kurihara and Ikusima, 1991)). Water-chestnut's preference for water depths of 1.5m or less is attributed to light requirements, as light penetrating the water column may be insufficient for germination in deeper waters. Furthermore, it seems that sharp fluctuations in water levels are harmful, and in Lithuania water-chestnut tends to grow in areas with low rainfall. Its freshwater requirements are confirmed by reports that germination fails at salt concentrations [NaCl] of 0.1 (Vuorela and Aalto, 1982). Although this information supports the reported habitat requirements of water-chestnut in North America, Vuorela and Aalto (1982) point out that the plant's subfossil and present distribution in Europe indicate wider tolerances to pH and nutrient conditions than the above data suggests. They also suggest that populations in different parts of the world may have developed somewhat different habitat preferences.

GEOGRAPHICAL DISTRIBUTION

Origin and history of introduction(s): Water-chestnut is considered native to the Old World, specifically southern temperate Europe and Asia (Kiviat, 1987; Methé *et al.*, 1993), as well as Africa (Daniel *et al.*, 1983), although its geographical origin(s) within this range are unknown (Pemberton, 1999). Today it is widespread in the Old World (Cook, 1978), ranging from western Europe and Africa to northeast Asia and eastern Russia, and south to southeast Asia through Indonesia (Pemberton, 1999) (Figure 1). It is widely cultivated in eastern Asia, Malaysia and India for its nuts, which contain starch and fat (Cook, 1978), and are eaten raw, boiled, roasted, fried (Haber,

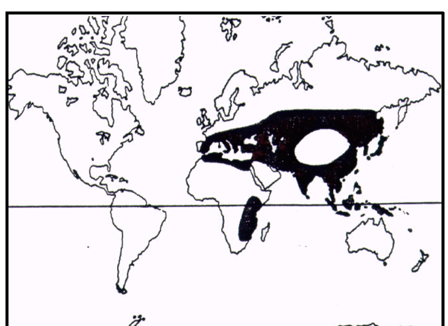


Figure 1: Current distribution of *Trapa spp*., not including naturalized populations in North America and Australia (from Cook, 1978)

1999), or pounded into flour to make dough (Mazumdar, 1985). Many of the Asian varieties go by different names, for example in India, cultivars are sometimes referred to as *T. bispinosa* or *T. quadrispinosa* (nuts have two or four slender spines, respectively) rather than as varieties of *T. natans* (Daniel *et al.*, 1983; Kumar et al., 1985; Ahmad and Singh, 1999). Likewise, in China the name *T. bicornis* may be used for a cultivated variety with two large horns (Kadono and Schneider, 1986), and in Japan *T. japonica* refers to a variety that grows wild and is harvested for sale of the nut in markets (Pemberton, 1999).

Historically, water-chestnut is thought to have been cultivated and used as food in much of its native range and this may have contributed to its wide distribution (Pemberton, 1999). In Europe, it had a larger distribution to the north during the hypsithermal period (postglacial warmth period, 6,500 - 500 BC) (Hultén and Fries, 1986), and probably reached its most northerly expansion between 3,000-500 BC (Vuorela and Aalto, 1982). This coincided with a climatic optimum when summers were at least 2^{o}C warmer than at present (Fenley *et al.*, 1975). Paleobotanical investigations in southern Finland suggest it was used by Neolithic people there in the region of 3,300 BC (Vuorela and Aalto, 1982), and indeed it was eaten and sold in European markets into the nineteenth century, and in Italy and Poland until the 1940s (Pemberton, 1999). Today, its European range is shrinking and it appears to have vanished from both southern Scandinavia and Spain as well as from the only known site in Switzerland and many sites in France and Poland. Many populations have declined in northern Italy, and the plant is considered rare in Germany (Pemberton, 1999). It has been the subject of conservation efforts in Europe, and is listed as a strictly protected species in the Bern Convention (Council of Europe, Convention on the Conservation of European Wildlife and Natural Habitats) (Haber, 1999). It is also red-listed in Ukraine, Bulgaria, and Romania (Vladimirov *et al.*, 1999) and southern Germany (Haber, 1999). The reasons for this decline are varied and not well understood, although climatic changes and/or the fact that it is no longer cultivated may be contributing factors (Fenley *et al.*, 1975; Pemberton, 1999).

By contrast, water-chestnut grows prolifically in the northeastern US where it is introduced and naturalized, and considered an invasive weed. It is thought to have been introduced as an ornamental, and it is reported to have first appeared in North America either sometime before 1859 near Concord, Massachusetts (Mills *et al.*, 1993), around 1874 in Massachusetts (Countryman, 1978, Kiviat, 1987), or in 1884 in New York State (Pemberton, 1999). In any case, in Massachusetts it had reached nuisance proportions by the end of the century, and subsequently became widely distributed and aggressive in the Concord and Sudbury rivers (Burk *et al.*, 1976; Mills *et al.*, 1993). In New York it was introduced at Collins (or Sanders) Lake, and it subsequently spread into the Mohawk and Hudson rivers and occupied between 2,500-3,500 acres by 1952 (Smith, 1955; Countryman, 1978; Kiviat, 1987). At that time, it was also known to have spread to Lake Champlain and as far west as Keuka Lake, in the Great Lakes basin (Smith, 1955). Water-chestnut has been the subject of control/eradication programs since as early as the 1920s (Elser, 1966), and yet it continues to

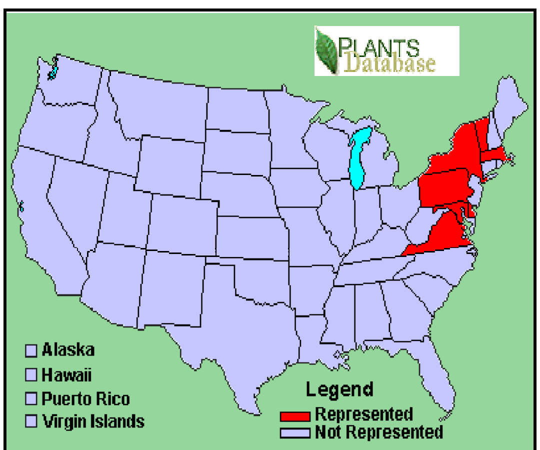


Figure 2: Current distribution of water-chestnut in the U.S., as shown in the PLANTS Database (from USDA, NRCS, 1999)

spread. Today, water-chestnut still occurs in Massachusetts and New York, as well as in Vermont, Pennsylvania, Delaware, Maryland and Virginia (USDA, NRCS, 1999) (Figure 2). Recent reports also point to new populations in New Hampshire (NHDES, 1999) and Connecticut (CDEP, 1999), and possible occurrences in New Jersey and Delaware (USGS, 2000) (Figure 3). It is a significant problem in the Hudson and Potomac Rivers, Lake Champlain, and the Connecticut River valley (Haber, 1999). It is subject to federal regulations that prohibit its interstate sale and transportation (Haber, 1999), and it is also prohibited in Florida and Arizona and designated a noxious weed in Massachusetts and North and South Carolina (USDA, NRCS, 1999).

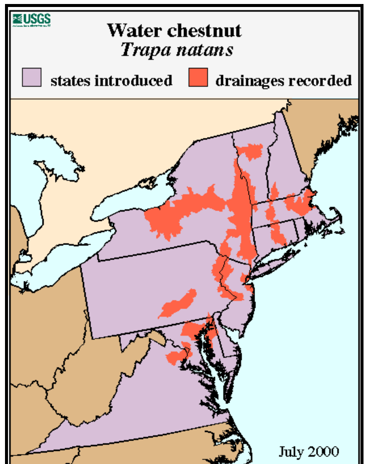


Figure 3: Drainages in the US where water-chestnut has been recorded (from USGS, 2000)

Water-chestnut has been the focus of research and control programs at the south end of Lake Champlain on the Vermont-New York border, since it was first introduced there in the 1940s (Bogucki et al., 1980) (Figure 4). Water-chestnut has recently been reported for the first time in Canada, in what is probably a northward expansion in this watershed (Haber, 1999). The Canadian population was first noted in 1998 in the Rivière du Sud in southwestern Quebec, just north of the Vermont border (Figure 5). The Rivière du Sud is a tributary to the Richelieu River, which flows out of Lake Champlain, joining the St. Lawrence River further north, and eventually, the Atlantic Ocean (LCBP, 1999) (Figure 6). Since 1998, the population has increased dramatically and now occupies 6-8 miles of Rivière du Sud from its confluence with the Richelieu, east to Henryville, Québec (VDEC, 2001b). Interestingly, although water-chestnut is also known to occur at Sodus Bay, NY, on the south shore of Lake Ontario (Mills *et al.*, 1993), it has not yet been reported from the northern shore in Canada (Haber, 1999). Water-chestnut is designated a prohibited plant by the Canadian Food Inspection Agency.

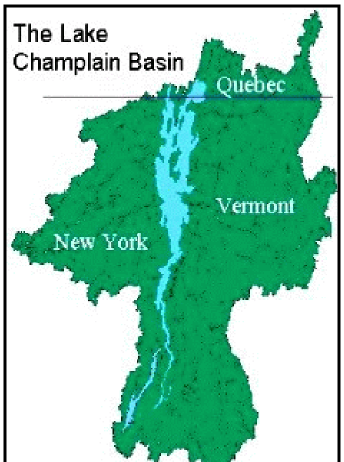


Figure 4: The Lake Champlain Basin (from LCBP, 1999)

Some reports suggest that water-chestnut has also been introduced and naturalized in Australia (Cook, 1978; Daniel *et al.*, 1983; Haber, 1999), although no Australian records were found. Water-chestnut is however, designated a prohibited noxious weed by Australia's quarantine and inspection service (AQIS, 2000).

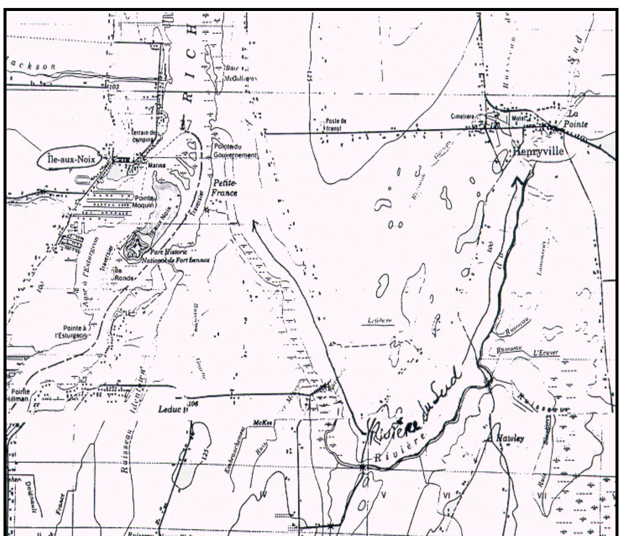


Figure 5: Location of Rivière du Sud and its confluence with the Richelieu River (from DEMR, 1987)

Specific country / regional reports:

Africa: Central, western, and southwestern Africa (Hultén and Fries, 1986), including Algeria, Angola, Botswana, Guinea-Bissau, Malawi, Mozambique, Namibia, South Africa, Sudan, Tanzania, Tunisia, Uganda, Zambia, Zimbabwe (USDA, ARS, 2001), Kenya, Zaire, Senegal (Holm *et al.*, 1991), and probably others.

Asia: Native and widespread from Europe through to northeast Asia and eastern Russia, and south to southeast Asia through Indonesia (Pemberton, 1999), including India, Georgia, Japan, Pakistan, Turkey, Vietnam (USDA, ARS, 2001), China, North and South Korea (Pemberton, 1999), Cambodia, Iran, Nepal, Thailand (Holm *et al.*, 1991) and probably others.

Australasia and Pacific Islands: Introduced in Australia (Cook, 1978; Daniel *et al.*, 1983).

Central America and Caribbean/West Indies: No reports found.

Europe: Native and widespread but declining, includes Albania, Austria, Belarus, Bulgaria, Czechoslovakia, France, Germany, Greece, Hungary, Italy, Poland, Romania, Spain (?) (incl. Baleares), Switzerland (?), Ukraine (incl. Krym), (former) Yugoslavia (USDA, ARS, 2001), Lithuania (Vuorela and Aalto, 1982), Belgium (Holm *et al.*, 1991).

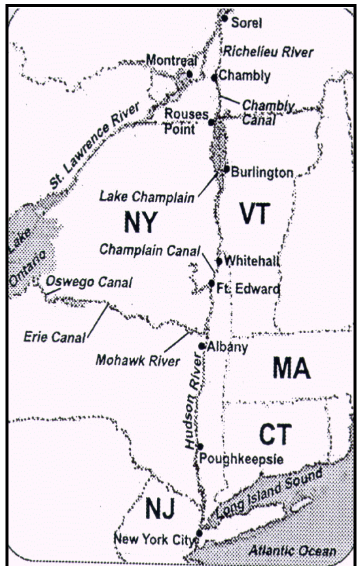


Figure 6: Lake Champlain flows into the Richelieu River, which in turn flows into the St Lawrence River (from Hauser, 1998)

North America: Introduced in northeastern US (Delaware, Maryland, Massachusetts, New York, Pennsylvania, Vermont, Virginia (USDA, NRCS 1999), New Hampshire (NHDES, 1999), Connecticut (CDEP, 1999), possibly New Jersey and Delaware (USGS, 2000)), Canada (Québec) (Haber, 1999; VDEC, 2001b).

South America: No reports found.

South Atlantic Islands: No reports found.

FIELD RECOGNITION / MORPHOLOGY

Water-chestnut is an aquatic plant with rosettes of glossy bright green leaves that float on the surface of the water, each borne on a long, flexible cord-like stem. Stems also bear feathery green underwater leaves and rose-coloured adventitious roots. Plants are usually rooted in the hydrosoil and anchored by means of a nut hull (Haber, 1999). Rosettes may consist of up to 50 leaves (Elser, 1966), and a single plant may produce up to 27 rosettes (Groth *et al.*, 1996), forming a cluster on the water surface of up to 10 feet in diameter and a tangle of stems beneath (Elser, 1966). Populations of water-chestnut tend to reach very high densities, and may grow to cover 100% of the water surface (Groth *et al.*, 1996) (Figure 7). When rosettes become so crowded they can no longer lie flat on the water surface, the leaves stand upright (Elser, 1966). Flowers are small, white and inconspicuous, and borne singly on a stalk from the middle of a rosette. The fruit (or chestnut) which develops underwater, is black and nut-like, about the

Figure 7: Dense mat of water-chestnut in Maryland (from MDNR, 2001)

size of a hickory nut (Elser, 1966), with typically four sharp barbed spines (See Figure 8 for full plant diagram).

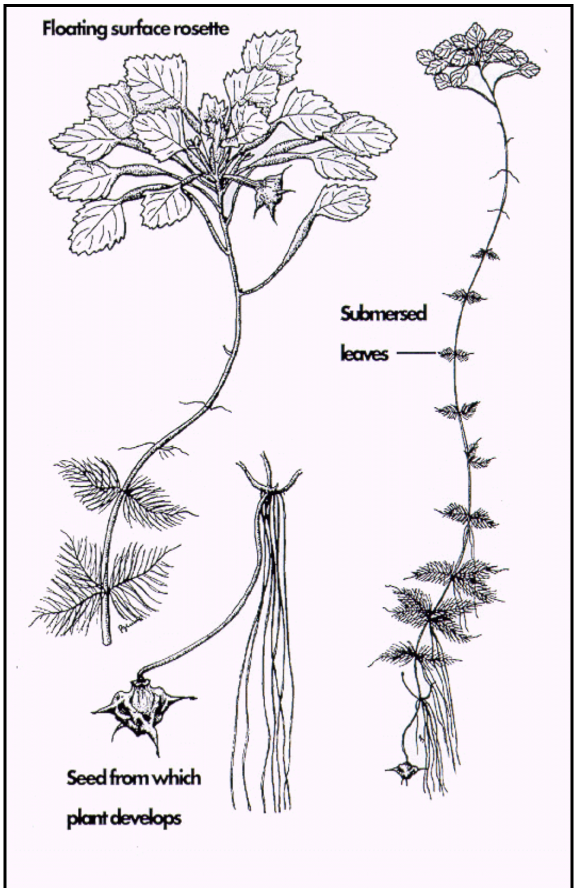


Figure 8: Illustration of water-chestnut (from VANR, NCV, 1998)

Roots: Like many other aquatic plants, water-chestnut has no primary root system. Instead, adventitious roots grow out from the hypocotyl, or later from the lower stem. These anchor the plant in the substrate, and as stems grow increasingly long so that lower sections lie on the substrate, these sections may also produce roots, so that the plant becomes anchored in more than one place (Groth *et al.*, 1996). Roots are rose-coloured, long and unbranched (Elser, 1966).

Stems: Stems are long, flexible, and cord-like, rarely branching, and may reach lengths of up to 16 feet (VDEC, 2001b). They are thicker near the top, where they form a stalk that supports the rosette (Elser, 1966). Stems have numerous nodes with feathery, submerged, root-like leaves or adventitious roots (Kiviat, 1987).

Leaves: Leaves are of two types, floating and submerged. The floating leaves are alternate and grow in rosettes, and are deltoid (triangular) or rhombic, conspicuously toothed, waxy, and about 3-5 cm long (Figure 9). They have long petioles (leaf stalks), each up to 15 cm long, with a bladder-like swelling filled with air and spongy tissue that serves to keep the leaf afloat (Kiviat, 1987, Haber, 1999). The stems of new plants also support early, deciduous, linear submersed leaves that are abscised after about two weeks (Groth *et al.*, 1996). These are then replaced with more permanent submersed leaves, that are green, feather-like and finely pinnatisect (with very fine segments), up to 20 cm long and borne in opposite pairs or whorled segments at nodes along the stem (Elser, 1966). As the plant matures these submerged leaves eventually turn black (Countryman, 1978). They have been considered by some to be roots rather than leaves, and Groth *et al.* (1996) report that their developmental origin is unclear, although their primary function is the absorption of nutrients.

Figure 9: Water-chestnut rosette (SCDNR, 2001)

Flowers: Flowers are small, usually white, and inconspicuous, bisexual, and borne singly on short, erect stalks in the axils of some of the leaves, so that they appear to grow out of the middle of a leafy rosette (Elser, 1966; Haber, 1999). Flowers lower in the rosette usually begin to mature while upper ones are still in the bud stage (Elser, 1966). Each flower has four petals, usually white but sometimes lilac (Cook, 1978) and each about 8 mm long (Haber, 1999).

Figure 10: Water "chestnut" (from MDNR, 2001)

Sepals are also four, triangular, connected to the ovary, and develop into horns or spines on the nut (Cook, 1978). Each flower has four stamens and a two-chambered ovary (Cook, 1978; Haber, 1999).

Fruit and Seeds: The fruit, or chestnuts (technically drupes), are two-seeded, woody, nut-like structures, with a fleshy, green, deciduous pericarp, and two to four sharp spines derived from the sepals (Groth *et al.*, 1996) (Figure 10). Each spine has several recurved barbs (Countryman, 1978). The nuts are generally black, and measure about 2-3 cm across (Kiviat, 1987). The seed is without endosperm, but with very unequal cotyledons; one large, and the other small and scale-like (Hutchinson, 1969).

BIOLOGY / LIFE CYCLE

Water-chestnut may persist as a short-lived perennial in warmer climates (Cook, 1978; Haber, 1999), but in North America it behaves as a true annual, overwintering only by seed (Methé *et al.*, 1993; Groth *et al.*, 1996). In the northeastern US seed germination occurs in late May and by early June a dense canopy of leafy rosettes is formed on the water surface (Methé *et al.*, 1993). Bud formation in the rosettes begins in late June and flowering begins in early July and continues until plants senesce in October (Methé *et al.*, 1993; Groth *et al.*, 1996). Flowers are reportedly pollinated by insects (Haber, 1999), although studies of *T. natans* var. *japonica* in Japan showed that it was primarily self-pollinated, although also cross-compatible as well as apomictic, and that insects should be considered only incidental pollinators (Kadono and Schneider, 1986). Once the ovules are fertilized the flower stalks bend over so that the nuts mature underwater (Haber, 1999). Nuts ripen in about a month, with the first ones reaching maturity by August, and once mature they detach from the stalk and fall to the sediment (Methé *et al.*, 1993). A portion of the seeds produced in a year will germinate the following spring, while the remainder will accumulate in the seed bank (Methé *et al.*, 1993). Seeds germinate under oxygen-deficient conditions (Kiviat, 1987; Menegus *et al.*, 1992) and if stored out of water, they will dry up and die (Menegus *et al.*, 1992). Studies have shown that each rosette of a water-chestnut plant can produce up to 20 nuts, and that under the right conditions individual seeds can remain viable for up to 12 years (Madsen, 1993). Nuts may weigh between 1-9 g (Kiviat, 1987), and Groth *et al.* (1996) showed that although nuts could differ in size up to 100-fold (0.02 g - 2.10 g) and still remain viable, larger nuts gave a competitive advantage to the seedling at the beginning of the growing season (Groth *et al.*, 1996).

Water-chestnut owes much of its success as an invasive plant to its ability to increase its production of clonal offshoots in response to low-density conditions. Groth *et al.* (1996) explain that when germination occurs in the spring, only one of the seeds in each nut will develop. The radicle perforates the top of the nut, and the seed will then produce three primary rosettes that develop in a specific order ((1) from the centre of the nut, (2) from the side opposite the hypocotyl, and (3) from between the first shoot and the hypocotyl). If the stem bearing one of these is cut, a fourth may be produced. The primary growth of a plant then, produces 3-4 floating rosettes on long stems that are anchored in the substrate by the nut hull. However, as soon as these primary shoots develop into stems with floating leaves, additional offshoots begin to form from vegetative buds on the upper stems. These offshoots consist of stolons that support secondary floating rosettes. As internodes continue to grow and elongate, the point of stolon origin on the primary stem drops deeper below the water surface, eventually coming to rest on the substrate and sprouting adventitious roots of its own. Water-chestnut plants continue to propagate clonally in this manner until they begin to set fruit in late July. At that point, vegetative bud production ceases abruptly and the number of rosettes stabilizes. However, in the time between germination and fruit setting, plants may produce a large number of rosettes, including third- and fourth-order as well as primary and secondary ones.

The results of Groth *et al.* (1996) show that water-chestnut plants in low density conditions produced ten times as many rosettes as those in high density conditions, as well as having a greater proportional allocation of biomass to reproductive structures. In high density locations, plants showed a typical response to overcrowding, and mortality of rosettes occurred throughout the season. Much of the plants' nutrient absorption is through the feathery leaves that are submersed in the water column, but plants must compete for light on the two-dimensional water surface. However, the populations maintained 100% cover, and the authors relate that in five years at the study site the vegetation changed from a varied aquatic flora to a virtual monoculture of water-chestnut. They point out that the segregation within each plant, of clonal propagation at the beginning of the growing season, and seed production in the latter part, reduces the level of competition for resources between these two activities, and effectively allows them both to be optimized within a single season. As a result of this flexible growth habit, and despite producing fewer, larger seeds than most typical annual weeds, water-chestnut is a highly successful colonizer, and in Japan has even been shown to outcompete many perennial species (Groth *et al.*, 1996).

MEANS OF MOVEMENT AND DISPERSAL

Dispersal of water-chestnut can occur either by seed (nuts) or by detached rosettes. Within a given growing season, rosettes detached from a water-chestnut plant can float a considerable distance downstream, and still mature nuts that then drop to the substrate in the new location (Kiviat, 1987; Groth *et al.*,1996). Nuts themselves can be moved downstream by currents, and can also be dispersed by birds, as they are thought to get stuck in bird's feathers. They have also been found in the digestive tracts of ducks (Kiviat, 1987). It is likely that the retrorse barbs on the spines of the nut could get caught in animal fur, making animals agents of dispersal as well (Elser, 1966; Kunii, 1988b). Humans may be the most successful agents of long-range dispersal of water-chestnut, as the nuts are known to cling to nets and ropes, and to "hitchhike" on boats (Kiviat, 1987).

PEST SIGNIFICANCE

Economic Impact:

Dense infestations of water-chestnut can affect water quality, impede the passage of boats, and interfere with recreational and other uses of water bodies. Many of the economic impacts of water-chestnut infestations are not quantified in the literature, although they clearly exist, and are interconnected with the environmental impacts outlined below. The Maryland Department of Natural Resources posts the following on their web site (MDNR, 2001), describing the impacts of water-chestnut on the Potomac River:

> "Motorboats and sailing craft could not use thousands of acres formerly available during the summer months. The splendid duck hunting and fishing grounds for thousands of sportsmen were lost because water chestnut destroyed the native plant life essential for waterfowl and game fish. Sanitary problems arose because of the fact that the thick beds collected and held quantities of organic waste, thus creating water pollution hazards, and swarms of mosquitoes bred prolifically among the plants. The recreational value of all bathing beaches to the mouth of the river was seriously lessened because of the spines of the drifting pods" (Reprinted from the Maryland Conservationist, Winter 1945, Volume 21).

Such impacts are likely to cause significant losses of income wherever water-chestnut infests a waterway that is used for commercial purposes. Examples include: Irrigation canals, navigable canals where the movement of boats could be affected, and particularly, lakes and rivers that support the outdoor recreation and tourist industries (e.g. campgrounds, parks, hunting and fishing camps, boat and cottage rentals, sailing clubs, cruises, etc.). Waterfront property values and water-based industries such as aquaculture and, in Canada, wild rice production, may also be affected. The power industry is yet another that stands to lose from impacts of aquatic invasive species, as is illustrated by the case of zebra mussels which cost Ontario Hydro approximately $376, 000 per year per generating station by blocking pipes and water intakes (USACE, 2001).

The costs of water-chestnut control are somewhat easier to quantify, and the Vermont Department of Environmental Conservation lists US$3,680,338 as the amount spent on water-chestnut harvesting and hand pulling in Lake Champlain between 1982-2000 (VDEC, 2001b). The funds for the program have come primarily from Vermont and the U.S. Army Corps of Engineers, with smaller contributions from the Lake Champlain Basin Program and New York State. The amount spent in 2000 was U.S.$518,000 and an estimated U.S.$350,000/year is considered necessary for the next five years if the program is to meet its ongoing goals (VDEC, 2001a). In Maryland, a massive water-chestnut removal between 1939-1945 ran to an estimated cost of U.S.$2.8 million, converted from 1950 to 1992 dollars (MDNR, 2001). Costs of chemical and biological control were unavailable as no current control programs appear to employ these methods.

Environmental Impact: Water-chestnut is a serious environmental weed, and the impacts it can have on aquatic ecosystems are significant. As described above, its aggressive growth habit can result in the rapid colonization of suitable habitats (Figure 11). Its leafy rosettes form dense mats, often reaching 100% cover of the water surface, while a web of stems, submersed leaves and roots lies underneath (Bogucki *et al.*, 1980; Groth *et al.*, 1996). At such densities, 95% incident sunlight is intercepted by water-chestnut plants, and the lack of light below the surface seriously impacts any other plants or plant parts that lie under its canopy (Groth *et al.*, 1996). In this way, water-chestnut crowds out and replaces other plant species, thus posing a threat to native and endangered species.

Figure 11: Dense mat of water-chestnut in New York (from IPCNYS, 2001)

Water-chestnut has low food value for wildlife compared to the species it replaces (Groth *et al.*, 1996), although Kiviat (1987) reports that it is eaten by muskrat and other rodents. Nuts have been found in the digestive tracts of ducks, but it is unclear whether they were digested or caused injury (Kiviat, 1987). Interestingly, cattle apparently will eat the leaves avidly if they can get to them (Elser, 1966). Stands of water-chestnut do provide habitat for insects, crustaceans, other invertebrates and epiphytic algae, and these may be a source of food for small fish, although species and numbers have not been ascertained (Kiviat, 1987) or compared with those at undisturbed sites (i.e. the plant communities that were replaced may have served the same function).

In addition to impacts on the food chain, stands of water-chestnut can cause rapid sedimentation due to the trapping of silt and the deposition of cellulose from the plants themselves (Kiviat, 1987). They can contribute to sanitary problems and water pollution when the plants collect and hold organic waste (MDNR, 2001). Decomposition of plants at the end of the growing season reduces dissolved oxygen levels in the water, and in drinking water reservoirs, organic matter from water-chestnut may be a precurser to toxic trihalogenated methanes (Kiviat, 1987). Water-chestnut is also thought to provide a breeding ground for mosquitoes (Kiviat, 1987).

Dense stands of water-chestnut can have sociological impacts, impeding the passage of boats and interfering with the recreational use of water bodies (boating, fishing, swimming). Nuts also present a danger to humans and animals, with their sharp, barbed spines that are strong enough to penetrate thin shoe leather. Nut hulls float and often collect at swimming beaches where they can inflict painful wounds on bare feet (Elser, 1966; Steenis and Stotts, 1966).

Interestingly, the weedy characteristics of water-chestnut have also been documented in Asia, where the plants have long been cultivated for food. In Japan, the cultivated areas of water-chestnut have declined since World War II, but the plant has recently enlarged its distribution in stagnant water lakes and irrigation ponds, in some areas prompting mechanical and chemical control efforts (Oki and Une, 1989, Kunii, 1991). In India, where water-chestnut is still widely cultivated, it is nonetheless considered a nuisance when people cut their feet on the nuts, or when water levels are reduced in the summer and the leaves rot, making the water "turbid, stenchy and unusable" (Daniel *et al.*, 1983). Water-chestnut plants are reported to form dense mats for hundreds of metres in India, where no other plants can survive and leech populations are increased. Such stands have been known to entangle and drown buffalo, as well as humans who have gone in to their rescue (Daniel *et al.*, 1983).

Control/Management:

Control of water-chestnut can be difficult and expensive, but populations that are left unmanaged can increase dramatically (Bogucki *et al.*, 1980). Due to the plants' ability to form a seed bank, and the seeds' ability to remain viable for up to 12 years, control programs must be maintained over the long term. This is illustrated by the history of water-chestnut in Lake Champlain, where control efforts have been in place since 1949. The first control program was successful, and spraying and hand pulling had reduced the populations such that only eight bushels of water-chestnut had to be pulled from the lake in 1967 (as compared to a peak removal of 742 bushels in 1960) (Bogucki *et al.*, 1980; VDEC, 2001a). Control was stopped in 1968, and in 1969 it was found that

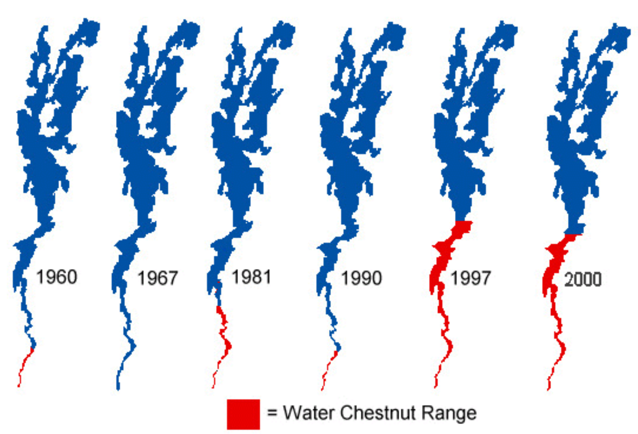


Figure 12: Distribution of water-chestnut in the south end of Lake Champlain, 1960 to present (from VDEC, 2001b)

water-chestnut infestations had increased tenfold in one year. Control programs were then resumed on a reduced scale until 1974 when bureaucratic and personnel problems led to the termination of all control activities (Bogucki *et al.*, 1980). By 1982, water-chestnut populations had spread to cover about 300 acres over 20 miles in the south end of Lake Champlain. In 1982 a new program was initiated, and this made significant headway in the first nine years. However, once again, funds were reduced between 1991 and 1996, and water-chestnut infestations rebounded. Water-chestnut now covers over 55 miles in the south of Lake Champlain, from Whitehall, New York, to Ferrisburgh, Vermont (VDEC, 2001a, 2001b) (Figure 12).

<u>Monitoring</u>: The monitoring of water-chestnut infestations is necessary to determine locations and densities, and to provide the basis for planning control programs. Bogucki *et al.* (1980) suggest remote sensing as one useful method for monitoring water-chestnut, as the plants have a distinct signature visible in colour-infrared imagery. Aerial surveys are used in Maryland (MDNR, 2001), and visual surveys may also be conducted by boat.

<u>Physical control</u>: Mechanical harvesting and hand-pulling are potentially effective methods for controlling water-chestnut, if they are maintained in the long term. Because water-chestnut is an annual, the key point in the life cycle is the formation of seeds. If plants are cut or pulled and removed from the water before seeds are produced, then no new seeds will be added to the seed bank. Harvesting must be continued each year until the seed bank is depleted. Mechanical harvesting has been the main method used for water-chestnut control in Lake Champlain since 1982, and the equipment used in 2000 included four mechanical harvesters (with cubic foot capacities of 650, 450 and 400), a high speed transport barge, two shore conveyors, a trailer conveyor and four dump trucks. A handpulling operation was used for small infestations and areas not accessible to the harvesters, and this employed kayaks, canoes, and a motorized pontoon boat (VDEC, 2001a).

A variation on harvesting is a cutting technique that was tested in a reservoir in New York, using a high-speed airboat with a metal blade 10 cm below the water surface. The blade cut the rosettes before seed setting and a reduction in seed production was observed (Madsen, 1993; Methé *et al.*, 1993). However, the cut rosettes were left in the water, and some seed production by cut rosettes did occur (Methé *et al.*, 1993). Likewise, cutting efforts in the early 1990s in Lake Champlain showed that cut plants had the ability to develop adventitious roots and continue to mature (VDEC, 1999b). This suggests that harvesting is an important component of mechanical control, that is, cut plants should not be left floating in the water. In Vermont, a portion of harvested water-chestnut is taken to farms to be composted or used as fill, while the rest is disposed of at approved upland sites. Finished compost can be used as a soil amendment, or as a bedding plant mix (VDEC, 2001a). In Maryland, water-chestnut harvested in 1999 and 2000 from the Bird and Sassafras Rivers was composted in the water in floating cages designed for the project (MDNR, 2001) (Figure 13). Presumably the mesh used to make the cages was fine enough to contain mature nuts and other plant parts.

Figure 13:Floating composter for water-chestnut harvested in Maryland (from MDNR, 2001)

It should be noted that physical control techniques may be time-consuming and prohibitively expensive in dense infestations (Kiviat, 1987). In the last few years, in Lake Champlain, such methods have succeeded in reducing infestations in some areas (VDEC, 2001a). However, Haber (1999) feels that physical techniques will only successfully eradicate water-chestnut in smaller, enclosed water bodies. In heavily infested areas of streams and large lakes like Lake Champlain, they will probably only serve as interim control measures.

Chemical control: Chemical control of water-chestnut has been primarily with 2,4-D, and primarily in New York State, although it has not been used there since the 1970s. Smith (1955) reports a program that began in 1946 and involved spraying 2,4-D in fuel oil from planes and helicopters. The program ended the following year after a series of claims for crop damage in adjacent areas (Countryman, 1978). A subsequent program in the 1970s also used 2,4-D in the Mohawk and Hudson Rivers, and Lake Champlain, and was almost successful in eradicating water-chestnut (Countryman, 1978; Methé *et al.*, 1993). This program involved spraying the herbicide undiluted at a rate of 2 gallons/acre, as it was found that lesser amounts were ineffective. This continued until 1976 when the program was terminated due to concern about adverse chemical effects on fish and aquatic invertebrates (Countryman, 1978; Methé *et al.*, 1993). Currently, U.S. federal regulations prohibit the use of 2,4-D in water bodies at concentrations that will kill water-chestnut (maximum allowed = 2lbs/acre acid equivalent) (Kiviat, 1987). Ammate X-NI was the only other herbicide mentioned in the literature, and Kiviat (1987) indicates that although it was approved for use against water-chestnut, its effectiveness was unknown. The environmental impacts of chemical control can be severe, and the use of any herbicide in an aquatic system poses a threat to other plants, microbial communities, animals, and humans (Kiviat, 1987). This, together with prohibitive legislation are likely the reasons why no current records were found of chemical control programs in the U.S.

Biological control: Biological control is still being researched as an alternative for water-chestnut management, and it has been successful with some other aquatic weeds (e.g. salvinia (*Salvinia molesta*) and aligatorweed (*Alternanthera philoxeroides*)). Water-chestnut is known to have natural enemies in its native range, and it has no close relatives in North America because the Trapaceae are restricted to the Old World (Pemberton, 1999). However, a recent survey of northeast Asia and western Europe conducted by Pemberton (1999), failed to turn up any obvious biocontrol agents. The most common natural enemy of water-chestnut in Asia was the leaf beetle *Galerucella birmanica*, which is capable of completely defoliating whole populations of plants so that the mats sink to the substrate. Nymphuline pyralid moths were also common, but both the beetle and the moths also feed and develop on unrelated plants, making them unsuitable as biological control agents in North America. Other potential agents found on plants in Asia and Europe included two *Nanophyes* weevils, some populations of polyphagous Homoptera, and some Chironomid midges but none of these were very damaging to the plants. Further research is called for, and it is noted that water-chestnut has a very wide native range, most of which has not yet been surveyed. Also, because of its native distribution in some tropical and subtropical areas, it is thought possible that there may be biocontrol agents that would be suitable for use if water-chestnut were to spread to warmer parts of North America (Pemberton, 1999).

Public awareness: Education and outreach are an important component of any control program, as an informed public can help to contain water-chestnut infestations, rather than inadvertently contributing to their spread. Several U.S. state governments and one Canadian invasive plant program have water-chestnut fact sheets posted on web sites, that provide information about the plant and its management (e.g. Haber, 1999; NHDES, 1999; IPCNYS, 2001; MDNR, 2001; VDEC, 2001b, etc). The Lake Champlain control program takes public awareness further than this, and includes funds for the development and distribution of educational materials such as signs, information packages and permanent displays. These are posted or distributed in such locations as public access areas, science centres, town offices, museums, schools, and festivals. In addition, the program provides training workshops to teach people who use waterways to identify water-chestnut plants and help in their control. A public service announcement for television is also under development (VDEC, 1999b; 2001a). In Maryland, a successful program has involved volunteers in the manual removal of water-chestnut from the Bird and Sassafras Rivers. Volunteers bring their own boats and are provided with a brief training course, and their meals (MDNR, 2001) (Figure 14).

Figure 14:Volunteer harvesting water-chestnut in Maryland (from MDNR, 2001)

STAGE 3: WEED RISK ASSESSMENT

Note: This Weed Risk Assessment is based on information presented and referenced in the Weed Fact-Sheet, above. Any additional information provided below is referenced in the body of the text. The risk ratings assigned for each section, with corresponding numerical scores provided in parentheses, are assigned using the PHRA Unit guidelines, shown in Appendix 2.

3.1 HAZARD IDENTIFICATION

Identity of Pest: *Trapa natans* L. (MYRTALES: Trapaceae), is a floating-leaved aquatic plant that is considered an invasive weed in the northeastern U.S. It is commonly referred to as European water-chestnut, or simply water-chestnut.

3.2 GEOGRAPHIC AND REGULATORY STATUS

Distribution in PRA Area: Water-chestnut was reported for the first time in Canada in 1998, in the Rivière du Sud in southwestern Québec. Since then, it has spread to infest about 6-8 miles along the river, from its confluence with the Richelieu, east to Henryville (see Figure 5). It is otherwise absent from natural ecosystems in Canada.

Existing Regulations Pertaining to PRA Area: All aquatic plants are subject to import requirements under the Plant Protection Act and Plant Quarantine Regulations. Water-chestnut is one of four taxa (*Elodea densa*, *Hydrilla verticillata*, *Myriophyllum* spp., and *Trapa* spp.) that are prohibited from Canada, although the edible parts of *Trapa* spp. can be imported for consumption. See directive 94-27, "The Plant Protection Import Requirements for True Aquatic Plants" (Sept 8, 1994) for details.

3.3 LIKELIHOOD OF INTRODUCTION — Rating = HIGH (3)

This stage of the assessment concerns the introduction potential of the weed and examines factors that affect the likelihood it will enter, and become established in, the PRA area. Normally, this process is used to assess weeds that are contaminants of commodities, and considers such factors as the prevalence of the weed in the area of origin, the likelihood that it would be associated with the commodity, that it would survive transit undetected, and so on.

Water-chestnut presents a slightly different case. It is not really a potential contaminant of commodities, although there is a chance it could arrive undetected on ships from Europe, Africa or Asia, or in commercial shipments of other aquatic plants destined for Canadian ponds and aquariums. There is evidence that it was considered an ornamental in U.S. ponds in the 1800s, and Mills *et al.* (1993) refer to its use in aquariums, but these references appear to be more historical than current. Today, water-chestnut is known primarily as an invasive weed in North America, and its sale and movement as a commodity is restricted by legislation in both the U.S. and Canada. By far the most likely pathway for the introduction of water-chestnut to

Canada is through the northward expansion of its existing populations in the lakes and rivers of the northeastern U.S.

Several vigorous populations of water-chestnut have persisted in the northeast U.S. and continue to spread despite active control and eradication programs that have been in place on and off since the 1920s (for general ranges of water-chestnut in the U.S. see above, Figures 2,3). These populations could spread northwards into Canada either by natural means of dispersal, or with the help of human activities. Water-chestnut seeds, or nuts, can be dispersed by birds and animals, and can also “hitchhike” on boats and other water craft, and equipment such as fishing nets. Nuts and plant parts can also be moved by wind and water currents over smaller distances and within connected waterways. Several watersheds span the U.S. - Canadian border, and the movement of people between the two countries is constant (88 million vehicles crossed the U.S.-Canada border in 1995, and the eastern section between the Atlantic Ocean and the Ontario-Michigan border accounted for 73% of this total (OTA, 1995-1998)).

The infestation of water-chestnut in Rivière du Sud in southwestern Québec is thought to represent a northward spread of the long-established populations in the south end of Lake Champlain, Vermont. While Rivière du Sud and Lake Champlain are connected by the Richelieu River, the new infestation in Québec is 125 kilometres north of the older ones in Vermont. It is unclear whether birds, animals or humans were responsible for this long-range dispersal, however the presence of water-chestnut in Rivière du Sud is confirmation that at least one pathway of introduction has proved effective.

Risk Rating: Likelihood of introduction in this assessment is rated “HIGH”.

3.4 ECONOMIC IMPORTANCE CRITERIA CONSEQUENCES OF INTRODUCTION (overall rating) Rating = HIGH (3)

This stage of the assessment considers the potential for establishment and spread of the weed in the PRA area, as well as the potential economic and environmental impacts that may result. It should be noted that, although an effort has been made to consider environmental and economic impacts separately, this separation is somewhat artificial, since these impacts are often interconnected.

3.4.1 ESTABLISHMENT POTENTIAL Rating = HIGH (3)

Climatic Suitability in PRA Area: Water-chestnut can clearly survive in southwestern Québec, as the populations observed in Rivière du Sud have overwintered and continued to grow and spread since the plant was first identified there in 1998. This is the most northern site to be colonized by water-chestnut to date in North America, although it is possible that it could continue to expand northwards. Climatic suitability in Canada is difficult to establish and no clear boundary for the spread of water-chestnut can be predicted. Literature sources suggest that water-chestnut has water temperature requirements for germination in the spring (8-10^{o}C reported from Japan, 12^{o}C from Lithuania). It is also considered a warmth-demanding plant that prefers full sunlight. However, these conditions might be met in calm, shallow areas of any number of water bodies across the country. Water serves to insulate plants from many climatic extremes, making climatic ranges more difficult to predict than for some terrestrial species.

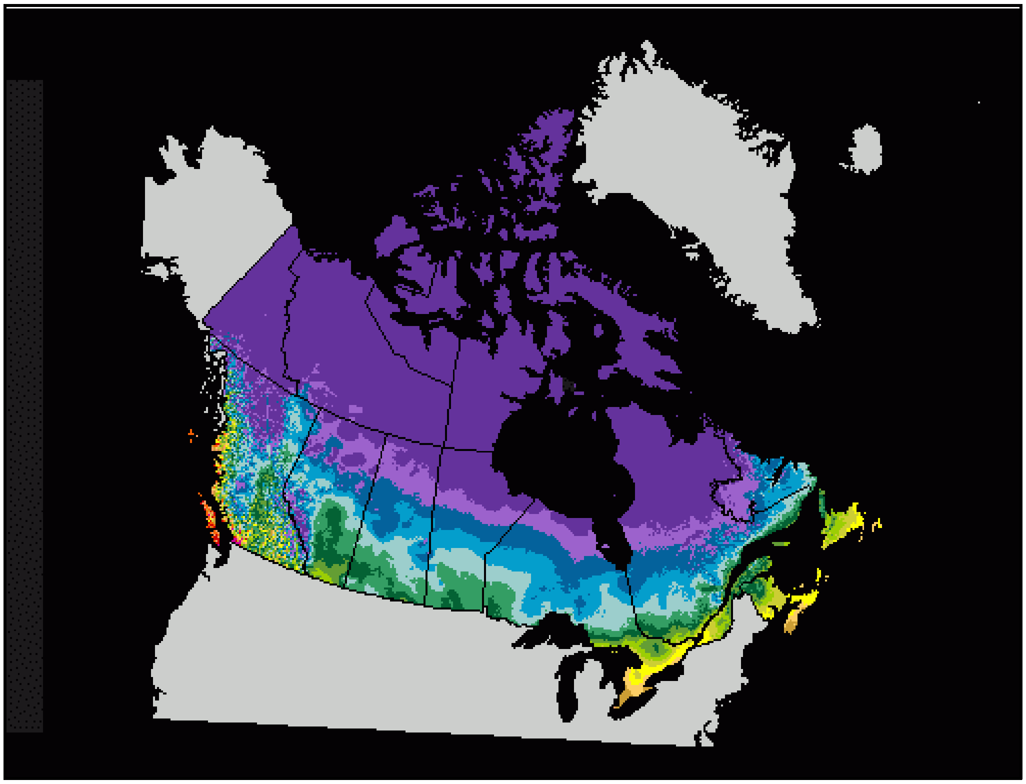
Water-chestnut is reported to prefer areas of low rainfall in Lithuania, however its occurrence in Rivière du Sud suggests that rainfall would not be a limiting factor in Canada. Southwestern Québec has as high an average annual rainfall as most areas in Canada, with the exception of the extreme west coast of B.C. (DEMR, 1974). There is no indication in the literature that cold winter temperatures might limit seed viability in water-chestnut, and seeds overwinter successfully in below-freezing temperatures in southwestern Québec. It is possible that if water-chestnut were to spread northwards in Canada, it would eventually be limited by length of the growing season, and plants would be unable to complete their life cycle during the period when water temperatures remained suitable. However, the presence of water-chestnut in the subarctic regions of northeastern China and eastern Russia, although they represent different varieties (or species in some cases, depending on the taxonomic interpretation), suggest the possibility that the North American plants might be capable of adaptation to harsh northern climates. Pemberton (1999) observed populations of *T. japonica* and *T. natans* growing in northeast Asia, as far north as Heilongjiang province, China, and along the Amur River. This area is classified as subarctic by Bailey (1995), an ecoregion classification that also covers a large portion of central and northern Canada.

Abundance of Suitable Habitats in PRA Area: Water-chestnut occurs in shallow, nutrient-rich (eutrophic) areas of lakes and ponds, slow-moving rivers and streams, wetlands, and freshwater regions of estuaries. North America, the “wet continent”, has a greater water surface area and more lakes than any other continent ; Canada has approximately three million lakes, some of the largest river systems in the world, and about a quarter of the world’s wetlands (Herbert, 2000). No information has been found to date which summarizes the various properties of water bodies across the country, indicating for example how many are considered eutrophic, and what proportion might fall in the pH range preferred by water-chestnut. However, the abundance of aquatic habitats in general suggests a likely abundance of habitats for water-chestnut, subject to nutrient, pH, and other requirements.

About half of Canada’s lake habitats are found in Ontario and Québec (Herbert, 2000). This, together with water-chestnut’s distribution in the northeastern U.S., on Lake Ontario, and its recent appearance in southwestern Québec, suggest that these two provinces are particularly at risk if water-chestnut is to become a problem in Canada.

Potential Range of Species in PRA Area: Based on its occurrence in Rivière du Sud, water-chestnut’s potential range in Canada would include at least plant hardiness zones 5 and 6, as defined by Natural Resources Canada and Agriculture and Agri-Food Canada (NRC, AAFC, 2000). This includes the yellow and orange areas outlined in the Plant Hardiness Zones map (Figure 15), which cover the southern ‘arm’ of Ontario, and a small piece of southwestern Québec, as well as all of Nova Scotia, parts of Newfoundland, eastern New Brunswick and parts of B.C. It is also likely that water-chestnut could survive in the milder climates of zones 7 and 8 (red and pink on the map), on the west coast of B.C.

It is possible that water-chestnut could continue to spread northwards, and it is difficult to predict what its northern limit in Canada would be. Water-chestnut populations in Asia occur in subarctic climates, up to 50^{o}N latitude in northeastern China and eastern Russia. The comparable climate zones in Canada, although mapped differently as ecoregions (Bailey, 1995) and plant hardiness zones (USDA, 1990; Widrlechner, 1997), cover most of the central and



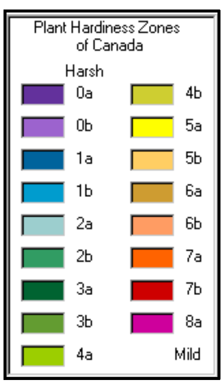


Figure 15: Plant Hardiness Zones of Canada (From NRC, AAFC, 2000)

northern parts of the country, with the exception of the extreme arctic regions. This suggests a possible range for water-chestnut, of at least plant hardiness zones 1-8 and possibly also 0b, which includes all of Canada except the harshest arctic and alpine zones that are dark purple on the map (Figure 15).

Potential for Adaptation of the Weed: Water-chestnut is clearly adaptable, as it ranges from the humid tropical climates of southeast Asia and Africa, to North America and the subarctic regions of northern China and eastern Russia. The plants behave as perennials in warmer climates, and as true annuals where winter conditions mean they must overwinter only by seed.

Risk Rating: Overall, the area in which North American populations of water-chestnut are certainly capable of surviving and becoming established comprises less than one third of the PRA area (the total area of Canada), which would earn it a "LOW" risk rating in this section. However, the worldwide distribution of *Trapa* spp. suggests that the potential range of water-chestnut covers a much larger area, possibly including all but the extreme arctic regions of Canada. To account for this additional risk, the rating given in this section is "HIGH".

3.4.2 SPREAD POTENTIAL

NATURAL SPREAD POTENTIAL **Rating = MEDIUM (2)**

Biology of Weed: Water-chestnut behaves as a true annual in North America, and overwinters entirely by seed. Plants use vegetative propagation to rapidly colonize new and low-density areas at the beginning of each growing season. They form dense mats on the water surface, made up of large numbers of leafy rosettes that in turn produce large numbers of seeds, protected in the hard shells of the "chestnuts". It is estimated that a single plant can produce 300 new seeds in a year (VDEC, 1999a). Seeds fall to the substrate, where a portion will germinate the following year, and a portion will remain in the seed bank. Seeds can remain viable up to 12 years, and can be dispersed locally by water currents. Regional dispersal of seeds can occur when they get stuck in the feathers of birds, or the fur of animals. Thus, water-chestnut has effective means of vegetative spread, of seed reproduction, and of both local and regional dispersal.

Suitability of PRA Environments for Natural Dispersal: The extensive networks of lakes, rivers and canals found in Canada, and particularly in Ontario and Québec, might facilitate the natural spread of water-chestnut through waterways.

History of Introductions / Behaviour Outside Natural Range: The introduced populations of water-chestnut in the northeastern U.S. have continued to spread since the 1880s, despite control and eradication programs that have been in place on and off since the 1920s. It is thought that water-chestnut was introduced in the U.S. as an ornamental, in Massachusetts and New York. From those points of origin it has spread to its current distribution in nine eastern states, with possible additional occurrences in two more. While control programs in the past have appeared to be effective (such as those that combined chemical and mechanical methods in the 1960s and 70s), water-chestnut populations have consistently rebounded and expanded their ranges when control programs were stopped. There is no reason to suspect that water-chestnut will behave any differently in Canada than it has in adjacent areas of the U.S. No reports were found on the behaviour of water-chestnut in other introduced ranges (i.e.

Australia).

Potential Hybridization with Natural Relatives in PRA area: Water-chestnut has no close relatives in North America.

Risk Rating: The potential for natural spread throughout the PRA area is considered "MEDIUM", as reproductive potential is high, but dispersal potential of propagules is only local and regional.

MAN-MADE DISPERSAL POTENTIAL

Movement with Commodities/Conveyances: Human activity could be a significant factor in the movement and dispersal of water-chestnut plants. Any activity that causes leafy rosettes to be cut from the plant will facilitate their travel downstream with water currents, where they can mature and deposit seeds in new locations. Water-chestnut seeds can also adhere to boats and other water craft, fishing gear and animals (i.e. pets). In Lake Champlain, for example, 7.9 million non-resident visitors entered the basin through 14 points of entry in 1992, and an average of 7,318 boats a year over the last five years have crossed into the lake at Rouses Point (LCBP, 1999). This level of human movement in and out of water bodies infested by water-chestnut is sure to contribute to the spread of populations. Shipping in the Great Lakes and the use of ballast water could also contribute to the spread of water-chestnut, particularly as plants have already been observed growing on the south shore of Lake Ontario. (See Appendix 3 for additional comments).

3.4.3 POTENTIAL ECONOMIC IMPACT Rating = HIGH (3)

Loss of Markets: Many of the economic impacts of water-chestnut infestations are not quantified in the literature, although they clearly exist. The impacts of severe infestations are likely to cause losses of income wherever water-chestnut infests waterways that are used for commercial purposes (e.g. irrigation, navigation, outdoor recreation and tourism). Although not yet quantified, these kinds of economic losses have the potential to be great, particularly where infestations restrict recreational use of water and thus the sizeable tourist industry. In Lake Champlain for example, the site of one US water-chestnut infestation, the tourist industry was worth $2.2 billion in 1990, with 40% of that ($880 million) being lake-related (LCBP, 1999). In Ontario, for a Canadian perspective, tourism is the third largest industry and generates billions of dollars of revenue each year ($13.4 billion in 1990) (Canada Information Office, 2001). A significant proportion of this income comes from the outdoor recreation sector, which includes activities such as camping and canoeing, boating, sailing, cruises, and fishing (OMTCR, 2001). Such activities depend on accessible waterways and could be threatened by water-chestnut infestations.

From a plant health perspective, another Canadian industry that has the potential to be affected by water-chestnut is wild rice production. Wild rice production is a growing industry in Canada, and figures given by Aiken *et al.* (1988) show that exports were worth $2.8 million in 1981. Wild rice (*Zizania palustris* L.) is native to Canada, and occurs in most provinces, with active production in Alberta, Saskatchewan, Manitoba and Ontario. Wild rice grows in shallow lakes and rivers, and has been shown to be adversely affected by other emergent and submerged aquatic plants that compete for resources or affect the amount of light penetrating the water column (Aiken *et al.*, 1988). This suggests that water-chestnut could have serious impacts on wild rice production if it were to establish in the same waterways.

Indeed, a related species of wild rice (*Zizania aquatica* L. var*. aquatica*) is known to occur in the Richelieu River watershed. *Z. aquatica* var. *aquatica* is not generally harvested for its grain, but is considered rare, and some concern has been expressed in Québec that local populations may be threatened by the water-chestnut infestation in Rivière du Sud (*Le Devoir*, Les Actualités, Mercredi 30 Mai). Another potentially threatened, and biologically significant form of wild rice is *Z. aquatica* var. *brevis* which occurs in a highly restricted area of the St. Lawrence River, downstream from the Richelieu. In addition to environmental implications, the loss of either of these varieties to a water-chestnut infestation would mean the loss of genotypes which could in turn impair crop development. Any impacts on wild rice production may also have sociological as well as economic implications as the crop was traditionally, and still is primarily, grown by First Nations.

Another Canadian industry that could be affected by water-chestnut is aquaculture. Aquaculture is considered a relatively new industry in Canada, but is growing, with businesses in all provinces and territories, and a value of $611 million in 1999 (OCAD, 2001). Some other uses of water in Canada include power generation (hydroelectric and nuclear), shipping, and the withdrawal of water from natural sources that is piped or channelled inland for household and industrial activities, and agriculture (irrigation) (EC, 2000). An example of the impact that invasive aquatic species can have on these water-based activities is provided by the zebra mussel, which costs Ontario Hydro an estimated $376,000 per year per generating station due to blocked pipes and water intakes. While it is by no means certain that water-chestnut would ever affect all of these industries and water uses, it is nonetheless important to consider the extent and variety of water use in Canada, and what might be at stake if these were disrupted by an invasive aquatic species.

Cost of Control: Somewhat more information exists on the costs of controlling water-chestnut, and the Vermont Department of Environmental Conservation lists U.S.$3,680,338 as the amount spent on harvesting and hand pulling in Lake Champlain between 1982-2000 (VDEC, 2001b). The amount spent in 2000 was U.S.$518,000 and an estimated U.S.$350,000/year is considered necessary for the next five years if the program is to meet its ongoing goals (VDEC, 2001a). In Maryland, a massive water-chestnut removal between 1939-1945 ran to an estimated cost of U.S.$2.8 million, converted from 1950 to 1992 dollars (MDNR, 2001). Note that these are costs of limited control, as populations continue to spread. Costs of chemical and biological control were unavailable as no current control programs appear to employ these methods.

Capacity to Vector Other Plant Pests: No specific records found in the literature, although the CFIA Regulatory Directive D-94-27 (See above, Section 1.2) states that “inspectors examining aquatic plants should wear rubber gloves for protection since snails serving as vectors for human disease organisms may be present”.

Risk Rating: Costs of controlling water-chestnut could be locally significant, particularly where infestations must be treated repeatedly before they are brought under control. However, it could be those kinds of economic losses not quantified in the literature that are ultimately the greatest, particularly where water-chestnut infestations restrict recreational use of water bodies, or interfere with other water-based industries. Of particular significance to Canadian agriculture are the potential effects on wild rice production. It should also be noted that, although the areas in which water-chestnut is certainly capable of establishing may seem limited relative to the total area of Canada (e.g. southern Ontario, southwestern Québec), those southern plant hardiness zones are also the areas with the highest population densities in Canada, and therefore the most intensive water use – in short, the areas where there is the greatest potential for economic damage. Potential economic impact is rated "HIGH".

3.4.4 POTENTIAL ENVIRONMENTAL IMPACT — Rating = HIGH (3)

Impacts on Ecosystem Processes: Water-chestnut grows very quickly and is considered a highly invasive plant. Once established in a suitable water body it forms large populations that can cause rapid sedimentation and water pollution. Thick tangles of stems below the surface can trap silt, debris, and organic waste. Decomposition of plants at the end of the growing season can further contribute to sedimentation and can also reduce dissolved oxygen levels in the water. In drinking water reservoirs, water-chestnut is a suspected precurser to trihalogenated methanes. It is likely that water levels and nutrient cycling are also affected by infestations of water-chestnut, although no references were found that documented this.

Impacts on Natural Community Composition: Water-chestnut is highly competitive, and tends to shade out and eliminate populations of other submerged aquatic plants. By multiplying rapidly and reducing the amount of light in the water column it can eliminate native plant species from areas where it dominates. It is often observed as a monoculture, and although an annual it has been seen to outcompete many perennial species. It is considered to have low value to wildlife compared to the species it replaces, and although it does appear to provide habitat for some insects, crustaceans, and invertabrates, its value as habitat compared to undisturbed sites is unclear. In some cases, water-chestnut has appeared to increase numbers of leeches in the water, and serve as breeding grounds for mosquitoes. Interestingly, Daniel *et al.* (1983) note that populations in India can themselves be outcompeted by other invasive weeds such as *Eichhornia crassipes* and *Salvinia molesta*, and Kiviat (1987) notes that although water-chestnut may eliminate submerged aquatics, it does not do so well in competition with robust emergents like cattail (*Typha*).

Impacts on Natural Community Structure: Infestations of water-chestnut can intercept 95% of incident sunlight, severely reducing light levels in the water column.

Sociological Impacts: Water-chestnut can cause problems in a number of different kinds of water bodies. Pollution can result from infestations in reservoirs and other sources of drinking water. Water-chestnut can impede the passage of boats and seriously interfere with the recreational use of waterways (boating, fishing, swimming). Effects on aesthetics, recreation, and property values could result if extensive water-chestnut infestations were to occur, for example in the lakes and waterways of Ontario and Québec cottage country.

Impacts on Human/Animal Health: The spines on the nuts of water-chestnut can cause injury to humans and animals, as they are sharp enough to penetrate shoe leather. As mentioned above, water-chestnut can cause sanitary problems if dense infestations trap and hold waste, and organic matter from plants may also cause pollution and fouling of drinking water in reservoirs.

Impacts of Associated Control Programs: The invasive nature of water-chestnut makes it a difficult and costly weed to control. Once it has established throughout a water system, efforts at eradication must be maintained year after year until the seed bank is depleted. Control programs are best established early, when populations are small. Control measures discussed in the fact sheet (above) include manual/ physical, chemical and biological methods. Each of these methods will have some environmental impacts.

Manual / Physical: All current U.S. control programs appear to be using a combination of mechanical harvesting and hand-pulling to control water-chestnut infestations. Such manual / physical methods are perhaps the most environmentally benign of the three options. No environmental impacts are listed in the literature, although clearly the use of mechanical harvesters and other water craft will involve the burning of fossil fuels and some disruption of natural aquatic communities. It also seems possible that non-target organisms would be cut and/or harvested along with the water-chestnut. It should also be noted that some authors feel these methods will be ineffective in controlling large infestations, suggesting that the less environmentally dangerous approaches may also be less effective controls.

Chemical: Chemical methods appear to have been effective in controlling water-chestnut in the past, particularly when used in combination with manual removal of the plants. However, the only chemical known to be effective in the control of water-chestnut (2,4-D) is no longer used due to its associated environmental impacts. Indeed, its use in aquatic environments is restricted in the U.S. to concentrations below those that are effective on water-chestnut. Pesticide regulations would also be a limitation in Canada, where all registered pesticides for applications in aquatic environments such as rivers, lakes and irrigation canals are designated “restricted class” by Canada’s Pest Management Regulatory Agency (PMRA, 1993) and require additional permits from provincial / territorial authorities that set out strict and site-specific conditions for use (PMRA fact sheet).

Biological control: Biological control methods for water-chestnut are still being researched, and to date no appropriate natural enemies have been identified for use in control programs. Biological control methods involve adding yet another exotic species to an ecosystem, and environmental implications can be far-reaching.

Risk Rating: Overall, the environmental impacts are significant, both directly, and indirectly through the impacts of associated control programs. Although more research is need to to clarify and quantify many of these effects, their potential is considered clear enough to merit a risk rating of “HIGH” in this section.

3.5 CONCLUSION

Overall Risk Rating: HIGH

This rating was obtained by considering both the likelihood of introduction and the consequences of introduction of water-chestnut into Canada, using the guidelines presented in Appendix 2.

The likelihood of introduction was assigned a risk rating of “HIGH”. The consequences of introduction were also rated “HIGH”, calculated as follows:

CUMULATIVE SCORES FOR CONSEQUENCES OF INTRODUCTION	ASSIGNED RATING	NUMERICAL SCORE
Establishment Potential	**HIGH**	**3**
Natural Spread Potential	**MEDIUM**	**2**
Economic Impact	**HIGH**	**3**
Environmental Impact	**HIGH**	**3**
TOTAL SCORE	**HIGH**	**11**

The overall risk rating “HIGH” indicates that specific phytosanitary measures are strongly recommended. It is suggested as a result of this assessment, that water-chestnut should 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 larger the seed bank, and the more difficult it will become to eradicate the population. It is further recommended that public education programs be developed to raise awareness about water-chestnut and other invasive aquatic species in general. Such programs may or may not be the responsibility of the CFIA, but should be initiated and aimed at such groups as, for example, boaters, cottagers, hunters and fishers, waterfront residents, aquarists, and people in the shipping industry. Specific programs could be established in pet and aquarium stores (to discourage the disposal of aquarium plants and animals in natural waterways), and at border crossings (to ensure that boats and other water craft are free from “hitchhiking” organisms before crossing the border).

<u>Note</u>: All *Trapa* spp. are currently prohibited from Canada. While this report shows that *T. natans* is the species of greatest concern, the taxonomic uncertainty within the genus suggests that regulations should continue to apply to all *Trapa* species.

Level of Uncertainty: There is some uncertainty on present evidence as to: 1) the pathway responsible for the introduction of water-chestnut into southwestern Québec and the most likely pathways for future movement across the Canada-U.S. border, 2) the precise distances that the different pathways or vectors identified are capable of dispersing water-chestnut seeds, 3) the extent to which water-chestnut might also be a contaminant of commercial shipments of other aquatic plants, or might be introduced through other shipping activities, 4) the northern limits of water-chestnut's potential range in Canada, and whether the range of northeastern Asian populations should be used to help predict this, 5) the related questions of whether the Asian populations represent different varieties and/or species, and whether they differ significantly in habitat requirements, and 6) the proportion and distribution of Canadian freshwater ecosystems that are considered eutrophic and otherwise meet the habitat requirements of water-chestnut. Further research is also needed to provide more details as to the nature and extent of the environmental impacts of water-chestnut and associated control programs, and the economic impacts caused by loss of income to water-based industries. Despite these uncertainties, it is clear that where water-chestnut becomes established, it is harmful to other plant species and can cause significant, if not yet quantified, economic and environmental damage.

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APPENDIX I: ADMINISTRATIVE AND TRACKING INFORMATION

ADMINISTRATIVE INFORMATION

To: PHRA (D. E. Watler)
From: Plant Health & Production Division (Grains and Field Crops)
Priority: Regular track (Changed to fast-track in June, 2001)
Date Submitted: November 22, 2000
Requested Return Date: March 15, 2001
Estimated Return Date: November, 2001

TRACKING FORM

Names	Locations		Dates
Process Initiation:			
D. Oudit (sender)	PHPD, Camelot, Nepean	(submitted)	Nov. 27, 2000
D. Watler (receiver)	PHRA, ADRI, Nepean	(received)	Nov. 27, 2000
Risk Assessment (initial & updates):			
C. Wilson	Plant Health Risk Assessment Unit (PHRA) Science Division, ADRI, Nepean		July, 2001
C. Wilson	(Complete with revisions from external review)		Nov., 2001
Assessment Review:			
Dr. Doreen Watler ¨ Dr. John Garland ¨ Louise Dumouchel ¨	Plant Health Risk Assessment Unit (PHRA), Science Division, Canadian Food Inspection Agency		
Stephen Darbyshire	Botany Section, Eastern Cereal and Oilseed Research Centre (ECORC), Agriculture and Agri-Food Canada (AAFC)		
Mark Hovorka	Canadian Wildlife Service, Environment Canada		
Dr. Erich Haber	National Botanical Services, Ottawa		

APPENDIX 2: RATING GUIDELINES

1. Guidelines for Rating the Likelihood of Introduction:

Rating = negligible (numerical score is 0): The likelihood of introduction is extremely low given the combination of factors including the distribution of the weed at source, management practices applied, low commodity volume, low probability of weed survival in transit, or low probability of distribution in the PRA area given the intended use of the commodity.

Rating = low (1): The likelihood of introduction is low but clearly possible given the expected combination of factors necessary for introduction described above

Rating = medium (2): Weed introduction is likely given the combination of factors necessary for introduction described above

Rating = high (3): Weed introduction is very likely or certain given the combination of factors necessary for introduction described above

2. Guidelines for Rating Establishment Potential:

This rating reflects the potential range of a weed or invasive plant introduced into new areas. Introduced plants can be expected to behave as they do in their native area (or in other areas where they have been introduced) if suitable habitats and climatic conditions are present. The establishment potential is rated from negligible to wide with consideration of suitable habitats (e.g. precipitation, temperature, soil type) and their geographic range and pattern of distribution. Analysis may involve the use of geographic information systems (GIS) and other computerized systems such as CLIMEX to model and map potential distributions in PRA area.

Rating = negligible (numeral score is 0): The weed has no potential to survive and become established in the PRA area.

Rating = low (1): The weed has potential to survive and become established in approximately one third or less of the PRA area.

Rating = medium (2): The weed has potential to survive and become established in approximately one third to two thirds of the PRA area.

Rating = high (3): The weed has the potential to survive and become established throughout most or all of the PRA area.

3. Guidelines for Rating Natural Spread Potential:

This rating reflects natural means and potential rate of spread of the weed, both into and within the PRA area. Natural means of spread include wind, water, soil, and live vectors, all of which can transport seed, pollen, and vegetative plant parts, sometimes over great distances. Regulatory control may or may not be a feasible management option depending on the weed's current distribution. Man-made dispersal potential is discussed in this section, but is not included in the risk rating.

Rating = negligible (numerical score is 0): The weed has no potential for natural spread in the PRA area.

Rating = low (1): The weed has potential for natural spread locally in the PRA area within a year (some reproductive potential and/or some mobility of propagules)

Rating = medium (2): The weed has potential for natural spread throughout a physiographical region of the PRA area within a year (e.g. It has either high reproductive potential OR highly mobile propagules).

Rating = high (3): The weed has potential for rapid natural spread throughout its potential range in the PRA area (e.g. It has high reproductive potential AND highly mobile propagules).

4. Guidelines for Rating Potential Economic Impact:

The weed may have direct effects on the specific crop concerned in the PRA area, and may also spread to other crops. Factors considered here include impacts on crop production costs, yield, quality, and marketability, and variability of impacts among crop cultivars or varieties. Crops considered include cultivated and forest species, but only those that are managed. This section excludes impacts on natural plant communities that have no economic value to domestic agriculture or forestry (see part 2.3.4 for environmental considerations). A more detailed economic assessment than provided here may be required in some cases.
Note: Indirect impacts the weed might have on potential trade, such as export significance are not the focus of this assessment. This issue is dealt with as a trade component of risk management. Potential to have an effect on international or domestic trade should be highlighted but should not be included in the score.

Rating = negligible (numerical score is 0): The weed has no potential economic impact (e.g. Causes none of the above-listed impacts)

Rating = low (1): The weed has a limited potential to cause economic impacts (e.g. Causes one of the above-listed impacts).

Rating = medium (2): The weed has moderate potential to cause economic impacts (e.g. Causes two of the above-listed impacts OR any one of these impacts on a wide range of economic plants, plant products, or animals (over 5 types)).

Rating = high (3): The weed has significant potential to cause economic impacts (e.g. Causes all the above-listed impacts, OR causes any two of these impacts on a wide range of economic plants, plant products, or animals (over 5 types).

5. Guidelines for Rating Potential Environmental Impact:

This section considers potential impacts of the weed or invasive plant on non-agricultural host(s) and natural ecosystems. This may include subjective consideration of direct biotic effects on endangered or threatened natural species and reduction of biodiversity. Examples of abiotic impacts considered include ecosystem destabilisation, environmental degradation, fire, and impacts on recreation and aesthetic values. Also considered are impacts on human and animal health, and indirect environmental effects of risk management options (e.g., pesticides).

Rating = negligible (numerical score is 0): The weed has no potential to degrade the environment or otherwise affect ecosystems.

Rating = low (1): The weed has limited potential to affect the environment (e.g. Causes one of the above-listed impacts, unless there is potential to reduce populations of threatened or endangered species, in which case rating should be HIGH).

Rating = medium (2): The weed has potential to cause moderate changes in the environment, such as obvious change in the ecological balance (affecting several attributes of the ecosystem), as well as moderate recreation or aesthetic impacts. (e.g. Causes two of the above-listed impacts

Rating = high (3): The weed has potential to cause major damage to the environment with significant losses to plant ecosystems and subsequent physical environmental degradation (e.g. has potential to reduce populations of threatened or endangered species, OR affects three or more of the above-listed impacts).

6. Guidelines for Rating Consequences of Introduction:

The individual ratings given in examining the four factors, i.e., establishment potential, natural spread, economic and environmental impacts, are taken into consideration to produce a rating for the consequences of introduction of a weed. This is done by adding up the individual numerical scores to produce a cumulative score. Depending on the cumulative score, the consequences of introduction will be rated as negligible (0-2), low (3-6), medium (7-10) or high (11-12). The underlying assumption behind the proposed rating system is that all four factors are equally important for all pests, thus allowing comparison between pests. The table below is provided as a guide.

CUMULATIVE SCORES Establishment Potential + Natural Spread Potential + Economic Impact + Environmental Impact	RATING FOR CONSEQUENCES OF INTRODUCTION	NUMERICAL SCORE FOR CONSEQUENCES OF INTRODUCTION
0 - 2	NEGLIGIBLE	0
3 - 6	LOW	1
7 - 10	MEDIUM	2
11 - 12	HIGH	3

7. Guidelines for Overall Risk Rating:

Select a risk rating for each pest in considering the likelihood of introduction and the consequences of introduction using the following table as a guide. The overall risk rating will be the product of the scores for likelihood of introduction and consequences of introduction, and is assigned as follows: negligible (0), low (1-3), medium (4-6) and high (9). After assigning an overall risk rating for a weed, discussion of the rating and information on possible phytosanitary options may be provided.

LIKELIHOOD OF INTRODUCTION (RATING AND NUMERICAL SCORE)	CONSEQUENCES OF INTRODUCTION (RATING AND NUMERICAL SCORE)	OVERALL RISK RATING
NEGLIGIBLE (0)	NEGLIGIBLE (0)	NEGLIGIBLE
NEGLIGIBLE (0)	LOW (1)	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 (3)	NEGLIGIBLE (0)	NEGLIGIBLE
HIGH (3)	LOW (1)	LOW
HIGH (3)	MEDIUM (2)	MED
HIGH (3)	HIGH (3)	HIGH

8. Interpretation of Overall Risk Rating:

Negligible: The likelihood of introduction is negligible. No specific phytosanitary measures are necessary.

Low: No specific phytosanitary measures may be necessary. Various factors including production practices, pre-shipment inspection, packaging, current port-of-entry inspection, end-use, season of importation, etc. are expected to provide sufficient phytosanitary security.

Medium: Specific phytosanitary measures may be necessary.

High: Specific phytosanitary measures are strongly recommended. Port-of-entry inspection alone is not considered sufficient to provide phytosanitary security.

APPENDIX 3: REVIEWER'S COMMENTS

The following comments made by reviewers of this document were not incorporated into the text:

<u>Dr. Erich Haber, National Botanical Services</u>

- I would suggest that the assessment ranking system, as presently followed, is flawed considering that man-made dispersal potential is only discussed but not ranked. I recognize that the present assessment simply follows established protocols for assessment as outlined in Appendix 2 section 3. However, to exclude the most important agent for dispersal from the ranking scheme, an agent that in one form or another is likely the greatest means of spread of invasive plants, is a considerable deficiency in the process. Since this section recognizes that regulatory control may or may not be a feasible management option, it is particularly incongruent that human dispersal is not evaluated and given a numerical ranking. This is an area where regulatory controls could likely be effectively initiated or, at the very least, some guidelines could be introduced to minimize spread by humans.

  I agree with the assessment of overall likelihood of introduction being high since there is a high probability that further spread into Canadian waterways adjacent to those in the USA is likely to occur. This will probably result through various human agencies rather than natural spread. Natural spread, however, will likely continue in SW Quebec since, once introduced, as it is now, aquatics such as this species will be difficult to eradicate through controls. Monitoring in some fashion should be established in southern Ontario and SW Quebec, perhaps through contacts with regional natural history clubs. The Invasive Plants of Canada Project (IPCAN) has in the past undertaken such contacts. As a result of the IPCAN web site, where the Canadian introduction in SW Quebec was first announced, greater public attention has been drawn to the expansion of this species.

  I would also agree with other assessments provided in this document such as the high establishment potential over large areas of Canada. Its natural potential for spread is based, however, on mainly regional expansion giving the species a medium ranking for this criterion. Given that the economic impact is high, establishment potential across much of the PRA is high and the recognition in the assessment that human dispersal potential is significant, and likely the most significant factor in the spread of the species (personal assessment of the reviewer), an additional ranking for human dispersal should be included in the assessments. Nevertheless, even without this additional ranking, the species is ranked, overall, and correctly so, as a species with a high potential for invasion on a broad scale.

  This document, representing the first attempt to provide an assessment for an invasive weedy species, provides an excellent overview and an appropriate overall ranking for the invasive potential of this exotic aquatic plant.