Invasive Species of the Pacific Northwest:

Yellow floating heart, *Nymphoides peltata*

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Aquatic Invasion Ecology 423: Julian Olden

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Figure 1. *Nymphoides peltata* is a beautiful water lily that is invasive to North America, and its spread is on the rise (A. Mrkvicka 2007).

DIAGNOSTIC INFORMATION

Order: Asterales

Family: Menyanthaceae

Genus: *Nymphoides*

Species: *N. peltata*

Common names: Yellow floating heart, fringed water lily, marshflower

Plant Identification and Morphology

Roots and Stems

N. peltata grow roots along the bottom of slow-moving bodies of water approximately 0.5-4 meters deep, and have long, branched stems below the surface (USGS 2014) (Fig. 1). Stolons (stems that form adventitious roots) creep in and along the bottom layer and can be divided into long and short shoots, which morphologically differ only in the length of internodes (van der Velde et al. 1979). The short shoots are whitish in color, and serve to anchor the plant to the bottom with roots. These thickened roots hibernate during the winter, and form new leaves and long shoots in the spring (van der Velde et al. 1979). From the axil of a leaf emerging from a short shoot, a long shoot can develop. Long shoots produce nodes, which can possess 2-7 adventitious roots and one leaf per node. This branching pattern can repeat itself in this way several times, so that one plant alone can cover a considerable area (van der Velde et al. 1979).

Leaves

N. peltata leaves are circular or heart shaped with diameters 3-12 cm, and grow along the stem in opposite and unequal patterns (USGS 2014). Leaf length varies with bottom composition, water depth and the time of the year in which they are produced (van der Velde et al. 1979). The leaves also have slightly wavy margins, are green to yellow-green in color, and often have purple-colored undersides with darkish glandular spots (Darbyshire and Francis 2008, USGS 2014)(Fig. 4). The leaves are nearly always floating on the water surface, yet have been observed to be submerged 1 cm below during the winter (van der Velde et al. 1979). Leaf size changes depending on the season and water depth. In the winter, only very small, non-floating leaves are present. In spring and early summer, small folded leaves appear, which gradually unfold in response to increasing light and temperature (van der Velde et al. 1979).

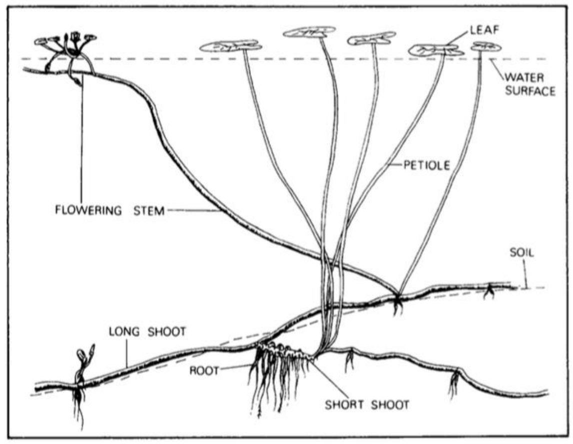


Figure 2. The general structure of *N. peltata* (van der Velde et al. 1979). The forking placement of long shoots and short shoots give rise to a complex and expansive network of leaves and flowering stems.

Figure 3. An underwater view of the network of roots and shoots (John Preuss).

Figure 4. A circular *N. peltata* leaf with slightly-wavy margins adjacent to a budding stem (Skawinski 2009).

Petals

N. peltata is a day-flowering species, meaning the flowers only bloom when exposed to sunlight (van der Velde and van der Heijden 1981). The bright, fluorescent yellow flowers of *N. peltata* have five petals that measure 2.5-4 cm in diameter when fully open (van der Velde 1979) (Fig. 5). Each petal bears a broad membranous margin on both sides, which are wavy to slightly ruffled, creating a short, irregular fringe (Darbyshire and Francis 2008). The fringed petals might not only be for show, but also an adaptation to fluctuating water levels by creating upward buoyancy through surface tension interactions (Armstrong 2002).

Figure 5. *N. peltata*'s five petals have fringed borders and are vibrant yellow, which attract an array of insects for pollination.

LIFE HISTORY AND BASIC ECOLOGY

Life Cycle

The flowers of *N. peltata* reproduce by different forms of reproduction, including insect and self-pollination. Using their large, vibrant yellow petals, insects are attracted to the well-defined central area of ultra-violet absorption. As a result, the pollinators are guided towards the basal nectaries, where they exchange the transport of pollen for glucose-rich nectar (van der Velde and van der Heijden 1981). However, *N. petltata* can undergo self-pollination, which occurs within a single flower or between different flowers on the same genetic individual (Larson 2007). Despite this convenience, self-fertilization occurs at low frequencies to avoid inbreeding depression (Takagawa et al. 2006).

Either insect or self-pollination occurs within a few hours of flower opening, after which the corolla (petals) begin to wither (Darbyshire and Francis 2008). The pedicel (stem that connects to the bud) lengthens and deflects, and subsequent fruit development takes place just below the water surface (van der Velde and van der Heijden 1981). Each flower produces one beaked capsule about 2.5 cm long, which splits along one side to disperse many smooth seeds with winged margins (USGS 2014) (Figs. 6, 7).

Seeds are released from the fruits at the end of the season and form floating chains. The seeds can stay afloat on the surface due to a coating of a weak hydrophobic substance and by the marginal hairs (Cook 1990). Depending on the aquatic habitat, seed dispersal can be mitigated by currents, digestion by amphibious animals or birds, or attachment to boats (Darbyshire and Francis 2008). A recent study revealed that undisturbed buoyant *N. peltata* seedlings could float for more than three months, enabling dispersal to other areas within the same body of water (Huang et al. 2014). If the floating seeds are disturbed by rain and forced underwater, the seeds sink to the bottom, where the germination stage of the life cycle begins (van der Velde and van der Heijden 1981).

The germination process can occur in seeds resting on the substratum surface in shallow water, floating at the surface, or even on saturated mud substrates, such as exposed mud flats (Smits and Wetzels 1986). Germination cannot occur on exposed dried-up sediments, however experiments have shown that desiccated seeds can retain viability for as long as 30 months (Guppy 1897). Additionally, crowded habitats promote germination growth, however crowding is not required for successful seed development (Richards and Cao 2012). These reproductive adaptations strengthen *N. peltata*'s ability to be an effective invasive species, even before the plant has sprouted.

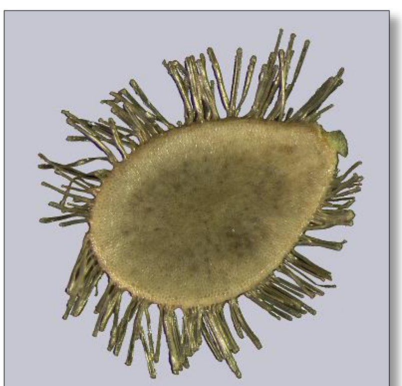


Figure 6. (Top) Once the flower is pollinated, the bud bursts open with several, smooth seeds (Fred Hrusa 2003). Figure 7. (Bottom) *N. peltata* seeds have winged margins which aid in temporary buoyancy (University of Wisconsin, Tippery Lab).

When the fall season begins and temperatures decline, rhizomes remain buried in the substrate after above-ground tissues die, and give rise to new growth in the spring (Darbyshire and Francis 2008)

Physiological Adaptations

Vascular plant species inhabiting wetland sites and freshwater aquatic habitats have developed characteristic adaptations to oxygen deficiency and anoxic soil conditions. Common physiological adaptation mechanisms include reduced rates of consumption of storage material, reduced metabolic activities, and the transformation of fermentation products into non-toxic metabolites (Darbyshire and Francis 2008).

Plants growing in wetlands or shallow lakes depend on improved internal aeration of their submerged parts due to the significant reduction of oxygen diffusion rates in water compared to air (Armstrong 1979). *N. peltata*, along with other water lilies, largely depend on the supply of oxygen to its buried tissue to support root respiration (Dacey 1980). Due to the complex structure of this species, *N. peltata* is able to efficiently exchange oxygen and inorganic carbon from the air, water and sediment (Brock et al. 1983). *Nymphaeid* water plants have a ventilation system in which a flux of air down the petioles of the youngest leaves forces an efflux of CO2-enriched gas from the rhizome towards the older leaves simultaneously (Dacey 1981). Within a single *N. peltata* plant, gas enters through the younger leaves, moves down to the node, and returns to the atmosphere through the older leaves of the same whorl (Grosse and Mevi-Shutz 1987) (Fig. 8). This physiological feat improves the oxygen supply to the roots and enables the *N. peltata* to colonize habitats such as slow flowing rivers and ponds, which are commonly characterized by oxygen shortages.

Additionally, *N. peltata* has adapted reproductive traits to prevent self-pollination. A past study has shown that *N. peltata* has evolved a strong incompatibility system that prevents self and intramorph fertilization. This feature works to avoid inbreeding depression and increases the strength of the local gene pool (Wang 2005).

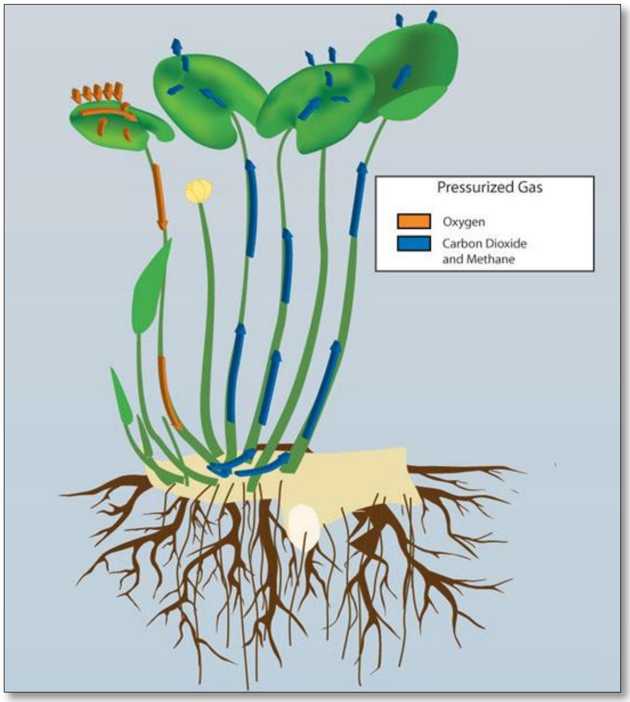


Figure 7. The diagram above represents the aeration ventilation process in which wetland plants can counter low oxygen conditions. Gaseous transport results in the flow of oxygen from the atmosphere to the roots, and carbon dioxide and methane from the roots to the atmosphere (Dacey 1981).

HABITAT

N. peltata is a perennial, floating aquatic plant that commonly inhabits slow moving eutrophic waters such as lakes, rivers, reservoirs, canals, and ponds usually 1-2 m deep (Darbyshire and Francis 2008). Optimal substrates include clay, organic mud (sapropel), or a mixture of both (van der Velde et al. 1979).

BIOTIC INTERACTIONS

Insects

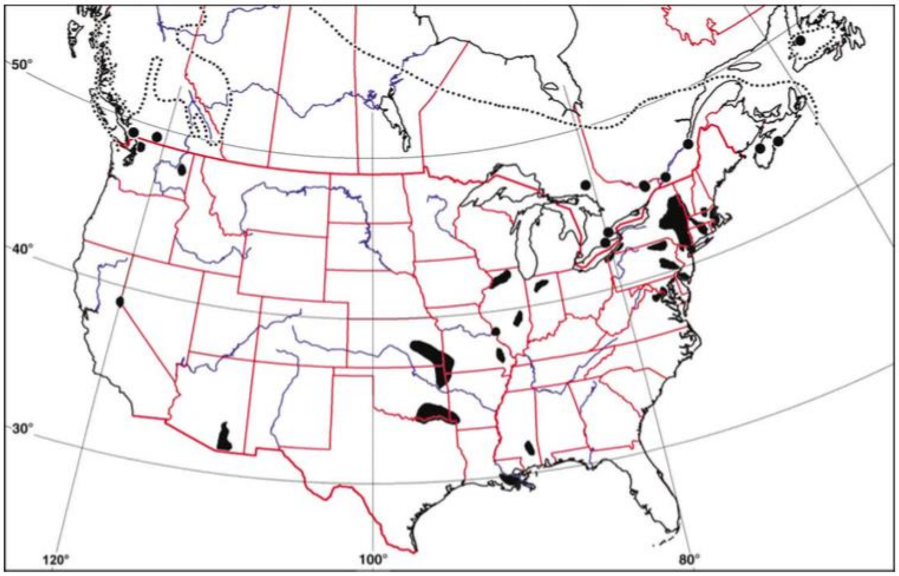
Successful pollination of *N. peltata* does not require a specific insect type. However, the five nectaria are sheltered by hairy staminodes to a height of 0.5-0.6 cm, therefore only flower visiting insects with long tongues can reach the nectar (van der Velde and van der Heijden 1981). The pollen grains contain protein, fat, carbohydrates, and various inorganic mineral substances that provide an important food source for many insects, including pollen-eating flies and beetles (Proctor and Yeo 1973). At the end of the pollinating season, insect larvae from several families aid in the decomposition of *N. peltata*, contributing to the detritus that is then further decayed by bacteria and fungi (Brock 1984).

Birds and other vertebrates

Several species of birds and other vertebrates have been observed to live in *N. peltata* communities, such as mallards (*Anas platyrhynchos* L.), Euraian coots (*Fulica atra* L.), painted turtles (*Chrysemys picat marginata* Agassiz), and fish. However, very few of these animals have been observed to consume *N. peltata* (Darbyshire and Francis 2008). In an experimental setting, common carp (*Cyprinus carpio* L.) refused to eat the seeds of *N. peltata* unless they were starving, suggesting little or no natural predation by that species (Smits et al. 1989). In the Netherlands, *N. peltata* formed dense mats within a canal where introduced grass carp were prioritizing other aquatic weeds, thus served as an ineffective control (Pitlo 1986).

Mammals

Few reports exist with observations of herbivory on *N. peltata* by mammals. Muskrats are one of the only wild species that have been observed to consume multiple parts of the plant (Francis and Darbyshire 2008).



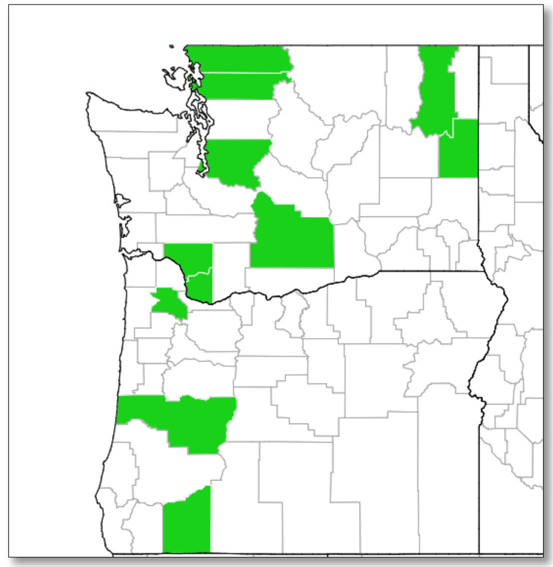


Figure 9. (Left) Distribution of *N. peltata* in North America. Areas where *N. peltata* is known and/or establish are indicated by solid circles (Darbyshire & Francis 2008). Figure 10. (Right) Known counties in the Pacific Northwest with *N. peltata* invasions are highlighted in green (EDD Maps 2014).

CURRENT GEOGRAPHIC DISTRIBUTION

N. peltata is indigenous to Central Europe and Asia Minor, inhabiting temperate and subtropical regions to about 64°N latitude (Larson 2007). The distribution of this species has drastically changed in the past few decades, and is established across multiple sites globally (Huang et al. 2014) (Fig. 9).

N. peltata is considered an invasive species in North America and New Zealand (Huang et al. 2014), yet is a threatened aquatic plant in Japan (Nishihiro et al. 2009). Predominately invasive in the southern United States, *N. peltata* has spread as far as the uppermost corner of Washington State (Figure 10).

HISTORY OF INVASIVENESS

N. peltata was first documented in the United States in 1882, around the same time it was being grown in New York City's Central Park Terrace Pond for aesthetic reasons (Darbyshire and Francis 2008). Evidence suggests that *N. peltata* has been marketed within the U.S. ornamental plant trade since 1891 (Berent and Howard 2014).

By 1930, *N. peltata* was first found in the western United States growing in Long Lake, eastern Washington. It has continued to spread to other parts of the Pacific Northwest, including sites in Oregon (Berent and Howard 2014).

N. peltata has been listed as an invasive or noxious weed in several states, including CT, ME, MA, OR, VT, and WA (Federal and State Noxious Weeds USDA 2014). Considering general climate requirements and physiological resilience, it could potentially be recognized as an invasive species to additional states in the future.

INVASION PROCESS

There are several pathways in which *N. peltata* can be introduced to non-native areas and has proven to be efficient at dispersing across multiple vectors. Although some vectors are part of the natural food chain, such as being digested by aquatic animals, other vectors are anthropogenically-induced. Pathways such as horticultural and aquarium trade, boating, angling, and other water activities provide vectors for this species to establish and spread (Millane and Caffrey 2014).

Because this species is used in pond horticulture and is involved with international trade, it is provided several opportunities to establish across an array of ecosystems. This species is available to purchase on the internet, and is imported via horticultural and aquarium vendors, which sell them in public garden centers (Kelly and Maguire 2009). Sites marketing *N. peltata*, such as www.watergarden.org, sell each plant for $5.95 USD. Granted, states that have listed *N. peltata* as invasive prohibit incoming shipments. However, considering *N. peltata*'s environmental plasticity, perhaps this plant should be prohibited entirely from horticultural and aquarium trade outside of its native range.

Due to its life history characteristics, this species can rapidly spread and infest areas given a single opportunity. In Sweden, a single plant introduced to a lake in 1933 was reported to have spread to cover an area of 0.45 km^2 by 1975 (Josefsson and Andersson 2001). In the shallow, eutrophic lake Grand Lieu in France, the area covered by *N. peltata* nearly doubled within one year, spreading from 17.5 ha in 1996 to 29.5 ha in 1997 (Marion and Paillisson 2003). Therefore, early identification is key to preventing the successful and efficient spread of this floating aquatic species.

Factors Influencing Establishment and Spread

a) Human Activities

- Horticultural and aquarium trade provides multiple opportunities to establish in non-native ranges
- Recreational boating
- Fishing
- Water activities

Other transport mechanisms include attachment of the seeds or plant fragments to boats or other objects moved by humans from one body of water to another (Johnson et al. 2001).

b) Plant Physiology and Life History

- Tolerates a wide thermal range (Francis and Darbyshire 2008)
- Can reproduce from seeds, broken stems, and leaves with some stem attached (Millane and Caffrey 2014)
- Can colonize large areas within one growing season (Brock et al. 1983)
- Seeds are resilient to desiccation (Guppy 1897)
- Does not require specific insect pollinators (Darbyshire and Francis 2008)
- Can occupy crowded, low oxygenated environments (Richards and Cao 2012)

Ecological Impacts

The invasion of *N. peltata* has produced detrimental environmental disturbances in areas of invasion, including the Pacific Northwest. Colonies can produce dense mats of leaves in a floating canopy, which block out sunlight for other vascular plants (Huang et al. 2014). As a result, flow is reduced, less light is penetrated past the surface, oxygen levels decrease, and nutrient cycling is disrupted (Darbyshire and Francis 2008). Additionally, due to the large influx of biomass, dissolved oxygen levels are further depleted in response to excess decomposition rates (Darbyshire and Francis 2008).

When colonies are dense, plants compete and displace indigenous vegetation, thus reducing biodiversity and altering faunal communities (Huang et al. 2014).

Figure 11 (top). *N. peltata* can form dense mats and crowd out native vegetation when given the right aquatic environment; slow moving waters are perfect for this the congregation of this species. This is a single population within Lake Spokane, Washington (University of Wisconsin, Tippery Lab). Figure 12 (bottom). A lake invasion of both *N. peltata* and its relative, the white water lily (*Nympaea ordrata*). Recreational boaters have compelling incentives for removing these invasive species.

Economic Impacts

In some locations, dense mats of *N. peltata* have interfered with or even prevented recreational boating, fishing, and other water activities (Fig. 10)(Kelly and Maguire 2009). Drainage from the water source can also be impeded when thick mats block water passageways (Darbyshire and Francis 2008). Even as an indigenous species in China, *N. peltata* is expanding rapidly in waterways and lakes, threatening commercial shipping and recreational vessels (Huang et al. 2014).

Populations of *N. peltata* have often become so extensive and dense, that control methods are both necessary and costly (Larson 2007). Both roots and rhizomes are able to withstand mechanical removal by dredging, and it is too expensive to be considered as a sole method of weed control (Josefsson and Andersson 2001). The current cost to mechanically cut and remove all fragments of *N. peltata* is estimated to be $9,000 USD per hectare annually (Gren et al. 2007).

CURRENT MANAGEMENT STRATEGIES AND CONTROL METHODS

Regulations

In Washington State, *N. peltata* has been listed as a threat to agriculture, environmental quality and natural resources, and thus have been put under noxious weed seed and plant quarantine list (Washington Administrative Code 2005). Gardeners cannot purchase this species in states that have it listed as invasive, potentially invasive, or as a noxious weed. New Zealand and the states of Washington, Maine, New Hampshire, Connecticut, Vermont, South Carolina, and Canada attempt to use regulations as a preventative measure to control the spread of this invasive species (Global Invasive Species Database 2006)

Control

Invasive waterlilies, including *N. peltata*, can be controlled by cutting, harvesting, covering with bottom barrier materials, and aquatic herbicides such as glyphosate (MDEP 2006). Smaller infestations are best dealt with by clearing manually (Figs. 13, 14), while larger sites can be controlled by laying down bottom barriers to essentially starve these substrate-rooted species from oxygen and sunlight (MDEP 2006). Due to the growth habit of *N. peltata*, bottom barriers have to be installed in early spring before excessive growth occurs. (MDEP 2006).

Other herbicides besides glyphosate may work with this species, but may be more intrusive due to potential impacts on the water column (MDEP 2006). When considering an herbicide control agent, the impacts, target concentration, and timing of application must be thoroughly investigated before applying to a wetland ecosystem.

Figure 13. Botanist Barbara Mumblo hauls a kayak load of *N. peltata* from upper Squaw Lake (USDA 2011).

Figure 14. Eradication of *N. peltata* is tedious and laborious. This man is clearing plants in Lake Gordon, Wisconsin (AIS Projects).

Prevention

Due to costly eradication measures, prevention is the key to avoid future invasions. Educating others, particularly horticulturists, about the ecological and economic impacts aquatic invasive plant species can have on local communities will help stop future establishments. You can help by practicing the following techniques when dealing with any aquatic invasive plant species (AIS 2005):

- Dispose of unwanted aquarium and pond plants in the trash. Do not throw away unwanted plants in other water bodies.
- Rinse off equipment such as wading gear and boats before leaving a launch area in a pond or lake.
- Remove all plant fragments from all equipment. Even the introduction of a small stem fragment into a new water body can promote a colonization event.
- Buy local: use native, not invasive, plants in ornamental ponds! Research plants you're ordering for ornamental purposes before introducing them to an exotic range.

CURRENT MANAGEMENT EFFORTS AND OBJECTIVES

In both Oregon and Washington, control of even small populations has proven difficult. Bottom covers are being attempted to smother infestations, and chemicals such as glyphosate are being used in Sweden, yet long-term success of these tactics is unknown (ODA 2005). Several regions in the United States have started requiring that recreationists drain all water and clean off all gear (such as boats, trailers, and fishing equipment) used on water bodies to minimize spread of invasive plants such as *N. peltata* (Nault and Mikulyuk 2009).

Prevention of this species is the most effective strategy for avoiding mass infestations. Educating people involved with horticulture and aquarium trade is critical because those are the groups who provide *N. peltata* with frequent opportunities to establish in non-native habitats. Several informational fact sheets and posters are available online with detailed identification keys. Immediate reporting of any *N. peltata* sightings to your local county can make a substantial difference in controlling these rapidly expanding plant populations.

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OTHER KEY SOURCE OF INFORMATION AND BIBLIOGRAPHIES

Aquatic Invasive Species (AIS 2005): Yellow floating heart fact sheet:

http://www.in.gov/dnr/files/YELLOW_FLOATING_HEART.pdf

Global Invasive Species Database 2006: http://www.issg.org/database/species/ecology.asp?si=225&fr=1&sts=&lang=EN

Federal and State Noxious Weeds USDA 2014:

http://plants.usda.gov/java/noxComposite

Maine Department of Environmental Protection (MDEP): Rapid Response Plan for Invasive Aquatic Plants, Fish, and other Fauna

http://www.maine.gov/dep/water/invasives/rrp_part1final.pdf

Oregon Department of Agriculture (ODA): Plant Pest Risk Assessment for Yellow Floating Heart, Nymphoides peltata 2005:

http://www.oregon.gov/ODA/shared/Documents/Publications/Weeds/PlantPestRiskAssessmentYellowFloatingHeart.pdf

Pacific Northwest Noxious Weed List: http://www.pnw-ipc.org/pnwnoxiousweedlist.shtml

USGS 2014 *Nymphoides peltata* Fact Sheet:

http://nas.er.usgs.gov/queries/greatlakes/SpeciesInfo.asp?NoCache=2%2F6%2F2011+12%3A14%3A07+AM&SpeciesID=243&State=&HUCNumber=DGreatLakes

Washington Administration Code. 2005. Noxious weed control, Chapter 16-752f: http://plants.usda.gov/java/noxious?rptType=State&statefips=53

EXPERT CONTACT INFORMATION IN PNW

Report N. peltata sightings to your Washington State county's local Weed Board. Find specific contact information for your county at:

http://www.nwcb.wa.gov/nwcb_county.html

Washington Invasive Species Council online reporting form:

http://www.invasivespecies.wa.gov/report.shtml

Regional Contacts

Regional Botanist of the Pacific Northwest Headquarters (Oregon and Washington):

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For more botanist and ecologist contact information in the Pacific Northwest, visit the USDA Forest Service page at:

http://www.fs.usda.gov/detailfull/r6/plants-animals/plants?cid=stelprdb5297503&width=full