Management Resources for Yellow Floating Heart (*Nymphoides peltata*) and Water Primrose (*Ludwigia ssp.*)

Compiled by the Oregon Department of Agriculture
Noxious Weed Program
2018 Noxious Weed Forum

Contents

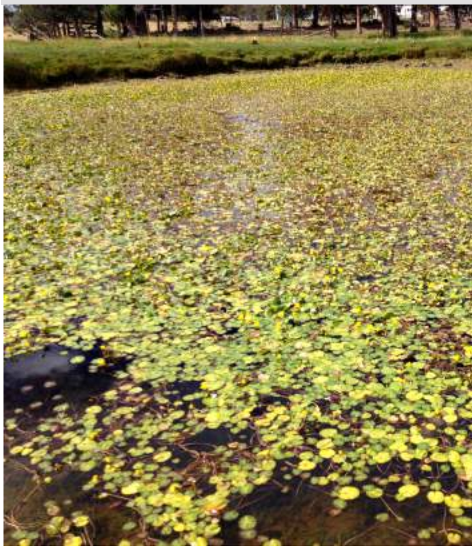
Yellow Floating Heart

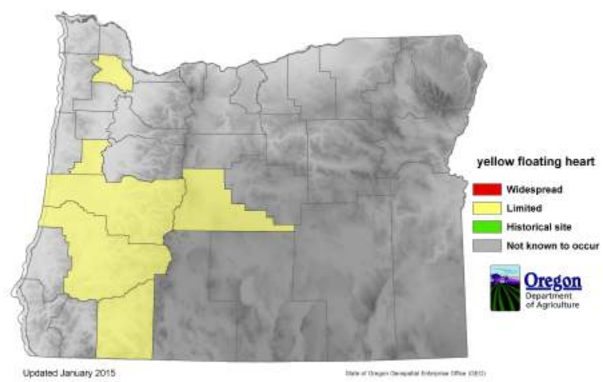
Please call 1-866-invader if you suspect you have found this species

Yellow floating heart
Nymphoides peltata

Other common names: Asaza, entire marshwort, floating heart, fringed water lily

USDA symbol: NYPE
ODA rating: A, T





Introduction: *Nymphoides peltata* is native to the temperate regions of Europe, Asia and the Mediterranean region. Introduced to the U.S. as an ornamental pond plant, it has been sparingly sold in the aquatic plant trade. Though it is an attractive plant for water gardens, if introduced into the wild, it can rapidly colonize lakes, ponds and slow moving streams covering them in a dense mat of vegetation.

Distribution in Oregon: In 2004, Oregon's first confirmed site was found in Washington County. In 2005 another infestation was located in Lane County. Since then, 2 sites in Douglas and 1 site in Jackson have been confirmed. In 2013, 6 infested ponds were identified in Deschutes County.

Description: Yellow floating heart is an aquatic emergent perennial with creeping rhizomes and stolons and floating heart-shaped leaves. The 3-5 inch diameter leaves are much smaller than the native yellow pond lily common in the Northwest that sports 12-14 inch leaves. Yellow floating heart is also distinguished by having smaller blooms than the native. Flowers are 1-2 inches in diameter, bright yellow with 5 fused petals. The native pond lily flowers are globular and larger. Flowering occurs from May to October. Reproduction is by seed and by plant fragments.

Impacts: Yellow floating heart grows in dense stands, excluding light for native species and creating stagnant areas unsuitable for other species. Large infestations make it difficult to fish, water ski, swim or paddle. At its worst it displaces native plants and animals decreasing pond or lake diversity. Should it enter irrigation canals, it would impede water flow and increase mosquito populations.

Biological controls: Biological control agents are not used on "A" listed weeds in Oregon. All sites are targeted for eradication.

Oregon Department of Agriculture • Noxious Weed Control Program
635 Capitol Street NE • Salem, OR 97301
503-986-4621 www.oregon.gov/ODA/programs/Weeds/Pages/Default.aspx

Photos by Glenn Miller and Mike Crumrine, ODA

Oregon Department of Agriculture
Pest Risk Assessment for *Nymphoides peltata*
February 2005 (Rev. 2/2018)

Yellow floating heart (*Nymphoides peltata* (J.G. Gmel) Kuntz) synonyms water fringe, fringed water lily, entire marshwort.

Family: Menyanthaceae

Findings of this review and assessment:
Yellow floating heart, *Nymphoides peltata*, was evaluated and determined to be a category "A" rated noxious weed, as defined by the Oregon Department of Agriculture (ODA) Noxious Weed Policy and Classification System. This determination was based on a literature review and analysis using two ODA evaluation forms. Using the Noxious Qualitative Weed Risk Assessment v. 3.6, floating heart scored 70 indicating a Risk Category of A; and a score of _21_ with the Noxious Weed Rating System v. 3.1, indicating a "A" rating.

Summary: Yellow floating heart and two closely related species are marketed as aquatic garden ornamentals and are well adapted to garden pools, shallow lakes and slow moving rivers. Wherever it has been introduced into the wild, it has proven to be a prolific grower with the capability to dominate shallow lake surfaces. Fish and wildlife habitat, recreational access and water quality are all negitively impacted by dense mats of leaf material. Dissolved oxygen, light penetration, species diversity and fish productivity all decrease in infested waters. Fortunately, the plant is rare in Oregon.

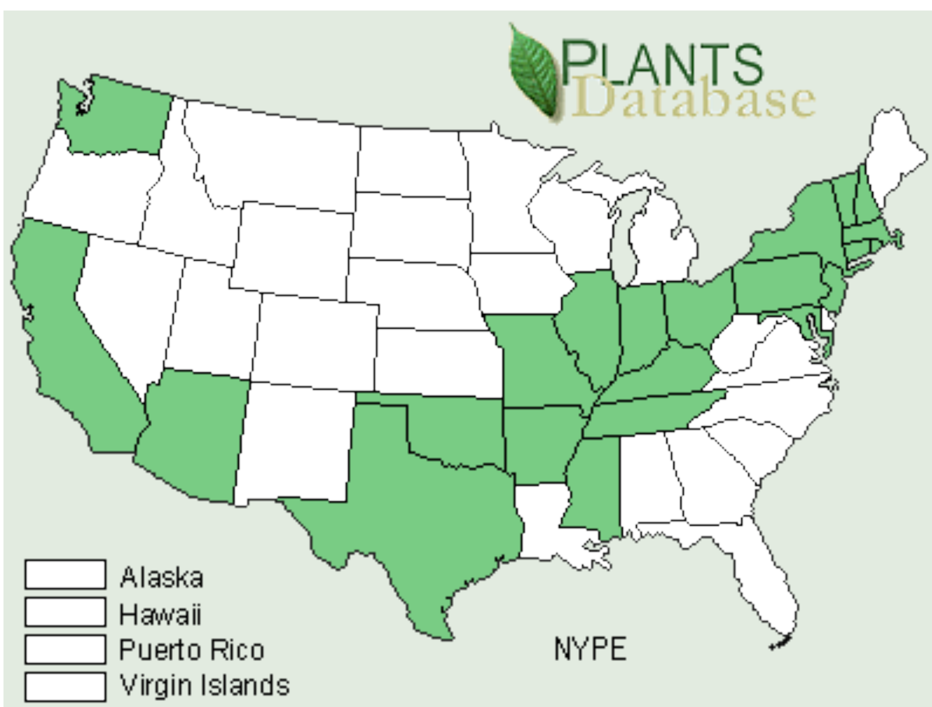
Growth habit: *Nymphoides peltata* prefers slow moving rivers, lakes, reservoirs, ponds and swamps. It can grow on damp mud and in water depths from 0.5 to 3-4 meters where it forms a thick mat of floating leaves. It is a bottom-rooted perennial with long branched stolons extending horizontally up to one meter or more and lying just beneath the water surface. Stolons develop numerous roots at nodes. The floating, heart-shaped to almost circular leaves are 3-10 cm long on long stalks which arise from creeping underwater rhizomes. The leaves are frequently purplish underneath, with slightly wavy, shallowly scalloped margins. The flowers are bright yellow, 5-petaled and 3-4 cm in diameter. The flowers are held above the water surface on long stalks, with one to several flowers per stalk

Reproduction: This species reproduces vegetatively through its habit of rooting at nodes and from plant fragments. Seeds are produced in some populations and can remain viable in anaerobic conditions, as are found in lake sediments, forming a persistent seed bank. Seeds in aerobic conditions germinate readily once they have undergone a brief period of cold stratification. Floating seeds are disk-shaped and tend to aggregate into rafts or chains and are dispersed by currents and waterfowl (Cook 1990). They are slightly hydrophobic with marginal trichomes that readily attach to waterfowl aiding dispersal to new habitats.

Habitat availibility: Thousands of acres of small lakes, ponds, lake edges, sloughs and slow moving streams exist in Oregon as suitable habitat for N. peltata. Shallow coastal lakes are especially vulnurable.

Native Distribution: *Nymphoides peltata* is native to the temperate regions of Europe, Asia and the Mediterranean region.

United States Distribution



Weedy populations in Western U.S.: Yellow floating heart is established in Lake Spokane, Stevens Countie Wahington, where it dominates many acres of the site. It has also been found in Whatcom county, NW Washinton and in Yakima county. It is found in Arizona, in Trout Lake in the California Sierra Nevada mountains, and several locations in Oregon in Lane county, Washington county, Douglas county and Jackson county.

Probability of detection: Yellow floating heart can be confused with the native water lilies and escape notice for many years. It usually requires a human element for dispersal so it can be counted on to show up where people have planted it or dumped it. The largest site in Oregon with over 1 acre net coverage resulted from illegal dumping and escaped identification for many years. There may be private ponds in Oregon that are infested and have not been reported.

Dispersal: Humans are the main culprit with this species. Planting in small ponds and aquatic gardens can disperse this species far and wide. Flood events may then transport plant material downstream. Dispersion by animals has not been a factor in Oregon yet.

Factors effecting establishement in Oregon: Healthy, clear water bodies offer good rooting opportunities for seeds and stem fragments. Northwest temperatures are mild, even in the winter and pond substrate does not freeze. Most water bodies on the western half of Oregon do not fully dry up and remain moist for newly established plants. Yellow floating heart displays great tolerance for fluctuating water tables and so is not regulated by them (Paillisson 2011).
Grazing by mammals is limited and little feeding damage by insects is visible. Lack of grazing pressure insures that this species expresses its full biological potention.

Hardiness zones: Grows in zones 5-10(Missouri botanical).

Economic impacts: Infested waters become unavailable for fishing, swimming and other aquatic recreation without expensive weed removal. Water bodies can face decreases in dissolved oxygen for fish production and increased populations of mosquito's. Control of this plant can be difficult and expensive. Root fragments and stolons easily separate in mechanical control treatments to take root reducing success. The addition of herbicides to waterways for weed control is controversial and may complicate control efforts on larger infestations.

Ecological impacts: Dense patches, exclude light for native species creating stagnant areas with low oxygen levels underneath the floating mats. Species diversity is reduced as is fish production.

Control: Fabrics and benthic barriers have been used in southern Oregon to smother infestations at the sediment layer. Success requires overlapping of fabric edges and annual maintenance of barrier edges. Elongation of stolons outside the edge of the covering has been an issue. Bottom barriers are not a solution in ponds with large amount of debris (stumps, rocks, etc.). The removal of barriers, once in place, can be quite difficult and cost-prohibitive and thus are often just left in place. Another consideration in using benthic barriers is that a barren zone, free of life, is created underneath fabrics. How to dispose of volumes of water-logged fabrics, should they be successfully retrieved, is another consideration.

Manual removal must be conducted with care, since stem and root fragments can quickly recolonize a site. Yellow floating heart has nearly been eradicated from Little Squaw Lake, on the Rogue River- Siskiyou National Forest. Intense manual and cultural methods employed over a five-year period, included: hand removal, digging, dive teams, barriers, and the use of kayaks as barges to remove the volumes of plant material. Once the yellow floating heart core populations were significantly reduced, remaining plants were removed by hand during annual monitoring visits. 2017 was the first year that no plants were detected. Monitoring will continue until no plants are found for five-consecutive years.

The use of aquatically approved herbicides applied to emergent plants has shown results. Both Imazapyr (Habitat, Polaris) and Imazamox (Clearcast) have proven to be quite effective in controlling yellow floating heart in various sized ponds. Aquatic glyphosate formulations have not offered adequate control in Oregon. Check label for effective application rates. Field observations of plant grazing by nutria that create fragments that grow into new infestations in subsequent years have resulted in reduced success rates at some sites. Success at ponds with drinking water restrictions have been limited as well since the availability of effective herbicides is limited.

Noxious Weed Qualitative Risk Assessment
Oregon Department of Agriculture

Common name: Yellow floating heart
Scientific name: Nymphoides peltata
Family: Menyantaceae

For use with plant species that occur or may occur in Oregon to determine their potential to become serious noxious weeds. For each of the following categories, select the number that best applies. Numerical values are weighted to increase the value of important factors over less important ones. Choose the best number that applies, intermediate scores can be used.

Total score 70 Rating: A

GEOGRAPHICAL INFORMATION

1. 6 Invasive in other areas

0 Low- not known to be invasive elsewhere

2 Known to be invasive in climates dissimilar to Oregon's current climates.
6 Known to be invasive in geographically similar areas.

Comments: Invasive in temperate zone environments throughout the country.

2. 6 **Habitat availability:** Are there susceptible habitats for this species and how common or widespread are they in Oregon?
1 *Low* – Habitat is very limited, usually restricted to a small watershed or part of a watershed (e.g., tree fern in southern Curry County).
3 *Medium* – Habitat encompasses 1/4 or less of Oregon (e.g., oak woodlands, coastal dunes, eastern Oregon wetlands, Columbia Gorge).
6 *High* – Habitat covers large regions or multiple counties, or is limited to a few locations of high economic or ecological value (e.g., threatened and endangered species habitat).

Comments: It is invasive in aquatic systems.

3. 0 **Proximity to Oregon**: What is the current distribution of the species?
0 *Present* – Occurs within Oregon.
1 *Distant* – Occurs only in distant US regions or foreign countries.
3 *Regional* – Occurs in Western regions of US but not adjacent to Oregon border.
6 *Adjacent* – Weedy populations occur adjacent (<50 miles) to Oregon border.

Comments: Found in several locations in Oregon

4. 10 **Current distribution**: What is the current distribution of escaped populations in Oregon?
0 *Not present* – Not known to occur in Oregon.
1 *Widespread* – Throughout much of Oregon (e.g., cheatgrass).
5 *Regional* – Abundant (i.e., occurs in eastern, western, central, coastal, areas of Oregon) (e.g., gorse, tansy ragwort).
10 *Limited* – Limited to one or a few infestations in state (e.g., kudzu).

Comments: Known from less that 10 locations.

BIOLOGICAL INFORMATION

5. 3 **Environmental factors**: Do abiotic (non-living) factors in the environment effect establishment and spread of the species? (e.g., precipitation, drought, temperature, nutrient availability, soil type, slope, aspect, soil moisture, standing or moving water).
1 *Low* – Severely confined by abiotic factors.
2 *Medium* – Moderately confined by environmental factors
4 *High* – Highly adapted to a variety of environmental conditions (e.g., tansy ragwort, Scotch broom).

Comments: Limited to shallow, ponds and lakes or slow moving streams.

6. 6 **Reproductive traits:** How does this species reproduce? Traits that may allow rapid population increase both on and off site.

0 *Negligible* – Not self-fertile, or is dioecious and opposite sex not present.
1 *Low* – Reproduction is only by seed, produces few seeds, or seed viability and longevity are low.
3 *Medium* – Reproduction is vegetative (e.g., by root fragments, rhizomes, bulbs, stolons).
3 *Medium* – Produces many seeds, and/or seeds of short longevity (< 5 years).
5 *High* – Produces many seeds and/or seeds of moderate longevity (5-10 years) (e.g., tansy ragwort).
6 *Very high* – Has two or more reproductive traits (e.g., seeds are long-lived >10 years and spreads by rhizomes).

Comments: Produces long lived seeds and stolons.

7. 4 **Biological factors:** Do biotic (living) factors restrict or aid establishment and spread of the species? (What is the interaction of plant competition, natural enemies, native herbivores, pollinators, and pathogens with species?)

0 *Negligible* – Host plant not present for parasitic species.
1 *Low* – Biotic factors highly suppress reproduction or heavily damage plant for an extended period (e.g., biocontrol agent on tansy ragwort).
2 *Medium* – Biotic factors partially restrict or moderately impact growth and reproduction, impacts sporadic or short-lived.
4 *High* – Few biotic interactions restrict growth and reproduction. Species expresses full growth and reproductive potential.

Comments: Plant expresses full biological potential.

8. 3 **Reproductive potential and spread after establishment - Non-human factors:** How well can the species spread by natural means?

0 *Negligible* – No potential for natural spread in Oregon (e.g., ornamental plants outside of climate zone).
1 *Low* – Low potential for local spread within a year, has moderate reproductive potential or some mobility of propagules (e.g., propagules transported locally by animals, water movement in lakes or ponds, not wind blown).
3 *Medium* - Moderate potential for natural spread with either high reproductive potential or highly mobile propagules (e.g., propagules spread by moving water, or dispersed over longer distances by animals) (e.g., perennial pepperweed)

5 *High* – Potential for rapid natural spread throughout the susceptible range, high reproductive capacity and highly mobile propagules. Seeds are wind dispersed over large areas (e.g., rush skeletonweed)

Comments: Can be dispersed by moving water, perhaps by wildlife.

9. 3 **Potential of species to be spread by humans**. What human activities contribute to spread of species? Examples include: interstate or international commerce; contaminated commodities; packing materials or products; vehicles, boats, or equipment movement; logging or farming; road maintenance; intentional introductions of ornamental and horticultural species, or biofuel production.

1 *Low* – Potential for introduction or movement minimal (e.g., species not traded or sold, or species not found in agricultural commodities, gravel or other commercial products).

3 *Medium* – Potential for introduction or off-site movement moderate (e.g., not widely propagated, not highly popular, with limited market potential; may be a localized contaminant of gravel, landscape products, or other commercial products) (e.g., lesser celandine, Canada thistle).

5 *High* – Potential to be introduced or moved within state high (e.g., species widely propagated and sold; propagules common contaminant of agricultural commodities or commercial products; high potential for movement by contaminated vehicles and equipment, or by recreational activities) (e.g., butterfly bush, spotted knapweed, Eurasian watermilfoil).

Comments: Not a popular plant in the nursery trade. Cannot be sold in Oregon.

IMPACT INFORMATION

10. 7 **Economic impact**: What impact does/can the species have on Oregon's agriculture and economy?

0 *Negligible* – Causes few, if any, economic impacts.

1 *Low* - Potential to, or causes low economic impact to agriculture; may impact urban areas (e.g., puncture vine, pokeweed).

5 *Medium* – Potential to, or causes moderate impacts to urban areas, right-of-way maintenance, property values, recreational activities, reduces rangeland productivity (e.g., English ivy, Himalayan blackberry, cheatgrass).

10 *High* – Potential to, or causes high impacts in agricultural, livestock, fisheries, or timber production by reducing yield, commodity value, or increasing production costs (e.g., gorse, rush skeleton weed, leafy spurge).

Comments: May interfere with fishing, recreation, property value of lakefront homes.

11. 6 **Environmental Impact**: What risks or harm to the environment does this species pose? Plant may cause negative impacts on ecosystem function, structure, and biodiversity of plant or fish and wildlife habitat; may put desired species at risk.

- 0 *Negligible* – None of the above impacts probable.
- 1 *Low* – Can or does cause few or minor environmental impacts, or impacts occur in degraded or highly disturbed habitats.
- 4 *Medium* – Species can or does cause moderate impacts in less critical habitats (e.g., urban areas, sagebrush/ juniper stands).
- 6 *High* – Species can or does cause significant impacts in several of the above categories. Plant causes severe impacts to limited or priority habitats (e.g., aquatic, riparian zones, salt marsh; or T&E species sites).

Comments: Can completely dominate suitable habitat creating loss of habitat for fish, native plants, alters light penetration, oxygen levels in water.

12. **5** **Impact on Health:** What is the impact of this species on human, animal, and livestock health? (e.g., poisonous if ingested, contact dermatitis, acute and chronic toxicity to livestock, toxic sap, injurious spines or prickles, causes allergy symptoms

- 0 *Negligible* – Has no impact on human or animal health.
- 2 *Low* – May cause minor health problems of short duration, minor allergy symptoms (e.g., leafy spurge)
- 4 *Medium* – May cause severe allergy problems, death or severe health problems through chronic toxicity, spines or toxic sap may cause significant injury. (e.g., giant hogweed, tansy ragwort).
- 6 *High* – Causes death from ingestion of small amounts, acute toxicity (e.g. poison hemlock)

Comments: Can significantly increase mosquito populations where canopy is dense.

CONTROL INFORMATION

13. **5** **Probability of detection at point of introduction**: How likely is detection of species after introduction and naturalization in Oregon?

- 1 *Low* – Grows where probability of early detection is high, showy and easily recognized by public; access to habitat not restricted (e.g., giant hogweed).
- 5 *Medium* – Easily identified by weed professionals, ranchers, botanists; some survey and detection infrastructure in place. General public may not recognize or report species (e.g., leafy spurge).
- 10 *High* – Probability of initial detection by weed professionals low. Plant shape and form obscure, not showy for much of growing season, introduction probable at remote locations with limited access (e.g., weedy grasses, hawkweeds, skeletonweed).

Comments: Plant is showy but may not be recognized as invasive.

14. 6 **Control efficacy:** What level of control of this species can be expected with proper timing, herbicides, equipment, and biological control agents?

1 *Negligible* – Easily controlled by common non-chemical control measures (e.g., mowing, tillage, pulling, and cutting; biocontrol is very effective at reducing seed production and plant density) (e.g., tansy ragwort).

2 *Low* – Somewhat difficult to control, generally requires herbicide treatment (e.g., mechanical control measures effective at preventing flowering and but not reducing plant density; herbicide applications provide a high rate of control in a single application; biocontrol provides partial control).

4 *Medium* – Treatment options marginally effective or costly. Tillage and mowing increase plant density (e.g., causes tillering, rapid regrowth, spread from root fragments). Chemical control is marginally effective. Crop damage occurs or significant non-target impacts result from maximum control rates. Biocontrol agents ineffective.

6 *High* – No effective treatments known or control costs very expensive. Species may occur in large water bodies or river systems where containment and complete control are not achievable.

Comments: Aquatic infestations are expensive to control and very controversial. Complete control may not be possible.

Category Scores:
22 Geographic score (Add scores 1-4)
19 Biological Score (Add lines 5-9)
18 Impact Score (Add lines 9-12)
11 Control Score (Add Lines 12-14)

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70 **Total Score** (Add scores 1-14 and list on front of form)

Risk Category: 55-90 = **A** 24-54 = **B** < 24 = unlisted.

This Risk Assessment was modified by ODA from the USDA-APHIS Risk Assessment for the introduction of new plant species
Vers. 3.6 12/2/2010

OREGON DEPARTMENT OF AGRICULTURE
NOXIOUS WEED RATING SYSTEM

Yellow floating heart	***Nymphoides peltata***
Common Name	**Scientific Name**

Points: 21 **Category: A**

1. __3___ **Detrimental Effects:** Circle all that apply, enter number of circles

1. **Health: Causes poisoning or injury to humans or animals**
2. **Competition: strongly competitive with crops, forage,or native flora.**
3. Host: host of pathogens and/or pests of crops or forage
4. Contamination: causes economic loss as a contaminate in seeds and/or feeds.
5. **Interference: interferes with recreation, transportation, harvest, land value, or wildlife and livestock movement**

2. ___4___ **Reproduction and Capacity for spread** Circle the number that best describes situation.

1. Few seeds, not wind blown, spreads slowly
2. Many seeds, slow spread
3. Many seeds, spreads quickly by vehicles or animals
4. **Windblown seed, or spreading rhizomes, or water borne**
5. Many wind-blown seeds, high seed longevity, spreading rhizomes, perennials

3. ___3___ **Difficulty to Control** Circle the number that best describes, enter

1. Easily controlled with tillage or by competitive plants
2. Requires moderate control, tillage, competition or herbicides
3. **Herbicides generally required, or intensive management practices**
4. Intensive management generally gives marginal control
6. No management works well, spreading out of control

4. ___6___ **Distribution** Circle the number that best describes, enter

1. Widely distributed throughout the state in susceptible habitat
2. Regionally abundant in a part of the state, 5 or more counties, more than 1/2 of a county
3. Abundant throughout 1-4 counties, or 1/4 of a county , or several watersheds
4. Contained in only 1 watershed, or less than 5 square miles gross infestation
5. Isolated infestation less than 640 acres, more than 10 acres
6. **Occurs in less than 10 acres, or not present, but imminent from adjacent state**

5. ___5___ **Ecological Impact** Circle the number that best describes, enter

1. Occurs in most disturbed habitats with little competition
2. Occurs in disturbed habitats with competition
4. Invades undisturbed habitats and crowds out native species

5. Invades restricted habitats (i.e., riparian) and crowds out native species

__21____ **TOTAL POINTS**

Note: Noxious weeds are those non-native plants with total scores of 11 points or higher. Any plants in 4.1, 4.2, 4.3 should not be classified as "A" rated weeds. Ratings: 16+ = A, 15 – 11= B

Produced by Glenn Miller Oregon Department of Agriculture.
2005. Revised 2011. Control information updated in March 2018.

References:

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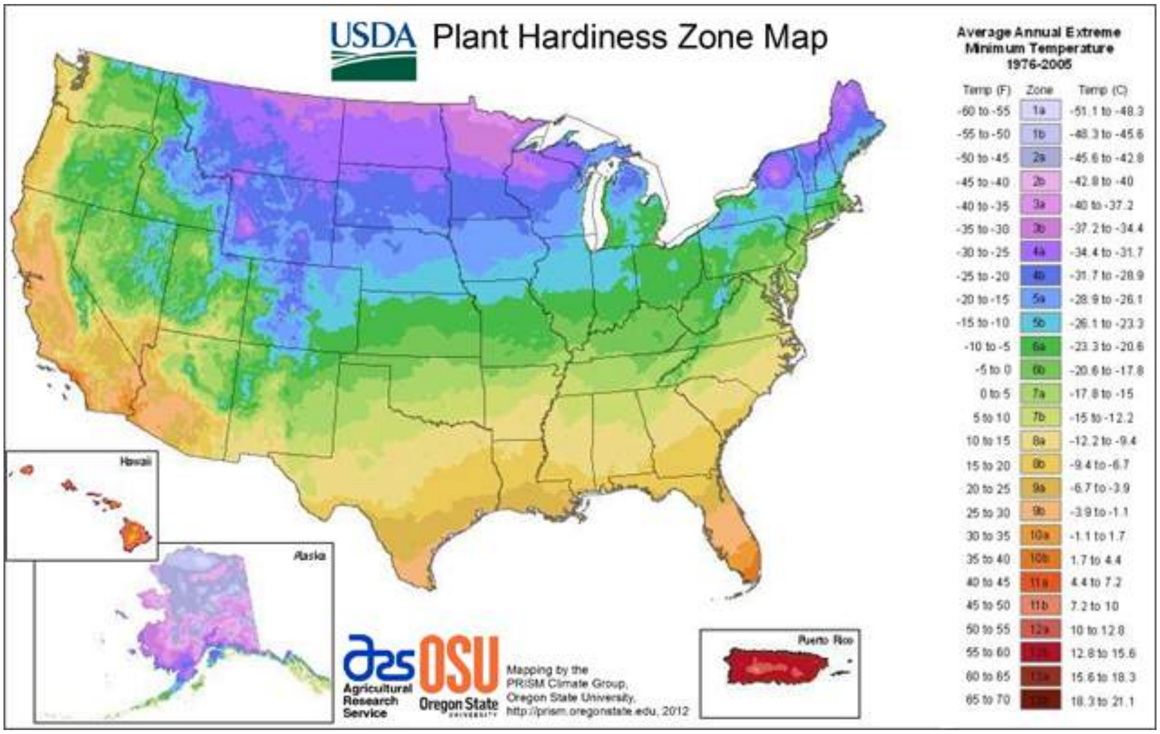
New Zealand Web Site: http://www.boprc.govt.nz/www/green/weed12.htm

Paillisson J., Marion L. 2011 Water level fluctuations for managing excessive plant biomass in shallow lakes. Ecological Engineering 37 (2011) 241–247

Smits A.J.M.; Van Avesaath P.H.; Van Der Velde (1990), "Germination requirements and seed banks of some nymphaeid macrophytes: *Nymphaea alba* L., *Nuphar lutea* (L.) Sm. and *Nymphoides peltata* (Gmel.) O. Kuntze," Freshwater Biology 24, no.2 p. 315-326.

Smits AJM.: Van Ruermonde R.; Van Der Velder (1989), "Seed disperal of three nymphaeid macrophytes," Aquatic Botany 35, no.2 p.167-180

Attachment 1


USDA Plant Hardiness Zone Map
Average Annual Extreme Minimum Temperature 1976-2005
Temp (F) Zone Temp (C)
-60 to -55 1a -51.1 to -48.3
-55 to -50 1b -48.3 to -45.6
-50 to -45 2a -45.6 to -42.8
-45 to -40 2b -42.8 to -40
-40 to -35 3a -40 to -37.2
-35 to -30 3b -37.2 to -34.4
-30 to -25 4a -34.4 to -31.7
-25 to -20 4b -31.7 to -28.9
-20 to -15 5a -28.9 to -26.1
-15 to -10 5b -26.1 to -23.3
-10 to -5 6a -23.3 to -20.6
-5 to 0 6b -20.6 to -17.8
0 to 5 7a -17.8 to -15
5 to 10 7b -15 to -12.2
10 to 15 8a -12.2 to -9.4
15 to 20 8b -9.4 to -6.7
20 to 25 9a -6.7 to -3.9
25 to 30 9b -3.9 to -1.1
30 to 35 10a -1.1 to 1.7
35 to 40 10b 1.7 to 4.4
40 to 45 11a 4.4 to 7.2
45 to 50 11b 7.2 to 10
50 to 55 12a 10 to 12.8
55 to 60 12.8 to 15.6
60 to 65 15.6 to 18.3
65 to 70 18.3 to 21.1
Hawaii
Alaska
Puerto Rico
Agricultural Research Service
Oregon State University
Mapping by the PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, 2012

J. Aquat. Plant Manage. 52: 47–56

Evaluation of aquatic herbicide activity against crested floating heart

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ABSTRACT

Crested floating heart [*Nymphoides cristata* (Roxb.) Kuntze] is a rapidly spreading invasive aquatic plant found in the southeastern United States. This plant exhibits a nymphaeid growth form producing dense mats of overlapping, floating leaves at the end of long stems in water up to 3 m in depth. To date, most operational strategies have relied on aquatic herbicides; however, results have been inconsistent and anecdotal. The objective of this research was to evaluate the majority of registered aquatic herbicides for activity against crested floating heart. A series of small-scale tank experiments was conducted to determine efficacy of the active ingredients: (2,4-dichlorophenoxy)acetic acid (2,4-D), [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid (triclopyr), 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid (endothall), 6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazinediium ion (diquat), X,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoic acid (carfentrazone), 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propanyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione (flumioxazin), 2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoic acid (bispyribac-sodium), *N*-(phosphonomethyl)glycine (glyphosate), 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid (imazamox), (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid (imazapyr), and 2-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]triazolo[1,5-*c*]pyrimidin-2-yl)-6-(trifluoromethyl)benzenesulfonamide (penoxsulam) applied via foliar and subsurface applications. Herbicides were applied at concentrations near maximum and half-maximum label use rates in the late spring through summer on plants that had formed a surface canopy. The submersed treatments were evaluated at 24 and 96-h exposure periods. Harvest at 4 wk after treatment indicated that most of the herbicides were not active after either the 24 or 96-h exposure at the highest test rate. In contrast, the liquid subsurface treatments of endothall at 0.25 and 0.5 mg ae L^{-1} provided complete control after 24 and 96-h exposures, whereas diquat at 0.18 and 0.37 mg ai L^{-1} provided 91 to 95% control after a 96-h exposure. Endothall also provided 24 to 60% biomass reductions after granular applications of 3 mg ae L^{-1} for a 96-h exposure. Foliar-applied imazamox and imazapyr at 1.2 kg ai ha^{-1} provided similar levels of control ranging from 81 to 83% control respectively. The other foliar-applied herbicides, including 2,4-D, triclopyr, and glyphosate, were not effective. For herbicides tested as both foliar and submersed applications, it was found that method of application had limited impact on activity and efficacy. Furthermore, aside from the amine salt of endothall, we did not detect a difference between liquid and granular formulations for submersed applications. These data indicate that most of the herbicides tested had limited activity on crested floating heart in our experimental system. These results suggest the amine salt of endothall and diquat as submersed applications and imazapyr and imazamox as foliar applications were the most effective. Further testing is needed to determine optimal timing, use rates, and products for efficacy under field conditions.

Key words: endothall, foliar, imazapyr, imazamox, *Nymphoides*, subsurface.

INTRODUCTION

Crested floating heart [*Nymphoides cristata* (Roxb.) Kuntze] is a floating leaf aquatic plant native to Southeast Asia (Vietnam, Thailand, India, Sri Lanka, and southern provinces of the People's Republic of China). Despite the native status in Asia, the plant is often considered to be a pest in rice fields (Burks 2002a). It was introduced to North America through the water garden trade where it is readily available for purchase from a multitude of online aquatic plant distributors and aquarium stores. It is often marketed as water snowflake because it can cover a water surface in tiny white flowers, giving the appearance of snow throughout the long flowering season. The plant was first confirmed outside of ornamental culture in 1996 in Horseshoe Lake, Collier County, FL (Burks 2002a). Crested floating heart now exists in expanding, invasive populations in many waterways in Florida as well as South Carolina, Texas (Center for Invasive Species and Ecosystem Health 2010), and Louisiana (A. Perret, pers. comm.). The Florida Exotic Pest Plant Council (FLEPPC) listed crested floating heart as a category 1 invasive species, meaning it is a nonnative species that has been observed altering native plant community structures and ecological functions and is present in natural areas (FLEPPC 2009).

One of the most significant infestations currently known has occurred in the 64,750-ha Santee Cooper reservoir system in South Carolina where ∼2,400 ha of water are currently impaired by dense crested floating heart growth

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(Westbrooks et al. 2012). The Santee Cooper infestation suggests that all water bodies in Florida and in much of the Southeast United States are within a climate zone favorable for sustaining invasive growth of the plant. Crested floating heart has been observed forming dense mats in water from 0.6 to 3 m deep in the Santee Cooper system (C. Davis, pers. comm.). This would suggest the potential for crested floating heart to infest significant areas of numerous shallow water bodies throughout the Southeast. It can also survive extended periods in moist soil, suggesting that the plant can persist through periods of low water levels and drawdowns (Willey and Langeland 2011).

In areas where crested floating heart has become established, overlapping, floating leaves form dense mats that interfere with boat traffic and recreational water uses. The mats also shade the water column below, reducing light availability to submersed native vegetation and phytoplankton, lowering dissolved oxygen levels, and reducing water flow and aeration (Burks 2002a). Studies on similar mat-forming floating leaf vegetation have shown that submersed macrophyte growth beneath these mats is significantly reduced (Janes et al. 1996).

Despite prolific production of flowers, viable seeds are not produced. Reproduction and spread of the plant is facilitated via fragmentation, which can be caused by contact with boat motors, wave action, and mechanical harvesting (Burks 2002a). Spread is also facilitated through the production of clonal reproductive structures called ramets, commonly referred to as daughter plants, which develop beneath the floating leaves and protrude from the stems of the plant as a tuber cluster with several small leaves. These propagules easily separate from the parent plant and form new colonies or expand the parent colony (Burks 2002a).

In terms of potential management options, triploid grass carp (*Ctenopharyngodon idella*) did not consume this plant even when provided no other option (Van Dyke et al. 1984, Singh et al. 1966). Many lakes in Florida and other southeastern reservoirs are stocked with grass carp for hydrilla [*Hydrilla verticillata* (L.f.) Royle] control and these systems could create an environment where crested floating heart could thrive in areas previously dominated by hydrilla. For example, the Santee Cooper system is stocked with grass carp (109,000 in 2012 in addition to 750,000 previously stocked) to control hydrilla and many of these areas are now experiencing dense infestations of floating heart (C. Davis, pers. comm.). Drawdowns on Santee Cooper that exposed the plants to desiccation and potentially short-term freezing temperatures did not prevent recovery the following spring (Page 2010). Data from a study in India showed that crested floating heart was able to recover quickly from mechanical cutting (Middleton, 1990, Burks 2002a). At this point, no classical biological control organisms have been identified for crested floating heart.

Herbicides are the best current option for managing this species; however, herbicide activity is not well documented and reports from managers tend to be anecdotal and often conflicting. Current literature from Burks (2002b) states that a maximum of 4 mo of control has been achieved when using foliar applications of a 2% *N*-(phosphonomethyl)glycine (glyphosate) solution combined with (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid (imazapyr) (amount not stated) and a surfactant. Other research performed by Puri and Haller (2010) stated that 98 to 100% control was achieved with 6-wk static exposures to the dipotassium salt of 7-oxabicyclo[2.2.1]heptane-2,3-dicarboxylic acid (endothall). There are several published articles reporting herbicide efficacy on nymphaeid plants with similar morphology to crested floating heart (Seddon 1981, Baird et al. 1983, Hanlon and Haller 1990, Langeland et al. 1993, Skogerboe and Getsinger 2001, Glomski and Nelson 2008), which suggests that a broad array of herbicides should be evaluated for activity on crested floating heart. It has also been hypothesized that different herbicide formulations (e.g., liquid vs. granular) or methods of application (e.g., foliar vs. submersed) may also influence efficacy on floating leaf plants (Wersal and Madsen 2010).

The lack of published information for managing crested floating heart suggests that additional studies would be of value to aquatic managers. The objectives of this study were to comparatively evaluate selected aquatic herbicides for activity on crested floating heart, determine if method of application influences efficacy, and to determine if herbicide formulation has an influence on efficacy.

MATERIALS AND METHODS

Subsurface herbicide applications

Experiments were conducted at the University of Florida, Center for Aquatic and Invasive Plants in Gainesville, FL in 2011. Entire plants and ramets used for establishing the initial stock were collected in January 2011 from a canal near Storm Water Treatment Area 1 East in South Florida. Ramets were planted in 1-L plastic containers that were filled with Margo Professional Topsoil[1] (92% sand, 4% silt, 4% clay) amended with fertilizer (Osmocote® 15–9–12)[2] at 1g kg^{-1} of soil. Plants were cultured in 95-L tanks in a greenhouse from January 2011 until early March 2011, then moved into outdoor 1,000-L mesocosm tanks until ramets were produced. Ramets were collected from this culture and planted in 1-L pots filled with the previously described potting soil and fertilizer addition to conduct herbicide studies. After planting, ramets were transferred to 95-L tanks and allowed to grow until leaves emerged at the surface and flower production was observed. Herbicide application took place when flower production was observed on all plants. A pretreatment biomass sample was collected at the time of treatment. Herbicides applied subsurface were evaluated using liquid and granular formulations (Table 1). To evaluate the impact of herbicide exposure time, plants were exposed to all submersed treatments for periods of 24 and 96 h. Current literature suggests that, depending on the rate of water exchange and size of treatment area in relation to water body size and other characteristics in a natural system, the half-life of the herbicide concentration may range from as low as a few hours (Poovey et al. 2004) to as long as a few weeks (Simsiman and Chesters 1975, Langeland and Warner 1986,

TABLE 1. TREATMENT RESULTS COMPARED WITH UNTREATED CONTROL FOR SUBMERSED APPLICATIONS AT HIGHEST CONCENTRATION USED AND 96-H EXPOSURE[1].

Herbicide	Treatment method[2]	Concentration[3] mg L^{-1}	P-Value Study 1	Study 2
Triclopyr	S	2.5	0.987	0.051
2,4-D amine[4]	S	2.5	0.400	<0.001[5]
Endothall dipotassium[4]	S	3.0	< 0.001	0.136
Endothall amine[4]	S	0.5	< 0.001	0.001
Diquat	S	0.37	< 0.001	< 0.001
Flumioxazin	S	0.4	0.128	0.452
Carfentrazone	S	0.2	0.755	0.326
Bispyribac	S	0.03	0.061	0.176
Triclopyr	G	2.5	0.105	0.028[5]
2,4-D ester[4]	G	2.5	0.100	< 0.001[5]
Endothall dipotassium[4]	G	3.0	< 0.001	0.001
Endothall amine[4]	G	0.5	0.168	< 0.001

[1]Data only shown for highest evaluated concentration and 96-h exposure. In cases where the high concentration and exposure weren't effective, analysis found that the lower concentration and shorter exposures were also ineffective.
[2]Abbreviations: S = subsurface, G = granular.
[3]Concentration listed is highest concentration tested; all lower concentrations tested were 50% of this value. Carfentrazone and bispyribac were only tested at the concentration listed.
[4]Herbicide treatment concentration and rate are acid equivalence; all others are active ingredient.
[5]Significant P-values are due to treatment biomass being greater than the control.

Green et al. 1989). As a key objective of this screening was to evaluate comparative efficacy, we decided to focus on one short-term exposure time (24 h) and one moderate exposure (96 h) for submersed herbicide applications. All trials were conducted in 95-L tanks.

Herbicides were tested at concentrations near the maximum and half-maximum label rates. For the submersed applications we did not evaluate the herbicides 1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1*H*)-pyridinone (fluridone), 2-(2,2-difluoroethoxy)-*N*-(5,8-dimethoxy[1,2,4]-triazolo[1,5-*c*]pyrimidin-2-yl)-6-(trifluoromethyl)benzene-sulfonamide (penoxsulam), and 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid (imazamox) as part of this trial because of their requirement for a long-term aqueous exposure. Both imazamox and penoxsulam were evaluated as foliar applications (treatments described below). Two herbicides, X,2-dichloro-5-[4-(difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1*H*-1,2,4-triazol-1-yl]-4-fluorobenzenepropanoic acid (carfentrazone-ethyl) and 2,6-bis[(4,6-dimethoxy-2-pyrimidinyl)oxy]benzoic acid (bispyribac-sodium), were tested only at the maximum label rate. Although bispyribac-sodium has an acetolactate synthase (ALS) mode of action and typically requires long-term exposures for submersed plant control, it was selected to be evaluated under these shorter-term exposures. Liquid herbicides were applied using an adjustable pipette and the water was gently stirred to enhance mixing. Granular herbicides were weighed to within ± 0.02 g needed to achieve the target concentration using a digital scale (Denver Instrument APX-203)[3], then dropped into the water over the root crown. Granules that remained atop surface leaves were placed back into the water. Water samples were collected 1 d after treatment from all treatments of (2,4-dichlorophenoxy)acetic acid (2,4-D) ester and amine, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid (triclopyr) amine, and both formulations of endothall, and analyzed using an enzyme-linked immunosorbent assay (ELISA) (SDIX RaPID Assay)[4] to confirm that nominal herbicide concentrations were achieved. A small electric pump was used 24 and 96 h after treatment (HAT) to remove the treated water from each tank and the tanks were refilled with untreated well water as described by Wersal and Madsen (2010). Visual observations of phytotoxicity were recorded weekly. The first trial for 2,4-D and triclopyr was initiated 17 June 2011 and repeated 12 July 2011. The first trial for endothall, diquat, and bispyribac was initiated on 7 July 2011 and repeated 5 August 2011. Trials using bispyribac-sodium, carfentrazone, and 2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propanyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione (flumioxazin) were initiated on 24 June 2011 and repeated on 25 July 2011.

For each trial and herbicide evaluated, methods of harvest and data collected were consistent. Entire plants, including all live roots and foliage, were harvested 4 wk after treatment (WAT) and rinsed to remove algae, sediment, and dead tissue. Harvested plants were dried in a forced-air oven (76 C) for 1 wk. Treatment dry weight was compared with an untreated reference to determine percent control on the basis of mean dry weight.

TABLE 2. TREATMENT RESULTS COMPARED WITH UNTREATED CONTROL FOR FOLIAR HERBICIDE APPLICATIONS

Herbicide	Rate kg ha^{-1}	P-value Study 1	Study 2
Triclopyr	3.5	0.029[1]	0.748
2,4-D amine	2.2	0.700	0.039[1]
Endothall dipotassium	2.5	< 0.001	0.439
Diquat	2.2	< 0.001	0.001
Imazapyr	1.2	< 0.001	< 0.001
Imazamox	1.2	< 0.001	< 0.001
Penoxsulam	0.1	0.035	0.019
Glyphosate	2.4	0.669	0.454

[1]Significant P-values are due to treatment biomass being greater than the control.

Foliar herbicide application

Foliar applications were made using a CO_2-pressurized, single-nozzle spray system at the time of flowering. A spray volume equivalent to 934 L ha^{-1} (100 gal ac^{-1}) was used for all foliar treatments over an area of 0.185 m^2. Output pressure was regulated at 83 to 103 kPa, which allowed for a consistent spray with minimal misting of droplets. Foliar application use rates are listed in Table 2. Herbicides were applied with methylated seed-oil-type surfactant, except for glyphosate, which was used with a nonionic surfactant. All surfactants were applied at a rate of 0.25%. Tanks were drained 24 HAT following the foliar treatments and refilled with untreated well water to reduce confounding issues associated with herbicide concentrations remaining in the water column. Foliage was not rinsed during this process. Triclopyr, 2,4-D, 6,7-dihydrodipyrido[1,2-α:2′,1′-*c*]pyrazinediium ion (diquat), and endothall applications were performed at the same time as the respective submersed applications to allow for comparison by application method. The first trials for the amino acid-inhibiting herbicides were initiated on 21 June 2011 and repeated on 19 July 2011. Visual observations, harvest methods, and data collection followed the same procedure described previously for the submersed applications.

All studies were arranged in a complete randomized design with three replications of each treatment. Treatment effects on dry weight were analyzed using ANOVA ($P \leq 0.05$) with a post hoc Fisher's LSD test to compare treatments with the untreated control. Statistical analysis and graphical presentations of data were performed using SigmaPlot 11.0[5]. Data from each trial are reported separately for each herbicide tested.

RESULTS AND DISCUSSION

Subsurface herbicide application

Differences in activity were noted between herbicide active ingredients (Table 1). Only diquat and both formulations of endothall reduced crested floating heart biomass at the highest concentration tested after a 96-h exposure (Table 1, Figures 1 and 2). After the 24-h exposure, only plants treated with diquat and the amine salt of endothall at both tested concentrations reduced biomass compared with the untreated controls ($P < 0.001$). Diquat-treated plants rapidly developed symptoms. By 1 WAT, foliage was necrotic and stems had dropped away from the water surface; however, new leaves began to emerge by 2 WAT. During regrowth, this new foliage would become chlorotic, and then would either become necrotic or very slowly recover. Plants started to recover between 3 and 4 WAT, but regrowth remained limited, with some new foliage remaining chlorotic near the midvein of the leaf. The high water clarity associated with these applications (nephelometric turbidity units < 1) would strongly favor diquat activity in these trials. In field situations where higher turbidity is likely, the performance of diquat could be negatively affected due to the tendency of diquat to adsorb to inorganic suspended sediments (Hofstra et al. 2001; Poovey and Getsinger, 2002).

The amine salt formulation of endothall was the most effective liquid subsurface herbicide evaluated. These treatments resulted in 100% control in both trials at the rates tested for 24 and 96 HAT (Table 1; Figures 2A and 2B). Treated plants showed necrosis by 24 HAT. One WAT all plant material had dropped away from the water surface and by 4 WAT there was no observed regrowth. In this case, the granular applications of endothall were variable and less effective than liquid applications ($P \leq 0.001$) (Table 1). ELISAs indicated that endothall concentrations for both the granular and liquid treatments were within 10% of nominal treatment concentrations at 24 HAT.

Given the shallow nature of our treatment tanks, granules were not highly concentrated near the basal portions of the plant at the label rates tested. These root crowns support multiple shoots and it has been speculated that granules may be more effective in deeper water where the total amount of granular product applied is greater and short-term herbicide concentrations are much higher near the basal crown of the plant. Additional trials would be necessary to test this hypothesis.

The dipotassium salt of endothall also resulted in variable control depending on application method. Symptoms developed slowly after treatment. One WAT isolated spots of foliar desiccation were observed. Two WAT foliage and stems began to show signs of necrosis and dropped off the water surface; however, regrowth began between 2 and 3 WAT. In the first trial, the highest rate of liquid herbicide resulted in 57% reduction in biomass compared with the untreated control; however, the remaining biomass was still greater than the pretreatment reference. Moreover, this treatment was not different from the untreated reference in the repeated trial. Granular applications resulted in 60 and 24% reductions in biomass from the untreated control in both trials after 96-h exposures (Figure 3). The granular applications of dipotassium endothall were more effective than the liquid in the second trial. The 24-h exposures were much less effective than 96-h exposures, with plants recovering quickly and resulting in greater biomass than the untreated control. Early research on crested floating heart showed that dipotassium endothall was most effective after static exposures and 98 to 100% control was achieved using rates of 1.5 and 2.5 mg ai L^{-1} respectively at 6 WAT (Puri and Haller 2010). This high percentage of control could be due more in part to the exposure time than to the herbicide concentration.

To address the discrepancies between the findings of Puri and Haller (2010) and the findings of the current endothall trials, an additional trial was initiated 5 August 2011 to assess the efficacy of dipotassium endothall at 4.3 mg ae L^{-1} under a 4-wk static exposure. Dry weight of the plant was reduced below the untreated control by 80 and 83% after liquid and granular treatments respectively; however, regrowth was observed beginning 3 WAT. On the basis of these results, control could potentially be increased in systems where extended exposure times are possible; however, the observations of regrowth indicate that crested floating heart may tolerate even extended exposures to the dipotassium salt of endothall.

Five compounds, triclopyr, 2,4-D, bispyribac-sodium, carfentrazone, and flumioxazin, resulted in no reduction compared with the untreated control (or in some cases an actual increase in biomass) at 4 WAT regardless of application method or exposure time (Tables 1 and 2). Although initial injury was often noted after application, there was no evidence of sustained herbicide injury at the time of harvest. ELISAs indicated that 2,4-D and triclopyr concentrations were within 10% of nominal treatment concentrations at 24 HAT after both liquid and granular applications.

For triclopyr and 2,4-D, auxin-mimic-type symptoms began to develop by 1 WAT, with noticeable epinasty of the stems, elongated flower stalks, and leaf curling. These symptoms were transient and did not persist; by 2 WAT and 3 WAT the plants had completely recovered (no visible symptoms). Typically, broad-leaved aquatic plants of similar morphology to crested floating heart are susceptible to auxin-mimic herbicides. Previous studies have found that subsurface applications of 2,4-D ester at 1.5 and 2.5 mg ae L^{-1} to fragrant waterlily (*Nymphaea odorata* Aiton) resulted in less dry weight than the untreated controls (Glomski and

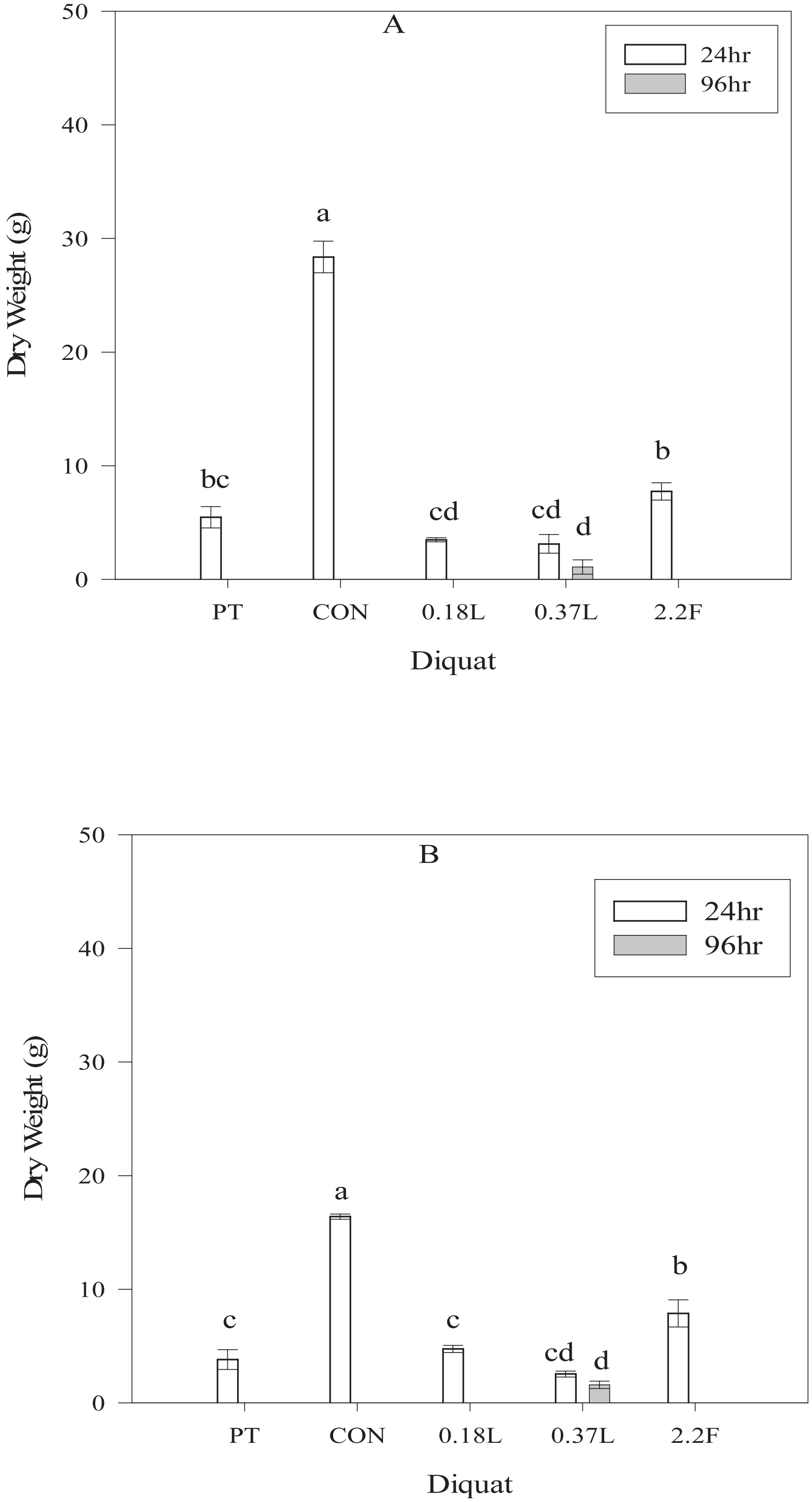

Figure 1. Combined dry weight of roots and foliage of crested floating heart 4 wk after treatment (WAT) in response to diquat at 24- and 96-h exposures in trial 1 (A) and in trial 2 (B). PT = pretreatment reference, CON = untreated control, L = liquid subsurface, and F = foliar rate in kg ae ha^{-1}. Liquid subsurface concentrations are in mg ai L^{-1}. Each bar represents the average of three replicates ± standard error.

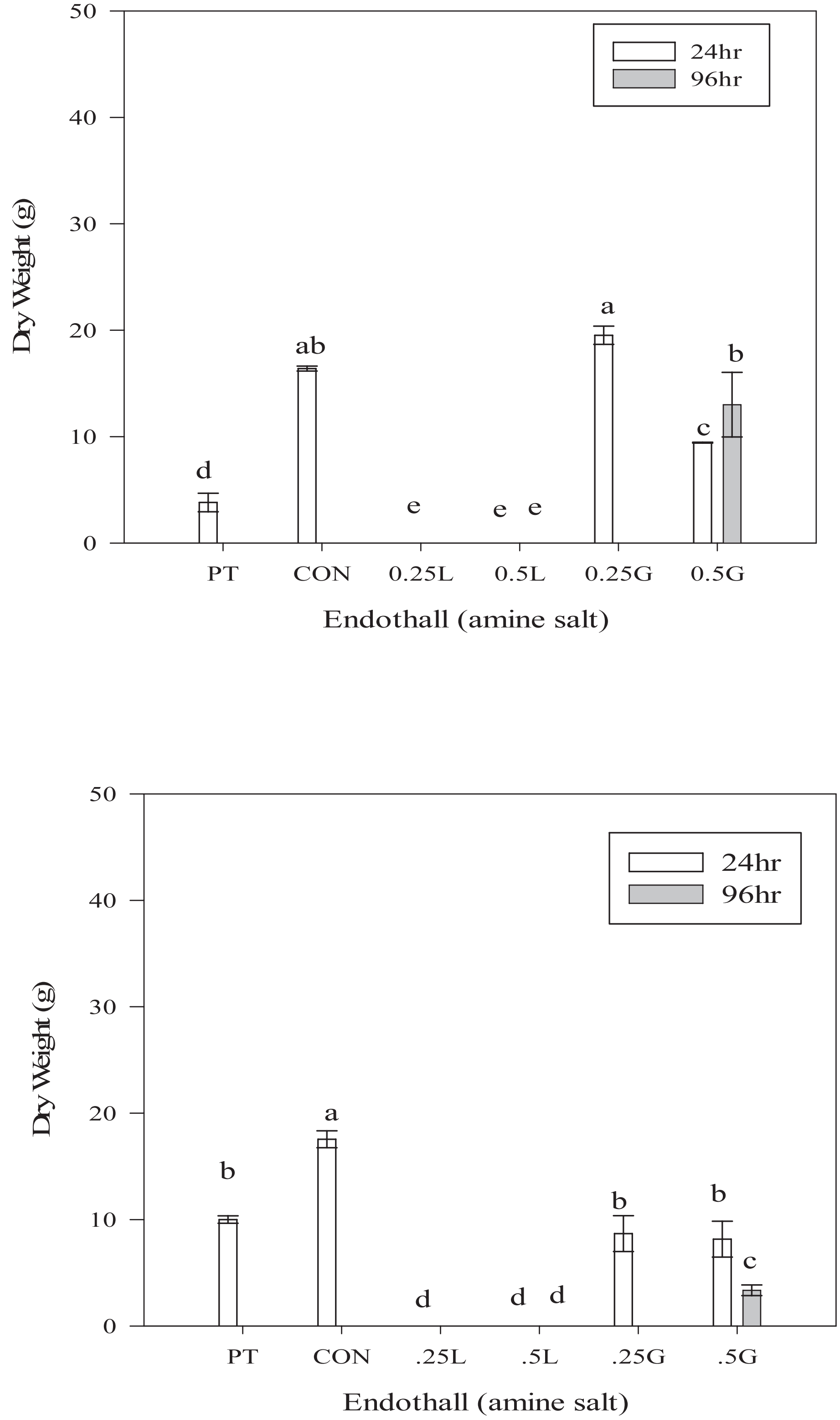

Figure 2. Combined dry weight of roots and foliage of crested floating heart 4 wk after treatment (WAT) in response to endothall (amine salt) for 24- and 96-h exposures in trial 1 (A) and in trial 2 (B). PT = pretreatment reference, CON = untreated control, L = liquid subsurface, G = granular subsurface. L and G subsurface concentrations are in mg ae L^{-1}. Each bar represents the average of three replicates ± standard error.

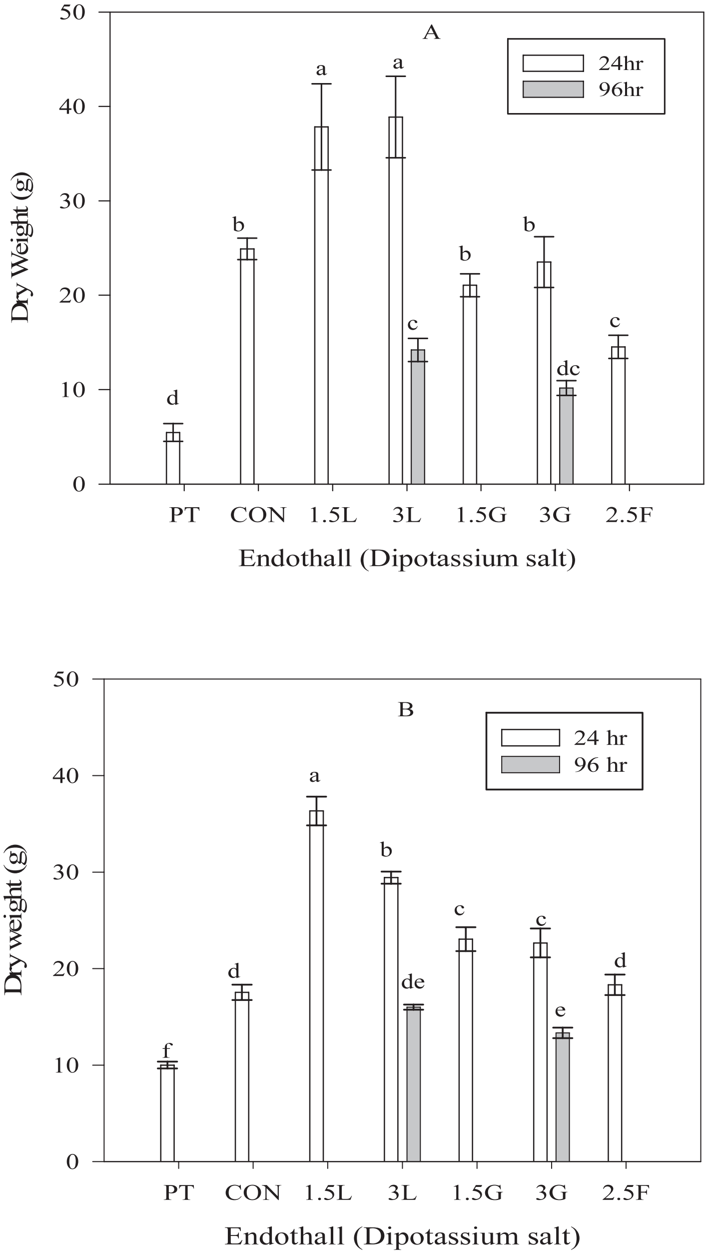

Figure 3. Combined dry weight of roots and foliage of crested floating heart 4 wk after treatment (WAT) in response to endothall (dipotassium salt) for 24- and 96-h exposures in trial 1 (A) and in trial 2 (B). PT = pretreatment reference, CON = untreated control, L = liquid subsurface, G = granular subsurface. L and G concentrations are in mg ae L^{-1}. Each bar represent the average of three replicates ± 1 standard error.

Nelson 2008). Spatterdock (*Nuphar advena* Aiton) dry weight was also reduced by the same rates of 2,4-D ester, as well as 2.0 mg ae L^{-1} triclopyr amine by 6 WAT (Glomski and Nelson 2008).

Symptoms were observed after the bispyribac exposures and flower production ceased at 1 WAT. By 2 WAT foliage began to turn red in color; however, plants quickly recovered and new growth was visible by 3 WAT. Bispyribac-sodium has been found to have activity on several emergent aquatic plants (Koschnick et al. 2007); however, extended exposure periods are usually needed. Under these short-term exposures, bispyribac resulted in initial injury symptoms, but rapid recovery.

Carfentrazone and flumioxazin are fast-acting protoporphyrinogen oxidase inhibitors that affect chlorophyll synthesis and cause cell membrane leakage in sensitive species (Senseman 2007). The pH of the water at the time of application was 6.8 and this should have provided in the range of a 24-h product half-life on the basis of estimation of pH-dependent hydrolysis. Neither of these herbicides reduced biomass below the untreated control by 4 WAT (Table 1). One WAT the foliage of the flumioxazin- and carfentrazone-treated plants had turned necrotic and had begun to drop away from the surface; however, rapid regrowth was observed 2 WAT. This result is in contrast to flumioxazin activity on several other nymphaeid species (e.g., American lotus, *Nuphar advena*, *Nymphaea odorata*) that have proven to be very sensitive to submersed applications of flumioxazin.

Foliar herbicide application

Foliar applications also resulted in strong differences in activity between herbicide active ingredients. The products diquat, imazapyr, and imazamox resulted in consistent biomass reduction after foliar treatment. Foliar applications of diquat resulted in 73 and 52% reductions in biomass below the control in trials 1 and 2 respectively (Table 2) (Figures 1A and 1B). Diquat-treated foliage died back from the surface quickly but began to recover within 2 WAT. Some of the foliage that reached the surface continued to show symptoms of chlorosis. A possible confounding factor regarding activity of diquat from a foliar application is the fact that aqueous concentrations resulting from treatment of shallow tanks resulted in nearly doubling the submersed label rate (0.65 mg ai L^{-1}) for a 24-h period. The combination of the rapid submersed activity of diquat and the near doubling of the label concentration in the water after a foliar application was unique to diquat. None of the other foliar-applied herbicides (auxin mimics, amino acid inhibitors) were subject to this potentially confounding issue.

Four amino acid-inhibiting herbicides were screened for foliar application (Table 2). Three of the herbicides (imazamox, imazapyr, and penoxsulam) are ALS inhibitors, whereas the fourth (glyphosate) is a 5-enolpyruvylshikimate-3-phosphate synthase inhibitor. Glyphosate was not different from the untreated control at 4 WAT. Imazamox and imazapyr resulted in 83 and 81% biomass reductions compared with the control, respectively (Figure 4). Penoxsulam also resulted in less biomass than the control, but was less effective than imazamox and imazapyr. The ALS herbicides resulted in cessation of growth by 1 WAT. Two WAT foliage from imazamox- and imazapyr-treated plants was not present on the surface, whereas foliage was still present on glyphosate- and penoxsulam-treated plants. No regrowth had occurred 4 WAT on imazamox- and imazapyr-treated plants, but the root systems were still intact upon harvesting. When penoxsulam-treated plants were harvested, it was noticed that even though shoot material was

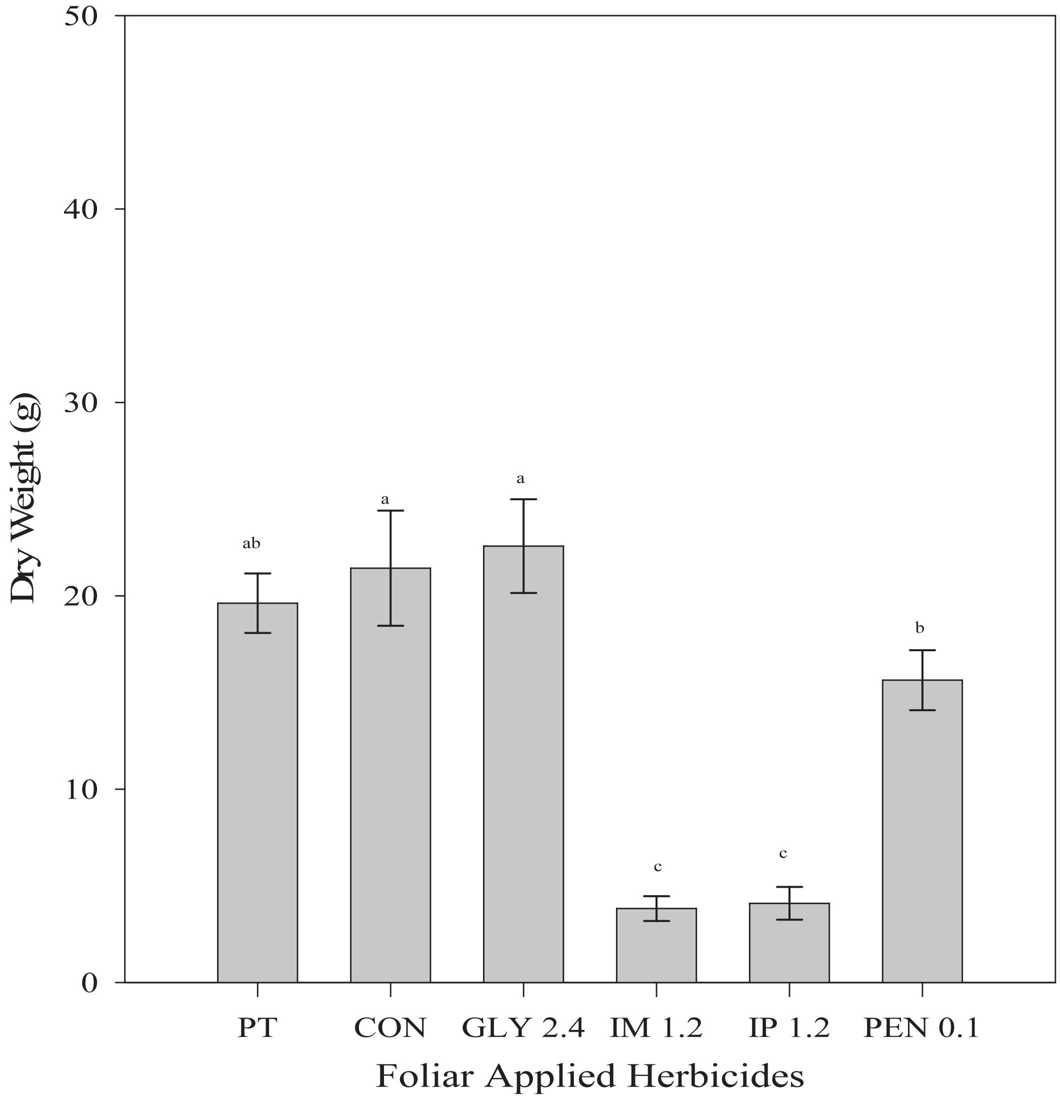

Figure 4. Combined dry weight of roots and foliage of crested floating heart 4 wk after treatment (WAT) in response to foliar-applied amino acid-inhibiting herbicides. PT = pretreatment reference. CON = untreated control. GLY = glyphosate, IM = imazamox, IP = imazapyr, PEN = penoxsulam. Numbers represent treatment rate in kg ai ha^{-1}. Each bar represents the average of three replicates ± standard error.

largely intact and green in color, the root system sustained severe damage with almost no viable root tissue recovered during the harvest. This observation suggests that further evaluation of foliar penoxsulam treatments is warranted.

Glyphosate-treated plants began to show signs of recovery 4 WAT with appearance of new flowers. The results for glyphosate were unexpected, as it is often suggested in crested floating heart control programs. Although we did not test the various surfactants available for aquatic applications, the general lack of activity in repeated trials would suggest that crested floating heart is not inherently sensitive to glyphosate. Other emergent plants such as fragrant waterlily and spatterdock are effectively controlled with glyphosate at rates of 2.5 kg ai ha^{-1}(Seddon 1981, Baird et al. 1983). Numerous applicators include glyphosate in combination with imazapyr as part of their current treatment regime for crested floating heart (Burks 2002b), but the results of this study show that glyphosate may have limited activity on this plant. Reported efficacy in the field with this combination suggests that further evaluation of herbicide combinations may be warranted.

Foliar applications of triclopyr and 2,4-D were ineffective (Table 2). Typical symptoms of these herbicides began to develop within 1 WAT but the plants quickly recovered by 2 WAT and continued growing until the study was harvested. Other studies examining effects of foliar applications have shown that rates of 2,4-D amine up to 4.48 kg ha^{-1} caused symptom development in spatterdock, but did not result in death of the plant tissue (Hanlon and Haller 1990). Waterlily has also been reported to be sensitive to triclopyr amine via foliar application, but no details were given pertaining to rates (Langeland et al. 1993, Glomski and Nelson 2008).

Dipotassium endothall applied to foliage resulted in symptom development of spotty foliar desiccation by

1 WAT, followed by quick recovery and emergence of new healthy leaves by 2 WAT. This treatment did not reduce biomass.

The screening of foliar-applied herbicides has identified imazamox and imazapyr as having good activity on crested floating heart. When making foliar applications of herbicides for crested floating heart, translocation likely plays a critical role in treatment efficacy. In the Santee Cooper system, it has been noted that posttreatment regrowth is slower at depths less than 1.5 m (C. Davis, pers. comm.). Furthermore, managers in South Florida have reported better control in shallower, quiescent areas (Burks 2002b). As a result of these observations, it is hypothesized that water depth may affect the ability of herbicides to translocate from foliage to roots (C. Davis, pers. comm.). The plant has been found to grow in up to 3 m of water. If water depth (stem length) has an impact on the ability of a herbicide to translocate, it may be difficult to control the root crowns of this plant in deep water when using foliar treatment strategies.

In-field observations have indicated that even the slightest water disturbance by wind, boat wake, etc. can result in the surface leaves of crested floating heart dipping momentarily below the water. This suggests that foliar applications may be subject to rapid wash-off. Although rainfastness is typically a consideration with emergent treatments, the somewhat unique tendency of crested floating heart leaves to dip below the water surface with limited disturbance could have a significant influence on emergent applications under sunny conditions. The plants treated in our tanks were not subject to potential wash-off from leaves dipping below the water surface.

On the basis of these evaluations, submersed applications of liquid endothall (amine salt) or diquat and foliar applications of imazamox or imazapyr had the most activity. There were few differences between liquid and granular formulations in the study system and results were variable. The findings of this study also suggest that in most cases foliar or subsurface applications have no strong influence on herbicide activity or efficacy. This result is similar to that reported by Wersal and Madsen (2010). It is important to note that not all treatment methods available were evaluated in this study. For example, using combinations of herbicides with different modes of action (e.g., diquat combined with dipotassium endothall) may increase activity. Moreover, we did not attempt to compare the vast range of surfactants available for foliar applications.

These small-scale trials can provide valuable information regarding the comparative activity of various herbicides on newly established crested floating heart. Subsequent field trials will help determine use patterns and optimal timing of various treatment strategies. These preliminary trials show that several of the herbicides can result in initial injury symptoms on crested floating heart; however, in many cases these plants rapidly recovered in our small-scale systems. The ability of larger and more robust field specimens to recover under less favorable environmental conditions (e.g., greater depth, turbidity, herbivory, etc.) remains difficult to predict using data from small-scale studies. Nonetheless, the results of these trials provide information for us to identify several products that are unlikely to provide a level of initial control or injury that would allow for environmental conditions to further reduce or limit growth of crested floating heart.

Management of crested floating heart will continue to remain a challenge because of the small number of herbicides that provide strong activity. The potential cost differential between submersed treatments and foliar applications will need to be weighed as managers evaluate product costs, application logistics, and treatment longevity. We did not evaluate the sensitivity of quiescent ramets, and the response of these propagules to submersed applications would be of significant interest to managers. The propensity of the surface leaves to dip below the water surface under minimal disturbance may create a unique challenge when using foliar applications to manage crested floating heart. The herbicides that have resulted in good efficacy during these trials are being further evaluated over a wider range of exposure times, concentrations, and environmental conditions to further develop an optimal treatment strategy.

SOURCES OF MATERIALS

[1]Margo Professional Topsoil, Margo Garden Products, Folkston, GA 31537.
[2]The Scotts Company, Marysville, OH 4304.
[3]Denver Instruments, Arvada, CO 80004.
[4]Strategic Diagnostics Inc., Newark, DE 19713.
[5]Systat Software Inc., San Jose, CA 95110,

ACKNOWLEDGEMENTS

Funding for this project was provided by the Florida Fish and Wildlife Commission, Invasive Plant Management section. Additional support was provided to L.N.W. with a student research grant from the Midwest Aquatic Plant Management Society and a grant from the Aquatic Ecosystem Restoration Foundation provided to the University of Florida Center for Aquatic and Invasive Plants to support graduate student projects. We also thank G. Hoyer and Z. Banks for assisting with data collection and maintaining plant stocks.

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Invasive Species of the Pacific Northwest:

Yellow floating heart, ***Nymphoides peltata***

Susan Harris

Aquatic Invasion Ecology 423: Julian Olden

Fall 2014

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).

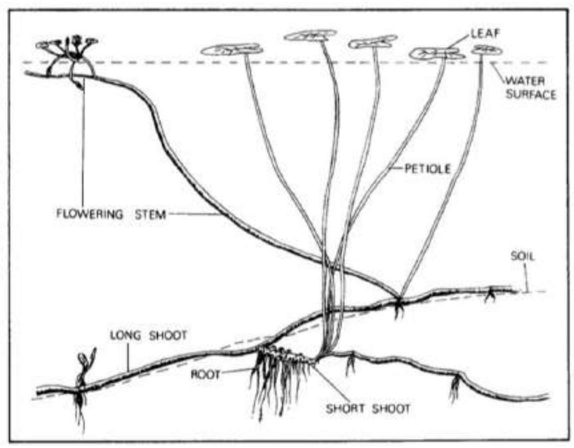


Figure 2. The general structure of *N. peltata* (van der Velde et al. 1979). The forking placement of long shoots and short shoots give rise to a complex and expansive network of leaves and flowering stems.

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).

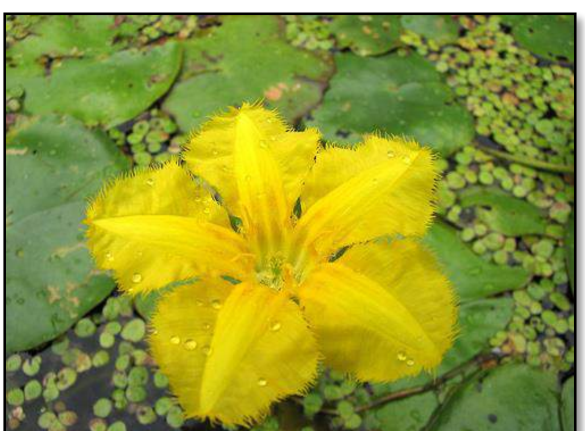


Figure 5. *N. peltata*'s five petals have fringed borders and are vibrant yellow, which attract an array of insects for pollination.

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.

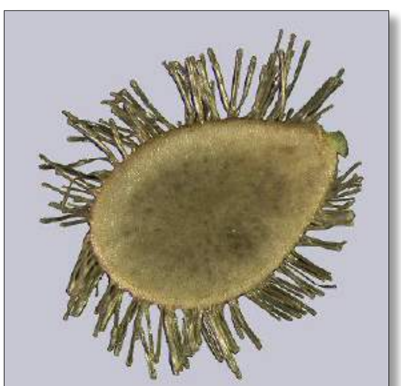


Figure 6. (Top) Once the flower is pollinated, the bud bursts open with several, smooth seeds (Fred Hrusa 2003). Figure 7. (Bottom) *N. peltata* seeds have winged margins which aid in temporary buoyancy (University of Wisconsin, Tippery Lab).

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 CO_2-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).

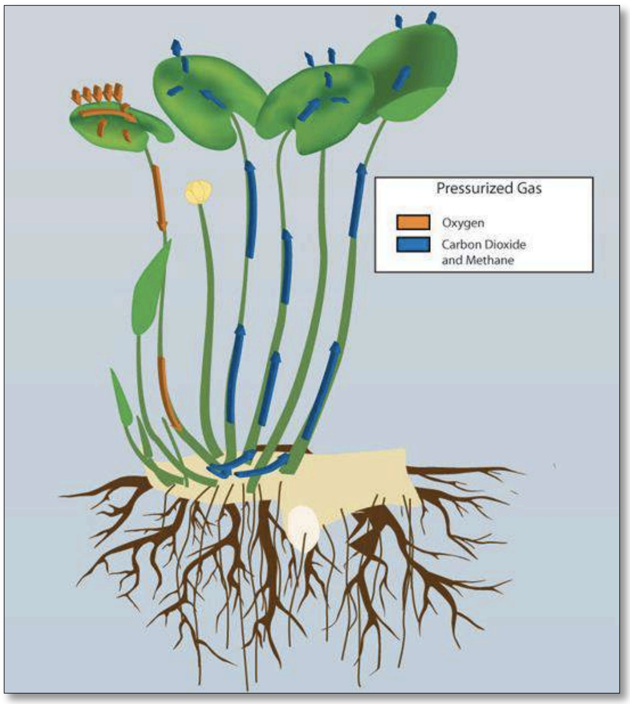


Figure 7. The diagram above represents the aeration ventilation process in which wetland plants can counter low oxygen conditions. Gaseous transport results in the flow of oxygen from the atmosphere to the roots, and carbon dioxide and methane from the roots to the atmosphere (Dacey 1981).

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

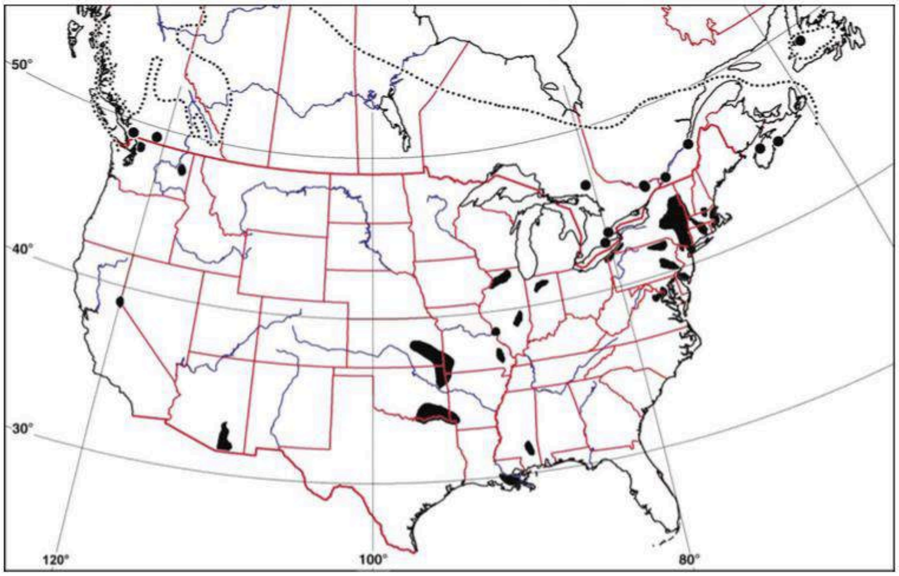
Successful pollination of *N. peltata* does not require a specific insect type. However, the five nectaria are sheltered by hairy staminodes to a height of 0.5-0.6 cm, therefore only flower visiting insects with long tongues can reach the nectar (van der Velde and van der Heijden 1981). The pollen grains 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).



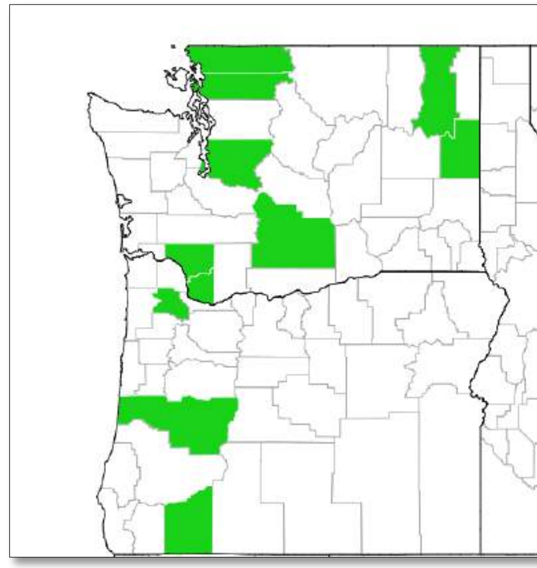


Figure 9. (Left) Distribution of *N. peltata* in North America. Areas where *N. peltata* is known and/or establish are indicated by solid circles (Darbyshire & Francis 2008). Figure 10. (Right) Known counties in the Pacific Northwest with *N. peltata* invasions are highlighted in green (EDD Maps 2014).

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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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

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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

Nymphoides peltata (J.G. Gmel.) Kuntze

Yellow floatingheart

Family: Nymphaeaceae
Range: Washington, California and Arizona.
Habitat: Lakes, reservoirs and ponds, and slow moving rivers.
Origin: Introduced from Eurasia and the Mediterranean region as well as Japan, China, and India. Yellow floatingheart is cultivated as a pond ornamental, but has been released into certain natural lakes where it has become a nuisance weed.
Impacts: Yellow floatingheart often develops dense mat-like patches that displace desirable vegetation. Dense mats can also reduce recreational activities and create stagnant low-oxygen conditions in the water below.
Western states listed as Noxious Weed: Oregon, Washington

Yellow floatingheart is a submersed perennial water lily-like plant with creeping rhizomes and stolons and floating rounded heart-shaped leaves 2 to 5 inches in diameter that may be confused with those of the water lilies. The flowering stems have opposite leaves.

The inflorescence is a simple umbel of showy yellow flowers with five ciliate-margined petals. The flowers are on long stalks that rise a few inches above the water. Yellow floatingheart reproduces by seed and vegetatively from rhizomes, stolons, rhizome and stolon fragments, and separated leaves. The seeds are water-dispersed individually or in chain-like floating rafts. Seeds can also be dispersed by waterfowl. Seeds readily germinate, but there is no information on seed longevity in the soil. Fragmented leaves with part of a stem still attached will also form new plants, and vegetative fragments can also be dispersed by water. Plants can survive exposure on wet mud.

NON-CHEMICAL CONTROL

Mechanical (pulling, cutting, dredging)	Mechanical control of *Nymphoides peltata* is very difficult due to its ability to propagate vegetatively through fragments, and through underwater roots and rhizomes. Mechanical harvesting may create abundant plant fragments, potentially aiding in dispersal to new locations. Leaf petioles cut by mechanical harvesting will eventually form new leaves, requiring one or two cuts each spring and summer to maintain controlled areas. Nevertheless, these plants are sometimes controlled by cutting, harvesting, and covering with bottom barrier materials (synthetic and natural fibers). In severe infestations, excavation may be necessary to remove plants, rhizomes and seed in the sediment. However, both roots and rhizomes are also able to withstand mechanical removal by dredging. Hand raking can be effective in very small, localized areas where fishing or navigation lanes need to be created.
Cultural	Use alternative native floating plants and keep contained within pots. Dewatering is usually not sufficient to control this plant because the below-ground propagules (rhizomes, stolons) often survive.
Biological	The (sterile) triploid grass carp (white amur) is a relatively nonselective herbivorous fish that may partially consume the seedlings and young, tender parts of floatingheart, but usually only after it first consumes its preferred submersed plants such as native pondweeds. Grass carp do not eat water lilies in Washington and it is not known if they would readily eat yellow floating heart.

CHEMICAL CONTROL

The following specific use information is based on reports by researchers and land managers. Other trade names may be available, and other compounds also are labeled for this weed. Directions for use may vary between brands; see label before use. Other herbicides may be effective, but few tests have been conducted to demonstrate which products control yellow floatingheart.

AROMATIC AMINO ACID INHIBITORS	
Glyphosate *Rodeo*, *Aquamaster*	**Rate:** Use a 2% v/v *Rodeo* or *Aquamaster* solution (1% a.e.) with an approved surfactant and spray to thoroughly wet the floating leaf surface. **Timing:** Postemergence in late spring to mid-late summer. **Remarks:** Repeated applications are generally necessary.

RECOMMENDED CITATION: DiTomaso, J.M., G.B. Kyser et al. 2013. *Weed Control in Natural Areas in the Western United States.* Weed Research and Information Center, University of California. 544 pp.

Yellow Floating Heart
ODA Treatment Success in Private Ponds
Douglas County, 2014-2017

Two treatments per season: early summer and fall treatments

Use of a backpack sprayer along edges with some success;
Best results seen with more volume applied with a handgun-tank sprayer

Initial treatments in 2014 with Imazapyr (1.5%)+ non-ionic surfactant
Treatments from 2015 - 2017 with Imazamox (100 ppb)+ MSO surfactant

For more information, Contact:

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Oregon Dept. of Agriculture
Noxious Weed Program
541-291-2680
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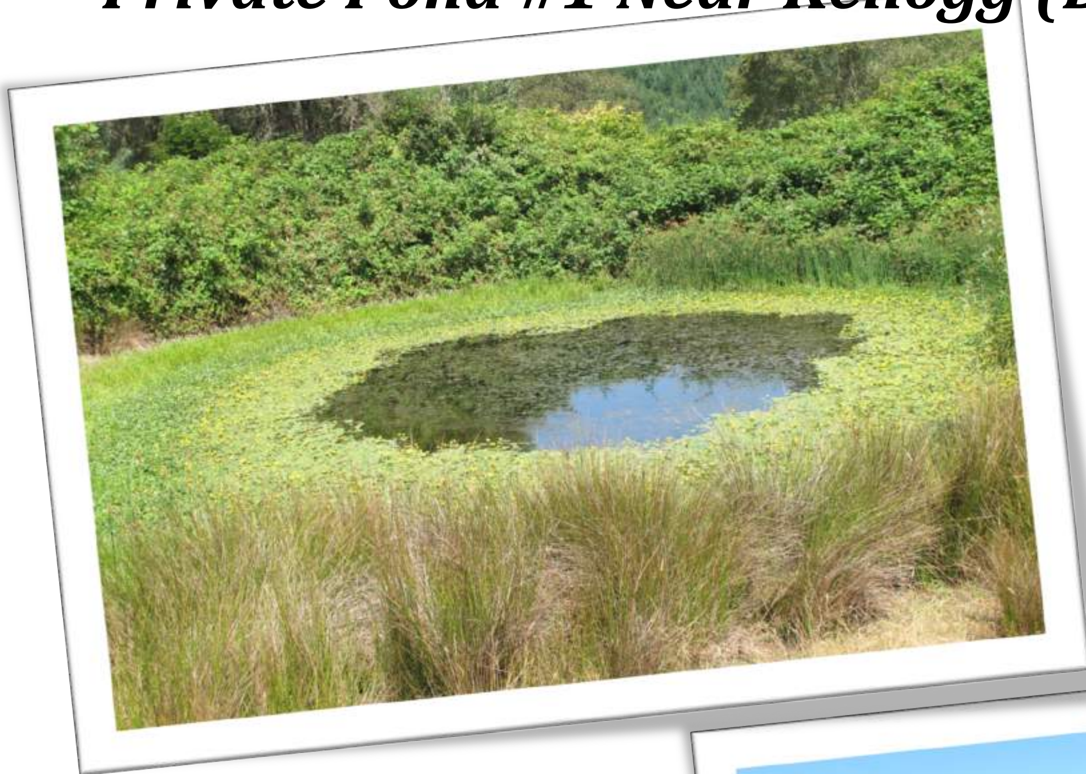
Golf Course Pond in Roseburg, Douglas County

Before Treatment (2014)

Three years after Treatment
No plants since 2015

Private Pond #1 Near Kellogg (Douglas County)



Before Treatment (2014)

Three years Post Treatment (2017)
A few plants remain along back edge of pond

Private Stock Pond Near Elkton (Douglas County)

Before Treatment (2015)

After Treatment (2017)
A few plants remain in the middle of pond

Private Pond Near Melrose (Douglas County)

This pond was just detected in 2017

Yellow floating heart just getting started in this small pond
A backpack sprayer was used to treat small patches along edge

Willow Sump – Yellow Floating Heart
Umpqua National Forest - North Umpqua Ranger District

- Yellow floating heart (*Nymphoides peltata*) was first discovered in Willow Sump during 2011 when surveys were conducted by the Center for Lakes and Reservoirs, Portland State University. During 2014 the population was mapped and it was determined that the infestation covered approximately 1.2 acres of the 2 acre sump.
- After the discovery of this population different treatment methods were implemented to try and eradicate this Class A invasive species.
  - The first attempt at eradication involved manual removal of the plant from the sump. Working with the local OYCC crew and North Umpqua/Diamond Lake botany crew over a three week period, 800 person hours were spent pulling yellow floating heart. After one month there was no evidence that treatments had occurred.
  - The second attempt at eradication involved placing benthic barriers on a small portion of the population (1/10th acre) during 2012. Benthic barriers were removed two years later and the results were promising with eradication from the chosen site. Due to the overall size of the infestation and the amount of vegetation (mostly willow species) that would need to be removed from the shoreline in order to place the benthic barriers on the bottom of the sump it was determined that this method would not be a feasible solution to eradicate the yellow floating heart.
- NEPA was initiated in 2012 and a signed decision occurred in May of 2015 for the EA.
  - The proposed action included conducting a foliar spray of aquatic labeled herbicide (glyphosate and imazapyr) that would be applied to the leaves of yellow floating heart.
  - Treatments would be conducted in late Summer and early Fall and continue until the population was eradicated. It was estimated that treatments could last up to ten years.
- Herbicide Treatments
  - Initial treatments with Imazapyr were conducted on September 10th 2015 with a follow up treatment occurring on September 22nd 2015. Monitoring of any detrimental effects were conducted within one week of application.
    - ODA (Oregon Department of Agriculture) treated the population during 2015.
    - Herbicide Detail: a 1.5% rate of Imazapyr was used during treatments – 96 oz. Polaris, 32 oz. MSO surfactant, and 16 oz. hi-light. Fifty total gallons were used to target the yellow floating hear mats.
    - Equipment Used: a truck mounted tank/hand gun and a catamaran mounted 25 gallon tank sprayer/ATV hand gun and a backpack sprayer.
    - Weather: Skies were clear with an average of 65-70 degrees and a slight breeze.
  - Second year treatments with Imazapyr were initiated for the remainder of the population on August 9th 2016. Follow up treatment will occur in September of 2016.
- First Year Results.
  - It is estimated that approximately 95% of the population was eradicated as a result of the first year treatments. See attached photo documentation for the results.
  - The site will continue to be monitored and treated in the future until we can be sure that this population has been eradicated.

Willow Sump – Looking North from the dam.

August 2015

August 2016

Willow Sump – Looking West from outflow.

Arrow points to the edge of where we placed benthic barriers during 2012 and removed during 2014. Arrows denote same location.

August 2015

August 2016

Willows were much thicker this year. Could not get the same exact picture.

Willow Sump – Looking West from the middle of the sump.

Dam is to the left.

August 2015

August 2016

Willow Sump – Looking West from the middle of the sump.

Location north of slide 3. Dam is to the left.

August 2015

August 2016

Willow Sump – Looking West from the middle of the sump.

Location north of slide 3. View looking slightly north of slide 4. Dam is to the left

August 2015

August 2016

Willow Sump – Looking East from the back of the sump.

Back side, northern portion, of the sump. Dam is to the right.

August 2015

August 2016

Willow Sump – Looking Southeast from the back of the sump.

Back side, northern portion, of the sump. Taken from same location as last pic (slide 5) but is looking south towards the dam. Arrow references snag sticking out of water.

August 2015

August 2016

Manual Treatments for Yellow Floating Heart and Results in the Applegate Valley 2008-2017

Barbara Mumblo (retired USFS Rogue River-Siskiyou National Forest)
Bruce Hansen (USFS Pacific Northwest Research Station)

In 2008, a neighbor of Star Ranger Station stopped by and said she found a different water lily in Little Squaw Lake and thought she could sell it on the internet. So I went to the lake and after searching on the internet realized it was *Nymphoides peltata*, Yellow floating heart, and that it was on list A of the Oregon Department of Agriculture's (ODA) noxious weed list. Searching on the internet at that time only turned up manual treatments had worked in New Zealand.

In 2009, I went out a couple days with two volunteers. We tried gathering some of the plants and removing them. It was slow going and hard to walk in the Condrey Mtn. schist on the lake bottom. We saw already formed capsules floating and tried to catch them. This large infestation was 130' long and grew 30' out into the lake in deeper water. Over time we saw that plants were reproducing by seed and plant parts (nodes and roots), that plants could root at the lake bottom and grow to the surface up to 20', and that capsules and seeds floated. The floating seeds were "fringed' around the edges which may allow them to be caught in waterfowl feathers.

In 2010, to figure out an attack plan, several of us got together. Ken French (ODA), Wayne Rolle (RRSNF Botanist), Leah Lentz (RRSNF noxious weed tech), Shawna Bautista and Rochelle Desser (Region 6 noxious weed specialists) met at the lake. Since the Rogue River NF noxious weed Environmental Analysis did not permit herbicide use within 50' of water, I hoped that the already stretched ODA might take over since it was over water. We realized that ODA couldn't take charge at that time and it would take too much time to do an EA for herbicide use so we decided to continue manual treatments to see if they would be successful.

In 2010, we began additional work. After further survey, we realized there were four small sites in addition to the large site. These ranged mainly along the northern shore with one of the small sites located where Squaw Creek entered the lake. We pulled/dug the small sites but the larger site took more creativity. We created a boom using PVC pipe around the large infestation to keep any floating material from escaping. We experimented working from boats so we wouldn't get our feet stuck in the muck. Plants were taken to the lake shore to dry and then removed for burning in the winter. Mark Systma (Portland State Univ.) was out there one day doing aquatic surveys and let us know the plants at some of the deepest areas were rooted about 20' below the surface. He suggested covering the lake bottom with a barrier. Since we could not drive to the lake shore and there is no boat dock at the lake, we were limited to ways to cover the plants. Luckily for us, Mel Culp, a scuba diver who worked on the neighboring district, came over and she and Rochelle tried a dive to see how that would work. They cut deep growing plants near the base and brought the material to the boats. Mel also found some old landscape material in their warehouse that we could use for a bottom barrier so we attempted laying that out to see how it worked. We removed all flowers/capsules to prevent further seed germination.

Also in 2010 at the ODA Noxious weed symposium, I learned that the FS had a scuba diving program with certified scuba divers. I was given Bruce Hansen's name. In 2011 we brought Bruce and his cadre of scuba divers into the mix.

Due to the soft substrate it was hard to wade, and there was zero visibility. Using SCUBA allowed divers to stay on the bottom to "dig up" and conduct initial clearing of the YFH. With their hands divers would follow a stalk down into the mud to pull intact plants when possible. Boats on surface collected YFH as floated to the surface. With assistance from the shore crew, the divers spread continuous fabric from shore out to the max depth of YFH. Often the cloth had to be worked around submerged logs. The jumbled bottom made it difficult to overlap adjacent stretches of cloth. Rebar was laid on fabric to hold in place. In repeat years divers would cover gaps and get new and "missed" plants.

This was a complicated work site with submerged logs to work around, lots of aquatic vegetation to get tangled in, boats above divers. Multiple divers had to work in close quarters laying out fabric and putting pieces of rebar down to hold the fabric without hitting each other. All in minimal visibility.

In 2012 we could tell the fabric was doing its job but we needed to cover more of the site. We developed a finely tuned operation to continue the covering. In 2013 we finished covering the site with the aid of the scuba divers

In 2014 and 2015 a couple of us pulled/dug plants that were found, In 2016 there were about 10 plants pulled from a small site – no plants were found at the larger site.

In 2017, no plants were found at any of the sites.

This project really was an adaptive management project. If anyone had an idea that might work we tried it.

Water Primrose

"B" Rated Weeds

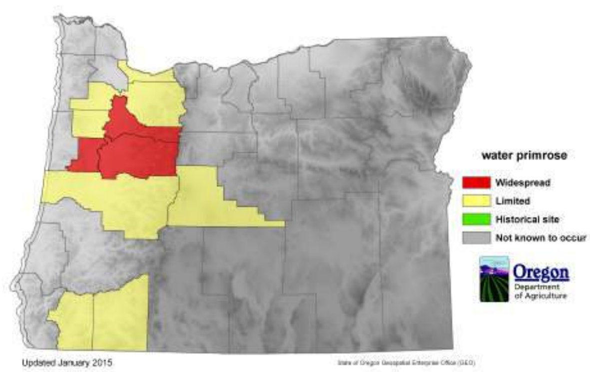
A weed of economic importance which is regionally abundant, but may have limited distribution in some counties

Waterprimrose
Ludwigia hexapetala, peploides

Other common names: Hairy waterprimrose

USDA symbol: LUHE
ODA rating: B and T

Introduction: Waterprimrose are native to Uruguay and southern Brazil. The two species have flourished in the U.S. for many decades but only in the last 10-15 years have they significantly expanded their range and density. There are multiple species and sub-species of primrose on the west coast and are now demonstrating highly invasive growth habits. These species were sold in the nursery trade as aquatic garden plants.



Distribution in Oregon: Multiple large infestations occur in sloughs, ponds and other waterways mostly in areas near the Willamette River and its tributaries. Populations are expanding at an alarming rate. Deschutes County also had one infestation that is currently under control.

Description: Waterprimrose are perennial occurring in marshes, swamps, ditches, ponds, and around lake margins, where they form dense floating mats up to 3 feet tall, crowding out native species. The stems root freely at the nodes either in the water or in damp soil. Reproduction occurs both by seeds and vegetatively through fragmentation. It produces light green, floating stems early in the season with rosettes of smooth, shiny, rounded leaves. Later the stems become erect, reddish-brown, and produce elongated, willow-like, pointed leaves arranged alternately along the stems. Flowers are solitary, up to an inch in diameter, having five to six bright yellow petals. Flowering occurs from mid to late summer and continues until a killing frost

Impacts: Significant clogging of irrigation canals and drainage ditches occurs in California where *Ludwidgia* has established a foothold. Due to the potential for crop damage and environmental concerns, plant removal is often limited to mechanical means that are expensive and time consuming. Recreation is impacted due to the loss of fish habitat, fishing access, clogging of boating waterways, and swimming areas. Wildlife habitats are degraded by monoculture infestations. Infested waterways suffer drops in dissolved oxygen, which kill fish and invertebrates reducing productivity. Waterfowl loose preferred food plants and feeding grounds. Species richness of all species drops significantly. Infested waterways build up significant populations of mosquitoes.

Biological controls: No approved biological control agents are available at this time.

Photos by Glenn Miller, ODA

Oregon Department of Agriculture
Noxious Weed Pest Risk Assessment for
Large-flower Primrose-willow, *Ludwigia grandiflora ssp grandiflora*
Floating Primrose-willow, *Ludwigia hexapetala*
Water primrose, *Ludwigia peploides*
Onagraceae
February 2011 (Revised 2/2016)

Findings of Review and Assessment: Three introduced Ludwigia spp, have been determined to be a potential "B" listed noxious weeds as defined in the ODA Noxious Weed Policy and Classification System. This determination is based on two independent risk assessments following a literature review. Using a rating system adapted from USDA-APHIS Weed Risk Assessment Guidelines, Ludwigia spp scored 54 out of a potential score of 90. Using the ODA Noxious Weed Rating system, Ludwigia spp. scored 16. The high scores reflected in the assessment are as result of the habitat the plant invades, its reproductive potential and vigor, high control costs and the potential for human health risk. Its widespread distribution precludes and "A" listing though.

Introduction: Primrose-willows have flourished in the United States for many decades, but only in the last 10-15 years have they rapidly expanded their range and density. There are multiple species and sub-species of primrose willows on the west coast of the United States. Introduced from their native range in Central and South America, they are now demonstrating highly invasive growth habits. Water primroses continue to be sold in the nursery trade as aquatic garden plants, which may explain their distribution nationwide. Ludwigia species are now causing economic and environmental damage in ponds, lakes, slow moving streams, irrigation canals and drainage ditches. Removal costs linked to these species are substantial.

Reproduction: Creeping waterprimroses are perennial, emergent plants native to Central and South America. Several species are also native to California1. Several are highly invasive, occurring in marshes, swamps, ditches, ponds, and around lake margins, where they form dense floating mats up to 3 ft. deep, crowding out native species2. The stems root freely at the nodes either in the water or in damp soil. Reproduction occurs both by seeds and vegetatively through fragmentation. Creeping waterprimroses produce light green, floating stems early in the season with rosettes of smooth, shiny, rounded leaves. Later in the season, the stems become erect, reddish-brown, and produce elongated, willow-like, pointed leaves arranged alternately along the stems. Wiry, branched roots form at the nodes giving the root system a feathery appearance. Emergent leaves and stems usually are slightly to extremely hairy, giving the plant another common name, "hairy waterprimrose". Flowers appear during early summer on stalks attached in the upper leaf axils of emergent stems. They are solitary, up to an inch in diameter, have five to six bright yellow petals, and may be covered with hairs, particularly on the stalks. Flowering occurs from mid to late summer and continues until a killing frost. Plants are attractive, brightly colored and easy to recognize. Many small, yellowish seeds are produced during the summer in elongated, woody capsules.

Factors Effecting Establishment: The waterprimroses reproduce both sexually by seeds and asexually by stem fragmentation. Long distance dispersal can be linked to humans through factors such as plant marketing in the ornamental trade, it may also be linked to waterfowl feeding and transport during migrations. Short distance dispersal occurs through flood events, waterfowl movement and through human disturbances.

Warmer temperatures and a longer growing season can be expected to provide an excellent growing environment for further expansion of water primroses. We can expect waterprimrose populations to increase in abundance and severity in the future. Ludwigia may be limited by cold winter temperatures which can freeze out overwintering stems and roots. In Oregon, the species can thrive well in Zones 7 and 8 in the western half of the state.

Probability of Detection: Easy to identify by weed professionals.

Distribution in Oregon: Multiple large infestations occurs in sloughs, ponds, and other waterways mostly in areas near the Willamette River and its tributaries. Populations are expanding at an alarming rate.

Environmental Impacts: Wildlife habitat becomes degraded by monoculture infestations of Ludwigia in a number of ways. Infested waterways suffer drops in dissolved oxygen which can kill fish and invertebrates reducing productivity. Waterfowl loose preferred food plants and feeding grounds. Species richness of all species drops significantly. Infested waterways often build up significant populations of mosquitos with the improved habitat conditions which provides protection for developing larvae.

Economic Impacts: Significant clogging of irrigation canals and drainage ditches occurs in California where Ludwidgia has established a foothold. Due to the potential for crop damage from herbicide applications and environmental concerns, plant removal is often limited to mechanical means. Such practices are expensive and time consuming. In the Pacific Northwest, there is noted only a few incidences of economic impact involving cooling ponds and a drainage district though additional irrigation and drainage districts will become impacted. A large part of the costs related to Ludwigia involve the substantial per acre control costs for plant removal. Often mechanical operations are required to remove plant material from irrigation canals with the transport and disposal of plant material adding to the expense. Recreation is also impacted due to the loss of fish habitat, fishing access, clogging of boating waterways and swimming areas.

Control: As with any invasive aquatic species control program, options may be expensive, controversial and with lots of non-target effects. Mowing offers only temporary relief because regrowth is rapid. Excavation of infested banks and lake bottoms is very disruptive and expensive. Fragmentation and regrowth are a major issue with this method. Aquatic labeled herbicides are effective but may cause serious oxygen depletion problems. Repeat applications for several years are needed to exhaust seed stocks in the soil. Covering of small patches is possible as long as high water levels and movement in the winter do not disturb the fabric. The most effective treatment method involves using any of the above methods in conjunction with an early detection program so that any response to a infestation can be minor.

Noxious Weed Qualitative Risk Assessment 3.8
Oregon Department of Agriculture

Common Name: Water primroses
Scientific Name: *Ludwigia spp*.
Family: Onagraceae

For use with plant species that occur or may occur in Oregon to determine their potential to become serious noxious weeds. For each of the following categories, select the number that best applies. Numerical values are weighted to increase priority categories over less important ones. Choose the best number that applies, intermediate scores can be used.

Total Score: **54** Risk Category: **A**

GEOGRAPHICAL INFORMATION

1) 6 **Invasive in Other Areas**

0 Low- not known to be invasive elsewhere.
2 Known to be invasive in climates dissimilar to Oregon's current climates.
6 Known to be invasive in geographically similar areas.

Comments: Plants are invasive on west coast states and southeast states.

2) 4 **Habitat Availability:** Are there susceptible habitats for this species and how common or widespread are they in Oregon?

1 *Low* – Habitat is very limited, usually restricted to a small watershed or part of a watershed (e.g., tree fern in southern Curry County).
3 *Medium* – Habitat encompasses 1/4 or less of Oregon (e.g., oak woodlands, coastal dunes, eastern Oregon wetlands, Columbia Gorge).
6 *High* – Habitat covers large regions or multiple counties, or is limited to a few locations of high economic or ecological value (e.g., threatened and endangered species habitat).

Comments: Ludwigia infests ponds, lake edges and slow moving streams.

3) 0 **Proximity to Oregon**: What is the current distribution of the species?

0 *Present* – Occurs within Oregon.
1 *Distant* – Occurs only in distant US regions or foreign countries.
3 *Regional* – Occurs in Western regions of US but not adjacent to Oregon border.
6 *Adjacent* – Weedy populations occur adjacent (<50 miles) to Oregon border.

Comments: Occurs in Oregon

4) 5 **Current Distribution**: What is the current distribution of escaped populations in Oregon?

0 *Not present* – Not known to occur in Oregon.
1 *Widespread* – Throughout much of Oregon (e.g., cheatgrass).
5 *Regional* – Abundant (i.e., occurs in eastern, western, central, coastal, areas of Oregon) (e.g., gorse, tansy ragwort).
10 *Limited* – Limited to one or a few infestations in state (e.g., kudzu).

Comments: Not uncommon in western Oregon

BIOLOGICAL INFORMATION

5) 2 **Environmental Factors**: Do abiotic (non-living) factors in the environment effect establishment and spread of the species? (e.g., precipitation, drought, temperature, nutrient availability, soil type, slope, aspect, soil moisture, standing or moving water).

1 *Low* – Severely confined by abiotic factors.
2 *Medium* – Moderately confined by environmental factors
4 *High* – Highly adapted to a variety of environmental conditions (e.g., tansy ragwort, Scotch broom).

Comments: Confined by winter temperatures and seasonal water availability.

6) 5 **Reproductive Traits:** How does this species reproduce? Traits that may allow rapid population increase both on and off site.

0 *Negligible* – Not self-fertile, or is dioecious and opposite sex not present.
1 *Low* – Reproduction is only by seed, produces few seeds, or seed viability and longevity are low.
3 *Medium* – Reproduction is vegetative (e.g., by root fragments, rhizomes, bulbs, stolons).
3 *Medium* – Produces many seeds, and/or seeds of short longevity (< 5 years).
5 *High* – Produces many seeds and/or seeds of moderate longevity (5-10 years) (e.g., tansy ragwort).
6 *Very high* – Has two or more reproductive traits (e.g., seeds are long-lived >10 years and spreads by rhizomes).

Comments: Reproduction occurs by both seeds and stem fragments.

7) 4 **Biological Factors:** Do biotic (living) factors restrict or aid establishment and spread of the species? (What is the interaction of plant competition, natural enemies, native herbivores, pollinators, and pathogens with species?)

0 *Negligible* – Host plant not present for parasitic species.
1 *Low* – Biotic factors highly suppress reproduction or heavily damage plant for an extended period (e.g., biocontrol agent on tansy ragwort).
2 *Medium* – Biotic factors partially restrict or moderately impact growth and reproduction, impacts sporadic or short-lived.
4 *High* – Few biotic interactions restrict growth and reproduction. Species expresses full growth and reproductive potential.

Comments: Plant expresses full growth potential.

8) 3 **Reproductive Potential and Spread After Establishment - Non-human Factors:** How well can the species spread by natural means?

0 *Negligible* – No potential for natural spread in Oregon (e.g., ornamental plants outside of climate zone).
1 *Low* – Low potential for local spread within a year, has moderate reproductive potential or some mobility of propagules (e.g., propagules transported locally by animals, water movement in lakes or ponds, not wind blown).
3 *Medium* - Moderate potential for natural spread with either high reproductive potential or highly mobile propagules (e.g., propagules spread by moving water, or dispersed over longer distances by animals) (e.g., perennial pepperweed).

5 *High* – Potential for rapid natural spread throughout the susceptible range, high reproductive capacity and highly mobile propagules. Seeds are wind dispersed over large areas (e.g., rush skeletonweed).

Comments: Plants have a moderate level of natural production by humans and water movement.

9) 3 **Potential of Species to be Spread by Humans**. What human activities contribute to spread of species? Examples include: interstate or international commerce; contaminated commodities; packing materials or products; vehicles, boats, or equipment movement; logging or farming; road maintenance; intentional introductions of ornamental and horticultural species, or biofuel production.

1 *Low* – Potential for introduction or movement minimal (e.g., species not traded or sold, or species not found in agricultural commodities, gravel or other commercial products).

3 *Medium* – Potential for introduction or off-site movement moderate (e.g., not widely propagated, not highly popular, with limited market potential; may be a localized contaminant of gravel, landscape products, or other commercial products) (e.g., lesser celandine, Canada thistle).

5 *High* – Potential to be introduced or moved within state high (e.g., species widely propagated and sold; propagules common contaminant of agricultural commodities or commercial products; high potential for movement by contaminated vehicles and equipment, or by recreational activities) (e.g., butterfly bush, spotted knapweed, Eurasian watermilfoil).

Comments: Plant is sold in the aquatic garden market but sales are not large.

IMPACT INFORMATION

10) 4 **Economic Impact**: What impact does/can the species have on Oregon's agriculture and economy?

0 *Negligible* – Causes few, if any, economic impacts.

1 *Low* - Potential to, or causes low economic impact to agriculture; may impact urban areas (e.g., puncture vine, pokeweed).

5 *Medium* – Potential to, or causes moderate impacts to urban areas, right-of-way maintenance, property values, recreational activities, reduces rangeland productivity (e.g., English ivy, Himalayan blackberry, cheatgrass).

10 *High* – Potential to, or causes high impacts in agricultural, livestock, fisheries, or timber production by reducing yield, commodity value, or increasing production costs (e.g., gorse, rush skeleton weed, leafy spurge).

Comments: Plant may impact fishing, recreation, water drainage and irrigation infrastructure.

11) 4 **Environmental Impact**: What risks or harm to the environment does this species pose? Plant may cause negative impacts on ecosystem function, structure, and biodiversity of plant or fish and wildlife habitat; may put desired species at risk.

0 *Negligible* – None of the above impacts probable.

1 *Low* – Can or does cause few or minor environmental impacts, or impacts occur in degraded or highly disturbed habitats.

4 *Medium* – Species can or does cause moderate impacts in less critical habitats (e.g., urban areas, sagebrush/ juniper stands).

6 *High* – Species can or does cause significant impacts in several of the above categories. Plant causes severe impacts to limited or priority habitats (e.g., aquatic, riparian zones, salt marsh; or T&E species sites).

Comments: Plant can cause significant impacts to aquatic environments but those environments are limited.

12) 4 **Impact on Health:** What is the impact of this species on human, animal, and livestock health? (e.g., poisonous if ingested, contact dermatitis, acute and chronic toxicity to livestock, toxic sap, injurious spines or prickles, causes allergy symptoms.

0 *Negligible* – Has no impact on human or animal health.
2 *Low* – May cause minor health problems of short duration, minor allergy symptoms (e.g., leafy spurge).
4 *Medium* – May cause severe allergy problems, death or severe health problems through chronic toxicity, spines or toxic sap may cause significant injury. (e.g., giant hogweed, tansy ragwort).
6 *High* – Causes death from ingestion of small amounts, acute toxicity (e.g. poison hemlock).

Comments: Plant may cause an increase in mosquito populations in selected areas.

CONTROL INFORMATION

13) 5 **Probability of Detection at Point of Introduction**: How likely is detection of species after introduction and naturalization in Oregon?

1 *Low* – Grows where probability of early detection is high, showy and easily recognized by public; access to habitat not restricted (e.g., giant hogweed).
5 *Medium* – Easily identified by weed professionals, ranchers, botanists; some survey and detection infrastructure in place. General public may not recognize or report species (e.g., leafy spurge).
10 *High* – Probability of initial detection by weed professionals low. Plant shape and form obscure, not showy for much of growing season, introduction probable at remote locations with limited access (e.g., weedy grasses, hawkweeds, skeletonweed).

Comments: Easy to identify by weed professionals.

14) 5 **Control Efficacy:** What level of control of this species can be expected with proper timing, herbicides, equipment, and biological control agents?

1 *Negligible* – Easily controlled by common non-chemical control measures (e.g., mowing, tillage, pulling, and cutting; biocontrol is very effective at reducing seed production and plant density) (e.g., tansy ragwort).
2 *Low* – Somewhat difficult to control, generally requires herbicide treatment (e.g., mechanical control measures effective at preventing flowering and but not reducing plant density; herbicide applications provide a high rate of control in a single application; biocontrol provides partial control).
4 *Medium* – Treatment options marginally effective or costly. Tillage and mowing increase plant density (e.g., causes tillering, rapid regrowth, spread from root fragments). Chemical control is marginally effective. Crop damage occurs or significant non-target impacts result from maximum control rates. Biocontrol agents ineffective.
6 *High* – No effective treatments known or control costs very expensive. Species may occur in large water bodies or river systems where containment and complete control are not achievable. Political or legal issues may prevent effective control.

Comments: Control costs expensive and marginal. Fragmentation easily occurs.

Category Scores:

15 Geographic score (Add scores 1-4)

17 Biological Score (Add lines 5-9)

12 Impact Score (Add lines 10-12)

10 Control Score (Add Lines 13-14)

54 Total Score (Add scores 1-14 and list on front of form)

Risk Category: 55-89 = A 24-54 = B < 24 = unlisted.

This Risk Assessment was modified by ODA from the USDA-APHIS Risk Assessment for the introduction of new plant species.

V3.8 2/19/2016

Oregon Department of Agriculture
Noxious Weed Rating System

Common Name: Water primrose
Scientific Name: *Ludwiggia Spp.*
Point Total: **16** Rating: **B**

1) Detrimental Effects: Check all that apply, add number of checks

- ☐ 1. *Health*: causes poisoning or injury to humans or animals
- ☒ 2. *Competition:* strongly competitive with crops, forage, or native flora
- ☐ 3. *Host*: host of pathogens and/or pests of crops or forage
- ☐ 4. *Contamination*: causes economic loss as a contaminate in seeds and/or feeds
- ☐ 5. *Interference*: interferes with recreation, transportation, harvest, land value, or wildlife and livestock movement

2) Reproduction & Capacity for Spread: Check the number that best describes, enter that number

- ☐ 1. Few seeds, not wind blown, spreads slowly
- ☐ 2. Many seeds, slow spread
- ☐ 3. Many seeds, spreads quickly by vehicles or animals
- ☒ 4. Windblown seed, or spreading rhizomes, or water borne
- ☐ 5. Many wind-blown seeds, high seed longevity, spreading rhizomes, perennials

3) Difficulty to Control: Check the number that best describes, enter that number

- ☐ 1. Easily controlled with tillage or by competitive plants
- ☐ 2. Requires moderate control, tillage, competition or herbicides
- ☐ 3. Herbicides generally required, or intensive management practices
- ☒ 4. Intensive management generally gives marginal control
- ☐ 5. No management works well, spreading out of control

4) Distribution: Check the number that best describes, enter that number

- ☐ 1. Widely distributed throughout the state in susceptible habitat
- ☒ 2. Regionally abundant, 5 or more counties, more than 1/2 of a county
- ☐ 3. Abundant throughout 1- 4 counties, or 1/4 of a county, or several watersheds
- ☐ 4. Contained in only 1 watershed, or less than 5 square miles gross infestation
- ☐ 5. Isolated infestation less than 640 acres, more than 10 acres

5) Ecological Impact: Check the number that best describes, enter that number

- ☐ 1. Occurs in most disturbed habitats with little competition
- ☐ 2. Occurs in disturbed habitats with competition
- ☐ 3. Invades undisturbed habitats and crowds out native species
- ☒ 4. Invades restricted habitats (i.e. riparian) and crowds out native species

16 TOTAL POINTS

Note: Noxious weeds are non-native plants with scores of 11 points or higher. Any plants in 4.1, 4.2, and 4.3 should not be classified as "A" rated weeds. Ratings: 16 + = A, 15 – 11= B
ODA Weed Rating System 2/22/16 V3.8

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Creeping waterprimrose: Ludwigia hexapetala Aquatic weed fact sheet. North Carolina State University [Internet] [Cited 12/21/2009] Available at http://www.cropsci.ncsu.edu/aquaticweeds

Ludwigia grandiflora ssp hexapetala LUGRH: USDA Plants Profile [Internet] [Cited 12/18/2009] Available from http://plants.usda.gov/java/profile?symbol=LUGRH

Ludwigia hexapetala: Washinton Depratment of Ecology, Non-native Invasive Freshwater Plants. [Internet] [Cited 12/18/2009] Available from: http://www.ecy.wa.gov/programs/w9/plants/weeds/waterprimrose.html

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Ludwigia peploides LUPE5: USDA Plants Profile [Internet} [Cited 12/21/2009] Available from http://plants.usda.gov/java/profile?symbol=LUPE5

Reported by:Glenn Miller, Oregon Department of Agriculture

NSW DEPARTMENT OF PRIMARY INDUSTRIES

REGIONAL WEED MANAGEMENT PLAN

1.1 PLAN TITLE: **Sydney-wide Regional Ludwigia Management Plan**

1.2 PLAN PROPONENTS

Regional Weeds Advisory Committee: **South West Sydney Regional Weeds Committee; Sydney Central Regional Weeds Committee; Sydney North Regional Weeds Committee; Sydney West ~Blue Mountains Regional Weeds Committee**
Contact person: **Phil Clunas - Noxious Weeds Officer**
Address: **Sutherland Shire Council, Locked Bag 17 Sutherland NSW 1499**
Telephone number: **9710 5733**
Facsimile number: **9710 5721**
Email address: **pclunas@ssc.nsw.gov.au**

Signature: .... Date: ....

1.3 NAME OF PLANT(S) **WONS** N

Botanical name(s):,	Common name(s):
Ludwigia peruviana	**Ludwigia, Peruvian Primrose**
Ludwigia longifolia	**Long Leaf Willow Primrose.**
Ludwigia repens	**Red Ludwigia**

NB: For the purposes of this plan, the term 'Ludwigia' refers to *Ludwigia peruviana* and *Ludwigia longifolia*.

1.4 PLAN PERIOD (not to exceed five years)

Starting date: **1 July 2008** Completion date: **30 June 2013**

1.5 AREA OF OPERATION: This plan extends over the geographical area represented by the four Regional Weeds Committees in the Sydney region.

1.6 AIM:
To reduce infestations and prevent the spread of Ludwigia on public and private land.

1.7 OBJECTIVES:
1. Determine the location and extent of new and existing Ludwigia infestations.
2. Strategically eradicate new Ludwigia infestations on public land within 2 years of detection
3. Contain and reduce existing Ludwigia infestations on public land within 5 years.
4. Ensure Ludwigia infestations on private land are controlled.
5. Increase the awareness, identification and control skills among Council/state agency staff and contractors.
6. Increase the awareness, identification and control skills among Bushcare/ Landcare volunteers and private landholders.
7. Obtain more information on the distribution, potential impact and control of *Ludwigia repens*.

2.0 STAKEHOLDERS

Signatories and other stakeholders include:
South West Sydney: Sutherland Shire Council, Wollondilly Shire Council, Camden Council, Campbelltown City Council, Liverpool City Council, Fairfield City Council, Bankstown City Council
Sydney Central: Canterbury City Council, Randwick City Council, Hurstville City Council, Botany Bay Council, Rockdale City Council
Sydney North: Warringah Council, Pittwater Council, Manly Council, Hornsby Council, Ku-ring-gai Council
Sydney West~Blue Mountains: Parramatta Council, Baulkham Hills Shire Council, and Hawkesbury River County Council
Participating State Agencies: Dept of Primary Industries (DPI), Department of Environment and Climate Change – NPWS (DECC), Centennial Parklands, Sydney Water Corporation, Department of Lands, Roads and Traffic Authority
Community: La Perouse Aboriginal Land Council, Cowan Catchment Weeds Committee, Ingleside Landcare Group, Dundundra Falls Bushcare group, and other private landholders and Bushcare and Landcare volunteers
All councils and stage agencies are critical to the success of this plan.

3.0 BACKGROUND and GENERAL FACTS

3.1 Weed Biology/Ecology

L. peruviana was introduced to Australia from Central and South America and cultivated at the Royal Botanic Gardens, Sydney, in 1907. It was first recorded as naturalised in Australia in the Botany Wetlands in 1970 and recognised as a potential weed in 1971. *Ludwigia peruviana* is a perennial wetland shrub which grows to approximately 4m in height. Leaves are 4-12cm long, broad, hairy, alternate and dark green or brownish green. The showy yellow flowers have 4 petals (rarely 5), only last one day, and are produced in succession at the end of the stems. In Sydney, flowering lasts from mid-summer to early-autumn. Four-angled fruit are produced, 1-2.5cm long, 0.6-1cm wide containing small seeds like finely ground pepper, with approximately 1000 – 3000 per capsule.

Ludwigia longifolia was first recorded in Australia near Sydney - National Herbarium of New South Wales Report 1993-94. An introduced aquatic plant from South America, it is an erect annual shrub up to 2.5 m tall. It has narrowly winged stems that usually branch near their ends, upper stems 4-angled. The alternate leaves are ovate to lanceolate, 5 to 35cm long and 0.5-2.5cm wide, covering upright, reddish stems. The flowers are pale yellow to cream, with notched petals about 2cm long. The fruit is similar to *L. peruviana* with tiny seeds approximately 1mm in size. Shallow fibrous roots.

Ludwigia repens, a native to California, is a new incursion in the Sydney North region. It was found and identified in the Lane Cove River in 2005 (originally mis-identified as *L. palustris)*. This is the only recorded occurrence of *L. repens* in NSW. It is an emergent aquatic herb with opposite green leaves that are red/purplish underneath broadly lanceolate-elliptic to suborbicular mostly 1–4.5 cm long, 4–27 mm wide, base tapering into a petiole 5–25 mm long. Tiny yellow flowers emerge during the warmer months, axillary, paired, bracteoles narrow, 1–5 mm long. Sepals 4, triangular. Petals 4, yellow, 1–3 mm long. Stamens 4. Fruit oblong, corners rounded to barely angled, 5–7 mm long, c. 2.5 mm wide, seeds free, yellowish brown, in several rows.

There is also a native Ludwigia species in the Sydney region, *Ludwigia peploides ssp. montevidensis* – a herb with creeping or floating vegetative stems and erect flowering stems to 50cm tall which is fairly common in ponds and streams on the Cumberland Plain.

3.2 Method of Spread

Ludwigia propagates by seed as well as vegetatively. The tiny seeds which are produced prolifically, readily adhere to moist surfaces and feathers, and are dispersed by water, wind, birds (especially ducks), machinery, footwear, clothing and mud. Machinery used to clean out drains, four wheel drive vehicles and boats can easily spread the minute seeds. Stem layering can occur where stems come into contact with moist soil. Dislodged branches and stem pieces can take root after dispersal by flood or machinery during removal, and develop into new plants.

3.3 Description of the Problem

Ludwigia is a vigorously opportunistic plant, clogging wetlands, slow moving watercourses and waterways, limiting their usefulness for recreational and navigational purposes as well as reducing biodiversity. Reducing the rate of flow in streams causes wide ecological damage through increased sedimentation and accumulation of additional organic material resulting in the deoxygenation of the water column. This leads to the death of aquatic fauna and a change in flora species composition. Dense stands of Ludwigia can intercept almost all incident light, dominate all other water plants and in some cases lead to the loss of native plants and animals. For example, in the Botany Wetlands, *Ludwigia peruviana* displaced all other wetland vegetation to the extent that bird populations were significantly reduced.

Ludwigia peruviana seedlings flower approximately two years after germination. Seed viability is high (up to 99% in the first year) declining significantly within 2 years. The small seeds germinate readily in spring, especially in drying mud at the edges of swamps and streams. According to a report on the Botany Wetlands (Jacobs, S. et. al., 1994), seed production in 1990-1991 was approximately 450 000 seeds m^2. In addition there were approximately 65 000 seeds m^2 in the soil seed bank and approximately 300 000 seeds m^2 in old fruits that remained on the stems over winter. An estimated 20% of seed may remain dormant for over 10 years, allowing dispersal through time.

According to Csurches and Edwards (1998), *L. longifolia* has the potential to spread along the eastern and northern coasts of Australia. Ecosystems most at risk include wetlands and riparian communities. *L. longifolia* plants can form dominant colonies that result in reduced biodiversity and habitat, threatening native species. It is not known how long *Ludwigia longifolia* seeds remain viable. In extreme growing conditions *L. longifolia* has been recorded as growing from a small seedling to a flowering plant in 2 months.

Ludwigia peruviana and *L. longifolia* were identified in the TOP 20 priority weeds in the Sydney Metropolitan CMA region in 2007, due to their invasive nature, current limited distribution and potential for spread.

Ludwigia repens is widely distributed and sold as an aquarium plant in Australia. It has been assessed as a high risk species requiring further information and evaluation, as part of a NSW DPI and National Aquatic Weeds Management group project which undertook the weed risk assessment of over 400 aquarium plants. It is a weed in other countries including the US. Very little is known about its current extent, potential impact and effective control.

3.4 Reason for the Plan

This plan has been developed to coordinate the regional, strategic management of Ludwigia in the Sydney region where it is listed as a high priority weed. Although its potential for spread is considerable, due to its current limited extent successful control and eradication is achieveable if adequate funds are available, as demonstrated in the Botany Wetlands and Warriewood Wetlands.

The initial five year Sydney-wide Ludwigia regional plan expired in June 2008. Implementation of that plan resulted in a significant reduction in levels of infestation in many areas. *Ludwigia peruviana* has now been eradicated from the Kogarah, Ku-ring-gai, Woollahra and Willoughby LCAs, and significantly reduced in the Canterbury, Hurstville and Manly LCAs. However, due to Ludwigia's high seed production and viability, on-going regional control and maintenance is still required, especially in the larger infestations and where significant seed sources remain. The previous plan also produced in an increased awareness of Ludwigia and the implementation of extensive survey and mapping which resulted in the discovery of new infestations, some only recently.

In Australia, *Ludwigia peruviana* is currently found only in the Sydney region where it is now well established and has spread south to Heathcote, north to Gosford and west to Campbelltown and Liverpool. At present it does not appear to be established elsewhere in Australia.

Ludwigia longifolia is less extensive in Sydney and mostly found in the Sydney North region. It has the potential to become as extensive as *Ludwigia peruviana*. Large infestations already exist in the Port Stephens LCA in the Hunter Valley.

Ludwigia repens has been included in this revised plan as it is a new incursion to the region. It has the potential to spread much further than its current limited distribution and requires close monitoring, further investigation and potential declaration as a Class 5 noxious weed. There is currently a need to understand more about its invasiveness, potential impact, potential distribution, and the feasibility of eradication.

The null hypothesis approach could result in Ludwigia becoming a major weed not only throughout the Sydney region, but up and down the east coast and along the north coast of Australia, to the detriment of native flora and fauna in wetland and riparian environments. It has already naturalised world wide and is recognised as a major weed problem in Asia, Indonesia and North America. Ludwigia would spread to new areas throughout the Sydney region, including LCAs where it does not currently occur. For example, Ludwigia is currently not found in the upper reaches of the Nepean River in the South West Sydney region, and if no action is taken, it could become established there and further impact the Hawkesbury Nepean Catchment.

In Sydney, controlling and reducing the spread of Ludwigia will help conserve the integrity of endangered ecological communities classified under the *Threatened Species Conservation Act 1995*, such as the Sydney Freshwater Wetlands and Swamp Sclerophyll Forest on Coastal Floodplains**.**

The control of Ludwigia will also ensure the protection of rare or threatened species, for example the rare plant *Grevillea longifolia* in the Sutherland LCA, due to its presence in the same habitat niche as Ludwigia infestations. Also in the Sutherland LCA, many of the wetlands on the Kurnell Peninsula are potential habitat of the (respectively) endangered and vulnerable amphibian species - *Litorea aurea* (Green and Golden Bell Frog) and *Crinia tinnula* (Wallum Froglet).

3.5 Distribution of the infestations

Considerable distribution mapping of Ludwigia was carried out by the Sydney Weeds Committees and the SMCMA during 2006 and 2007. Please refer to the maps on the following pages (5 – 6).

The South West Sydney Regional Weeds Committee established priority areas of works via the development of a matrix (see Attachment 1) which took into account variables, such as; impact on biodiversity, class of creek, impact on recreation, agricultural productivity, dispersal via commercial activity, core or isolated site and likeliness of success in treatment.

The Sydney West~Blue Mountains Weeds Committee established priority areas of works based on variables, such as; location in catchment, core or isolated site and likeliness of success in treatment.

As all the Sydney Central and Sydney North Ludwigia infestations are relatively small and isolated, but with significant potential for spread to new areas, all sites are managed as Priority 1 areas.

4.0 LEGISLATIVE and REGULATORY SITUATION

4.1 Current Declaration

Ludwigia peruviana is a declared Class 3 noxious weed under the Noxious Weeds Act 1993 in all the LCAs covered by this plan, except for Camden and Wollondilly. Class 3 means '*The plant must be fully and continuously suppressed and destroyed*'.

Ludwigia longifolia is a declared Class 3 noxious weed under the Noxious Weeds Act 1993 in all the LCAs covered by this plan. Class 3 means '*The plant must be fully and continuously suppressed and destroyed*'. It is also declared a Class 5 noxious weed throughout NSW *"The requirements in the Noxious Weeds Act 1993 for a notifiable weed must be complied with"* to prohibit its sale, propagation and distribution.

Ludwigia repens is not currently declared as a noxious weed anywhere in Australia. The Sydney Metropolitan CMA and Sydney North Regional Weeds Committee have listed *L. repens* as a Weed Alert.

4.2 Declaration Changes

It is proposed that *Ludwigia peruviana* be listed as a Class 3 noxious weed in the Camden and Wollondilly LCAs so they are consistent with the other LCAs in the region, and due to the fact that small infestations of this weed have been found and eradicated in both of these areas. This is not expected to result in a change in the estimated costs to control the weed, as the minimal work that is currently required to monitor the sites is already being undertaken.

NSW DPI and the National Aquatic Weeds Management group are investigating the possibility of a national ban for *Ludwigia repens* which would include listing it as a Class 5 noxious weed in NSW to prohibit its sale, propagation and distribution in aquariums. This plan supports the declaration of *Ludwigia repens* as a Class 5 noxious weed if, after further investigation, the National Aquatic Weeds Management group recommends a national ban on the species.

5.0 CONSIDERATIONS and OPPORTUNITIES

5.1 Opportunities to be exploited

To assist in the implementation of this plan, sources of funding will continue to be sought from state and federal government departments, including the Dept of Primary Industries and various regional funding programs through the Sydney Metropolitan and Hawkesbury Nepean catchment management authorities. For example, the Sydney Metro CMA funded the control of Ludwigia on DECC land during 2005/06 and 2006/07 and the catchment-wide mapping of Ludwigia in 2007/08.

Grants for weed control on Crown land will also continue to be sought from the Dept of Lands by Sutherland and Randwick LCAs.

5.2 Species Management

The **Noxious and Environmental Weed Control Handbook** (2007) published by DPI lists the following control techniques for Ludwigia:

Ludwigia peruviana:

Non-chemical options: Small plants can be manually removed. Dense stands can be slashed and burnt. Take care not to spread the seed.

Chemical and concentration	Rate	Comments
Glyphosate 360 g/L Various trade names for aquatic use only.	10 mL in 1 L of water	Actively growing at or beyond the early bloom stage of growth but before autumn change of colour. Thorough coverage is necessary for best results.
2, 4-D amine 500g/ L Various trade names. PER 6199 PER 7381 These are limited use permits.	125 mL in 100 L of water	Apply as direct application to foliage, minimising run-off from leaf surface. **Do not apply as a broadcast spray over water.**
Picloram 45 g/kg Vigilant ®	Undiluted	Cut stump/stem injection application. Apply a 3-5mm layer of gel for stems less than 20mm. Apply 5mm layer on stems above 20mm (see label).

Ludwigia longifolia:
Non-chemical options: small plants may be manually removed, taking care not to spread seed. For further information see the *Long-leaf Willow Primrose* Weed Alert.

Chemical and concentration	Rate	Comments
Glyphosate 360 g/L Various trade names for aquatic use only. PER 7344	1.0 L per 100 L of water. Undiluted.	Spot spray application. Scrape and paint.

No information is available on the control of *Ludwigia repens*.

Control will be undertaken in accordance with the *NSW Noxious Weeds Act 1993, Protection of the Environment Operations Act (1997),* and *the Pesticides Act (1999).*

No known research has been conducted on introduced biological control agents, although there is some evidence of ecological control by shading under dense planting. Because Ludwigia seedlings require high light levels for germination, it can be appropriate in some locations to establish dense, shady cover following clearing, thereby gaining lasting control. In the long term, reducing nutrient levels entering water bodies can also lower the risk of invasion or spread.

Chemical control should ideally be undertaken from just after the hibernation period (over wintering) to the flowering period. Where water bodies and/or native vegetation are within close proximity, initial manual slashing prior to flowering or stem scraping of dense stands can be undertaken, followed by the spraying of regrowth with Glyphosate 360 g/L. This reduces the risk of over spray of herbicide onto native flora and into water bodies. Results can be improved by slashing stands prior to flowering, then spraying the regrowth 2-4 weeks later. Repeat applications may be required for larger plants, and a follow up program will be required to deal with seedlings. If resources are not available for chemical control, branches can be removed during or just after the flowering period.

<u>Prevention of spread</u>
Correct disposal of seeding material is essential. Where fruit is formed, cut and bag these before removing the rest of the plant. Unless suitably contained on site, all seed capsules should be carefully handled and bagged in single use rip-proof bags and then carefully disposed of in domestic garbage.

Care should also be taken not to inadvertently spread seed attached to clothing. In addition, discarded plant material should never be left in contact with the soil as it may take root.

5.3 Extension and Education

The main focus of continuing education and extension activities will be to increase the skills of relevent council and public authority staff, bushcare volunteers and private landholders in the identification and control of Ludwigia, and make them aware of its regional importance. This will be carried out by:

- Undertaking regional aquatic weed field days/workshops which include Ludwigia
- Training of staff and volunteers in each organisation
- Media articles in local newspapers
- Ludwigia alerts and other brochures to be sent to private landholders with potential for Ludwigia establishment
- Inspections of nurseries re. sale of *Ludwigia longifolia* seedlings.

5.4 Links to other Strategies

The area covered by this plan falls within the Southern Metropolitan Catchment Management Authority (SMCMA) and the Hawkesbury Nepean Catchment Management Authority (HNCMA) regions. Consequently, this plan assists in the implementation of the following Catchment Action Plans:

Draft Sydney Metropolitan Catchment Action Plan:

- Catchment Target B5 – Invasive Species and Threats. By 2016, the impact of terrestrial and freshwater invasive species on biodiversity is reduced by decreasing the number, distribution and impact of invasive weeds, pest animal and pathogens

- Management Target B5.1 – Weed Management. By 2011, the actions identified in the Weed Management Strategy for the Sydney Metropolitan CMA Region have been reviewed and implemented.

Hawkesbury Nepean Catchment Catchment Action Plan:

- River Health Target – RH1: By 2016, an identifiable improvement in the health of riparian lands will be achieved as determined by:
  - maintenance of the condition of all lands identified as being in good condition in the RHS (this includes most reaches within national parks)
  - an increase in the extent and connectivity of native riparian vegetation in areas identified as a priority in the RHS
  - a decrease in key weed species (e.g. canopy invading species/new outbreaks) identified as a priority.

- Biodiversity Target B4: By 2016 there is a reduction in the negative impact of invasive species on both biodiversity and sustainable primary production in terrestrial and aquatic ecosystems.

The plan also contributes to the Natural Resource Commissions (NRC) Statewide target; 'By 2015 there is a reduction in the impact of invasive species'.

This plan sits under both the Weed Management Strategy for the Sydney Metropolitan CMA Region 2007-2011 and the draft Hawkesbury Nepean Catchment Weed Management Strategy 2007-11 (not yet released).

Weed Management Strategy for the Sydney Metropolitan CMA Region 2007-2011
Goal 2: Reduce the impact of existing priority weed problems.
Objective 2.2 Implement coordinated and cost-effective solutions for priority weeds and weed problems.

Action 1. Coordinate the development and implementation of regional weed management plans and projects for priority weeds.

The following National and State weed strategies also guide the overall direction of this plan:

The Australian Weeds Strategy
This plan assists in the implementation of Goal 1 of the Strategy: "Prevent new weed problems" and the following objectives:
1.2 Ensure early detection of, and rapid action against, new weeds.
1.3 Reduce the spread of weeds to new areas within Australia

NSW Weeds Strategy
The plan also meets several 'Desired Outcomes' of the **NSW Weeds Strategy**:

- The development and implementation of programs to reduce environmental degradation and the loss of biodiversity through weed invasions. This can be achieved through monitoring river systems and wetlands to identify aquatic weed problems at an early stage so that they can be controlled with minimal environmental damage, and implementing control programs for weeds which cause major environmental problems;
- The implementation and monitoring of weed control programs on public and State-owned and Crown Land to ensure that objectives are achieved in an efficient and cost effective manner.
- An effective and efficient system for delivery of noxious weeds control and the enforcement of weeds legislation.
- Community participation is supported and follow-up controls are integral to the plan to provide sustainable long-term benefits.

5.5 Barriers and Contingencies

Effective Ludwigia management will be achieved by overcoming the following barriers through the implementation of the respective Actions detailed in Section 6.0:

1. Lack of information on precise extent of Ludwigia in the region (Action 6.1);
2. Ease of spread of the weed and the need to control it before it seeds (Action 6.2);
3. Effective management requires strategic control of Ludwigia on public land (Actions 6.3 and 6.4);
4. Inability to treat Ludwigia on private land (Action 6.5);
5. Lack of awareness of Ludwigia and the potential it has to cause significant environmental degradation (Actions 6.6 and 6.7);
6. Lack of knowledge of the distribution, potential impact and control of the new incursion *Ludwigia repens* (Action 6.8)

6.0 ACTIONS and PERFORMANCE INDICATORS

ACTION PLAN FOR CONTROL	PERFORMANCE INDICATOR	WHO	ADDRESSES WHICH OBJECTIVES
6.1 Undertake surveys to locate and record new and existing Ludwigia infestations. Identify sites that are at risk of having new incursions.	- Surveys and inspections undertaken during Spring each year - All known infestations mapped on local and regional GIS systems by June 2009. - New infestations are recorded immediately. - Followup mapping undertaken annually to monitor progress and success of the plan	LCA's, DECC, CMAs, Sydney Water, RTA, DOL, Centennial Parklands	1. Determine the location and extent of new and existing Ludwigia infestations.
6.2 Strategically eradicate new Ludwigia infestations	- All new infestations are treated within 6 months of detection.	LCA's, DECC, Sydney Water, RTA, DOL Centennial Parklands	2. Strategically eradicate new infestations on public land within 2 years of detection
6.3 Plan and prioritise Ludwigia works eg. Target marginal infestations before core infestations; start at top of catchment; target sites of high biodiversity values first	- All infestations prioritised for treatment by June 2009 - Project plans developed by June 2009.	LCA's, DECC, Sydney Water, RTA, DOL Centennial Parklands	3. Contain and reduce existing infestations on public land within 5 years.
6.4 Control existing Ludwigia infestations on public land according to project plans and available funding.	- No. of hectares/m^2 of existing infestations treated per annum. - Infestations contained by stopping the seeding cycle.	LCA's, DECC, Sydney Water, RTA, DOL Centennial Parklands	3. Contain and reduce existing infestations on public land within 5 years.
6.5 Inspections, notifications and enforcement of the Noxious Weeds Act 1993 undertaken to control Ludwigia infestations on private land.	- No. of inspections and notifications - No. of private landholders who have undertaken Ludwigia control. - Follow up with s.18 notices if no action taken within 3 months.	LCA's, private landholders	4. Ensure Ludwigia infestations on private land are controlled
6.6 Educate and train LCA and agency staff (including management) in Ludwigia ID and control. Information sharing among staff and main contractors about control practices and weed seed spread protocols.	- 1 training workshop per region per year - 1 staff field day - Weed Seed Spread protocols for Ludwigia are distributed to LCA/agency staff and main contractors undertaking control. - Weed Seed Spread protocols are implemented by all LCA/agency/ contractor staff. - Management are aware of responsibilities to control Ludwigia - Ludwigia included in regional weed brochures, WEEDeck and the	LCA's, DECC, Sydney Water, RTA, DOL Centennial Parklands	5. Increase the awareness, identification and control skills among Council/state agency staff and contractors

	committees' website.		
6.7 Provide information, education and training for volunteers and landholders.	- Ludwigia alerts are sent to all high risk properties each year (ie properties with waterways, wet areas, ideal growing habitat) - Educational material attached to enforcement notices - Information distributed at 3 information stalls in the region each year. - 1-2 training workshops per region per year	LCA's, DECC, volunteers, private landholders	6. Increase the awareness, identification and control skills among Bushcare/ Landcare volunteers and private landholders
6.8 Undertake and encourage further investigation of the invasiveness, distribution, potential impact, and the feasibility of eradication of *Ludwigia repens*.	- Surveys of Lane Cove River undertaken annually - Distribution of *L. repens* on Lane Cove River mapped by June 2009 - Information on *L. repens* sought from all sources and disseminated. - Participate in research trials to develop best management practice - Support provided to DPI and National Aquatic Weeds Management Group during investigations and research of *L. repens* and for any subsequent recommendation for a national ban and declaration of Class 5 in NSW. - Weed Alert information on *L. repens* distributed to committee members.	LCA's, DECC, DPI, Royal Botanic Gardens, National Aquatic Weeds Management Group	7. Obtain more information on the distribution, potential impact and control of *Ludwigia repens*

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7.0 MONITOR and REVIEW PROCESS

All participants in this plan will monitor and review the progress of the plan in their area, against the performance indicators, in their reports to weeds committee meetings and annual reports for funding. The plan will also be reviewed annually to allow for any additional/new information.

All treated infestations will be monitored, and follow-up control undertaken where required, as part of the on-going implementation of the action plan. This control will be subject to agency priorities and available funding. The effectiveness of the control techniques will also be monitored and modified as required.

Followup mapping will be undertaken annually to measure changes in the extent of Ludwigia infestations and thus the success of this plan.

8.0 BENEFITS

The implementation of this plan will reduce the environmental damage caused by Ludwigia infestations on both public and private land, and prevent the establishment of new infestations in areas where it is not yet found, thus resulting in significant long term cost savings. Ludwigia has the potential to occupy every wetland and creekline in the Sydney region (as well as other parts of Australia) and the signatories to this plan are committed to preventing this from happening.

Controlling Ludwigia will be of enormous benefit to the biodiversity of both native flora and fauna in wetlands and riparian areas. It will assist in the conservation of various Endangered Ecological Communities and Threatened Plants listed under the *Threatened Species Conservation Act 1995*. It will also result in less sedimentation in wetlands and waterways due to excess organic matter causing deposition. This deposition can cause eutrophication resulting in deoxygenation of the water column, death of fauna and loss of biodiversity. Controlling Ludwigia will prevent the reduction of the rate of flow in waterways, which can result in flooding and will also ensure the continual use of waterways for recreational and navigational purposes.

9.0 RESOURCES

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Ensbey, R & Johnson, A. *Noxious and Environmental Weed Control Handbook – a guide to weed control in non-crop, aquatic and bushland situations 3rd edition* (2007) NSW DPI.

Robinson, L. (1994). *Field Guide to the Native Plants of Sydney*. Kangaroo Press, Sydney

NSW Agriculture (2003). *Weed Alert - Longleaf Willow Primrose Ludwigia longifolia*

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/144644/longleaf-willow-primrose.pdf
http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Ludwigia~repens
http://www.sydneyweeds.org.au
http://www.weeds.org.au
http://www.weeds.crc.org.au/weed_management
http://www.dpi.nsw.gov.au

ATTACHMENT 1

Matrix to determine Priority Areas of Works
for Aquatics / Semi-Aquatic Weeds

Developed by the South West Sydney Weeds Committee – July 2007

Variable		score
Isolated site - mobile		4
Isolated site - contained		1
Core site		1
Class of Creek	Class 1	4
	Class 2	3
	Class 3	2
	Class 4	1
Conservation significance	Endangered species, Endangered community, Endangered population	5
	Site is very close to endangered bushland, endangered species etc, or is part of a regional corridor.	4
	Intact local bushland	3
Impact on recreation	High	5
	Med	3
	Low	1
New infestation		4
Commercial activity - dispersal nurserys, aquariums, market gardens, car boot sales, earth works	High	5
	Med	3
	Low	1
Likliness of success	Eradication	3
	Reduction	2
	Containment	1
Agricultural productivity		5
Totals	**13 + = High Priority**	
	11-12 = Medium Priority	
	10 and less = Low Priority	

State of California
Department of Fish and Wildlife

Memorandum

Date: July 22, 2016

To: Ms. Lynn Sadler
Deputy Director
Department of Parks and Recreation

From: Sandra Morey, Deputy Director
Ecosystem Conservation Division

Subject: Risk Assessment for Uruguay waterprimrose (*Ludwigia hexapetala*)

Per the August 26, 2014, letter requesting risk assessments for five species of aquatic plants identified by the California Department of Parks and Recreation as potentially invasive, please find enclosed the California Department of Fish and Wildlife's (CDFW) risk assessment findings and determination regarding Uruguay waterprimrose (*Ludwigia hexapetala*). Per Harbors and Navigation Code, section 64.5, CDFW included in their assessment:

- Whether Uruguay waterprimrose may obstruct navigation and recreational uses of waterways;
- Whether Uruguay waterprimrose may cause environmental damage, including threats to the health and stability of fisheries, impairment to birds' access to waterways and nesting, roosting, and foraging areas, deterioration of water quality resulting from plant decay, and harm to native plants;
- Whether Uruguay waterprimrose may cause harm to the state's economy, infrastructure, or other manmade facilities such as state water storage facilities and pumping operations, by increasing flood risk, threatening water supplies by blocking pumps, canals, and dams necessitating early control efforts; and
- Whether Uruguay waterprimrose causes or is likely to cause any other harm to California's environment, economy, or human health or safety.

To ensure thorough consideration of the species' ecological characteristics and the specified impacts and threats, CDFW employed the U.S. Aquatic Weed Risk Assessment tool. As specified in sec. 64.5, CDFW consulted with the Department of Food and Agriculture, the Department of Water Resources, the State Water Resources Control Board, the Department of Pesticide Regulation, and the Office of Environmental Health Hazard Assessment, to develop the risk assessment findings and determination.

As fully detailed within the enclosed risk assessment, CDFW concludes that Uruguay waterprimrose should be considered an invasive aquatic plant that causes or is likely to cause economic or environmental harm or harm to human health in California.

CDFW staff have completed a draft risk assessment for coontail (*Ceratophyllum demersum*), which is currently undergoing internal review. CDFW staff has begun assessment of Carolina fanwort (*Cabomba caroliniana*), the fifth of five previously requested assessments, and will soon begin assessment of floating pennywort (*Hydrocotyle ranunculoides*), per your July 13, 2016 request.

If you have any questions regarding this risk assessment, or the others in process, please contact Ms. Martha Volkoff, Habitat Conservation Planning Branch, Invasive Species Program, at (916) 651-8658 or by email at Martha.Volkoff@wildlife.ca.gov.

Enclosure

cc: **California Department of Parks and Recreation**
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Aquatic Plant Risk Assessment

Uruguay waterprimrose, *Ludwigia hexapetala* (Hook. & Arn.) Zardini, Gu & Raven

July 22, 2016

Prepared by:
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INTRODUCTION

The California Department of Parks and Recreation's Division of Boating and Waterways (DBW) is the lead agency of the State for the purpose of cooperating with other state, local, and federal agencies in identifying, detecting, controlling, and administering programs to manage, control, and when feasible, eradicate invasive aquatic plants in the Sacramento-San Joaquin Delta, its tributaries, and the Suisun Marsh. Harbors and Navigation Code (HNC) §64.5 defines an "invasive aquatic plant" as an aquatic plant or algae species, including its seeds, fragments, and other biological materials capable of propagating that species, whose proliferation or dominant colonization of an area causes or is likely to cause economic or environmental harm or harm to human health. Per HNC §64.5, for aquatic plant species that DBW believes may be invasive and desires to manage, control, or eradicate, DBW shall request that the California Department of Fish and Wildlife (CDFW) conduct a risk assessment to determine if the species causes or is likely to cause economic harm or environmental harm or harm to human health. The risk assessment shall be documented in a way that clearly describes the severity and types of impacts caused or likely to be caused by a plant species determined to be an invasive aquatic plant. Within 60 days after completing the risk assessment, CDFW shall report its findings to DBW.

DETERMINATION

Per DBW's August 26, 2014 request, CDFW evaluated whether Uruguay waterprimrose, *Ludwigia hexapetala*, should be considered an invasive aquatic plant in California. To make the determination, CDFW selected a quantitative assessment tool that evaluated aspects of the species' ecology, reproductive potential, dispersal mechanisms, competitive ability, actual and potential impacts (including impacts to navigation and recreation, the environment, economy, and human health as specified in HNC §64.5), and resistance to management. Based on this evaluation and the findings contained herein, CDFW, in consultation with California Department of Water Resources (DWR), State Water Resources Control Board (SWRCB), Department of Food and Agriculture (CDFA), Department of Pesticide Regulation (DPR), and Office of Environmental Health Hazard Assessment (OEHHA), determines that Uruguay waterprimrose (UWP) is an invasive aquatic plant that causes or is likely to cause economic or environmental harm or harm to human health in California.

CURRENT DISTRIBUTION

Waterprimroses are a complex of species belonging to the genus *Ludwigia*, Family Onagraceae. *Ludwigia* species identification can be challenging due to morphological similarities and a history of varying identification in the literature. It is generally accorded that *Ludwigia hexapetala*, the species requested by DBW for assessment, was previously considered synonymous with *L. grandiflora* and *L. grandiflora* ssp. *hexapetala* (DiTomaso et al. 2013), all here referred to by the common name Uruguay waterprimrose, though recent genetic and taxonomic work indicates that *L. grandiflora* and *L. hexapetala* may be separate species (Zardini et al. 1991; Nesom and Kartesz 2000; DiTomaso et al. 2013).

UWP is native to South America, and has been introduced and is considered invasive in temperate to sub-tropical areas of North America (United States), Europe (Great Britain, Ireland, France, Belgium, Switzerland, the Netherlands, Germany, Spain, Italy, Turkey), Africa (Kenya), Australia, and New Zealand (EPPO 2011; Thouvenot et al. 2013). In France, UWP is considered to be the country's most invasive aquatic plant (Thouvenot et al. 2013). UWP was originally introduced into most countries, including the United States, intentionally as an ornamental aquatic plant for water gardens (Verdone 2004; Kaufman and Kaufman 2013). In the United States, UWP was introduced by the early 1900s (Kaufman and Kaufman 2013), though the timing of its introduction into California is not clear. UWP has been present in California as a naturalized weed for several decades (Cal-IPC 2016); however, it was not recognized for its invasive tendencies until recently. In Sonoma County, UWP has been present since at least 1975, but only began spreading around 2000 (Verdone 2004). UWP is now present throughout much of California, and has been documented in each of the following geographic regions, as classified by the State Wildlife Action Plan (CDFW 2015): Central Valley and Sierra Nevada, Cascades and Modoc Plateau, North Coast and Klamath, throughout the Bay-Delta and Central Coast, including the East, West, North, and South (San Francisco) Bay, and South Coast (Calflora 2016).

UWP (*Ludwigia hexapetala*) is listed by CDFA as a noxious weed, and is categorized as having a "high" (severe) level of negative ecological impacts in California (Cal-IPC 2006). Outside of California, UWP is identified as invasive or regulated as noxious, restricted, or prohibited in the states of FL, OR, WA, NC, SC, and OK (CISEH 2013; USDA-NCRS 2014; ODA 2016; ODWC 2016).

RISK ASSESSMENT

UWP was assessed using the U.S. Aquatic Weed Risk Assessment (USAqWRA) tool, which was modified for the U.S. by Gordon et al. (2012) from the New Zealand Aquatic WRA model (Champion and Clayton 2001). The USAqWRA functions as the aquatic alternative to the Australian WRA, which is widely accepted and applied, but inaccurately classifies nearly all aquatic species as invasive, thus requiring modification for the accurate assessment of aquatic plants (Gordon and Gantz 2011). The USAqWRA has been tested for accuracy and validated under the environmental conditions of the U.S. and is the only assessment tool developed for the U.S. that maximizes accuracy for aquatic plants and incorporates all of the factors outlined in HNC §64.5.

The USAqWRA defines non-invaders as having no evidence of establishment outside of cultivation (in non-native ranges). Minor invaders are defined as species that have established in non-native ranges, but with no described ecological impacts. Major invaders are defined as having established in non-native ranges, and having documented, negative ecological impacts. Species are categorized using a scoring system of <31 (non-invaders), 31 – 39 (evaluate further), and >39 (major invaders). Gordon et al. (2012) determined that using the threshold score of 39 to distinguish major invaders from both minor and non-invaders maximized overall accuracy of the assessment tool at 91%.

CDFW conducted a thorough search of peer-reviewed journals and government publications to accurately complete the assessment. The resulting evaluation of UWP invasiveness (Appendix A) produced a score of 76 predicting UWP to be a "major invader" of the Sacramento-San Joaquin Delta. The findings using the USAqWRA model are summarized below, along with additional findings relevant to assessing potential impacts.

ECOLOGY

UWP is an emergent, perennial macrophyte that exhibits an annual growth pattern. UWP dies back each winter, but the submerged or buried roots and rhizomes of established UWP plants survive winter temperatures as low as -11°C (12.2°F) and new shoots emerge from the rhizomes in the spring when temperatures reach 12 – 15°C (53.6 – 59°F), typical of springtime temperatures in the Delta (EPPO 2011; Santos et al. 2011; Thouvenot et al. 2013). Though UWP is an emergent plant, it is also known to creep on land; stems may become bushy and/or climb on other plants (Thouvenot et al. 2013; Hoch and Grewell 2016). UWP displays a high level of phenoplasticity depending on its environment (Hussner 2010; Lambert et al. 2010). Stems, when floating, are glabrous and produce white, spongy roots at the nodes; when erect, stems are spreading-hairy (Hoch and Grewell 2016). Growth occurs primarily in late spring and summer; once stems reach the water surface, rosettes of leaves are formed, after which branching occurs (EPPO 2011; Thouvenot et al. 2013). UWP flowers from late spring through fall; in the early winter, emergent parts of the plant break up and die back (Thouvenot et al. 2013; Calflora 2016).

UWP is common in a wide variety of habitats, including rivers, streams, irrigation canals, drains, lakes, ponds, marshes, and wet meadows (Branquart et al. 2007; Rolon et al. 2008; Hernandez and Rangel 2009; Haury et al. 2011; Thouvenot et al. 2013). It is limited by flow velocity, but does colonize river margins (EPPO 2011). UWP can be found at depths of up to 3 m, but generally prefers shallow water between 0.6 and 1 m; stems can emerge up to 0.8 m above the water surface (Lambert et al. 2010). UWP is tolerant of flooded, partially flooded, and drained soils (Hussner 2010). UWP tolerates fluctuating (by 3 m) water levels by differential production of root and shoot biomass, likely an advantage under predicted climate change models (Hussner 2010). UWP requires flooded or aquatic conditions to settle, but after establishment will tolerate moist terrestrial conditions for years (Haury et al. 2011). UWP is not limited by soil type or pH and can be found growing in mud, peat, sand, or gravel ranging from acidic to alkaline conditions (Hussner 2010; EPPO 2011; Thouvenot et al. 2013). UWP is a strictly freshwater plant and does not tolerate salinities in excess of 6 ppt (EPPO 2011). It grows best in mesotrophic to eutrophic waters, but is tolerant of oligotrophic conditions (Hussner 2010). Due to its production of pneumatophores, UWP is tolerant of anoxic conditions (EPPO 2011; Thouvenot et al. 2013).

REPRODUCTIVE POTENTIAL

UWP reproduces both sexually and vegetatively, through rhizomatous growth and fragmentation. Plant stems and rhizomes of UWP readily fragment year-round; stem fragments are buoyant and produce adventitious roots (EPPO 2011; Thouvenot et al. 2013). Plants produce yellow flowers from May to December in California (Calflora 2016), with shortened bloom periods in cooler climates (Thouvenot et al. 2013). Fruiting occurs in the fall, with dense infestations (> 80% cover) producing seed capsules on up to 70% of stems; potential seed set can reach up to 10,000 seeds/m^2 (DiTomaso and Healy 2003; Ruaux et al. 2009). Each capsule contains up to 59 seeds, which remain within fruits during dispersal. Capsules may float for more than 3 months, during which time they are dispersed by wind, water currents, fish, and aquatic birds (Ruaux et al. 2009; Thouvenot et al. 2013). Seed viability has been reported as high as 75%, though viability is reduced by over 50% when temperatures fall below freezing (Ruaux et al. 2009). Though UWP seeds persist at least overwinter, length of seed viability is unclear and germination cues are unknown (Ruaux et al. 2009; EPPO 2011). Though polyploid species such as UWP (2n = 80) often have increased seedling survival (Zardini et al. 1991; Okada et al. 2009; USDA-ARS 2016), Verdone (2004) suggests the UWP population in the Laguna de Santa Rosa (Sonoma County, California) produces sterile seeds. Further, Okada et al. (2009) suggest that California populations spread almost exclusively via vegetative reproduction, finding that within each of 27 distinct populations across California, 95% of ramets belonged to a single genet.

DISPERSAL MECHANISMS

Due to its attractive yellow flowers and shiny, dark green leaves, UWP was originally imported into the United States as an ornamental plant for use in horticulture and water gardens. Original populations are believed to have been established when the plant escaped or was dumped from unwanted water gardens (Ruaux et al. 2009; Thouvenot et al. 2013). UWP has also been intentionally planted as part of bioremediation efforts, as it sequesters nutrients very effectively (Verdone 2004). UWP populations have been present in California for decades as a naturalized non-native, but around 2000 began aggressively expanding and invading habitats (Meisler 2009). UWP expansion and dispersal occurs primarily vegetatively, through fragmentation, given that germination of UWP seeds in the field appears to be uncommon in California (Okada et al. 2009). Plant fragments and seed capsules may float for as long as 3 months and are readily dispersed by wind and water currents (Verdone 2004; Ruaux et al. 2009; DiTomaso et al. 2013; Thouvenot et al. 2013; Hoch and Grewell 2016). Fragments are also easily transported via human activities and may be transported by watercraft, trailers, and equipment (Verdone 2004; DiTomaso et al. 2013). UWP also spreads via animal-mediated dispersal; aquatic birds and fish may consume seed capsules and transport them to new locations, and waterfowl are thought to transport UWP fragments in their plumage (Verdone 2004; Ruaux et al. 2009).

COMPETITIVE ABILITY

When conditions are favorable, UWP is able to out-compete established native vegetation, both aquatic and terrestrial, and is considered to be a transformer or engineer species as it is capable of covering entire waterbodies and altering water quality (Verdone 2004; Lambert et al. 2010). Due to its matting growth, which shades other aquatic plants, UWP is able to out-compete species of other growth forms, including both submerged and floating aquatic vegetation (Stiers et al. 2011).

Recognizing the limitations of *Ludwigia* identification, CDFA reports, according to their observations, waterprimrose is among the most widespread and competitive of all aquatic plants in low-elevation, slower-moving, shallower waterbodies in California. In the Delta, it is in constant and intense competition with water hyacinth (*Eichhornia crassipes*) and floating pennywort (*Hydrocotyle ranunculoides*) to control the edges of channels or shallow flats, and the winner can change with location or time. CDFA reports having seen it outcompete and replace water hyacinth in undisturbed, shallow sloughs. Where it is competitive, it usually grows as a monoculture. UWP is not recognized for being able to significantly invade and displace tule stands or well-established cattails, but few other plants seem able to withstand it (P. Akers, CDFA, personal communication). In less favorable conditions, UWP may not be able to out-compete established vegetation, but will rapidly colonize previously de-vegetated areas or newly created habitat, especially in areas with disturbed hydrology and high nutrient loading (Verdone 2004; Lambert et al. 2010). Rate of UWP expansion is very rapid under ideal conditions. At Laguna de Santa Rosa, UWP reached 100% cover in over 3 miles of main channel within 2 years (1,450 acres; Verdone 2004). It often chokes out areas that are less than several feet in depth or slow-moving channels that are less than perhaps 40 feet wide (P. Akers, CDFA, personal communication).

REALIZED AND POTENTIAL IMPACTS

Obstruction of Navigation and Recreation

Both above and below the water surface, UWP forms expansive mats of dense vegetation that impede many recreational activities, including boating, swimming, fishing, and hunting (Verdone 2004; EPPO 2011). UWP infests main channels as well as shorelines, and recreational access from shore can be impossible in areas of dense cover (EPPO 2011). UWP is capable of clogging channels and boat launches to the extent that boating is no longer possible, or is severely restricted (Meisler 2009). In severe infestations, waterbodies may be closed (Thouvenot et al. 2013). According to CDFA, in California UWP presents major problems for boat access, or any other activity, is generally one of the major nuisances for marinas and boat ramps, and can stall even powerful boats (P. Akers, CDFA, personal communication). Boat propellers easily become tangled in the underwater stems of UWP and can chop UWP into fragments that float downstream, exacerbating the problem (Meisler 2009). Fishing and hunting access is similarly limited; fishing gear easily tangles in UWP mats, and fishing opportunities decrease as the underwater mats can be so dense as to impede fish movement (Verdone 2004). Although UWP dies back in the winter, decaying mats of UWP continue to impede recreational activities as well as decrease their appeal (Thouvenot et al. 2013).

Environmental Effects

Water quality – Dense mats of UWP cause a variety of environmental impacts, including chemical, hydrological, and ecological (Dandelot et al. 2005; EPPO 2011). Ecological and economic problems caused by UWP are so severe this species is considered the most invasive aquatic weed in France (Thouvenot et al. 2013) and a "transformer species" (Dandelot et al. 2005). UWP alters water quality and chemistry in areas of heavy infestation by reducing water flow, increasing sedimentation, and creating anoxic conditions through decomposition, root respiration, and its dense growing condition, which prevents surface exchange of oxygen and reduces light so submerged plants are unable to photosynthesize effectively (Dandelot et al. 2005; EPPO 2011). Water under UWP mats also has higher sulfide and phosphate concentrations, and lowered sulfate and nitrate concentrations (CABI 2014).

Native plants – A primary ecological impact of UWP is the reduction in the abundance and diversity of plants and animals. UWP has been shown to significantly reduce native plant abundance and diversity in both Europe (Dandelot et al. 2005; EPPO 2011; Stiers et al. 2011) and in California (Verdone 2004). In Belgium, infestations of UWP decreased native plant species richness by 70% compared to uninvaded areas; < 25% cover of UWP reduced species richness similarly to 100% cover of UWP (Stiers et al. 2011). In addition to out-competing native vegetation and invading newly created habitat (Lambert et al. 2010), UWP reduces competition via production of allelopathic compounds that decrease germination, increase mortality, disrupt seedling elongation, and inducechlorosis in other terrestrial and wetland species (Dandelot et al. 2008).

Birds and waterfowl – Bird habitat is severely degraded in areas heavily infested with UWP (Verdone 2004). Access to feeding areas, both from the shore and from above, becomes limited due to large mats of UWP (Kaufman and Kaufman 2013). As UWP reduces plant species abundance and diversity, food sources become more limited as well, although some waterfowl will consume UWP (Verdone 2004). The Delta, including the Laguna de Santa Rosa, is a part of the Pacific Flyway, and the UWP infestation in the Laguna has already reduced available feeding, nesting, breeding, and resting sites (Verdone 2004). Additionally, over one-third of bird species found in the Laguna are susceptible to West Nile Virus, most commonly vectored by mosquitoes of the genus *Culex*, for which UWP provides ideal habitat (Sears et al. 2006).

Health and stability of fisheries – In areas of dense growth, UWP also reduces biodiversity of native fauna, specifically fishes and invertebrates, likely by a combination of anoxic conditions and unsuitable substrate (heavy mats of decaying plant matter) (EPPO 2011; Stiers et al. 2011). In UWP invaded ponds in Belgium, increased invasive plant cover was negatively correlated (n = 22, $r = -0.46$, $P < 0.05$) with invertebrate abundance (Stiers et al. 2011). In UWP invaded (> 50% cover) ponds, invertebrate abundance was reduced by approximately 60% compared to uninvaded ponds, significantly reducing an important food source for fish populations (Stiers et al. 2011). Dense matting of underwater stems also excludes fish (Dandelot et al. 2005; EPPO 2011; Thouvenot et al. 2013). High densities of UWP become a barrier impeding fish passage, including migrations of salmonids through the Delta (Verdone 2004). Water amid UWP mats is also characteristically low in oxygen levels, which also reduces fish presence (Dandelot et al. 2005; EPPO 2011).

Economic, Infrastructure, or Man-made Facilities

UWP's habit of dense, matting growth in slow flowing water clogs irrigation and drainage canals, leading to impacts on water delivery for irrigation (EPPO 2011). Canals can provide ideal conditions for rapid biomass production; total infested area can double in as few as 15 days, exacerbating impacts to water delivery (EPPO 2011). However, CDFA suggests canals with higher rates of flow and steeper banks may provide less suitable conditions for UWP growth (P. Akers, CDFA, personal communication). Dense growth of UWP slows water velocities, increasing sedimentation rates and leading to increased risk of flooding (Meisler 2009). Additionally, UWP is a successful invader of wet and flooded meadows and displaces wetland grasses, but has low palatability to cattle and horses and can lead to reduced forage quality and increased feed costs for livestock farmers (EPPO 2011). A separate, but similar, species of waterprimrose, *Ludwigia hyssopifolia*, is a major weed of rice crops in Asia (Chauhan et al. 2011); the Delta is an important region for rice-growers in California and UWP has the potential to become a major weed in California's rice fields.

Human Health

Dense mats of UWP restrict water flow, creating ideal habitat for mosquito reproduction, especially primary vector species (*Culex* spp.) for West Nile virus (Sears et al. 2006). Additionally, UWP's dense surface growth inhibits effective (in-water) application of mosquito larvicides, necessitating aerial or broadcast applications of less-effective adulticides (Sears et al. 2006). In the Laguna de Santa Rosa, record numbers of mosquitoes were captured by the Marin/Sonoma Mosquito and Vector Control District near dense growth of UWP in 2004, the same year that West Nile Virus arrived in the area (Meisler 2009). As a result, a task force was formed to implement a multi-year control effort for UWP in the Laguna (Meisler 2009).

UWP's dense, matting growth can lead to increased water levels and flooding by slowing flow velocities and trapping sediments (Meisler 2009). Submerged aquatic plants, such as Eurasian watermilfoil (*Myriophyllum spicatum*) and hydrilla (*Hydrilla verticillata*), have been recognized for entangling swimmers in their dense underwater growth, in some cases leading to drowning (CAST 2014). Although UWP is not a submerged plant, and no studies have been found investigating its potential for contributions to drownings, given its dense, matting growth of underwater stems it is possible that UWP infestations could also contribute to drownings.

RESISTANCE TO MANAGEMENT

UWP can be controlled by various means, including hand removal, mechanical harvesting, cultural control, shading, biological control agents, and herbicides (Pine and Anderson 1991; Meisler 2009; Harms and Grodowitz 2012; DiTomaso et al. 2013; Hernández and Walsh 2014). Hand removal can be effective, but is time-consuming and impractical over large areas with dense cover. Mechanical harvesting, as found in the Laguna de Santa Rosa UWP control effort, produces UWP fragments that can float downstream, creating new populations and adding to existing ones (Meisler 2009). In the case of the Laguna de Santa Rosa, a pathway had to first be cleared by chopping a path through the UWP, creating numerous plant fragments, each capable of forming a new plant (Meisler 2009). These fragments had to be collected downstream using a silt screen attached to a floating boom (Meisler 2009). Once a path was cleared and herbicide could be applied, in some areas removal of the sprayed vegetation was determined to be prohibitively expensive, and had to be left in place (Meisler 2009).

Herbicide application can be problematic in areas of dense growth, where UWP is often thick enough to prevent even airboat passage. With adequate access, herbicides are an effective measure; DiTomaso et al. (2013) offers multiple options, several of which (glyphosate, 2,4-D, and imazamox) are registered with the U.S. Environmental Protection Agency and the California Department of Pesticide Regulation and are currently utilized by DBW in their treatment of floating aquatic vegetation in the Delta (L. Ramos, DBW, personal communication).

The aforementioned active ingredients are currently allowed for use under the Statewide General National Pollutant Discharge Elimination System Permit for Residual Aquatic Pesticide Discharges to Waters of the United States from Algae and Aquatic Weed Control Applications, Water Quality Order 2013-0002-DWQ. However, if additional aquatic pesticide active ingredients approved by DPR are proposed to be used for UWP control other than 2,4-D, acrolein, calcium hypochlorite, copper, diquat, endothall, fluridone, glyphosate, imazamox, imazapyr, penoxsulam, sodium carbonate peroxyhydrate, sodium hypochlorite and triclopyr-based algaecides and aquatic herbicides, and adjuvants containing ingredients represented by the surrogate nonylphenol, the SWRCB can amend the above referenced permit to add the DPR-approved aquatic pesticide(s). The amendment process typically requires around 4 months to process and is initiated by written request to the SWRCB-Division of Water Quality (R. Norman, SWRCB, personal communication).

As suggested by DiTomaso et al. (2013), cultural control would involve reducing nutrient loading and managing flood/dry conditions. However, cultural control may not be a viable management option given conditions in the Delta and UWP growth habits. There may be multiple options for biological control, primarily by insects (Pine and Anderson 1991; Harms and Grodowitz 2012; Hernández and Walsh 2014). Research has been conducted to identify specialist insect feeders on UWP, with some success (Harms and Grodowitz 2012; Hernández and Walsh 2015). However, the presence of a native *Ludwigia* spp. in California complicates the prospect of biological control. Grass carp will consume UWP, but preferentially feed on many other species before consuming UWP (Pine and Anderson 1991).

Only one case of eradication of UWP is thought to have been successful; a population in Southern England (Lambert et al. 2010). In England, UWP is not yet widespread, as it is in California (Gallardo and Aldridge 2013). In California, control efforts in the Laguna de Santa Rosa (herbicide and mechanical measures) produced mixed results (Meisler 2009). Success varied with channel depth; deeper channels retained reduced regrowth for up to 4 years, but shallow channels displayed significant regrowth each year (Meisler 2009). All *Ludwigia* removed from the Laguna de Santa Rosa was placed and composted on agricultural lands adjacent to the area it was removed. The remnant plants composted well, had no adverse odor, and easily incorporated into the soil once degraded (E. Larson, CDFW, personal communication).

Assessing UWP infestations in the Delta may be more difficult due to the potential presence of other *Ludwigia* species, some native and others also considered invasive. Given that few studies have been conducted on UWP invasion and management, USDA-ARS (2016) is currently conducting experiments on Russian River and Delta populations of UWP to evaluate factors influencing the establishment, spread, and management of *Ludwigia* species. Results from this study, which is expected to be completed in September 2016, may be useful in informing management decisions.

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APPENDIX A: Risk Assessment of Uruguay waterprimrose, *Ludwigia hexapetala*

Species: Uruguay waterprimrose*; Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
1.1	Temperature tolerance	**(0-3)** Score 3 if maintains photosynthetic tissue and summer growth form throughout winter, 2 if dies back to tuber/bulb/rhizome (or similar structure) during winter, 1 if adult plants completely die but viable seeds remain. Use a climate matching tool if direct evidence is not available. Default = 1 for annual species.	2	Dies back to rhizomes over winter. Minimum growth temperatures are 12-15 °C; can survive below -11 °C.	EPPO 2011; Thouvenot et al. 2013
1.2	Range of habitat	**(1-3)** Score 3 if able to grow from water to dry land, 2 if water to wetland, or from shallow to deep (>5 m) water, 1 narrow range. Default = 1 if no information is available; 2 for free-floating plants, unless more information is available.	2	Prefers shallow water, but grows in water up to 3 m deep. Can survive on flooded to drained soils.	Lambert et al. 2010; Haury et al. 2011
1.3	Water/ substrate type tolerance	**(1-2)** Score 2 if tolerant of sandy to muddy (or peaty) substrate, or oligotrophic to eutrophic waters, 1 if restricted by either. Default = 1 if no information is available.	2	Grows in nutrient-poor to nutrient-rich soils and gravel/sand.	Hussner 2010; EPPO 2011; Thouvenot et al. 2013
1.4	Water clarity tolerance	**(0-1)** Score 1 if unaffected by water clarity (i.e. floating or emergent, or submergents tolerant of very low light levels, such as *Myriophyllum spicatum* and *Hydrilla verticillata*), 0 if affected by water clarity.	1	Emergent plant, thus unaffected by water clarity.	Thouvenot et al. 2013; Hoch and Grewell 2016
1.5	Salinity tolerance	**(0-1)** Score 1 if species can tolerate saline conditions, 0 if not. Habitat information can be used to determine a score of 0 if species is only found to occur in freshwater habitats.	0	Intolerant of salinities in excess of 6 ppt.	EPPO 2011
1.6	pH tolerance	**(0-1)** Score 1 if tolerant of both acidic and basic pH or no information is available, 0 if restricted to neutral, basic, or acidic pH.	1	Tolerant of both acidic and alkaline conditions.	Thouvenot et al. 2013
1.7	Water level fluctuation - Tolerates periodic flooding/ drying	**(0-3)** Score 3 for species which have evidence of tolerating periodic flooding/drying with a specified time period longer than 1 month (e.g., "months"; "X months", "winter flooding"), 2 for evidence of tolerance of flooding/drying over a period of days/a couple of weeks, 1 for species that die back during periods of flooding/drying, and 0 for species that do not tolerate flooding/drying. Do not score if there is no information available.	3	Requires water for colonization, but once established as a terrestrial plant can survive for years.	Haury et al. 2011

Species: Uruguay waterprimrose; *Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
2.1	Lentic - rivers, streams, drains, or other flowing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	2	Present along river margins. Prefers slow-flowing waters.	EPPO 2011; Thouvenot et al. 2013
2.2	Ponds, lakes and other standing waters, including their margins	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed (common, but rarely or never dominant), 1 if present but not weedy, 0 if absent.	3	Dominates in standing waters.	Verdone 2004; Stiers et al. 2011; Thouvenot et al. 2013
2.3	Swamp, marsh, bog, or other wet areas not covered by 2.1 or 2.2	**(0-3)** Score 3 if major weed (reaches high density and dominates plant community), 2 if minor weed, 1 if present but not weedy, 0 if absent.	3	Dominates in standing waters.	Verdone 2004; Stiers et al. 2011; Thouvenot et al. 2013
2.4	Establishment – into existing vegetation	**(-5, -3, 0)** Score 0 if able to invade unmodified vegetation, -3 if the species can only colonize certain types of vegetation (e.g., turf-forming shoreline vegetation), -5 if there is no evidence that the species can move into intact vegetation. Default = 0 if there is evidence of establishment, but no specific information about level of invasion into existing vegetation and/or type of vegetation being invaded. Default = -3 for species that have not naturalized outside of their native range.	0	In favorable conditions, can out-compete existing native vegetation.	Lambert et al. 2010
2.5	Establishment – into disturbed vegetation	**(0, 1, 5)** Score 5 if able to aggressively colonize following vegetation clearance, newly constructed waterbodies or nutrient enrichment, 1 if the species grows in disturbed areas, but there is no other information, 0 if there is no evidence of establishment in disturbed areas. Information from either the native or introduced range may be used to answer this question. Default = 1 for no information.	5	Aggressively colonizes disturbed areas of vegetation.	Lambert et al. 2010; EPPO 2011; Thouvenot et al. 2013
3.1	Competition – between growth form	**(0, 1, 2)** Score 2 if species forms dense stands that are documented to displace other growth forms (submerged, floating, emergent), 1 if some suppression, 0 if no displacement. Default = 0 if species has been in the trade globally for >30 years and there is no information about the species displacing other growth forms.	2	Displaces wetland grasses and native floating and submerged plants by shading.	EPPO 2011; Stiers et al. 2011

Species: Uruguay waterprimrose; *Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
4.1	Dispersal outside catchment by natural agents (e.g. birds, wind)	**(0, 1, 3, 5)** Score 5 if species (including seeds, rhizomes, fragments etc.) well adapted, and likely to be frequently dispersed, by natural agents, 3 if transport by natural agents is possible but uncommon, 1 if propagule could be spread in bird crop, 0 if no, or extremely low, likelihood of dispersal by natural agents (e.g., *Hydrilla* is scored 1 because its turions can survive passage through duck guts, an agent of dispersal, but this is believed to happen rarely).	5	Floating fragments and propagules readily disperse via wind and water currents. Fish and birds also facilitate dispersal. Sexual reproduction is minimal in CA, but seed capsules can float for 3 months.	Verdone 2004; DiTomaso and Healy 2003; Ruaux et al. 2009; Thouvenot et al. 2013
4.2	Dispersal outside catchment by accidental human activity	**(1, 2, 3)** Score 3 if major pathway, seeds/fragments adapted for easy transportation (e.g., via boat/trailer, fishing gear), 2 if the species is a floating plant or a macrophyte, but no explicit mention of high spread in the literature, 1 not mentioned, not likely to be spread by human activity based on growth form and life history. Default = 1 if no information is available.	3	Fragments are easily transported by human activities.	Verdone 2004; DiTomaso et al. 2013; Thouvenot et al. 2013
4.3	Dispersal outside catchment by deliberate introduction	**(0-1)** Score 1 if species is desirable to humans (e.g., or used for medicinal, food, ornamental, restoration, etc. purposes in the U.S. or elsewhere). If species is not used or no information exists, score should be 0.	1	Originally imported into the U.S. as an ornamental. Produces some medicinal compounds. Used for nutrient sequestration.	Verdone 2004; Ruaux et al. 2009; Thouvenot et al. 2013
4.4	Effective spread within waterbody/ catchment	**(0-1)** Score 1 for extensive spread within a waterbody or among waterbodies, 0 for no spread. Occurrence along streams or riverbanks or in rivers can be used as evidence, as well as evidence of water dispersal. Do not answer if no information is available.	1	Populations expand via rhizomatous growth and readily disperse via floating fragments.	Thouvenot et al. 2013
5.1	Generation time (time between germination of an individual and the production of living offspring, not seeds or other dormant structures)	**(1, 2, 3)** Score 3 if rapid (reproduction in first year and >1 generation/year), 2 if annual or produces one generation every year including the first year, 1 if not reproductively mature in the first year. Default = 1 if no information is available.	3	Plants readily fragment beginning immediately after germination.	Thouvenot et al. 2013

Species: Uruguay waterprimrose*; Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
6.1	Seeding ability - Quantity	**(0-3)** Score 3 if >1000 seeds/plant/year, 2 100-1000, 1 <100 and/or evidence that seed are produced (in native or introduced range), 0 if seed not produced.	2	Each fruit capsule contains up to 59 seeds, with many fruits per plant.	Ruaux et al. 2009
6.2	Seeding ability - Viability/ persistence	**(0-2)** Score 2 if highly viable for >3 years, 1 low viability or evidence of seed production with no information on viability, 0 no viable seeds.	1	Seed viability very low in California; no information on length of seed viability. Plant primarily spreads vegetatively.	Verdone 2004
7.1	Vegetative reproduction	**(0, 1, 3, 5)** Score 5 for naturally fragmenting from rhizomes, stolons, or other vegetative growth into tissue capable of producing new colonies (e.g., *Egeria densa*), 3 if produces rhizomes/stolons, but there is no other information about the formation of new colonies elsewhere, 1 for clump-forming by vegetative spread, 0 for no vegetative spread.	5	Extensive rhizomatous growth. Readily fragments and forms new plants.	Okada et al. 2009; Thouvenot et al. 2013
8.1	Physical-water use, recreation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Completely covers waterways, impeding recreation.	Thouvenot et al. 2013
8.2	Physical – access	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Due to its tendency to grow in shallow waters, it can eliminate bank access.	Thouvenot et al. 2013
8.3	Physical - water flow, power generation	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Impedes water flow in heavily infested areas.	EPPO 2011
8.4	Physical - irrigation, flood control	**(0-2)** Score 2 for major nuisance, 1 for minor nuisance. Default = 0 if the species has not naturalized outside of its native range. If there is a reasonable amount of information about the species and it has naturalized outside of its native range, default = 0.	2	Traps sediment and can clog irrigation canals and drainages.	EPPO 2011

Species: Uruguay waterprimrose; *Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
8.5	Aesthetic - visual, olfactory	**(0-2)** Score 2 for both visual and odor problems, 1 either, 0 neither or no mention of these impacts. Surface matting of macrophytes scores 1 for visual impact.	0	No odor problem; creates dense mats along the surface, but has attractive yellow flowers and shiny, dark leaves.	Meisler 2009; Kaufman and Kaufman 2013
9.1	Reduces biodiversity	**(0, 1, 3, 5)** Score 5 for extensive monospecific stands, 3 for species that become dominant, 1 for small monospecific stands, and 0 if species does not become dominant over other species. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	5	Forms extensive monospecific stands.	Thouvenot et al. 2013
9.2	Reduces water quality	**(0, 1, 3)** Score 3 if evidence that this species causes deoxygenation (e.g., through extensive growth in shallow water) or other water quality loss (e.g., loss of water clarity because of high decomposition rates continuously during the growing season), 1 if deoxygenation or other water quality loss is likely based on seasonal growth cycles (e.g., macrophyte that gets to high density and dies off at end of summer), 0 otherwise. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	1	Causes seasonal deoxygenation through extensive growth in shallows and decomposition.	Dandelot et al. 2005
9.3	Negatively affect physical processes	**(0, 2)** Score 2 if species alters hydrology (e.g., increases the chance of flooding) or substrate stability (e.g., increases amount of sediment erosion or deposition), or other physical processes, 0 if the species has no history of modifying physical processes. Default = 0 for this question if species has been in the trade globally for >30 years and no information is found or if the species is not naturalized outside of its native range.	2	Increases chance of flooding; increases sedimentation.	Verdone 2004; Thouvenot et al. 2013
10.1	Human health impairment (e.g. drowning, poisonous, mosquito habitat)	**(0-2)** Score 1 for one effect, 2 for 2 or more effects.	1	Creates large areas of habitat for mosquito reproduction ideal for primary West Nile Virus vector species (*Culex* spp.); increased drowning risks possible, but unconfirmed.	Sears et al. 2006; Meisler 2009; CAST 2014

Species: Uruguay waterprimrose*; Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
10.2	Weed of agriculture, including crops, livestock and aquaculture	**(0-1)** Score 1 if a problem agricultural weed, 0 if no evidence that it is an agricultural weed, or if evidence states that species is in agricultural areas but not problematic.	1	Does invade wet meadows and pastures. Unpalatable and low preference forage for cattle and horses. Similar species of *Ludwigia* is a major weed of rice crops in Asia.	Chauhan et al. 2011; EPPO 2011
11.1	Management - Ease of management implementation	**(0-2)** Score 2 if accessibility to weed is difficult, e.g. dense tall impenetrable growths or growing in habitats that are difficult to access by roads or waterways (e.g., swamps). For species that have naturalized outside of their native range, default = 0-2 based upon evidence about habitat and/or growth form if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	2	Growth is impenetrable when dense and occurs in water up to 3 m deep. Often grows in difficult-to-access areas (e.g., marshes, across channels).	Meisler 2009; Thouvenot et al. 2013
11.2	Management - Recognition of management problem	**(0-1)** Score 1 if difficult to assess weed, e.g., submerged; looks like another species. For species that have naturalized outside of their native range, default to a score between 0-1 based upon growth form evidence if there is no direct evidence from the literature. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Identification of *Ludwigia* species is very difficult. Some species of *Ludwigia* are native to the Delta.	DiTomaso et al. 2013
11.3	Management - Scope of control methods	**(0, 1, 2)** Score 2 if no control method, 1 if only one control option. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	0	Multiple control methods are possible (mechanical, chemical biological), but mechanical or chemical are currently the most viable options.	Meisler 2009; DiTomaso et al. 2013; Thouvenot et al. 2013

Species: Uruguay waterprimrose*; Ludwigia hexapetala*					
	Question - USAqWRA	**Score and guidance – USAqWRA**	**Score**	**Justification**	**Reference**
11.4	Management - Control method suitability	**(0-1)** Score 1 if control method not always acceptable, e.g., grass carp, unregistered herbicide. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Not all herbicides are approved for aquatic use in California. Grass carp will consume *Ludwigia*, but prefer submersed plants and not viable option in Delta.	Pine and Anderson 1991; DiTomaso et al. 2013;
11.5	Management - Effectiveness of control	**(0, 1, 2)** Score 2 if ineffective, 1 if partial control. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Partial control possible over limited time periods of 1–3 years. Density is reduced more easily than area.	Meisler 2009
11.6	Management - Duration of control	**(0, 1, 2)** Score 2 if no control, 1 if control for 3+ months. If species has naturalized outside of its native range, and there is no direct evidence for either 11.1 or 11.2, do not answer if there is no information. If there is direct evidence for 11.1 and/or 11.2, default to 0 if there is no information for this question. Default = 0 if species has not naturalized outside of its native range and has been in the trade globally for >30 years.	1	Partial control for 1–3 years.	Meisler 2009
12.1	Problem in other countries	**(0, 1, 3, 4, 5)** Score 5 if species has been reported to be a widespread problem (i.e., a harmful weed in many other countries), 4 if species has been reported to be a harmful weed in 5 or fewer countries, 3 if species has been reported to be a widespread adventive (but not a harmful weed) in many other countries, 1 if species has been reported to be adventive in 5 or fewer countries, 0 if not adventive elsewhere.	5	*Ludwigia* is considered problematic in France, Ireland, Italy, Spain, Germany, Switzerland, the Netherlands, Great Britain, Belgium, Turkey, Australia, New Zealand, and Kenya.	EPPO 2011; Thouvenot et al. 2013
	USAqWRA Score		**76**		

Water Primrose *Ludwigia grandiflora*

A Management Guide for Landowners

Version 1 (2016)

Introduction

This document provides practical guidance and tools for the control and eradication of water primrose *Ludwigia grandiflora*, one of the most potentially damaging invasive species threatening our wetlands. It also provides the basis of an agreement between the Environment Agency and the landowner or person responsible for a site containing water primrose. This will help to deliver the eradication of the plant of behalf of the landowner. The national programme for the eradication of water primrose is being coordinated by the Environment Agency.

What is Water Primrose?

Water primrose *Ludwigia grandiflora* is a perennial plant associated with wetlands and the margins of watercourses, ditches, ponds and lakes. It has become a serious invader of wetlands in Western Europe, where it spreads by vegetative fragments and forms dense carpets of growth that exclude native species, increase flood risk and siltation and degrade amenity.

Water primrose is native to South and Central America and parts of the USA. It was introduced to France in 1830 and has become one of the most damaging invasive plants in that country. It has been introduced into the United Kingdom through the ornamental plant trade, but was banned from sale in England in April 2014.

In 2010 the GB Non-Native Species Secretariat (NNSS) identified a high risk that water primrose could spread across the whole UK. Water primrose then became the target of an Invasive Species Action Plan (ISAP) which describes plans for its eradication and tasks the coordination of that role to the Environment Agency (EA). The ISAP is shown in Appendix 1. Many of the ISAP actions are now complete and it will be updated shortly.

The task is urgent. It has been estimated that it will cost £73K to eradicate water primrose from GB, saving £242 million from what would be required if it spread unchecked (Defra commissioned report from CABI 2010: *The Economic Cost of*

Invasive Non-Native Species to the British Economy). Currently we know of 30 sites (29 in England, 1 in Wales), and we believe that ten of these sites have been eradicated successfully. If we succeed in eradicating water primrose, British wetlands may in the future achieve a particular European significance because we have preserved them from water primrose inundation.

Identification of *Ludwigia*

The plant has several growth forms depending on habitat and time of year, and can be hard to identify when not in flower. In the spring its stems spread out along mud or the surface of water, with small oval leaves. During summer the leaves become more spear shaped and the stems grow upwards. From July until October, distinctive bright yellow 5-petaled flowers form. In the winter the plant dies back leaving brown stems and seed pods.

Spring

Summer/Autumn

Winter

 

Good identification aids are readily available including identification sheets and images by the Non-Native Species Secretariat[1] (see Appendix 2) and a guide produced by Qbank[2].

Environment Agency staff can also verify possible records.

 

Several other species may be confused with *Ludwigia grandiflora*. Brooklime *Veronica beccabunga* (right hand image, above, taken in Feb) can resemble *Ludwigia* (left hand image, above, taken in May). Brooklime has more rounded leaves, and achieves this growth form in late winter/early spring, when water primrose is still dormant. Other plants with leaves that might be confused with *Ludwigia* include Water mint *Mentha aquatica* (characteristic minty smell), amphibious bistort (*Persicaria amphibia*) and forget-me-not *Myosotes scorpioides* (see Appendix 2).

Other Invasive *Ludwigia*

Ludwigia peploides is similar to *L. grandiflora,* but has not yet been confirmed in the wild in the UK. *L. peploides* stems grow more horizontally and it has petals usually 1.0-1.5 cm long, and anthers 1.0-1.7 mm, whereas *L. grandiflora* stems grow vertically and have larger petals and anthers. Additionally, the small leaves at the base of the flower are triangular to egg-shaped in *L. peploides*.

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[1] http://www.nonnativespecies.org/index.cfm?sectionid=47
[2] http://www.q-bank.eu/Plants/BioloMICS.aspx?Table=Plants%20-%20Species&Rec=64&Fields=All

Ludwigia x kentiana is a hybrid between the rare native Hampshire purslane *Ludwigia palustris* (below) and another non-native ornamental *Ludwigia repens*. It is essential to verify that the plant is not the rare native species before any control is performed. This requires genetic analysis, which Trevor Renals from the Environment Agency can facilitate on your behalf. If you believe your *Ludwigia* may not be *L. grandiflora*, seek advice from your EA contact.

Ludwigia palustris, Hampshire purslane. A rare native *Ludwigia*.

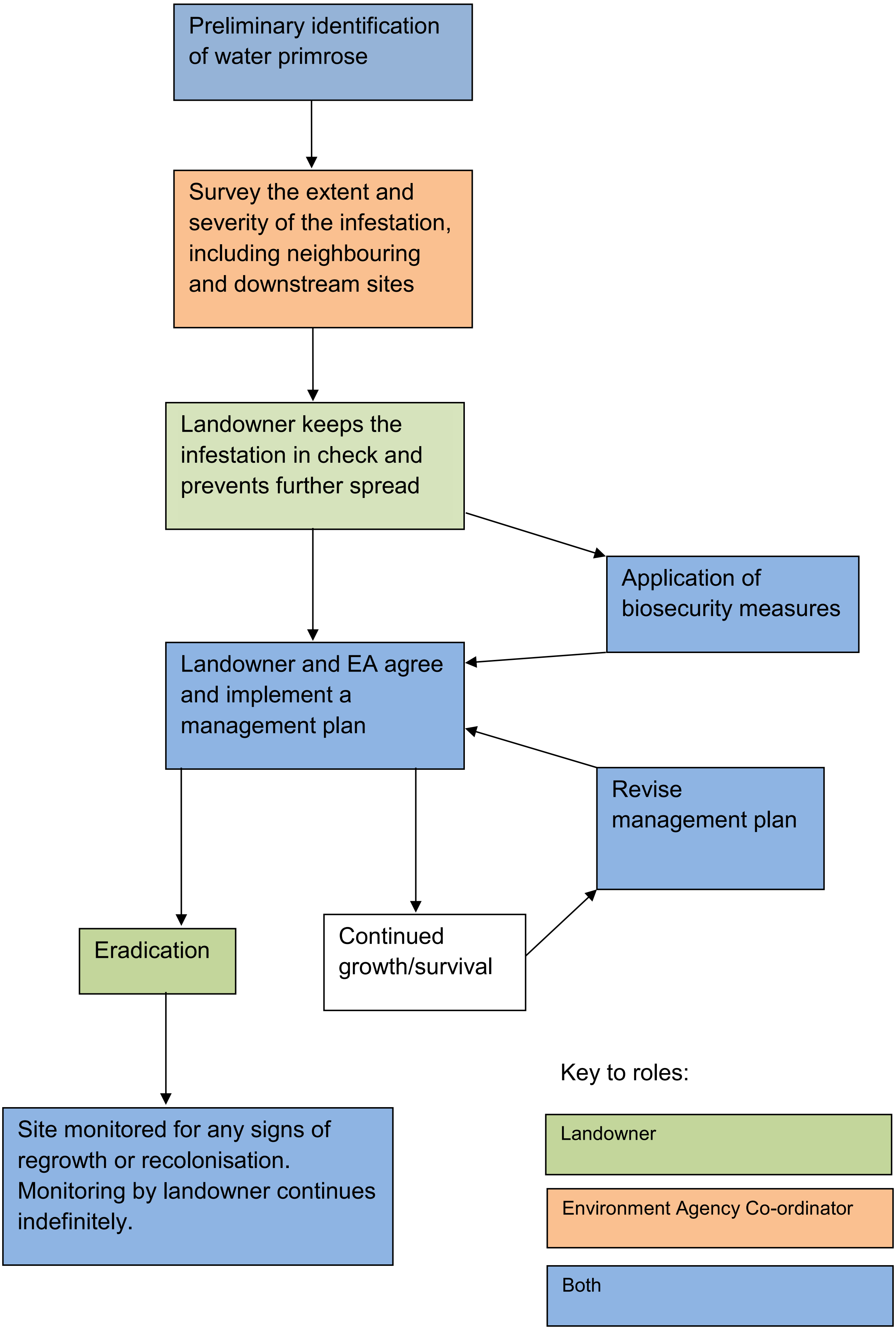
I believe I have water primrose. What do I do now?

If you believe you have water primrose, the first step should be to contact the Environment Agency who can arrange for it to be verified.

Once a new record of water primrose is verified, a programme of control should be planned and undertaken, culminating in eradication. Swift and effective action to eradicate the plant from your land is vitally important, and responsibility for this management rests with you. Most importantly, you must ensure the plant is kept contained. Allowing or causing it to spread may lead to prosecution. Your local EA contact will provide all possible help and support, and some financial help may be available.

The flow chart below shows steps that can be involved in eradication and these are explained in the following sections.

Flowchart showing steps in eradication of water primrose



Surveying the extent and severity of the infestation

As the landowner, you may have detected water primrose yourself and reported it, or been contacted by an EA officer who has verified that the plant is present. Water primrose is believed to be spread largely, and possibly solely, by vegetative propagation in GB, and you may be aware of important details of the site history. If there is no record of how the plant was introduced to the location, EA staff may survey potential routes of invasion and suitable nearby habitat and downstream water bodies to establish whether water primrose is established beyond the site of initial discovery. If the site is on-line with a watercourse, it is especially important for them to survey suitable habitats downstream. If you know where the water primrose originated from, please let the EA know. If you have given away any plant material to friends and neighbours for their ponds or lakes, please ensure they are made aware of the risk and perform a thorough inspection. If water primrose has established in their water feature, they will need to contact the Environment Agency.

My neighbour has water primrose but refuses to treat it. What should I do?

It is possible that water primrose may be present on your neighbour's property, and that they are not as willing as you to tackle the problem. The Invasive Alien Species (IAS) Regulation brings new powers to control invasive species listed under the regulation, which includes water primrose. Under Article 7 listed species may be not be kept, allowed to reproduce in or released from a contained holding. This will complement the current provisions of the Wildlife and Countryside Act (1981) under which it is illegal to allow water primrose to spread from your property.

In addition, under the Infrastructure Act 2015, Species Control Agreements (SCAs) have been introduced, with more stringent Species Control Orders (SCOs) obliging landowners to undertake control of species such as water primrose if a SCA proves ineffective. In effect this will introduce powers to encourage landowners to take action on invasive non-native species or permit others to enter the land and carry out those operations. The intention is that these powers should be used in exceptional circumstances where a voluntary approach cannot be agreed and there is a clear and significant threat from inaction. It is also intended that they will be used primarily to support national eradication programmes, as is the case with water primrose.

More detail on legislation is given in the Appendix 4 and 5

Containing the infestation and preventing further spread

Once the extent of infestation on your land is established, it is vital to prevent further spread from the site through effective biosecurity. The risk of escape may be influenced by site features. For example public access may increase the possibility of further spread or re-introduction, and water movement or fish stocking may present a risk of transferring propagules. Infestations that are in flowing water, or in sites that discharge to a watercourse are at high risk of causing spread and must be contained or isolated.

Water primrose is normally spread through transport of plant fragments, rather than seed which is thought to be rarely viable in the UK. Viable material can be transported by flowing water (e.g. between linked ponds), by movement of plant material or unscreened water (e.g. fish transfers), attached material (e.g. contaminated mud) on footwear, boats, tyres, livestock etc., or by deliberate re-planting by people with access to the infested site.

Containment of the site with barriers or fencing to prevent unauthorised access is a valuable first step, together with signage (e.g. 'This is a Water Primrose Eradication Site, please keep out') to raise awareness and highlight biosecurity.

All potential pathways for propagules leaving the site should be identified and practical measures taken to prevent further spread. This should include application of the 'Check-Clean-Dry' biosecurity protocol:

http://www.nonnativespecies.org/checkcleandry/

Agreeing and implementing a management plan

Each site will be different, and, together with your EA contact it is important to agree and implement a management plan. This needs to include an agreed initial approach to management techniques, communication and monitoring.

In order to adopt the most effective plan you will need to consider factors that may influence the control strategy. These include:

- Your wishes as landowner; for example you may prefer not to use herbicide or a mechanical digger.
- Designated conservation status at the site or the presence of protected species which may influence control choices and require early engagement with other bodies such as Natural England.

Site features and other vegetation that can influence the choice of control method. For example the site may be too deep or unsafe for manual removal, dense vegetation may hinder spraying, or fluctuating water levels may make herbicide use impossible at certain times. A great deal of experience has been gained from work at the 30 sites currently under management (see map in Appendix 3), and the EA contacts for these sites are a valuable resource of experience and advice. Four case histories are outlined below to illustrate different approaches:

i. <u>Successful eradication of a small infestation</u>

Lake at Watton, Norfolk. A small infestation detected at an early stage in 2010 and controlled by a Local Action Group. Initial hand removal including boat access led to apparent eradication. Small amounts re-occurred in 2011 and 2012 but following further hand removal the site is now believed to be clear.

ii. **Longer term problem with changes in control methods**

WWT London Wetland Centre. This was the first water primrose site to be managed in England. Hand pulling for several years from 1998 did not eradicate the plant, so control was changed to herbicide treatment in 2008 which worked well. However after apparently being clear for 3 years it re-appeared in 2013, prompting a change in guidance that a site needs to be clear for 5 years before declaring water primrose eradicated.

iii. Larger established population treated with herbicide

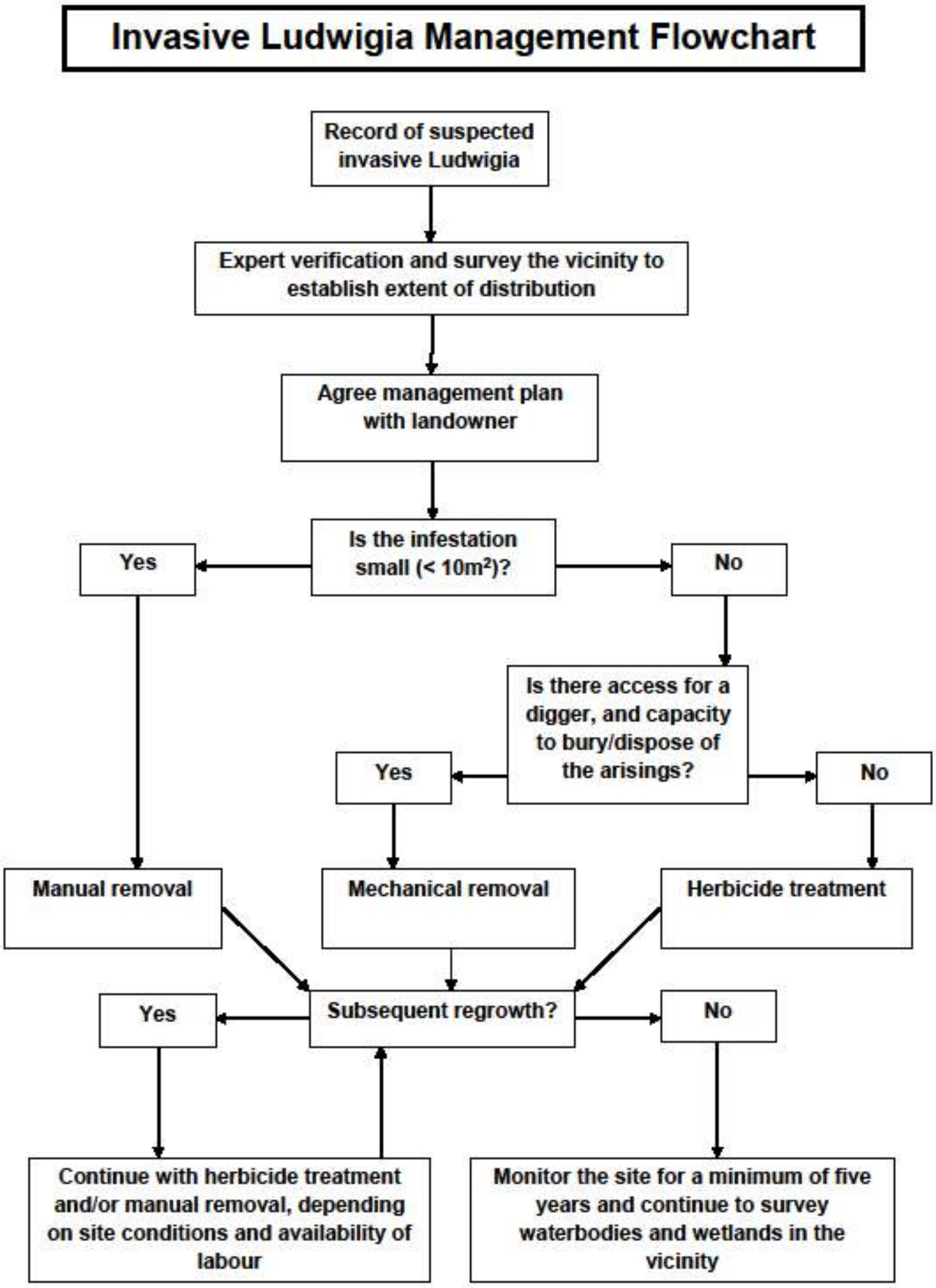
Farm pond, Isle of Wight. Pond 60m x 20m completely covered by water primrose. The site has been treated with herbicide (Glyphosate + Topfilm adjuvant) using a long lance sprayer from 2008 – 2014, with manual removal in 2015. The bulk of the plant was successfully eradicated in the first year or so, but subsequent years have seen the plant growing around the wetted margins of the pond. Not yet eradicated.

iv. Complex situation with fluctuating water table and protected species present

Breamore marsh SSSI, Hants. Water primrose was discovered in this SSSI in 2009. The site was subjected to 5 years of treatment including spraying several times a year and manual removal in 2010 and 2012. The site presented complex challenges including fluctuating water levels which interfered with herbicide application, introduction of grazing livestock, infestation with another invasive non-native plant and the presence of protected species including great crested newts. In November 2014 the infested silts were mechanically removed with a swing-shovel and taken off-site for burial. This required translocation of newts, planning permission and the creation of a Regulatory Position Statement (RPS 178) to permit the burial off-site. There has been subsequent manual removal of small quantities of water primrose from surviving propagules.

Management techniques

The management flow chart below provides a framework to choose the most appropriate control method: manual removal, herbicide treatment or mechanical removal. Use of the flow chart is not prescriptive and may be influenced by site considerations, such as those described in the case histories, above, and the table, below.



Method:	Manual removal	Herbicide treatment	Mechanical removal
Options	Small patches of *Ludwigia* can be carefully pulled up or dug using spades or forks. It can have thick, long rhizomes so digging may be more effective than hand pulling. This method also reduces the amount of damage to non-target species. After manually removing individual plants markers such as canes or GPS records can aid re-checking the exact spot the following year.	Two herbicides effective against *Ludwigia* are currently approved for use in or near water. Glyphosate (usually applied with an adjuvant such as Topfilm or codecide oil to aid adhesion to leaves) can be applied in or near water. 2,4-D amine is not approved for use in water unless an exemption is obtained from the Health & Safety Executive (HSE), but it can be applied near the water's edge. The use of an approved herbicide requires agreement from the Environment Agency via the AQHERB form approval process. A number of contractors have experience in spraying *Ludwigia*, and your EA co-ordinator can provide advice.	Mechanical removal is the favoured method of management in mainland Europe, where the use of herbicides in or near water is much more restricted. This involves using machinery (digger, dredger or bulldozer) to scrape off the top 10-20cm of infested material, followed by burial or other disposal that will not allow re-infestation. The Environment Agency has developed a Regulatory Position Statement (RPS 178) to facilitate the burial of silts infested with water primrose and other invasive alien plants without the need for a permit.
Advantages	Careful manual removal of small populations or plants re-growing following initial treatment can be an effective aid to eradication. Relatively cheap for small infestations. Doesn't require specialist equipment or training. Minimal non-target damage and waste generation.	Herbicides can provide effective treatment, especially where access is limited for manual or mechanical removal. Glyphosate is translocated into underground parts or material without affecting other vegetation, and if re-growth occurs in subsequent years spot spraying may be an effective aid or alternative to hand-pulling which may leave parts of roots behind. Herbicide treatment also clears surrounding vegetation, allowing *Ludwigia* regrowth to be detected more easily.	It provides rapid, effective control which is well understood. Providing sufficient material is removed there is a low risk of fragmentation, and it is easy to apply herbicide treatment or manual removal to any re-growth after digging. Mechanical removal also reduces the growing medium for any remaining *Ludwigia* propagules.
Dis-advantages	Not appropriate for large infestations which may require initial herbicide treatment or mechanical removal with manual removal of re-growth in subsequent years. The application of	Glyphosate is only effective on emergent or floating material (not underwater) so herbicide treatment may not be appropriate where water levels fluctuate. If possible you may need to reduce the water levels by	This approach is only feasible if there is access for a digger, a suitable site for disposal, and the capacity to bury or otherwise dispose of the arisings. This method is often the most expensive

	this method is limited by potential access difficulties, such as water depth, and available manpower.	pumping to expose the plant to chemical control and maintain these levels for at least 48 hours to allow the herbicide to take effect. Great care must be taken to avoid spreading fragments by pumping, for example by screening outlets to allow water flow but to catch fragments. Herbicide treatment often gives rise to 'bonsai' water primrose (see photo below) which is hard to detect. Herbicide treatment can require 7+ years of treatment to achieve eradication.	option. Mechanical removal must be undertaken in a methodical fashion with great care to prevent fragmentation, dispersal and further spread. Seeking a suitable disposal option is often the most problematic and costly aspect of this method and must be undertaken before the removal commences.
Timing	Best carried out during the growing season, although efforts to dig up rhizomes of marked plants (see below) can continue in the dormant season when access may be easier.	Spraying in early spring is most effective. Spraying later in the season can be hindered by other vegetation.	Mechanical removal is possible throughout the year, but timing may be restricted by factors such as access, water levels, vegetation and presence of nesting birds or protected species.
Advice	Great care needs to be taken not to break rhizomes when digging or pulling, as these can re-grow. In Wales hand pulling has been aided by floatation vests with careful pulling to 'feel' the roots coming out. Manual removal is hard work, but it can raise positive awareness with the public.	Adding an adjuvant (Topfilm, Ecoflex or Codecide oil) to the Glyphosate formulation aids sticking to leaves. A good option is to use an approved Glyphosate formulation such as Roundup Pro-biactive at 4 litres / hectare mixed with Topfilm at 1.2 l/ha. If approval for its use is obtained, 2,4-D amine can be more effective than Glyphosate if used alone or if mixed with it to aid translocation: use the normal level of Glyphosate plus 10% 2-4 D amine.	Address any required consents and permissions at an early stage, as these can take a long time to obtain. These might include ordinary water course consent, waste exemptions, waste permits, SSSI consent, planning permission, protected species licences and possible re-location of protected species (e.g. great crested newts). Your EA contact can support you with this.

Re-growth of 'bonsai' Ludwigia after spraying

Communication and monitoring

It is rare to know the source of a water primrose infestation, and good communication with other landowners and local residents may provide information on possible sources or new infestations, reduce the risk of further spread and lessen concerns about the control activity. Your EA contact can provide leaflets and letters to distribute in the area, and signage can be erected on site to raise awareness.

The involvement of volunteers or Local Action Group members can aid communication and positive publicity, and the use of Environmental Outcome Days for control by EA staff can also raise awareness and assist with manual removal.

Effective monitoring is required to assess the effectiveness of control and to check for re-growth. A monitoring plan should be established at the outset, and it is helpful to collect regular fixed-point photographs with known reference points throughout the control programme. If the source of infestation is not known then monitoring needs to continue after eradication in case of re-introduction.

The site should be revisited several times each year, between June and October, by a person familiar with the growth forms of water primrose Monitoring should then continue for at least 5 years: water primrose has been known to re-appear several years after presumed eradication.

Since eradication may take several years it is helpful to maintain consistency of the personnel involved if possible. If contractors are employed it can be useful to monitor their activity by joint visits to ensure as many plants as possible are tackled, and to reinforce the goal of eradicating water primrose, rather than simply keeping it in check.

Appendix

1. Invasive Species Action Plan (ISAP)

http://www.nonnativespecies.org/index.cfm?sectionid=92

NNSS

INVASIVE SPECIES ACTION PLAN

Version: 1.1. Last updated: August 2010

Water Primrose (*Ludwigia grandiflora)*

GB Priority - **HIGH**

Timescale - Immediate

Aim: To eradicate *Ludwigia grandiflora** from GB and prevent its re-invasion.

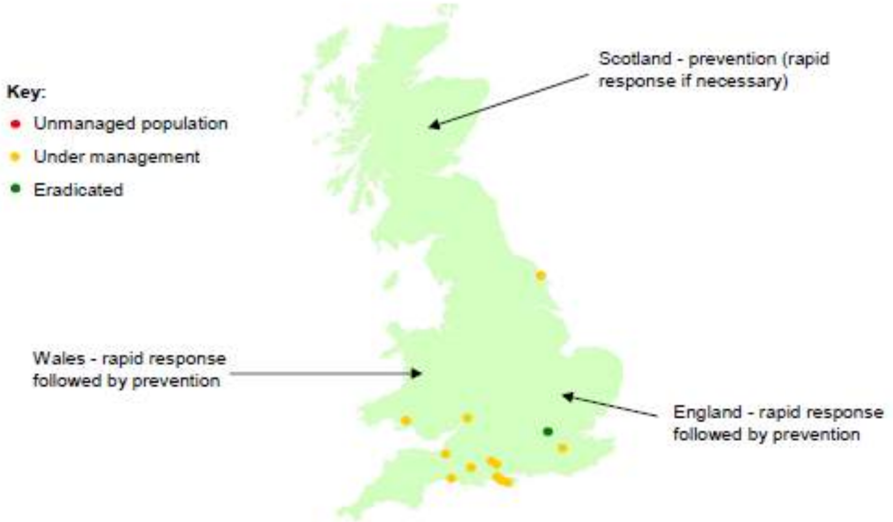
Objectives:

1. Consider use of legislation to prevent sale, release and improper disposal in GB
2. Increase public awareness about this species
3. Eradicate the known populations in England and south Wales
4. Set up suitable monitoring of water bodies in Wales and England
5. Maintain surveillance in Scotland and rapidly respond if found
6. Minimise the risk of re-establishment from releases and movement from existing locations

Aim	Action	Where	Co-ordinating body	Support	Start date
Prevention	Commence **Public Awareness Campaign** for water users and gardeners	GB	NNSS	Various	**Complete**
	Discourage sale and proliferate the message that this species **should not be planted or released in GB** and appropriate **disposal** methods should be used to remove it wherever it grows	GB	NNSS	plantlife EA, OATA, HTA	Ongoing
	Provide advice on **recognition** and **disposal**	GB	NNSS	plantlife	Ongoing
Surveil-lance / early detection / rapid re-sponse	**Monitor** existing/controlled sites	E / W	EA / NNSIP	BSBI / plantlife	Ongoing
	Survey suitable locations	E / W	EA / NNSIP	BSBI / plantlife	Ongoing
	Eradicate in England and Wales	E / W	EA	plantlife	Ongoing
	Watching brief and **contingency plan for eradica-tion** in Scotland	S	SNH / SEPA	RAFTS	Ongoing
Legislation	Consider adding to **Schedule 9** subject to normal consultation process.	GB	Defra, WAG, SG	-	**Complete**
	Consider **banning the sale of this species** subject to normal consultation process.	GB	Defra, WAG, SG	-	Ongoing
Research	Investigate **management techniques** (e.g. DeCLAIM project)	GB/ Netherlands	Defra	-	Mar 2009

*References to *Ludwigia grandiflora* include the following:
Ludwigia peploides synonyms: *Jussiaea californica. J. patibilcensis, J.peploides, J.polygonoides, J.repens.* sub-species: *L.peploides, L. glabrescens, L. montevidensis. Ludwigia grandiflora* synonyms: *Jussiaea grandiflora, L. uruguayensis, J.uruguayensis. Ludwigia hexapetala*

www.nonnativespecies.org



Risk Register		
Risk	**Location**	**Mitigation**
Refused access to land to enable control	England and Wales	Work closely with landowners to gain compliance. Consider whether access can be obtained under nuisance legislation.
Continued release: a. garden ponds b. water body owners	England and Wales	PR Campaign – on planting in the wild and disposal of aquatic plants Ban on Sale

Measurable Outcomes:
- Elimination of water primrose as a threat to the GB environment
- Increased understanding by the public of responsible plant management and disposal

Updating and review:
- This ISAP is subject to continual review and modification. See www.nonativespecies.org for most current version.
- This ISAP will be reviewed and re-issued, at the latest, by 1 April 2011

Supporting Documentation:
- Link to risk assessment documents
- Link to ID sheet
- Link to website fact sheet containing [TBC]:
  - Summary and technical information about the species
  - Distribution map
  - Identification guidance
  - Links to management information
  - Guidance on relevant legislation
  - Additional sources of information
- Links to other relevant websites (Pondcheck, RISC, RAFTS)
- CEH report 'Development of eradication strategies for *Ludwigia* species'
- Links to DeCLAIM project webpages (link to EUPHRESCO)

2. Identification of *Ludwigia*

Non-native Species Secretariat Identification Sheet:

NNSS
GB non-native species secretariat

www.nonnativespecies.org

Produced by Olaf Booy, Max Wade and Vicky White of RPS

Water Primrose

Species Description

Scientific name: *Ludwigia grandiflora*
AKA: Often incorrectly identified as *L. peploides* and labelled in garden centres as *Jussiaea*; Briallen d ŵr (Welsh)
Native to: South America
Habitat: Still or slow-flowing water

Quite distinctive in floating form, more care is needed to distinguish it from other species when it is growing in the margins of water bodies. Best searched for when in flower (July to August). Spreads primarily by plant fragmentation but also by seeds. There are few native species in the UK that are similar.

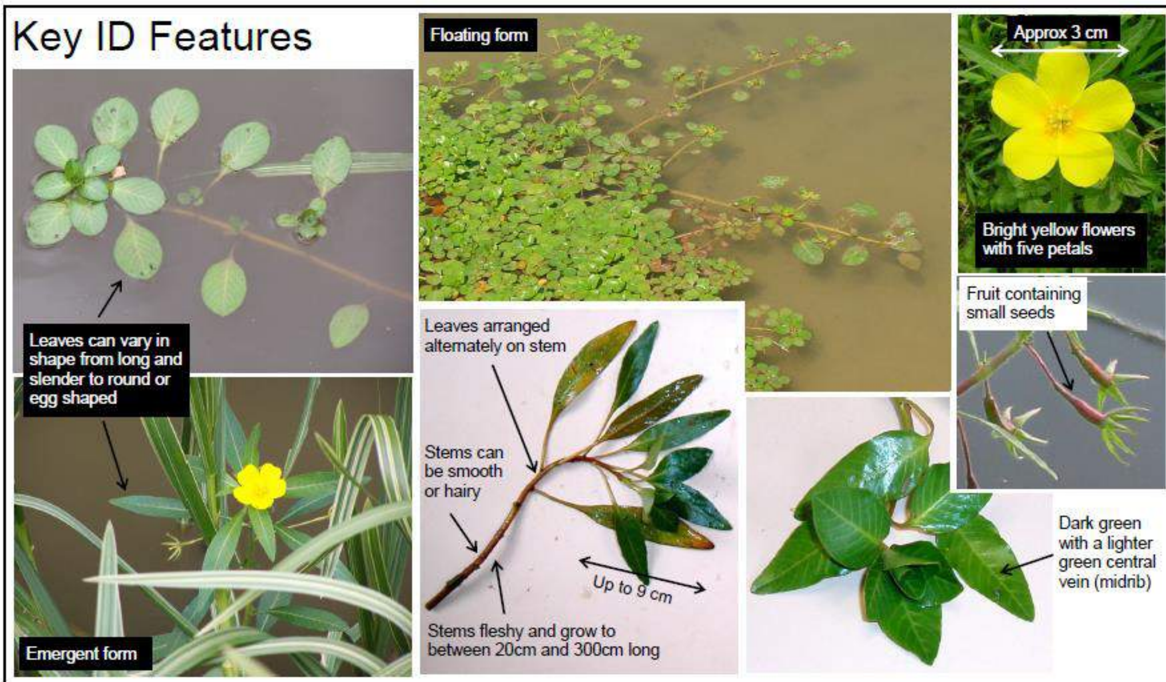
Only known from a few sites in the UK and it has been eradicated from some of these. *L. x kentiana* is the only other non-native species of Ludwigia known to occur in the UK. Distinguishing between non-native species of *Ludwigia* is very difficult. If this is required expert consultation may be necessary.

Introduced to Europe as an ornamental and water garden plant. Causes severe negative impacts, including out-competing native species and clogging waterways.

Water Primrose is listed under Schedule 9 to the Wildlife and Countryside Act 1981 with respect to England and Wales. As such, it is an offence to plant or otherwise allow this species to grow in the wild.

For details of legislation go to www.nonnativespecies.org/legislation.

Key ID Features

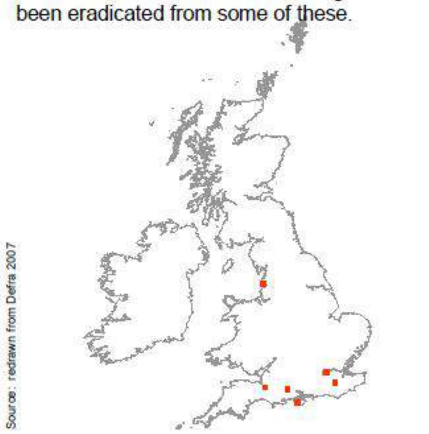


Identification throughout the year

Flowers from July to August. Vegetation dies back in winter leaving distinctive brown stems.

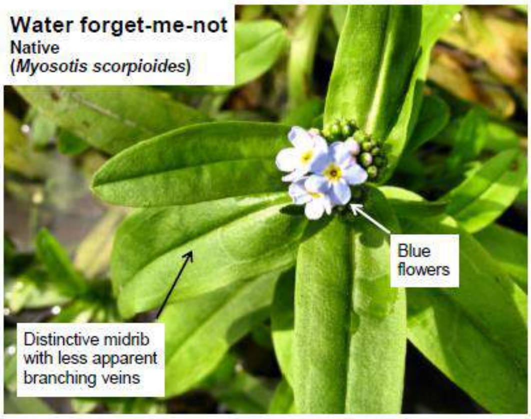
Distribution

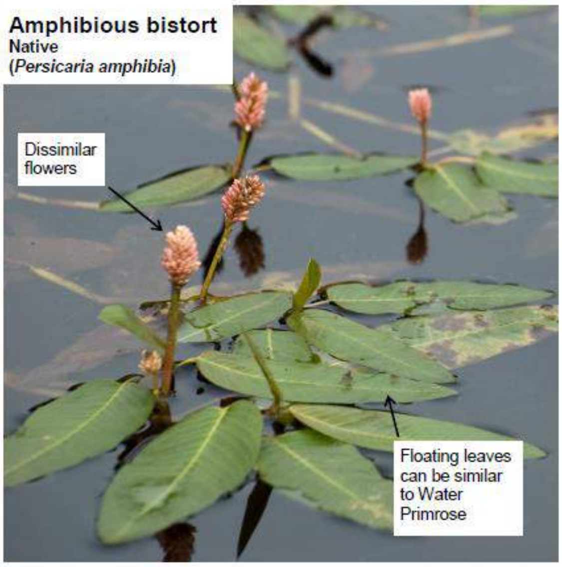
Has been present at a limited number of sites across the British Isles although it has been eradicated from some of these.

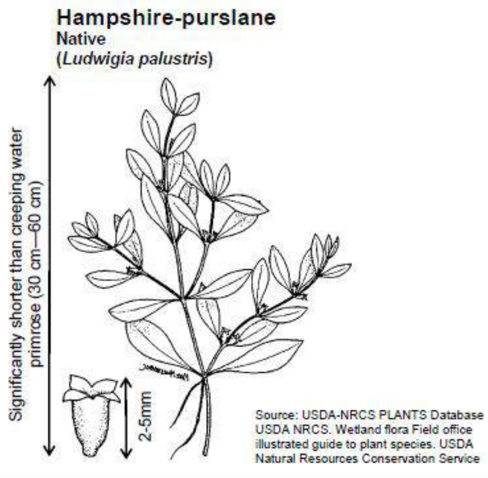


Similar Species

There are few similar species with which Water Primrose could be confused. The leaves of aquatic forget-me-nots (*Myosotis* species) have a distinctive midrib with less distinctive branching veins, unlike Water Primrose. When the floating leaves of amphibious bistort (*Persicaria amphibia*) first appear they resemble Water Primrose, but are significantly larger when full grown with dissimilar flowers. Hampshire purslane (*Ludwigia palustris*) is a very rare plant of boggy areas. Although closely related to Water Primrose, it is considerably smaller.







References and further reading:

Blamey, M, Fitter, R and Fitter, A (2003) *"The Wild Flowers of Britain and Ireland. The Complete Guide to the British and Irish Flora"*. A & C Black

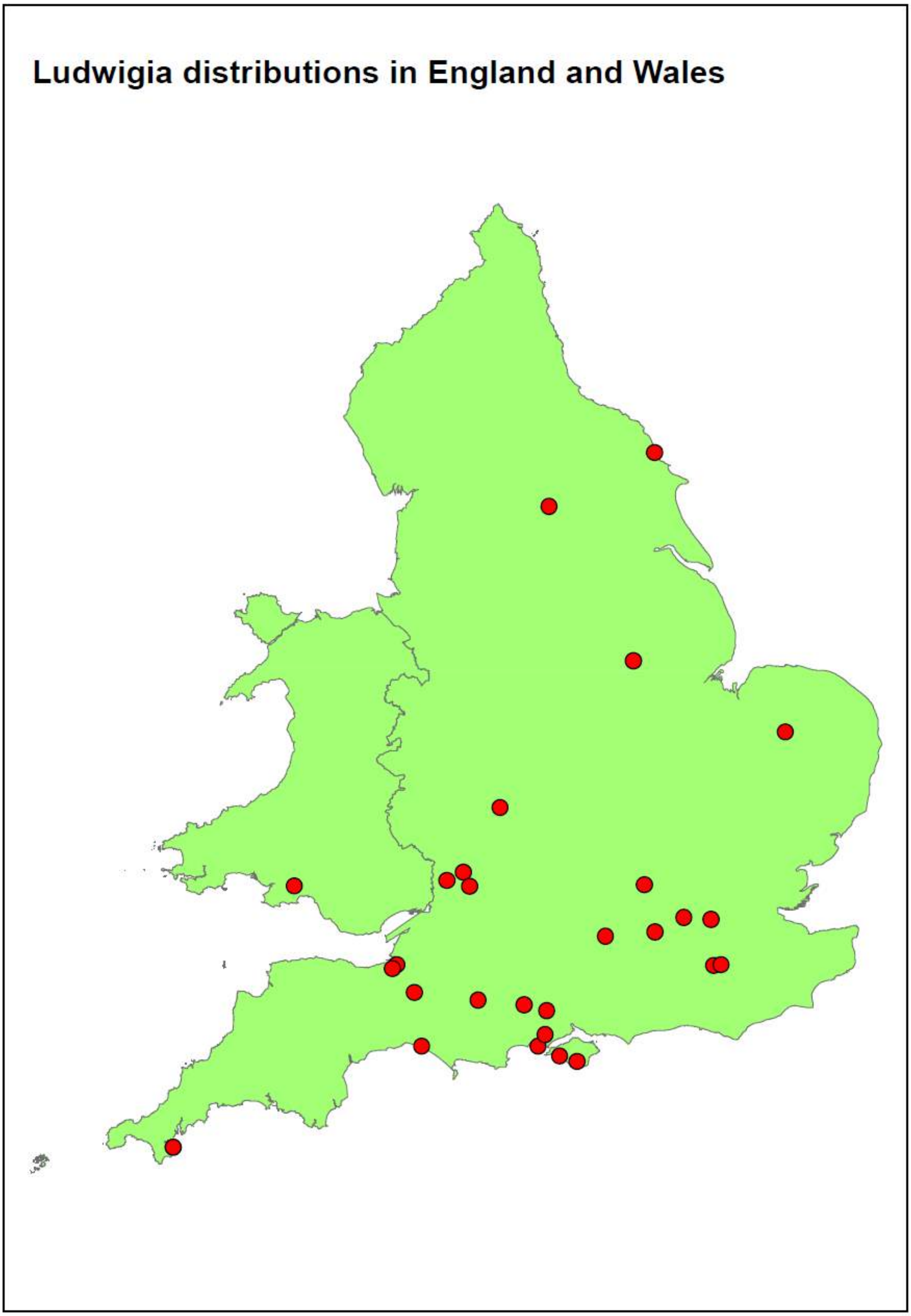
Defra (2007). "*Eradication strategies for invasive non-native* Ludwigia *species—PH0422*". Defra

Preston, C D, Pearman, D A and Dines, T A (editors) (2002) *"New Atlas of the British and Irish Flora"*. Oxford University Press

Stace, C (1999) *"Field Flora of the British Isles"*. Cambridge University Press

Photos from: Stephen Buchan, Alain Dutartre, Niall Moore, William Olsen, Donna Storz

3. **Location of known and eradicated *Ludwigia* sites**



4. Legislation pertaining to water primrose.

Article 7 of the **EU Invasive Alien Species Regulation** states that:

1. Invasive alien species of Union concern shall not be intentionally:

(a) brought into the territory of the Union, including transit under customs supervision;

(b) kept, including in contained holding;

(c) bred, including in contained holding;

(d) transported to, from or within the Union, except for the transportation of species to facilities in the context of eradication;

(e) placed on the market;

(f) used or exchanged;

(g) permitted to reproduce, grown or cultivated, including in contained holding; or

(h) released into the environment.

2. Member States shall take all necessary steps to prevent the unintentional introduction or spread, including, where applicable, by gross negligence, of invasive alien species of Union concern.

Ludwigia is listed under this Regulation, which will remain in force whilst the UK remains part of the European Union.

The purpose of section 14 of the **Wildlife and Countryside Act 1981(WCA 1981**) is to prevent the release into the wild of certain plants and animals which may cause ecological, environmental, or socio-economic harm. To achieve this, section 14 prohibits the introduction into the wild of any animal of a kind which is not ordinarily resident in, and is not a regular visitor to, Great Britain in a wild state, or any species of animal or plant listed in Schedule 9 to the Act.

Three species of water primrose are listed under Schedule 9 WCA 1981; *Ludwigia peploides, L.grandiflora* and *L.uruguayensis*. The hybrid, *L. x kentiana* is not listed. To date, the only species (as opposed to hybrid) recorded in the wild has been *Ludwigia grandiflora*.

With respect to plants, section 14(2) states:
'(2) Subject to the provisions of this Part, if any person plants or otherwise causes to grow in the wild any plant which is included in Part II of Schedule 9, he shall be guilty of an offence.'

In 2009, Defra published clarification (amended in 2010) on the interpretation of section 14 (Guidance on section 14 of the Wildlife and Countryside Act 1981). One of the issues that had prevented the use of section 14 had been what constituted 'in the wild'. The guidance states that:

> *In principle, we would define 'the wild' as being:*
>
> > *"The diverse range of natural and semi-natural habitats and their associated wild native flora and fauna in the rural and urban environments in general. This can also be broadly described as the general open environment."*
>
> *However, whether an introduction (release or escape) is into 'the wild' may well be dependent on the ecology of the species in question and the potentially affected environment: as such, what constitutes the wild must be judged on a case-by-case basis.*
>
> *For the offence to be committed, a release or allowing to escape into the wild or planting or causing to grow in the wild must occur. Therefore, to understand the application of section 14, one must also understand the offence in its entirety. These issues are considered in detail below.*

The guidance then describes what may constitute 'planting or causing to grow in the wild':

> *The legislation aims to prevent the planting of Schedule 9 listed plant material in the wild where it then poses a threat to our native biodiversity and ecosystems. Our views on the meaning of 'the wild' have been discussed above. We consider that planting in the wild would constitute intentionally placing viable plant material in or on suitable medium so that it can grow. This can include, for example, whole plants, seeds, rhizomes, bulbs, corms and cuttings.*
>
> *Although it is impractical to attempt to describe all possible circumstances, we would not consider planting on managed land, where it is expected that the spread of the plant will be kept under control, and where the plant is not having an appreciable adverse impact on habitats and their native biodiversity, as planting in the wild. It would follow that planting in private gardens would not be considered planting in the wild and, in general, this is also likely to apply to larger scale gardens, estates and amenity planting. Conversely, where the plant is inadequately managed or contained and is likely to have an adverse effect on habitats and their native biodiversity, it is more likely that the offence will have been committed. Therefore, whether or not planting is an offence should be judged on a case-by-case basis, taking into account the potential impacts on habitats and native flora and fauna of planting the species in question, and the existence or extent of management practices employed. Again it is worth noting that the legislation provides a defence if the accused can prove that all reasonable steps have been taken, and all due diligence has been exercised, in order to avoid committing the offence.*
>
> ***Causing to grow in the wild***
>
> *Section 14 does not impose an explicit obligation to manage Schedule 9 species not introduced onto your land by your own actions. However, the law is not entirely clear as to the full scope of the phrase "causes to grow". See for example case law on cases involving the offence in section 85(1) of the Water Resources Act 1991 (offence of 'causing' or 'knowingly permitting' polluting matter to enter controlled waters). Based on certain indications in that case law, it may be possible to argue that a landowner who knowingly allows a Schedule 9 species that he did not introduce, to accumulate*

on his land and create a problem as it spreads to other areas of the wild, and who makes a conscious decision to do nothing about it, is 'causing it to grow'. However, this interpretation has not been tested, and whether the offence could apply in these circumstances would have to be established in the courts. The Department is therefore unable to offer a firm view on circumstances of that nature. The requirements of the defence in section 14(3) of the Act should be borne in mind.

We would expect that where plants listed in Schedule 9 are grown in private gardens, larger scale gardens, estates and amenity areas etc, reasonable measures will be taken to confine them to the cultivated area so as to prevent their spreading to the wider environment and beyond the landowner's control. It is our view that any failure to do so, which in turn results in the plant spreading to the wild, could be considered as 'causing to grow in the wild' and as such would constitute an offence. If the person responsible for the presence of a species in this way does not have sufficient ability or the resources to manage it so as to prevent its spreading to the wild, thereby exposing him or herself to the risk of committing an offence, he/she should seriously consider whether planting a Schedule 9 species is appropriate.

Negligent or reckless behaviour, such as inappropriate disposal of garden waste, where this results in a Schedule 9 species becoming established in the wild would constitute an offence.

In essence, in England and Wales a landowner may be breaking the law if he/she allows unmanaged Ludwigia to harm biodiversity or spread. Case law for section 14 is poor, and the guidance has yet to be tested. However, it does provide a very useful clarification that does enable us to describe an incentive for management to landowners. In Scotland, the Wildlife and Natural Environment (WANE) Act 2011 creates provision for species control agreements with landowners which, if not completed, can result in species control orders enforcing the eradication of invasive non-native species.

A Species Control Order will allow a Defra agency access onto land for the purposes of managing an invasive non-native species. **The Infrastructure Act 2015**, which came into force on 12 Feb 2015, makes provision for species control agreements and orders. These powers may be exercised by the Secretary of State, the Environment Agency, Natural England and the Forestry Commission. SCOs are a last resort, if a species control agreement has been refused or breached. For the large majority of sites, we will continue to cooperate with landowners without the need for a formal agreement or order.

The new powers allow enforcing bodies to compile Species Control Agreements (SCA) with landowners to permit access to manage invasive non-native species. If the agreement is not honoured, a Species Control Order (SCO) may ensue. The Secretary of State must be informed of any agreement or order, and landowners have a right of appeal.

The powers extend to any non-native plant or animal, introduced by humans, that is likely to cause environmental or socio-economic detriment. It also includes formerly native animals, such as Eurasian Beaver. The powers are intended for species that are the target of national or local eradication programmes or a threat to sensitive areas. Control measures need to be viable and proportionate.

5. **Regulatory Position Statement 178 pertaining to the disposal of Ludwigia**

The treatment and disposal of invasive non-native plants

If you comply with the requirements below, we will allow you to dispose of invasive non-native plant material, and the substrate in which it is rooted,

Background

Invasive non-native plants have been introduced into the environment from a variety of sources, usually from ponds and gardens. They lack the pests and diseases that moderate their growth in their native environment. In their invaded range they have the potential to form dense monocultures that exclude native species, increase flood risk, degrade amenity and cause a variety of other social, environmental and economic impacts.

There are a number of drivers for invasive plant management. The Great Britain Invasive Non-Native Species Strategy 2015 establishes a framework for prioritising invasive species management, based on risk assessment. This requires public bodies to contribute towards controlling invasive species. Legislation, including the Wildlife & Countryside Act 1981, requires landowners to prevent the spread of invasive species, and prevent them from causing nuisance. The EU Invasive Alien Species Regulation 2015 also places additional responsibilities on Member States to prevent the transportation of invasive non-native species of EU concern, which are listed within the Regulation.

Due to increasing restrictions on the use of biocides, particularly in or near water, options for invasive plant management are becoming highly restricted. Demand for mechanical control options for invasive plants is likely to increase and we need an appropriate waste position on the fate of material arising from these operations. The disposal of waste into or on land requires an environmental permit. However, we consider that this would be disproportionate for the safe burial and treatment of invasive plants and substrate.

Our approach

We will not pursue an application for an environmental permit for the treatment and/or burial of any non-native invasive species plant material where:

You have made and maintain a document, such as a knotweed management plan, which sets out how the material will be excavated, treated or buried so that further growth and/or spread of the invasive species beyond the site is prevented. The document to be available to us on request.

Burial takes place on land that is of low habitat value in an area that is likely to be undisturbed, more than 7 metres away from an adjacent landowner's site.

The material does not contain pollutants likely to pose a threat to groundwater quality.

Once excavated the material is stored for less than 12 months prior to treatment or burial

And where in addition either 1, 2 or 3 below is followed

1. Burial of plant material, other than Japanese knotweed

Burial only takes place because other options which reduce the volume of material, and its reuse for composting and/or soil improvement, have been discounted because they are a less preferred environmental option, for example they pose an unacceptable bio-security risk.

The majority of the plant material for burial consists of invasive non-native plant species from aquatic, riparian and wetland habitats.

The total volume of material to be buried does not exceed 1000 tonnes.

2. Burial of soils containing plant propagules, other than Japanese Knotweed

Burial of soils containing seeds, rhizomes, corms, viable vegetative fragments, etc is carried out to a minimum depth of 2 metres on the site of production

3. Burial and disposal of Japanese knotweed (including propagules)

Japanese knotweed, ash from burned knotweed and/or soils containing potential Japanese knotweed is buried on the site where it arises.

Japanese knotweed material is buried, either:

with at least 5 metres of cover, or:

encapsulated in a geotextile membrane and buried with at least 2 metres of cover, where that geotextile membrane is:

- used without damage;
- large enough to minimise the need for seals;
- sealed securely;
- Can remain intact for at least 50 years;
- Can resist UV damage if exposed to sunlight.

We are notified at least one week prior to the burial.

NB Where Japanese knotweed cannot be suitably disposed of on-site it must go to an appropriately permitted landfill site or incineration facility. We should be notified of its removal from site and destination.

And in addition to all the above

You meet the relevant objectives of the Waste Framework Directive;

'… ensuring that waste management is carried out without endangering human health, without harming the environment and in particular:
(i) without risk to water, air, soil, plants or animals;
(ii) without causing a nuisance through noise or odours; and
(iii) without adversely affecting the countryside or places of special interest.'

To note: Plant material may be burned at the site of production

You will need to register a paragraph D7 exemption, which also covers storage of material prior to burning.

You must take into account local by-laws and not cause a nuisance.

Ash and remaining material should be disposed of on-site (as described in parts 2 and 3, above) or taken for appropriate disposal to a permitted landfill.

Enforcement

In not pursuing an application for a permit, we will not normally take enforcement action unless the activity has caused, or is likely to cause, pollution or harm to health. For a more detailed explanation of this enforcement position, please see our Enforcement and Sanctions statement.

This statement is based on our understanding of the relevant legislation. It applies to England only. You can get advice on the approach being taken in Wales from Natural Resources Wales.

This regulatory position will be reviewed by 2018

MWRP RPS 178 Version:5
Issued: 2016

Doc Ref: 167_15

Ludwigia Control Project
Final Report

Laguna de Santa Rosa, Sonoma County, California

February 2008

Laguna de Santa Rosa Foundation

Prepared by Julian Meisler,
Restoration Program Director

Final Report: Ludwigia Control Project

Laguna de Santa Rosa, Sonoma County, CA

Date of Report: February 2008

Executive Summary

Ludwigia sp. is a non-native invasive aquatic plant from South America that has invaded the Laguna de Santa Rosa watershed. The scale of the invasion threatens water quality, biodiversity and channel capacity and hampers efforts to control mosquitoes. The Ludwigia Control Project (LCP) was a three-year effort to reduce the extent and density of the *Ludwigia* sp. in two of the worst affected areas of the Laguna de Santa Rosa. Spearheaded by the Laguna de Santa Rosa Foundation, the general approach included application of aquatic herbicide followed by mechanical removal of biomass. The total project area comprised 5.3 miles of channel and 99 acres of floodplain.

The results of the effort varied considerably by site and were strongly influenced by water depth and the ability to remove treated vegetation. Deeper channels treated with herbicide and subsequently cleared retained excellent control for two seasons. However, the dry winter of 2007 resulted in low water levels and some of these areas experienced strong late season regrowth as a result. Shallow channels experienced strong regrowth despite successive years of herbicide application and mechanical removal. Shallowly inundated floodplain areas did not have sufficient water during the project season to enable access for mechanical removal equipment. These sites could only be sprayed. Although the herbicide-only treatments reduced the biomass considerably each season, cover remained high throughout the project duration.

Although removal of dense *Ludwigia* mats can improve water quality, spraying plants without removing subsequent decaying biomass further reduces dissolved oxygen and should be avoided except under special conditions.

Ludwigia is symptomatic of underlying problems in the Laguna. These problems will be solved only through watershed-level efforts including reduction of nutrient, sediment and summer water inputs, as well as physical changes to the problem areas including large-scale restoration. Because these actions take considerable time, efforts should be taken to ensure that ground gained through the project period is not lost.

Introduction

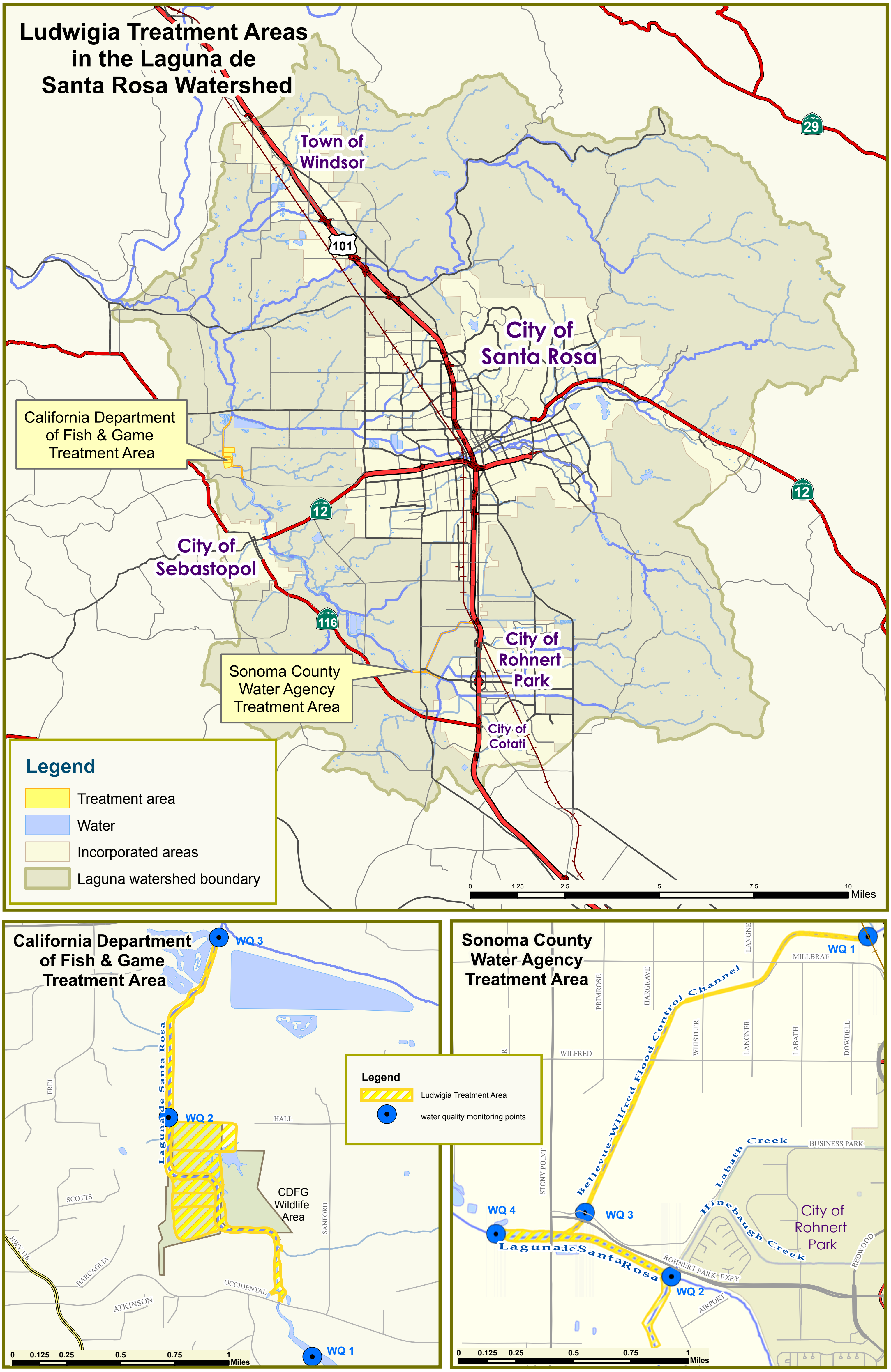
The Ludwigia Control Project (LCP) was a three-year effort to reduce the extent and density of the non-native aquatic plant *Ludwigia* sp. in two of the worst infested areas of Sonoma County's Laguna de Santa Rosa (Figure 1). The aggressive growth exhibited by *Ludwigia* negatively impacts the Laguna in numerous ways. As a strong competitor forming large dense mats over open water, *Ludwigia* contributes to a loss of biodiversity and may drive changes in ecological community dynamics including food webs. Its biomass reduces water holding capacity within the Laguna's channels and may contribute to more frequent and longer duration flooding. Decomposition of accumulated biomass can further depress already low dissolved oxygen levels. Finally, the presence of the thick vegetation mats hampers efforts to control mosquitoes in the Laguna. With the spread of West Nile Virus to Sonoma County, barriers to mosquito control are perceived as a public health threat.

The plan of action included treating *Ludwigia* with herbicide followed by mechanical removal of dead vegetation where feasible. The two field sites included 41 acres of Sonoma County Water Agency (SCWA) maintained channels and 111 acres of the Laguna Wildlife Area owned by the California Department of Fish & Game (CDFG).

The LCP was carried out by the Laguna de Santa Rosa Foundation (Laguna Foundation) and followed the recommendations of the Invasive *Ludwigia* Management Plan for the Laguna de Santa Rosa, Sonoma County, California 2005-2010. The plan was developed by the Laguna Foundation in consultation with the Ludwigia Task Force, a multi-agency group focused on *Ludwigia* issues in the Laguna. Funding for the project was provided by SCWA, California Wildlife Conservation Board, the Marin Sonoma Mosquito & Vector Control District, and the Santa Rosa Subregional Wastewater Treatment Plant. The term of the LCP was 2005-2007.

Target Invasive Species

Appendix 1 provides a summary of the taxonomic status of the invasive *Ludwigia* species targeted for control as well as information on the *Ludwigia* genus. The summary was prepared by botanical expert Dr. Brenda Grewell of the USDA-ARS.



Laguna de Santa Rosa Foundation

Map ID: 470-A

Figure 1

General Locator Map for Ludwigia Control Sites

within the Laguna de Santa Rosa

Project Location

The first project site, owned by SCWA, is located west of Rohnert Park in unincorporated Sonoma County near the intersection of Stony Point Road and Rohnert Park Expressway. It includes a 4,000-foot section of the main Laguna channel (referred to hereafter as Laguna Main), the 11,000-foot Bellevue Wilfred flood control channel (referred to hereafter as BW channel), and a 1,600-foot section of Gossage Creek (Figure 1).

Laguna Main is part of the primary Laguna de Santa Rosa Channel but has been severely altered over the decades. The channel was straightened in the 1960s and widened in 1994. A narrow band of thirty-foot tall willows lines most of the 120-foot wide channel and provides some shading to the channel margins. The channel is fed by numerous tributaries. Although most of the tributaries contain water year-round, only one, Copeland Creek, is naturally perennial. The others are fed by urban and agricultural runoff during the dry season. The substrate is primarily silt with some areas of sand.

BW channel is a straight trapezoidal flood control channel that flows into Laguna Main. BW channel contains water year-round and is fed by urban and agricultural runoff in the dry season. During this time it averages 75 feet in width and 1-3 feet in depth. Some woody riparian vegetation has been planted but the channel is largely unshaded.

Gossage Creek is a tributary to Laguna Main. It retains water year round but is not naturally perennial. There is a well established but narrow riparian strip that provides significant shading to portions of the 40-foot wide channel. The substrate is silt and sand underneath an average depth of 2 feet.

All of the channels are characterized by low energy flow that increases substantially in depth during winter and stands virtually stagnant in summer. Taken together the site spans roughly 41 acres and is bordered by agricultural and rural residential properties. Approximately 90% of the site was covered with *Ludwigia* prior to project activities.

The second site, the CDFG-owned Laguna Wildlife Area, is located north of Sebastopol between Occidental Road and Guerneville Road in unincorporated Sonoma County (Figure 1). Included are 2.1 miles (11,300 feet) of Laguna channel and 99 acres of floodplain which together comprise a total of 111 acres. The channel was created in the 1960s to convey floodwater and to enable reclamation of the floodplain for agriculture. It was dredged regularly until the early 1980s. In 1994 SCWA sold the property to CDFG.

During the dry season the channel averages 46 feet in width and 2 feet in depth. The floodplain is divided by the channel into north and south sections. Previous reports refer to the floodplain area as "flooded fields" because of the former agricultural use and the current state of perennial inundation.

Aerial photos from 1942 depict the site as heavily forested with small ponded areas, channels and possibly emergent marsh. Today the riparian forest is limited to the western edge of the site. Whereas until recently the floodplain would drain each summer, it currently retains up to ½ - 3 feet of water during the dry season. Approximately 15% of the floodplain and 80% of the channel was covered with *Ludwigia* prior to project activities.

The Laguna Wildlife Area is bordered by private lands in the north, south and west. Substantial acreages of the private lands are also infested with *Ludwigia* but were not part of the project area. Landowners were generally interested in seeing the results of the project before including their own properties.

Permitting

The project operated under the following permits:

- *Statewide General NPDES Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States.* This permit is issued by the North Coast Regional Water Quality Control Board (RWQCB). A separate permit was required for each site in each of the three years. Each year the Laguna Foundation prepared Aquatic Pesticide Application Plans (APAP) on behalf of SCWA and CDFG. The APAP formed the basis of the NPDES permit.
- *Waiver of Waste Discharge Requirements for Minor Dredging and Fill Activities.* Also known as a 401 permit this RWQCB issued permit was required each year that vegetation removal occurred.
- *County of Sonoma 3836R roiling permit.* This was required at the CDFG Laguna Wildlife Area during years with mechanical removal. SCWA maintenance activities are exempt from this permit.
- *California Environmental Quality Act (CEQA)*. The SCWA project site was administered under a Class 1 Categorical Exemption, pursuant to the California Environmental Quality Act, as a maintenance activity on an existing facility. The CDFG project site was also administered under a categorical exemption under Class 4(d), Section 15304 of the CEQA guidelines.

Public Notification

Prior to commencement of project activities each year, the Laguna Foundation mailed letters to 55 surrounding households, and issued press releases to the *Santa Rosa Press Democrat*, *West County Times* and the *Rohnert Park Community Voice.* Paid public notices were posted in the *Press Democrat*. During the active season, the Laguna Foundation emailed regular progress updates to over 100 individuals including members of the public, grantors, regulatory agency staff and local officials. Numerous interviews were given to local newspapers and local radio stations throughout the project.

Methods

Herbicide Application

The first step of the two-step process intended to control *Ludwigia* was application of aquatic herbicide to all *Ludwigia* plants within the project area. To avoid any potential take of federally listed salmonids that may pass through the project area during winter and spring months, herbicide application was limited to the period between June 15 and September 30 of each year.

Two herbicides were used, glyphosate and triclopyr. Glyphosate is the active ingredient in several terrestrial and aquatic herbicides and was applied at a rate of 3 quarts per acre.[1] Limited efficacy of this herbicide prompted a switch to triclopyr in the latter half of the 2006 field season.[2] Triclopyr was applied at a rate of 1 quart per acre. Adjuvants included surfactant (Cygnet Plus), drift control agent (Sta-Put), blue dye and water. Herbicides were applied either by truck, airboat or Marshmog.[3] Because the density of the plant prevented the airboat from traveling at controlled speeds, a path had to be cleared using a machine called a cookie cutter. Appropriate best management practices were followed including cessation of application if wind speeds exceeded 10 miles per hour and spraying from downstream to upstream to avoid accumulation of herbicide.

Vegetation Removal

Three to five weeks following herbicide application, vegetation was mechanically removed from the sites where feasible. Wide channels were cleared using the cookie cutter and aquatic harvesters. Narrow channels with good access roads were cleared using a long-reach excavator. To reduce the amount of sediment removed by the excavator, a custom "skeleton" bucket was built by the contractor which allowed water and sediment to drain out before loading plant biomass into trucks for disposal.

A floating boom with a silt screen was erected downstream of the removal operations to prevent fragments from floating downstream and to reduce movement of turbid waters offsite. The most effective management practice for reducing turbidity during removal was to operate in an upstream to downstream direction. In this manner, standing *Ludwigia* biomass downstream helped filter sediment moving downstream.

Agreements were made to dispose of the materials in nearby farm fields where it was left to dry before being bulldozed and ultimately disked into the soil. Because significant amounts of trash were intermingled with the biomass, crews pulled out trash once the piles were bulldozed.

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[1] The product used was Glypro, a glyphosate-based herbicide registered for aquatic use. The U.S. Environmental Protection Agency rates glyphosate in its least toxic category for herbicides. Glyphosate is a broad spectrum herbicide and can kill both monocots and dicots.

[2] The product used was Renovate 3, a triclopyr-based herbicide registered for aquatic use. The U.S. Environmental Protection Agency rates triclopyr in its least toxic category for herbicides. Triclopyr is marketed as dicot-specific, it does not kill monocots.

[3] The Marshmog is similar to a snow cat used at ski areas but is designed to operate in up to 3 feet of water.

Vegetation Monitoring
Photo monitoring was used to provide a qualitative assessment of the project. A total of 48 photo points were established at the two sites. Photos were taken before herbicide application, after herbicide application and after mechanical removal in each of the three field seasons. An annotated subset of these photos is provided in Appendix 2.

The quantitative assessment was limited to the floodplain of the CDFG site. Four east-west bearing transects (43 plots) were established in the floodplain treatment area.[4] In 2006 one quasi-control transect (5 plots) was established in an adjacent untreated area of privately owned floodplain. Although the untreated area was hydrologically connected to the treatment area, particularly during winter high water, it was chosen because of the absence of physically similar sites upstream. Stagnant conditions in the floodplain helped ensure minimal water exchange between the treated and untreated control site. Transect plots were 4m x 5m and were established every 10-15m. The southwest corner of each plot was marked using a Garmin Vista GPS.[5] Within each plot the cover of each species observed was estimated and assigned a cover class (1: 1-5%, 2: 6-25%, 3: 26-50%, 4: 51-75%, 5: 76-95%, 6: 96-100%).

Water Quality Monitoring
Water quality monitoring was an integral part of the LCP as a condition of the NPDES permit and the Waiver of Waste Discharge permit. In response to public concerns about the use of herbicides and to a lesser extent mechanical removal, the RWQCB required substantial water quality monitoring, the intensity of which well exceeded that required by the general permit.

Grab sampling was carried out over the course of the field seasons to analyze multiple water quality parameters. Residual herbicide monitoring, a standard requirement under the NPDES permit, entailed taking grab samples upstream, within, and downstream of the treatment area before, immediately following and 3-7 days post-herbicide application. Samples were shipped on ice to a lab to analyze for residuals of the herbicides, metabolites, and water hardness. Grab samples were also taken at the same locations on a weekly basis and analyzed in the field for dissolved oxygen, temperature, specific conductivity and pH. Equipment included a handheld YSI 85 and a YSI Ecosense pH10 meter. Grab samples were also taken to monitor turbidity during mechanical removal. Turbidity data was collected using a Hach 2100P turbidimeter.

To capture diurnal patterns a continuous monitoring data sonde was deployed downstream of the SCWA project site and upstream and downstream of the CDFG project site. Sondes were deployed 2 weeks prior to herbicide and mechanical removal activities and continued for 2 weeks following completion of activities, though the timing varied from year to year. Sondes collected data every 15 minutes and were typically

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[4] In 2006 and 2007 three additional transects were sampled to better characterize the site. However, it was determined that because the transects had not been sampled prior to herbicide treatments in 2005, the data could not be used.
[5] Because the accuracy of the Garmin Vista GPS is limited to 15 feet, the plots may not overlap entirely in all cases.

deployed for 12-15 days at a time. Data parameters collected included dissolved oxygen, temperature, specific conductivity and pH. Figure 1 shows the sampling locations at each site.

Results

Herbicide Application

At the SCWA site the total project increased in area by 21% from 2005-2007 while the total acreage sprayed with herbicide decreased by 9%. While this suggests herbicide effectiveness, it is likely more complicated. Deeper areas where mechanical removal was possible exhibited little regrowth, particularly in the Laguna Main, and these areas required limited herbicide application in later years. In contrast, the shallow BW channel experienced intense regrowth every year despite repeated herbicide application and mechanical removal. The relationship between regrowth and water depth was reinforced in late 2007 after an exceptionally dry winter left much of the Laguna Main at one third of its normal depth. Despite triclopyr applications, regrowth began at the margins and quickly spread to mid-channel where seeds and new sprouts were exposed to sunlight. By October 2007 much of the Laguna Main was covered with *Ludwigia* (see photo sequence Appendix 2).

At the CDFG site the total project area increased 4% in 2006 with no additional area added in 2007. The acreage treated over the same period decreased by 57%. Again, this appeared to be due largely to factors other than herbicide efficacy. Areas where mechanical removal was possible experienced very minor regrowth in both 2006 and 2007. Removal areas included the entire channel and roughly 5 acres of the floodplain where depth was sufficient to allow access for equipment. However, the rest of the floodplain where removal was impossible experienced strong regrowth after the herbicide application in 2006. In 2007 intense regrowth in this area prompted the Laguna Foundation and CDFG to call off herbicide application in the floodplain except where temporary biomass reductions were beneficial to mosquito control. The channel was treated where necessary.

The switch from glyphosate to triclopyr at both sites was prompted by a visual determination that the glyphosate was not working. Three weeks following the 2006 glyphosate application the majority of the plants showed little sign of impact and many began to flower. Potential reasons for the limited efficacy may have been the high density of *Ludwigia*, which could limit foliar coverage, timing of application, or, in the case of the Marshmog and airboat, the unavoidable coating of the plants in muddy water during application. Glyphosate binds readily to sediment and becomes inactive. It has also been suggested that the rate of application may have limited the efficacy of glyphosate but this is not verified.

Table 1. Summary of volume of herbicide applied, acreage treated, annual changes, and cost per acre, SCWA field site, 2005-2007.

	Volume of glyphosate applied (gallons)[1]	Volume of triclopyr applied (gallons) [1]	Total acreage of project site	Acreage sprayed[1]	Percentage of site sprayed	% change in acreage of project site since 2005	% change in acreage sprayed since 2005	Cost per acre
2005						N/A	N/A	$1,294.09
Initial treatment	17	0	34	23	68%			
Follow-up treatment	10.4	0	34	14	41%			
2006						+12%	+43%	$1341.45
Initial treatment	25	0	38	33	87%			
Follow-up treatment	0	2.5	38	10	26%			
2007						+21%	-9%	$1,773.51
Initial treatment	0	5.3	41	21	51%			
Follow-up treatment	0	2.1	41	8	20%			

[1]Values derived from herbicide use reports submitted by Clean Lakes, Inc.

Table 2. Summary of volume of herbicide applied, acreage treated, annual changes, and cost per acre. CDFG Laguna Wildlife Area, 2005-2007.

	glyphosate used (gallons)[1]	Volume of triclopyr used (gallons) [1]	Total acreage of project site	Acreage treated[1]	Percentage of site sprayed	% change in acreage of project site since 2005	% change in acreage sprayed since 2005	Cost per acre
2005						N/A	N/A	$531.96
Initial treatment	64.88	0	107	87	81%			
Follow-up treatment	26.25	0	107	35	33%			
2006						4%	-28%	$997.74
Initial treatment	18.19	16.59	111	63	57%			
Follow-up treatment	0	11.63	111	47	42%			
2007						4%	-57%	$636.16
Initial treatment	0	9.25	111	37	33%			
Follow-up treatment	0	0.75	111	3	3%			

In sharp contrast, the triclopyr, even at the low application rate, impacted the plants almost immediately with leaves wilting and stem strength deteriorating within 24 hours. This raised concerns that the herbicide would fail to act systemically. Systemic herbicides should act more slowly to enable translocation to the roots before the plant completely shuts down.

The average cost of herbicide treatment during the 3-year project period was $1,470 per acre at the SCWA site and $722 per acre at the CDFG site. Cost included the sum total of equipment mobilization, herbicide application, and materials, divided by the number of acres in the initial treatment. Touchup applications were not included because they are considered a re-treatment of the same initial acreage. While these figures can be used to calculate the cost of treating these sites in the future, they do not include the substantial associated costs of project management, reporting, water quality monitoring, and lab analysis. When extrapolating to other areas, local conditions such as access, water depth, vegetation density, economy of scale, and other factors should be considered.

Vegetation Removal

Over 12,000 cubic yards of biomass were removed from the SCWA site by the close of the 2005 field season (Table 3). Laguna Main remained virtually free of *Ludwigia* in 2006 and early summer 2007 with most regrowth limited to the channel margins. However, as described above, the shallow conditions prevailing in 2007 resulted in significant regrowth in Laguna Main by the close of the 2007 season.

Regrowth was strong each year in the BW Channel where shallow stagnant water enabled *Ludwigia* to root across the entire channel rather than just the margins. Dredging restrictions largely prohibited removal of sediment; therefore any roots not killed by the herbicide remained intact each year.

In 2007 a new and densely infested section of Gossage Creek was added to the project area bringing the total volume of biomass removed to 24,546 cubic yards.

The bulk of the mechanical removal in the CDFG Laguna Wildlife Area occurred in 2005 when 3,875 cubic yards removed from the channel and a 5-acre section of the floodplain (Table 4). This was the only portion of the floodplain accessible to floating equipment and, as a result, biomass in the rest of the floodplain was left to decompose in place. The cleared areas remained virtually free of *Ludwigia* in 2006 and the project area was extended downstream where another 1,401 cubic yards were removed. By early summer 2007 minor regrowth occurred in the shallower parts of the channel but not enough to justify the cost of removal. As in the SCWA site, shallow conditions prevailed by late 2007 and *Ludwigia* began to regrow in sections of the channel.

Table 3. Summary of mechanical removal in each year, SCWA field site, 2005-2007.

	Method	Biomass removed (cubic yards)	Acres cleared (acres)	Avg biomass per acre (cubic yards)	Cost per acre of removal[1]
2005					
BW Channel: Millbrae Road to confluence with Laguna	Long reach excavator	12,126	22.7	534	$11,835
Laguna Main from confluence of BW Channel to west end of project area	Cookie cutter and aquatic harvester				
Laguna Main from confluence of BW Channel to east end of project area (north half only)	Long reach excavator				
2006					
BW Channel: Millbrae Road to Rohnert Park Expressway	Long reach excavator	3,840	14.6	263	4,462
2007					
BW Channel: Millbrae Road to Rohnert Park Expressway	Long reach excavator	8,580	17	505	$6,054
Gossage Creek: From confluence with Laguna Main extending 1,600 feet upstream	Excavator				
Total		**24,546**	**54.3**		

[1]The cost per acre in 2007 is based on 14.6 acres only. The additional 2.4 acres of Gossage Creek removal was carried out by the Sonoma County Water Agency under Laguna Foundation direction. Therefore the project budget was not charged.

Table 4. Summary of mechanical removal in each year, CDFG Laguna Wildlife Area, 2005-2007.

	Method	Volume of biomass removed (cubic yards)	Acres cleared	Avg biomass per acre (cubic yards)	Cost per acre of removal
2005					
Main Channel: From Occidental Road to north end of north field	Cookie cutter and aquatic harvester	3,875	13.9	292	$17,187
North field: 5-acre pond					
2006					
Main Channel: From north field to Gallo ponds	Cookie cutter and aquatic harvester	1,401	3.4	350	$30,627
2007	No removal occurred				
Total		**5,276**	**17.3**		

The average cost of mechanical removal was $7,450 per acre at the SCWA site. When using only the long-reach excavator, as in 2006, the average cost dropped to $5,360 per acre. By comparison the $23,907 average cost of removal at the CDFG site was three times higher. The disparity is related to project size and conditions. A loaded aquatic harvester carries 4 cubic yards of biomass. The marshy conditions throughout most of the project area limited the number of haul out sites available to two. As a result, slow moving harvesters had to travel as much as ½ mile each way from the removal area to the haul out area. This contrasts with the much smaller SCWA site where travel distances were shorter and a substantial portion of the removal work was done with a long-reach excavator working from access roads.

Cost estimates inlcude mobilization of machinery, removal, hauling and disposal of biomass. The cost may be higher or lower depending on vegetation density and access. As with the herbicide application, the cost does not include associated project management and monitoring costs.

Vegetation Monitoring
In June 2005, prior to the onset of management efforts at the CDFG site, the cover of *Ludwigia* was extremely high with 79% of all plots sampled (n=43) having 96-100% cover and 91% of plots with greater than 50% cover. No plots were absent of *Ludwigia* in 2005 (Figure 2). By June 2007, following two years of herbicide treatment[6], only 12% of plots had 96-100% cover, 34% had greater than 50% cover and 14% of plots were absent of *Ludwigia*. Untreated control plots (n=5) showed nearly complete coverage by *Ludwigia* in 2006 and 2007 (Figure 3). Although biomass data is not provided, the observed density, stature, and height of *Ludwigia* in the control plots was markedly higher than in the treatment area.

Because *Ludwigia* tends to occupy all available space, the cover of open water was also monitored to help elucidate changes over the project period. In June 2005, only 9% of the sampled area had >50% open water cover (Figure 4). The majority of plots (77%) had 1-5% cover and there were no plots without open water. By 2007, 26% of plots had >50% cover of open water but the majority of plots (57%) had no open water. However, two factors besides the management actions may account for this change. First, the drought conditions of 2007 enabled some areas of the floodplain to dry out. Second, the cover of *Azolla filliculoides* (water fern) in otherwise open water areas increased dramatically. Whereas *A. filliculoides* was not recorded in 2005, it was present in 88% of plots sampled in 2007 (Figure 4). Of these plots, 33% had 96-100% cover of *A. filliculoides*. Whether the rise in *A. filliculoides* was a response to management actions, the low water levels, or some other factor is unknown but there were reports of large outbreaks elsewhere in California.

[6] In the floodplain, mechanical removal was limited to a small area so the results presented here are primarily from herbicide application only.

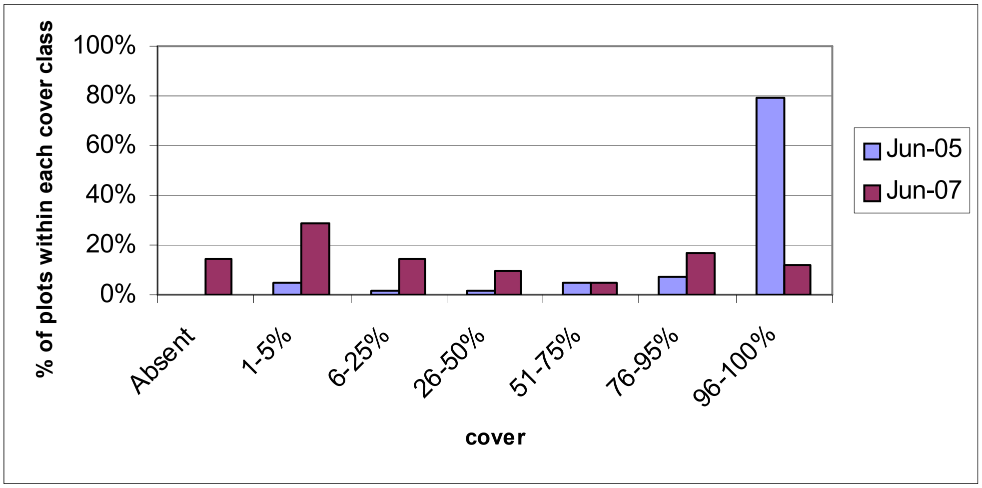


Figure 2. Comparison of the frequency of *Ludwigia* cover classes in the Laguna Wildlife Area floodplain in 2005 and 2007. The floodplain was treated with herbicide twice between the two sampling events. (n=43)

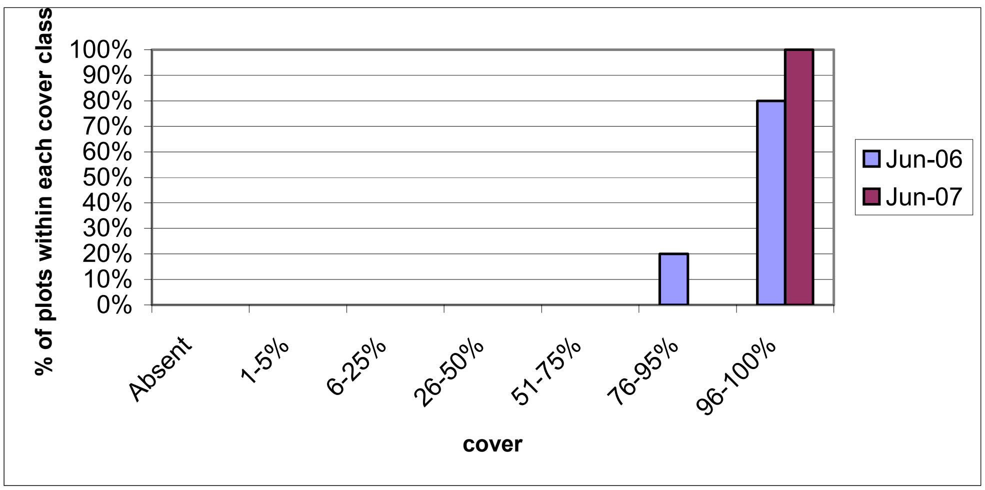


Figure 3. Comparison of the frequency of *Ludwigia* cover classes in the non-herbicide treatment area of the floodplain located adjacent to the Laguna Wildlife Area. (n=5)

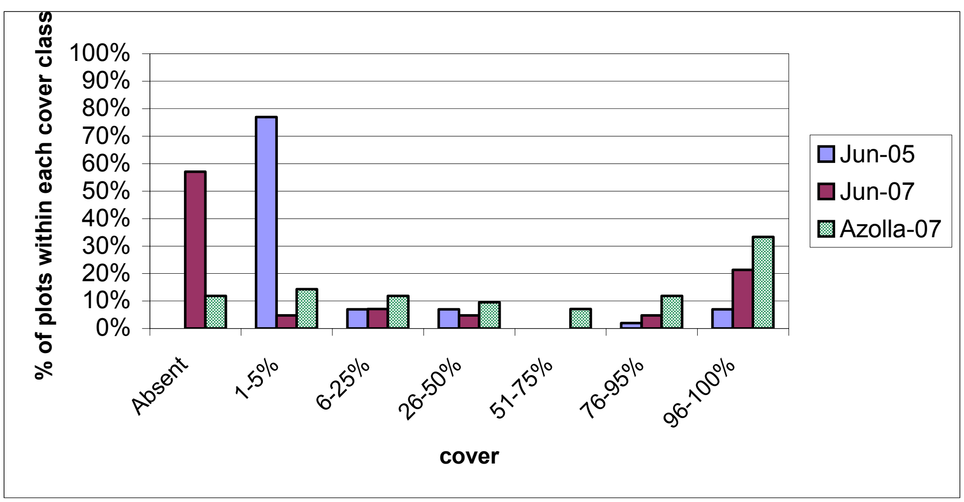


Figure 4. Comparison of the frequency of open water cover classes in 2005 and 2007 and *Azolla filliculoides* in 2007 in the Laguna Wildlife Area floodplain area. (n=43)

Although not reported here, numerous other species were present in the floodplain including *Alisma* sp., *Paspalum distichum, Cyperus eragrostis, Schoenoplectus americanus, Typha latifolia, Xanthium strumarium, Calystegia subacaulis, Lotus* sp., *Myriophyluum aquaticum, Lythrum hyssopifolia, Polygonum* spp., *Rumex crispus, Salix* spp., and several unknown graminoids. All of these species were present in low numbers.

Water Quality Monitoring
Residual herbicide monitoring throughout the three-year project period revealed traces of herbicide residue at sampling sites within and downstream of the project areas (Table 5 and 6). Concentrations detected were low in all cases. A summary of the results is presented here.

- **Glyphosate:** This is the active ingredient in the herbicide Glypro. The highest detection at the SCWA site was 59µg/L. The sample was taken at the downstream end of the BW Channel 3-7 days after herbicide application in 2006. The highest detection at the CDFG site was 27µg/L. The water sample was taken downstream of the treatment area 3-7 days after herbicide application in 2005. Glyphosate was also detected at the downstream sampling location prior to herbicide application indicating use by a neighboring landowner. The NPDES General Permit states that the water quality objective (WQO) is 700µg/L. The 96-hour LC50 (concentration lethal to 50% of test organisms) is 120,000 µg/L in bluegill sunfish and 86,000 µg/L in rainbow trout.[7] Glyphosate was not used in 2007.
- **Aminomethyl-phosphonic acid (AMPA):** This is the principal metabolite of glyphosate after it has broken down. Because glyphosate degrades rapidly in the environment, AMPA is an important measure of chemical persistence. The highest detected concentration of AMPA at the SCWA site was 54µg/L. The sample was taken at the downstream end of the BW Channel 3-7 days after herbicide application in 2006. AMPA was not detected in any of the sampling events at the CDFG site. No WQO has been established for AMPA.
- **Limonene:** This is the active ingredient in the surfactant Cygnet Plus. There were no detections of limonene in any sampling events.
- **Triclopyr:** This is the active ingredient in the herbicide Renovate 3. Triclopyr was applied in 2006 and 2007. The highest detection at the SCWA site was 100µg/L. The sample was taken at the downstream end of the BW Channel within 24 hours after application in 2007. The highest detection at the CDFG site was 17µg/L. The sample was taken downstream of the treatment area within 24 hours after the application in 2007. While the NPDES permit does not provide a WQO for triclopyr, the LC50 for this chemical is 117,000 µg/L for rainbow trout and 148,000 µg/L for bluegill sunfish.[8]
- **Oxamic acid:** This is a primary metabolite of triclopyr after breakdown and is an important measure of the persistence of the herbicide. There were no detectable levels of oxamic acid.

[7] http://extoxnet.orst.edu/pips/glyphosa.htm
[8] http://extoxnet.orst.edu/pips/triclopy.htm

Table 5. Summary of residual herbicide and metabolites, surfactant and water hardness in upstream, within and downstream project locations taken before, immediately following and 3-7 days following herbicide application at the SCWA field site, 2005-2007.

	glyphosate (µg/L)			**aminomethyl phosphonic acid (µg/L)**			**triclopyr (µg/L)**			**oxamic acid (µg/L)**			**limonene (µg/L)**			**Hardness (mg/L)**		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Before herbicide application																		
WQ1 (upstream)	ND	ND	-	ND	ND	-	-	ND	ND	-	ND	ND	ND	ND	ND	330	340	380
WQ2 (upstream)	ND	ND	-	ND	ND	-	-	ND	ND	-	ND	ND	ND	ND	ND	300	300	280
WQ3 (within)	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	ND	ND	-	400	410
WQ4 (downstream)	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	ND	ND	-	330	320
Within 24 hrs following herbicide application																		
WQ3 (within)	-	-	-	-	-	-	-	-	100	-	-	ND	-	-	ND	-	-	430
WQ4 (downstream)	ND	6.7	-	ND	ND	-	-	4	29	-	ND	ND	ND	ND	ND	240	260	370
3-7 days post herbicide application																		
WQ1 (upstream)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WQ2 (upstream)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WQ3 (within)	28	59	-	9.2	54	-	-	-	80	-	-	ND	ND	-	ND	310	400	430
WQ4 (downstream)	ND	9.2	-	ND	10	-	-	7.6	14	-	ND	ND	ND	ND	ND	330	290	350

ND indicates no detection
– indicates that no analyte was submitted for the given date or parameter, per the NPDES monitoring requirements

Table 6. Summary of residual herbicide and metabolites, surfactant and water hardness in upstream, within and downstream project locations taken before, immediately following and 3-7 days following herbicide application at the CDFG Laguna Wildlife Area, 2005-2007.

	glyphosate (µg/L)			**aminomethyl phosphonic acid (µg/L)**			**triclopyr (µg/L)**			**oxamic acid (µg/L)**			**limonene (µg/L)**			**Hardness (mg/L)**		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
Before herbicide application																		
WQ1 (upstream)	ND	ND	-	ND	ND	-	-	ND	ND	-	ND	ND	ND	ND	ND	-	230	230
WQ2 within)	ND	ND	-	ND	ND	-		ND	ND		ND	ND	ND	ND	ND	-	190	190
WQ3 (downstream)	6.4	ND	-	ND	ND	-	-	ND	ND	-	ND	ND	ND	ND	ND	-	210	73
Within 24 hrs following herbicide application																		
WQ3 (downstream)	ND	ND	-	ND	ND	-	-	ND	17	-	ND	ND	ND	ND	ND	140	190	240
3-7 days post herbicide application																		
WQ1 (upstream)	-	ND	-	-	ND	-	-	ND	-	-	ND	ND	-	ND	ND	-	220	210
WQ2 (within)	-	ND	-	-	ND	-	-	ND	1.6	-	ND	ND	-	ND	ND	-	150	74
WQ3 (downstream)	27	ND	-	ND	ND	-	-	ND	13	-	ND	ND	ND	ND	ND	240	190	160

ND indicates no detection

– indicates that no analyte was submitted for the given date or parameter

The physical characteristics of the grab sample locations within and between project sites were vastly different in terms of depth, width, flow, and canopy cover making it difficult to draw meaningful comparisons between them or to relate the data to project activities. Furthermore, grab samples were only taken during daylight hours so the strong diurnal fluctuations common to the Laguna were not captured.

In its Basin Plan, the RWQCB set numeric water quality objectives for dissolved oxygen (DO) and pH in the North Coast Region.[9] In 2007 the dissolved oxygen levels were frequently well below the minimum water quality objective, even at the upstream monitoring sites (Table 7). Minimum values typically occurred in the morning before photosynthesis caused the concentration to rise. Maximum DO concentrations often coincided with supersaturated conditions in the late afternoon when photosynthesis was at its peak. DO values at the downstream end of the CDFG site (WQ3) never rose above the minimum water quality objective of 7.0 mg/L. This held true even before management activities began for the season. However, continuous monitoring sondes did record values above the WQO at night. The extremely low 0.3 mg/L DO value at this site was recorded on October 26, 2007 following the flooding of a nearby field that had recently been disked. The field contained high *Ludwigia* cover but was not part of the project area. Water pH was mostly within the water quality objective at all locations.

Turbidity was the biggest water quality issue directly attributable to management activities in all years. Specifically, mechanical removal was responsible for temporary spikes in turbidity. Figure 5 compares turbidity levels at upstream and downstream sampling locations of the SCWA field site during the 2007 field season and identifies when removal operations occurred. At the downstream sampling location the average turbidity increased 39% during the Gossage Creek removal operations and 127% during the BW Channel removal operations. Background turbidity levels resumed within a week.

Although no mechanical removal took place at the CDFG site in 2007, Figure 6 provides a sense of background conditions upstream, within and downstream of the site based on a limited number of grab samples. The upstream sampling site, characterized by its 150-foot wide channel and 15-foot depth, averaged higher turbidity than the narrow and shallow downstream location. Turbidity values taken within the project site were highest. This was also the shallowest sampling location. Downstream values were, on average, lower than upstream turbidity values. Figure 7 provides a more detailed look at turbidity at the downstream location. The data sonde at this location was equipped with a turbidity probe. Figure 7a spans June 30-July 26, 2007. Turbidity values are concentrated between 25 and 55 NTU. The same concentration is evident during the period September 8-20 (Figure 7b). Outlying values occur frequently but are not correlated to any particular management actions or time of day. The largest outliers were eliminated from the data set.

[9] http://www.waterboards.ca.gov/northcoast/programs/basinplan/basin.html

The most effective measure taken to reduce turbidity was to work from upstream to downstream thus allowing the existing vegetation to filter turbid water moving downstream. Installation of a silt curtain also helped contain turbid waters.

Table 7. Maximum, minimum, and average values for daytime grab samples taken at monitoring stations WQ1-WQ4, June-October 2007, SCWA field site.

	DO%	**DO (mg/L)**	**Temp (C)**	**pH**
Basin plan water quality objective	*none*	*7.0 minimum*	*none*	*6.5-8.5*
WQ1				
max	127.6	11.3	28.9	8.5
min	26.6	2.5	15.9	7.0
avg	90.0	7.6	22.7	8.0
WQ2				
max	132.1	10.9	25.0	8.2
min	32.1	3.1	15.2	0.0
avg	58.9	5.4	19.5	7.8
WQ3				
max	138.0	10.4	30.4	8.5
min	28.4	2.5	16.0	0.0
avg	84.4	6.8	24.9	7.8
WQ4				
max	219.9	17.3	29.3	8.2
min	17.2	1.5	16.1	7.1
avg	78.4	6.5	23.0	7.7

Table 8. Maximum, minimum, and average values for daytime grab samples taken at monitoring stations WQ1-WQ3 June-October 2007, CDFG Laguna Wildlife Area.

	DO%	**DO (mg/L)**	**Temp (c)**	**pH**
Basin plan water quality objective	*none*	*7.0 minimum*	*none*	*6.5-8.5*
WQ1				
max	171.5	14.0	28.9	8.7
min	34.0	2.9	18.4	7.0
avg	83.0	6.8	24.8	7.9
WQ2				
max	105.4	8.5	30.8	7.8
min	9.5	0.9	14.3	6.6
avg	51.9	4.3	23.3	7.4
WQ3				
max	76.8	6.3	34.9	8.3
min	2.6	0.3	16.0	6.9
avg	33.5	2.8	22.9	7.6

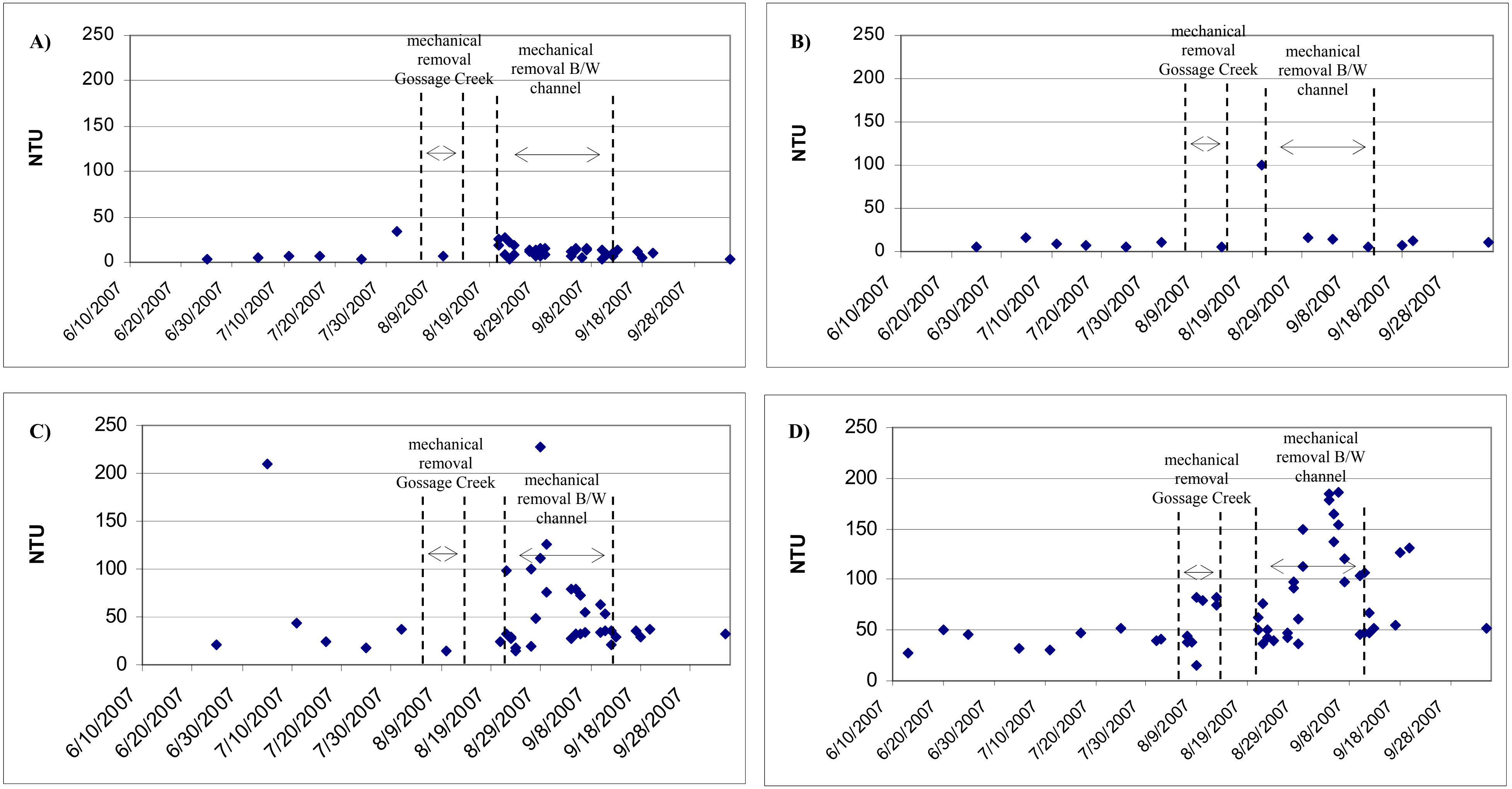


Figure 5. Turbidity grab sample monitoring at upstream and downstream locations at the SCWA field site, June-Sept, 2007. A) Sampling point WQ1 located upstream of project site in Laguna Main channel. B) Sampling point WQ2 located at the upstream end of the Bellevue Wilfred Channel. C) Sampling point WQ3 located at downstream end of Bellevue Wilfred Channel. D) Sampling point WQ4 located downstream of project site in Laguna Main channel. Mechanical removal activity occurred from August 6-13 in Gossage Creek and August 21-September 12 in Bellevue Wilfred Channel.

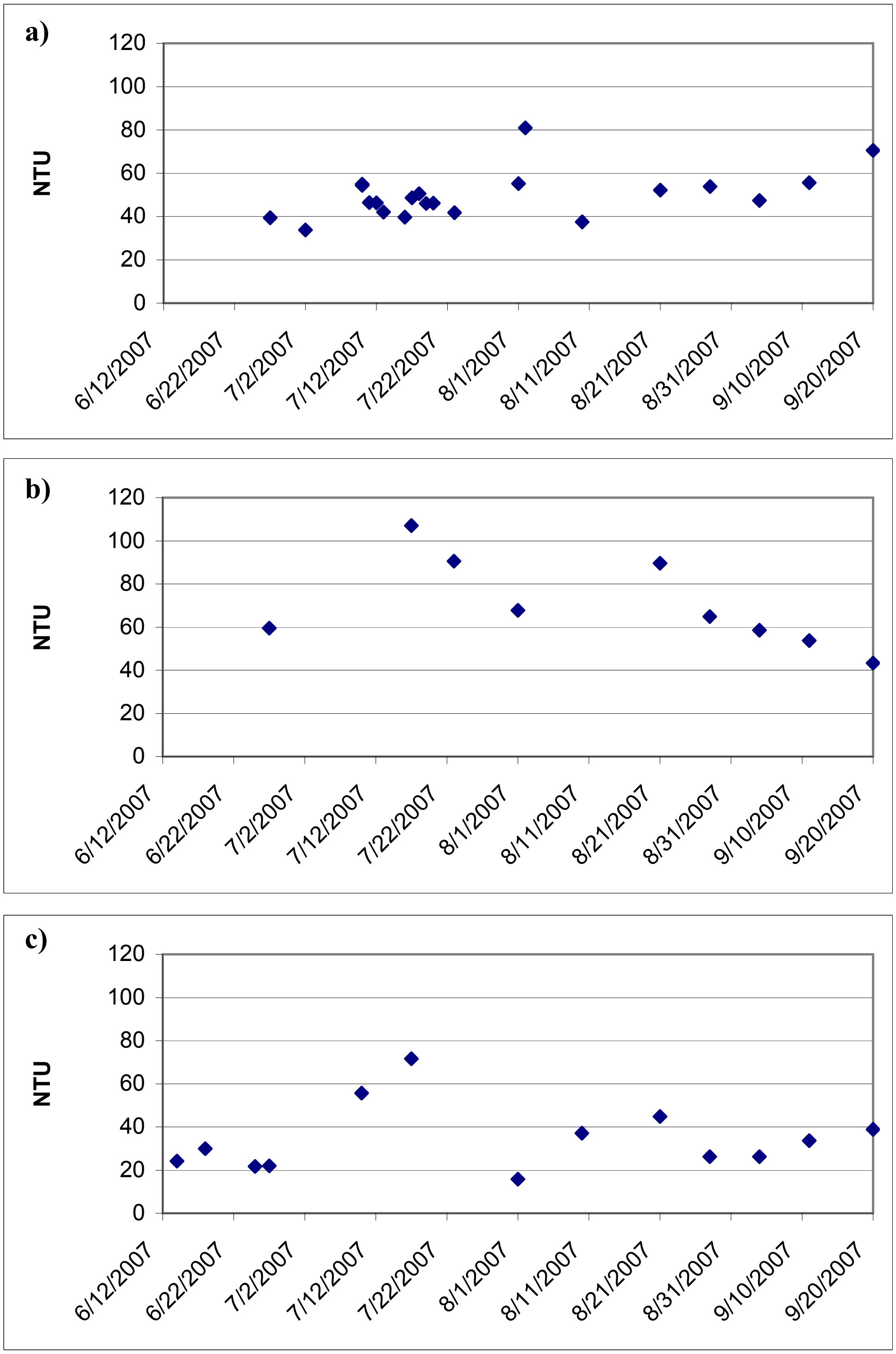
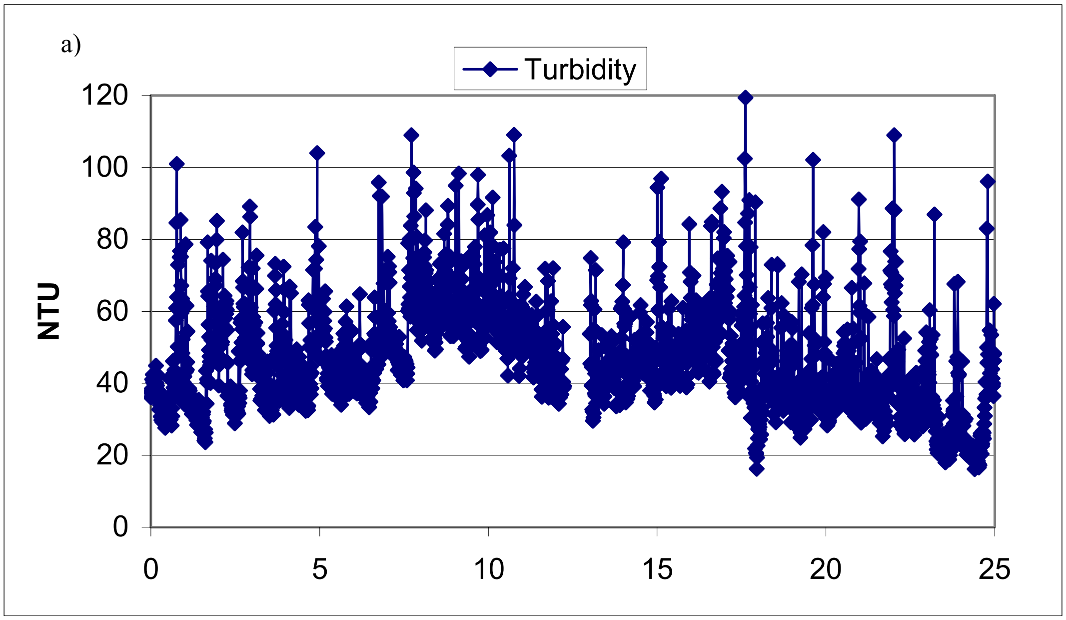


Figure 6. Turbidity grab sample monitoring, CDFG Laguna Wildlife Area, June-September, 2007. A) Sampling point WQ1 located upstream of the treatment area. B) Sampling point WQ2 located within the treatment area. C) Sampling point WQ3 located downstream of the treatment area.



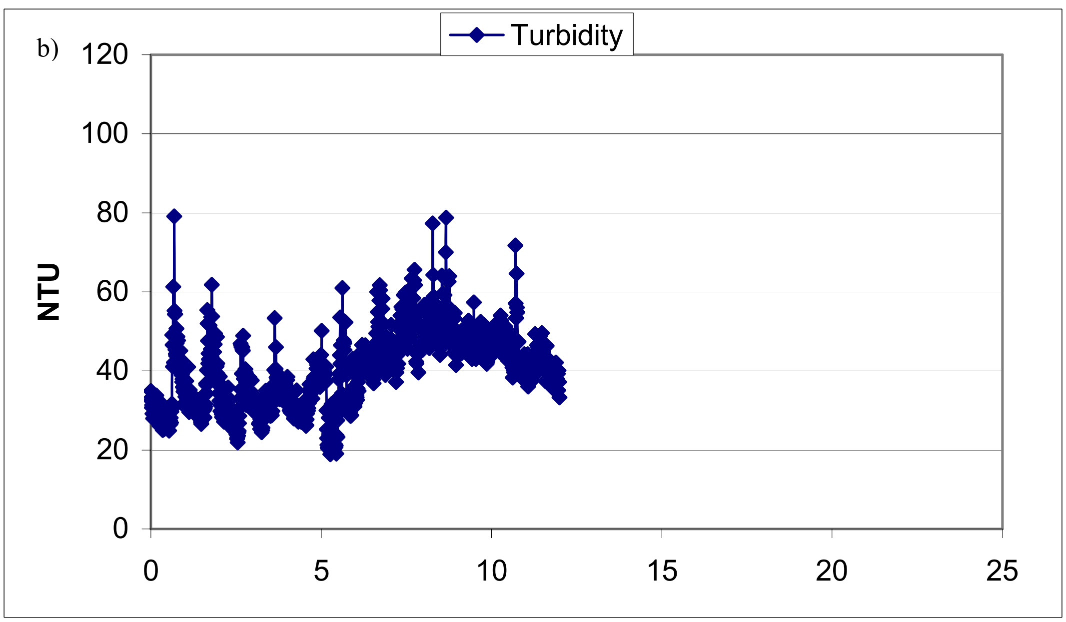


Figure 7. Turbidity monitoring data collected using data sonde at downstream sampling site (WQ3), CDFG Laguna Wildlife Area from a) June 30-July 26, 2007 and b) September 8-20, 2007.

As with turbidity, continuous monitoring sondes provided the largest data set for other water quality parameters and captured important diurnal fluctuations at the project sites. However, a combination of user error and frequent equipment malfunction during data sonde operations reduced the amount of usable data through the project period. For example, during much of the 2005 field season the sonde was deployed at a location downstream of the SCWA site that was not properly connected to the project site during low flow periods (i.e. summer). The site, chosen jointly by the Foundation, its consultants, and RWQCB staff, was relocated late in the season after the site dried. The 2005 data would have been the most informative year because it represented the before and after effects of herbicide and mechanical removal during the year in which the cover of *Ludwigia* was by far the largest.

Nonetheless, available data from 2007 reveals important patterns at both sites and provides a picture of the water quality response to herbicide application. Generally speaking, the Laguna exhibits typical diurnal patterns with regard to dissolved oxygen (DO) and temperature. However, the range between the high and low DO values is wide and lows are well below the Basin Plan objectives. Figure 8 illustrates continuous daily temperature and DO (% saturation and concentration) data collected by the data sonde at the downstream end of the SCWA site from June 26-July 3. The dissolved oxygen level rises from roughly 11 am to 10 pm and is consumed from 10 pm to 11 am. Peak concentrations occur from 6-9 pm while minimum concentrations occur from 8-10 am. Super saturation, a condition in which the dissolved oxygen level is greater than 100% of the water's oxygen holding capacity at a given temperature, occurs between 4 and 10 pm. Super saturation occurs in water bodies where water is agitated, as in a cascade, or water bodies in which algal production is high.

Herbicide applications made on June 27, June 29 and July 2 did not appear to disrupt the diurnal patterns. This suggests that two years after the removal of the large quantity of biomass in Laguna Main, *Ludwigia* was no longer the principal driver of photosynthetic oxygen production or the primary consumer of oxygen through respiration or decomposition. Although this seems likely given the low cover of *Ludwigia* and other aquatic vegetation in Laguna Main during the application period, the data is unavailable for the week following the herbicide application due to equipment failure. It is possible that a delayed impact would have been apparent. DO values later in the season were lower on average but this trend was observed in all monitoring locations including areas upstream of the project.

Downstream of the CDFG site the data sonde revealed a decline in both the high and low dissolved oxygen values beginning 3-5 days after herbicide application (Figure 9). The greater cover of *Ludwigia* in the channel at this site suggests that spraying *Ludwigia* and leaving the biomass in the water does lead to a measurable decline in DO and the downward trend continues through the season.

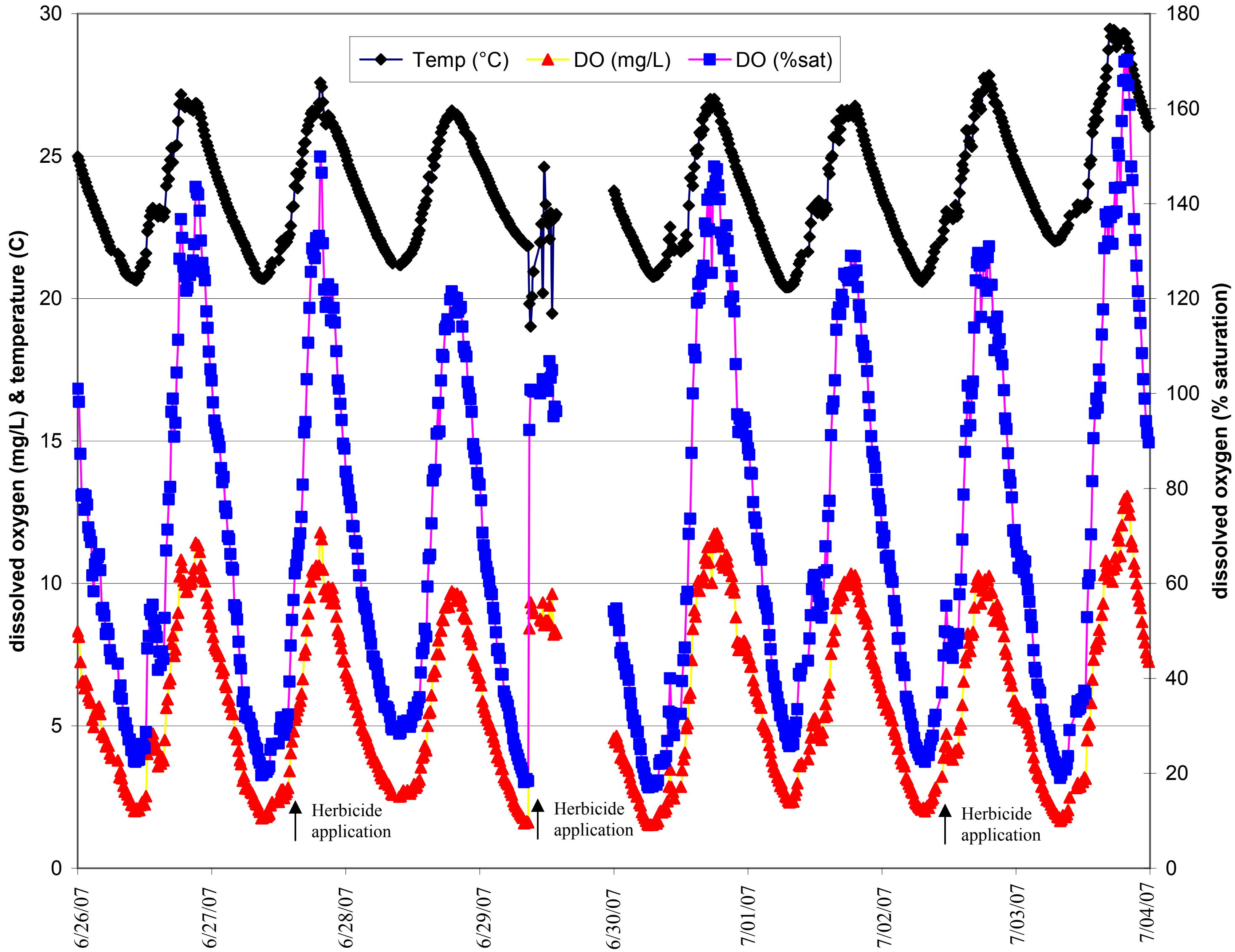


Figure 8. Continuous monitoring sonde data for the period June 26-July 3, 2007 located downstream of the SCWA site (WQ4). Three herbicide applications occurred during this period. The data sonde was pulled from the water for cleaning and calibration on June 29 resulting in a data gap.

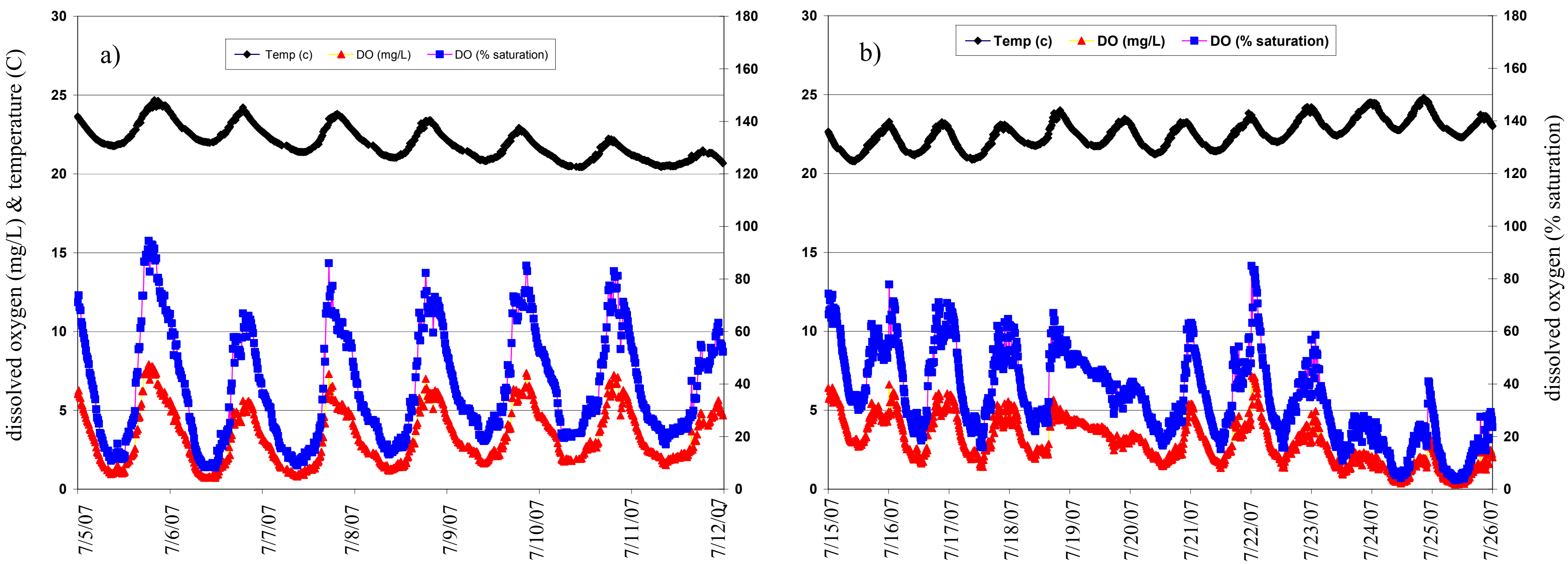


Figure 9. Continuous monitoring sonde data for the period a) July 5-12, 2007 and b) July 15-25. The sonde was located downstream of the CDFG site (WQ3). Herbicide application occurred on July 11 and July 12.

Mosquito Control

A primary driver of this project was mosquito control. In 2002 the Marin Sonoma Mosquito & Vector Control District expressed concerns about the cost and difficulty of controlling mosquitoes in densely infested *Ludwigia* areas and the related public health threat posed by West Nile Virus, a mosquito borne disease. Although the issues of biodiversity, water quality, and channel capacity were equally important, the mosquito issue provided the most urgent call to action. Some community members even postulated that the presence of *Ludwigia* increased mosquito production though this has not been accurately tested or verified. It is more likely that *Ludwigia* areas appeared to have higher production because mosquito control operations were less effective there.

Table 9 summarizes data on adult mosquito abundance and larvicide operations from 2005-2007 at *Ludwigia* control sites. It is recognized that presence or lack of adult mosquitoes does not prove or disprove elevated or reduced larval levels; it is impossible to know the origin of the adults. What is clear, however, is that the acreage requiring larvicide treatments declined substantially over the project period. Although this may have been due to the LCP, other factors such as rainfall and temperature may also have contributed to decline.

Table 9. Summary of mosquito trapping and larvicide application at Ludwigia project sites, 2005-2007. Data submitted by Marin/Sonoma Mosquito & Vector Control District.

	Number of adults trapped	**Number of larvicide applications applied**	**Total number of acres treated**
SCWA: Bellevue Wilfred Channel			
2005	3,819	unknown	19.5
2006	314	unknown	10.8
2007	641	0	0
SCWA: Laguna Main Channel			
2005	4,022	unknown	14.3
2006	195	0	0
2007	1,200	1	0.2
CDFG: Laguna Wildlife Area			
2005	731	5	326.5
2006	1191	16	221.5
2007	531	4	15.2

Discussion

Herbicide application provided mixed results, many of which are difficult to disentangle from other contributing factors including annual precipitation, spring air temperature, channel size and depth, herbicide application rate, and whether biomass was removed after spraying. However, in general, the pattern from the two sites is clear. Areas in which *Ludwigia* was sprayed and then removed provided control for 2 years *if* the water was deep, though minor touchup spraying was required. Under shallow water conditions these methods appear unable to provide effective control for even a single season. Application of herbicide to densely infested areas where biomass cannot be removed is not effective and contributes to poor water quality. Application of herbicide to small patches along channel margins may provide sustained control as long as applications occur every year.

Although both glyphosate and triclopyr are systemic herbicides, neither seemed to act systemically. The fact that glyphosate adsorbs readily to soil particles and becomes inactive makes it a poor choice of herbicide if conditions require the use of airboats or Marshmogs to drive over plants. This equipment causes plants to become coated with muddy water. However, this is not sufficient to explain its failure to provide control because large areas, such as the BW channel, were treated from the bank and therefore were not coated by muddy water during the application.

The label for Renovate 3, the triclopyr-based herbicide, recommends an application rate of 2-8 quarts per acre for aquatic and emergent weeds including water primrose (*Ludwigia*). Even at the greatly reduced rate of 1 quart per acre triclopyr acted too quickly on *Ludwigia* and generally failed to work systemically as a result. Therefore under shallow water conditions Renovate 3 also seems like a poor choice for control of *Ludwigia*, particularly if the biomass cannot be removed following the application.

It is important to repeat that the herbicides used may have been more effective at different application rates. For instance, glyphosate has been used effectively in other parts of California but there is little data reporting on the duration of control.

Each year herbicide applications occurred between June 15 and September 30 in compliance with NOAA Fisheries regulations. Yet in a typical year *Ludwigia* has already experienced significant growth and gained competitive advantage by June 15. This prompted discussion of an earlier application to young plants as soon as they emerge. This might work if the *Ludwigia* plants are directing more photosynthetic energy to root development at this time and if the herbicide truly works systemically. However, in areas where *Ludwigia* is well established, observations suggest that an early application might kill the early growth but as water levels drop through the growing season newly exposed banks will be open to a second wave of growth. This would require an additional application. If the water level dropped enough, as it did in 2007, *Ludwigia* could then begin to grow from the middle of the channel and require yet another application. Nonetheless, this approach may be worthy of a test. But if spraying occurs prior to June 15, a salmonid take permit would be required.

Although this discussion of herbicide use suggests that it is ineffective against *Ludwigia,* it should be acknowledged that different site conditions can yield very different results. For example, one area within the SCWA site dried out following the droughty winter of 2007. This was an area where mechanical removal had never been possible (southeast section of Laguna Main channel). Following one season of glyphosate treatment and two seasons of triclopyr treatment the site was nearly free of *Ludwigia*. Numerous other species quickly colonized the available mudflat including *Polygonum* spp. and various graminoids. This suggests that in addition to deep water, the absence of water can control or limit the growth of *Ludwigia*, particularly if it is sprayed with herbicide.

However, because most of the problem areas in the Laguna do not dry out, the continued use of herbicide (triclopyr), if any, should be limited to areas where biomass is low, areas where immediate control is needed (e.g. for mosquito control), or areas where it is part of an active restoration plan. Herbicide should not be applied to large patches unless it can be removed. In all cases herbicide should be considered a temporary fix while more effective solutions are planned. Efficacy trials using the herbicide Habitat (active ingredient imazapyr) to control *Ludwigia* are underway elsewhere in California and may yield better results.

As mentioned, herbicide application followed by mechanical removal provides longer lasting control in areas where the water is deeper. Although *Ludwigia* produces adventitious roots from its floating nodes, it must ultimately root in sediment. In deeper water the available rooting surface is limited to the channel margin. The plant must then "creep" across the surface. Although the minimum water depth required is unknown, observations over the three years suggest a minimum of 3 feet of water. Given time, however, *Ludwigia* will easily cover the water surface at this depth. Areas that had remained open prior to the onset of project activities were more on the order of 5 or more feet deep.

It is unclear whether spraying herbicide prior to mechanical removal increases control. The practice of spraying first is intended to reduce the threat of spreading fragments downstream. However, floating booms erected to prevent turbid waters from moving downstream should also serve to collect floating fragments. If so, it may be more effective to remove the vegetation first and then spray regrowth. This would also result in less volume of herbicide being used. Regardless of the order of operations, however, lasting control is unlikely with either spraying or mechanical removal alone though these actions may be an important component in larger restoration plans.

It is important to understand how water quality is affected by both the presence of *Ludwigia* and by efforts to control it. As a photosynthesizing macrophyte, *Ludwigia* helps boost dissolved oxygen levels each day just as it consumes oxygen each evening during respiration. As a dense mat it may even help mediate extreme temperature fluctuations in shallow water. But the effect of the decomposition on dissolved oxygen probably outweighs any benefits. Spraying *Ludwigia* without removing it amounts to a speeding up of this process and is detrimental to the system. Additionally, allowing the biomass to decompose in place releases all the stored nutrients back into the system, a process that may boost further *Ludwigia* growth. In all of this it is important to remember that although *Ludwigia* can affect water quality in both negative and positive ways, its presence is a response to poor water quality and ecosystem perturbation, not a cause.

Conclusion

The three-year effort to control *Ludwigia* through herbicide application and mechanical removal has yielded mixed results at considerable cost. The degree and duration of control are closely linked to physical conditions at the site and annual variations in temperature and precipitation. Clearly there continues to be a need to address to the underlying conditions that promote *Ludwigia* growth in the watershed. Long-term *Ludwigia* control will require systemic approaches that address the primary stressors in the Laguna. Reducing inputs of nutrients and sediment is paramount. This process will begin when the Regional Water Quality Control Board completes its TMDL pollution plan, sometime around 2011. Although measurable differences may be more than a decade away, it is a positive step.

The focus in the shorter term should shift to manipulation of physical conditions as part of larger restoration plans. Perhaps the most effective action will be water level manipulation. This entails creating conditions that promote either deep water or the absence of water during summer months. Methods may include targeted sediment removal, creation of low flow channels, and reduction of summer irrigation runoff. Because accumulated sediment is very likely enriched with nutrients, its removal in key areas will also serve to remove accumulated nutrients from the system. Because sediment removal will create considerable disturbance, it should always be accompanied by restorative actions such as establishment of riparian forest.

Recommendations

Management of *Ludwigia* within the Laguna watershed and within the current project sites will require sustained attention over the long term. This section begins with an update and recommendations for strategies to improve conditions and to prevent further introductions in the watershed. Following this are short and long term recommendations for both the SCWA field site and the CDFG Laguna Wildlife Area. Because some of the ideas presented here are under development and have not been approved by stakeholders, only general descriptions are provided.

Watershed-level strategies

TMDL
The Laguna provides ideal conditions for rampant growth of *Ludwigia* and other invasive aquatic species. Abating this threat will require reduction of future inputs of sediment and nutrients. This is the purpose of the TMDL pollution plan recently initiated by the RWQCB and expected to be completed by 2011. RWQCB will set numeric objectives for nitrogen, phosphorous, sediment, dissolved oxygen, temperature, and mercury and increase awareness of the specific actions needed to meet these objectives.

Coordinated restoration and management
Many agencies and organizations that work within the watershed are involved in restoration and management projects. There is a growing awareness of each other's work and increasing desire to collaborate. The Laguna Foundation convened its first Laguna Watershed Stakeholder Council meeting in October 2007 in which several agencies and organizations shared the work they were doing in the watershed. These meetings will continue to be held and it is hoped that smaller committee meetings on special topics will evolve out of this process.

Public education
The threat of new introductions of *Ludwigia* and other highly invasive species is omnipresent. Public education through interpretive signage can serve as a strong preventative measure at likely introduction points such as Spring Lake and Lake Raphine as well as at already invaded sites like Riverside Park. Outreach to local aquatic plant nurseries will also be important.

Strategies for the SCWA field site – Short Term

Channel Maintenance
It is important not to lose ground gained during the project period. This will require ongoing maintenance until physical conditions at the site are no longer conducive to *Ludwigia* growth. Recommended actions include mechanical removal followed by herbicide application to regrowth if needed. This reversal of the order of operations is derived from lessons learned and is intended to reduce the volume of herbicide used. Mechanical removal also serves to remove stored nutrients from the system. Because

live fragments will be created during removal, floating booms must be erected downstream to capture these potential propagules.

Channel maintenance is proposed every 2-5 years until longer term actions are accomplished. The frequency will be dictated by conditions. A long-reach excavator is recommended for removal in the BW channel and Gossage Creek and an aquatic harvester in the Laguna Main. Because the cost of contracting aquatic harvesters is very high, purchase of the equipment is strongly recommended. The most logical owner of the harvester would be SCWA or the Marin/Sonoma Mosquito and Vector Control District.

<u>Strategies for the SCWA field site – Long Term</u>

Reduction or elimination of summer water inputs
The only perennial stream entering Laguna Main is Copeland Creek yet summer flows occur in many local tributaries including Hinebaugh Creek and Gossage Creek. There is no perennial water source entering the BW channel yet it retains flow year-round. The likely sources are irrigation runoff into storm drains from agriculture, private lawns, golf courses, and car washing. This runoff is almost certainly rich in nutrients from fertilizers. Adding nutrient rich water to accumulated sediments in the infested areas perpetuates the ideal growing conditions for *Ludwigia* and other aquatic invasives in the Laguna. The first step in reducing or eliminating this input will be identification of sources through monitoring. This should begin immediately in summer 2008. Once major contributors of water are identified, essential efforts can be made to reduce or eliminate the input.

Low flow channels and targeted sediment removal
Although the elimination of *Ludwigia* is unlikely, containing its extent is possible by reducing the amount of channel available for colonization. Low flow channels can be created within the pre-existing channels to confine summer flow to a smaller area. In concept a low flow channel can be made deep enough to limit *Ludwigia* to its margins and the remainder of the channel would then dry out creating the two conditions that suppress *Ludwigia* growth, deep water and absence of water. Laguna Main is an excellent example of where a low flow channel is urgently needed. The roughly 120-foot wide channel is inundated by shallow water in the summertime. Excavation of a 15-foot wide by 8-foot deep channel would reduce the wetted area by 85%. Not only would the deeper water would be more resistant to *Ludwigia* growth, but it would have lower water temperature and higher dissolved oxygen as well.

Although the idea of a low flow channel is conceptually simple, implementation is not. Design, permitting, and maintenance costs could be high particularly if sedimentation is rapid or channel sides unstable. These issues are being studied by SCWA. Potential locations for low flow channels include the BW channel from Millbrae Avenue to the confluence with the Laguna, Laguna Main from the confluence of Gossage Creek and Hinebaugh Creek to the constriction point west of Stony Point Road, and Laguna Main from the constriction point and Llano Road. The process of constructing low flow channels would cause considerable disturbance and would necessarily be part of an active restoration project.

Strategies for CDFG field site – Short Term

Mechanical Removal
As described above and throughout this document, mechanical removal can provide effective short-term control of *Ludwigia*, particularly in deeper channels. In the coming years the channel through the CDFG Laguna Wildlife Area will gradually fill in with *Ludwigia* again. Mechanical removal should be used to clear the channel every 2-5 years until large-scale restoration begins. Herbicide may be used to stem regrowth along the channel margins following the removal if needed. As described above, it will be far more cost effective if a local agency purchases an aquatic harvester for the mechanical removal efforts.

Ludwigia will become worse in the floodplain without herbicide application but continued spraying without removal is not justified except under exceptional conditions such as emergency efforts to stem mosquito production following unusually high larval detection rates.

Strategies for CDFG field site – Long Term
The Laguna Wildlife Area is a highly disturbed site. The forested floodplain shown in the 1942 aerial photo was reclaimed for agriculture decades ago and the pilot channel that dissects the site is entirely artificial. Lack of drainage in the last decade has resulted in flooded conditions year round. Suppressing *Ludwigia* at this site will require large-sale, multi-objective restoration that includes participation by surrounding landowners. This process will be initiated in spring 2008. An expert team will be assembled to assess potential restoration options which will then be weighed against relevant ecological, social, and financial factors. A preferred alternative will be chosen with the participation of surrounding landowners. Implementation will follow.

Appendix 1
Target Invasive Weed
Prepared by Dr. Brenda Grewell, Ecologist, USDA-ARS

During project planning, the invasive *Ludwigia* species invading extensive areas of the Laguna was thought to be *Ludwigia hexapetala*, which is taxonomically described and considered a native California species in the Jepson Manual: Higher Plants of California (Hickman et al. 1993). Early in the project, botanical experts (Dr. Brenda Grewell and Dr. Cristina Hernandez USDA-ARS, and Keenan Foster, SCWA) carefully examined these plants in the field and determined that the primary invader in the Laguna consistently did not key to the taxonomic description of *Ludwigia hexapetala* in the Jepson Manual and did not key to the description of *Ludwigia hexapetala* by Zardini, the South American expert for the *Ludwigia* genus. However, the invasive *Ludwigia* species in the Laguna did fit the less-detailed description of *L. hexapetala* in the Flora of Sonoma County (Best et al. 1996). Chromosome counts can be used to differentiate among confusing *Ludwigia* species, and have been the basis for accurate taxonomic determinations elsewhere. Because precise identification of invasive weeds can be critical for the development of effective management strategies, USDA-ARS and UC Davis scientists launched a comprehensive cytological and morphometric evaluation of invasive *Ludwigia* taxa throughout the Laguna, the greater Russian River Basin, and the Pacific west states. Chromosome counts and morphometric analyses (Grewell et al. manuscript in review) confirm four *Ludwigia* taxa in the Laguna de Santa Rosa watershed, and companion molecular studies (Okada et al. manuscript in preparation) indicate hybrids are also present. All of these taxa co-occur in the project areas. Independent of this research, a global phylogenetic re-evaluation of the genus is underway. As results become available, nomenclature for taxa may change and taxonomic keys including the Jepson Manual will be revised. For now, as determined by ploidy levels, we can refer to the two primary invasive weeds in the Laguna as *Ludwigia hexapetala* and *Ludwigia peploides* ssp. *montevidensis*, and *L. hexapetala* is currently the more abundant of the two in both project locations. Both taxa will be treated as exotic invasive species from South America in taxonomic key revisions (Grewell, personal communication), and corrections to the taxonomic keys are in progress. The native *Ludwigia peploides* spp. *peploides* and *Ludwigia palustris* are also present, co-occur with the exotic species in the Laguna, and all four taxa are present in the management project areas. In addition, *Ludwigia peploides* hybrids have been confirmed in the Laguna.

Appendix 2:

Select Photo Monitoring Series from the SCWA and CDFG Treatment Areas
2005-2007

Bellevue Wilfred Channel, SCWA Field Site: Photo Point A-01

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking southwest off the Millbrae Road Bridge. Prior to project activities *Ludwigia* covered roughly 75% of the channel. Following 2005 spray/removal activities the channel was clear. In spring 2006 regrowth was moderate. Following another season of spray/removal, regrowth was strong in 2007and Ludwigia reoccupied at least 75% of the channel though the density was reduced from pre-project levels. Note that much of the growth is occurring from the east (left) side of the channel where a mudflat provides ideal medium for germination, growth from fragments, and sprouting from existing roots. Removal of this sediment during the creation of a low flow channel could stem the regrowth in this section.

Bellevue Wilfred Channel, SCWA Field Site: Photo Point D-07

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking north toward the Wilfred Bridge. Photo taken from cross bridge within channel. Note the open water in the foreground following the first year. Although *Ludwigia* can easily creep across this deeper water (~36 inches), the time required to reoccupy it is greater than in uniformly shallow areas. The important point is that deeper water will limit *Ludwigia* growth for a period of time but not indefinitely as is obvious from the pre-spray July 2005 photo. Following the 2007 spray/removal activities, this section was once again clear.

Bellevue Wilfred Channel, SCWA Field Site: Photo Point E-08

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking north from cross bridge within channel (just north of Rohnert Park Expressway). Dense infestation in July 2005 was growing on shallowly inundated mudflat. Regrowth in June 2006 was limited partly from cool wet spring. By mid-summer regrowth was more pronounced. Regrowth in June 2007 was stronger following a warm spring and drought winter. Note the natural low-flow channel in June 2007. If this were made deeper it is possible the soil on the adjacent mudflats would not be saturated and would be less conducive to *Ludwigia* growth.

Laguna Main Channel, SCWA Field Site: Photo Point I-13

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Post-spray
September 2007

Main Laguna channel looking west from the Stony Point Road Bridge. Prior to project activities this relatively deep section was heavily infested. Following the first year of spray/removal the channel was largely clear and remained so in June 2006. No removal occurred in 2006. The drought of 2006/2007 resulted in shallow conditions in spring/summer 2007 allowing *Ludwigia* to root mid-channel. Despite two herbicide applications, the channel experienced significant regrowth in 2007 as well as large algal blooms. A low flow channel to contain summer flow would limit the area of the channel available for colonization.

Laguna Main Channel, SCWA Field Site: Photo Point O-22

Post-removal
October 2005

Pre-spray
June 2006

Post-spray
October 2006

Post-spray
September 2007

Main Laguna channel looking east of confluence with Bellevue Wilfred Channel. No photo available for June 2005. This section was treated with herbicide each year. Mechanical removal occurred only in 2005. Note that in September 2007 *Ludwigia* only occurs in the wetted channel and even here it is low density. The vegetation on the sides is not *Ludwigia* and the soil underneath is largely dry. This is the goal of a low flow channel, to contain water to a small area where *Ludwigia* can easily be contained and to keep the remainder of the channel dry during summer. Although water levels would be higher outside of a drought year, a constructed low flow channel would be deeper and the net result would likely be the same.

Floodplain, CDFG Laguna Wildlife Area: Photo Point C-11

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

Pre-spray
August 2007

Looking south over the northern floodplain of the CDFG Laguna Wildlife Area. Because mechanical removal was not feasible in the floodplain, herbicide was the only management method used. Despite a promising appearance following spraying in 2005 and 2006, regrowth was strong by the following spring of each year. Although this portion of the floodplain was sprayed again in 2007, much of the floodplain was not sprayed in 2007 due to the limited efficacy of previous efforts. Decaying biomass left in place following spraying also degrades water quality by consuming dissolved oxygen and releasing stored nutrients.

Floodplain, CDFG Laguna Wildlife Area: Photo Point Q-46

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

August 2007

Looking west over the southern section of the Laguna Wildlife Area floodplain. As in the previous photo series, limited efficacy was achieved through spraying. Although the October 2006 photograph shows a strong component of non-*Ludwigia* species including *Polygonum* sp. and *Xanthium strumarium*, *Ludwigia* quickly regained a competitive edge by the following spring. This area was not sprayed in 2007.

Channel, CDFG Laguna Wildlife Area: Photo Point L-38

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

Post spray
August 2007

Channel through CDFG Laguna Wildlife Area. Spraying occurred each year. Mechanical removal occurred only in 2005. The channel remained quite clear until late 2007 when shallow water conditions prevailed following a low rainfall winter. Ongoing maintenance will be required to keep the channel clear. Mechanical removal is the preferred method and will need to occur every 2-5 years depending on the rate of regrowth. Maintenance will continue until the underlying issues that encourage rapid growth of *Ludwigia* are addressed. Planning efforts to restore the site will begin in spring 2008.

Channel, CDFG Laguna Wildlife Area: Photo Point K-35

Pre-spray
July 2005

Pre-spray
June 2006

Post spray
August 2007

Channel through Laguna Wildlife Area. Spraying occurred each year. Mechanical removal occurred only in 2005. This deeper section of channel retained excellent control throughout the project period.

Ludwigia spp.

Waterprimroses

Family: Onagraceae
Range: Primarily in the coastal states, Washington, Oregon and California; creeping waterprimrose is also found in Arizona and New Mexico.
Habitat: Slow-flowing rivers, lake and reservoir margins, and in the shallow waters of canals and floodplains.
Origin: Most species are native to South America. *L. peploides* ssp. *peploides* is native to California, Arizona, New Mexico, Texas, and Louisiana; ssp. *glabrescens* (Kuntze) Raven is native to the central and eastern U.S.; and ssp. *montevidensis* (Spreng.) Raven is introduced from southern South America. *L. peploides* is sometimes sold as an aquarium or pond ornamental.
Impacts: Dense stands degrade natural communities, reduce water quality and floodwater retention, and prevent effective mosquito control. Plants can develop a tangled mat of stems that can reduce water flow in irrigation channels and drainage ditches.
Western states listed as Noxious Weed: *L. grandiflora,* Washington
California Invasive Plant Council (Cal-IPC) Inventory: *L. hexapetala,* High Invasiveness (Alert); *L. peploides,* High Invasiveness

Waterprimroses are floating to emergent perennials with stems to 10 ft long. Stems and leaf veins are often reddish. Leaves are alternate with smooth margins. Species, or even subspecies or varieties, differ in hairiness. Plants expand by creeping rhizomes.

The taxonomy of *Ludwigia* is still very confusing. Two or three species are problematic, including creeping waterprimrose (*L. peploides* (Kunth) Raven) and Uruguay waterprimrose (*L. grandiflora* (Michx.) Greuter & Burdet; = *L. hexapetala* (Hook. & Arn.) Zardini, Gu & Raven and *L. uruguayensis* (Camb.) Hara var. *major* (Hassler) Munz). Recent evidence suggests that *L. grandiflora* and *L. hexapetala* are two distinct species.

Flowering stems are usually creeping and floating to ascending. Flowers are solitary in upper leaf axils, trumpet-shaped with a long slender tube (inferior ovary). Flowers have five petals, generally bright yellow and showy. Plants reproduce by seed and vegetatively from creeping stems and stem fragments, and to some degree from rhizomes. The fruits are hard, narrowly cylindrical capsules, 4 to 5-chambered, 1 to 2 inches long, typically bent downward. The fruits contain numerous small seeds, float in water and are easily dispersed by currents. Seeds do not individually disperse from capsules. Despite the production of numerous seeds, seedlings are rarely encountered. The plants also produce creeping submerged stems that root at nodes and produce aerial shoots. Floating vegetative mats or shoot fragments readily break off and are carried away by flowing water.

NON-CHEMICAL CONTROL

Mechanical (pulling, cutting, roguing)	Ideally, mechanical control measures should include removal of plant material that contains viable propagules (fruit, rhizomes, seed). Equipment that can dig up, plow or "rogue" the stands of *Ludwigia* spp. usually is capable of lifting and depositing it on trucks.

	Mowing devices typically leave fragmented pieces that can reinfest or disperse downstream. However, mowing may be used as part of an integrated program if done before seed set and in conjunction with properly applied herbicides.
Cultural	Preventing accumulation of nutrients and sediment can reduce the spread of *Ludwigia* spp., but this usually requires significant reduction in existing nutrient sources. Managed flood/dry conditions can be used in conjunction with both mechanical removal and approved herbicides.
Biological	The native flea beetles *Lysathia flavipes* and *L. ludoviciana* can defoliate some *Ludwigia* species. The chrysomelid *Altica cyanea* has been investigated for use in China. The USDA-ARS Exotic and Invasive Research Lab at UC Davis has begun a search for potential agents in South America. The grass carp (white amur, *Ctenopharyngodon idella*) is a relatively nonselective herbivorous fish that will consume some *Ludwigia* species, particularly those producing prostrate, floating mats. However, since the grass carp prefers submersed plants, its use must be weighed against potential impacts to native submersed plants.

CHEMICAL CONTROL

The following specific use information is based on published papers and reports by researchers and land managers. Other trade names may be available, and other compounds also are labeled for this weed. Directions for use may vary between brands; see label before use. Herbicides are listed by mode of action and then alphabetically. The order of herbicide listing is not reflective of the order of efficacy or preference.

GROWTH REGULATORS	
2,4-D *Weedar 64*	**Rate:** Broadcast foliar treatment: 1 to 2 pt product/acre (0.48 to 0.95 lb a.e./acre) with a non-ionic surfactant **Timing:** Optimal timing is to apply 2,4-D postemergence from spring to early summer. However, applications from mid-summer to early fall can also be effective in suppressing growth. **Remarks:** 2,4-D is a relatively fast-acting, selective systemic herbicide.
Dicamba + diflufenzopyr *Overdrive*	**Rate:** 4 to 8 oz product/acre **Timing:** Postemergence to rapidly growing plants. **Remarks:** Reported effective on some waterprimrose species. Diflufenzopyr is an auxin transport inhibitor which causes dicamba to accumulate in shoot and root meristems, increasing its activity. Higher rates should be used when treating perennial weeds. Add a non-ionic surfactant to the treatment solution at 0.25% v/v or a methylated seed oil at 1% v/v solution. This product does not have an aquatic registration and cannot be used near water.
Triclopyr *Renovate*	**Rate:** Broadleaf foliar treatment: 2.67 to 5.33 pt product/acre (1 to 2 lb a.e./acre) with a non-ionic surfactant **Timing:** Postemergence, spring to early summer, is optimal. However, mid-summer applications can also be effective in suppressing growth. Late summer to fall applications can reduce subsequent spring regrowth. **Remarks:** Triclopyr is a selective, relatively fast-acting systemic herbicide.
AROMATIC AMINO ACID INHIBITORS	
Glyphosate *Rodeo, Aquamaster*	**Rate:** Spot foliar treatment: 1 to 2% v/v solution (*Rodeo* or *Aquamaster*) with approved surfactants. **Timing:** Postemergence from spring through fall. **Remarks:** Nonselective, slow-acting systemic herbicide. Efficacy can be reduced if plants have dust and debris on the petioles (leaves). Applications made after rains remove the dust can often increase efficacy.
BRANCHED-CHAIN AMINO ACID INHIBITORS	
Imazamox *Clearcast*	**Rate:** Broadcast treatment to emergent shoots: 2 pt product/acre (4 oz a.e./acre). Spot spray-to-wet treatment: 0.25 to 5% v/v solution. Direct in-water treatment: 50 to 100 ppb. Efficacy may be improved by adding 1 qt/acre glyphosate (*Rodeo* or *Aquamaster*). **Timing:** All applications (in-water or foliar) should be made from early spring to early summer during the period of rapid growth. **Remarks:** Use an approved surfactant. Aerial application is approved in some states.
Imazapyr *Habitat*	**Rate:** Broadcast treatment to emergent shoots: 4 to 6 pt product/acre (1 to 1.5 lb a.e./acre). Spot treatment: 1.5% v/v solution in 100 gal/acre for adequate coverage. **Timing:** Early spring to early summer (when new growth is present)

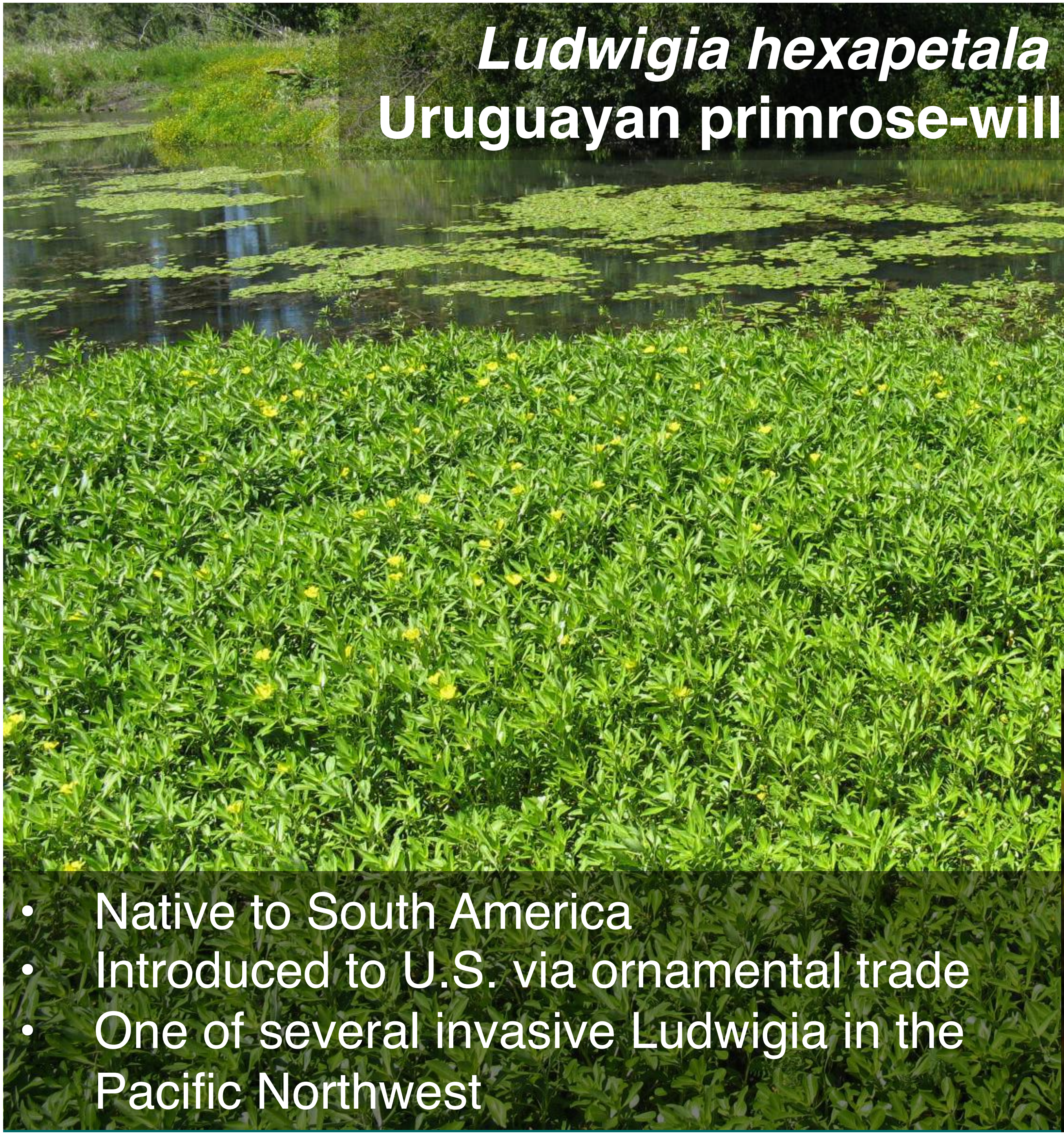
	Remarks: Use repeated applications to achieve desired concentration for 5 to 7 weeks. Do not tank mix with glyphosate for *Ludwigia* control.
CONTACT PHOTOSYNTHETIC INHIBITORS	
Diquat *Reward*	**Rate:** Spot (emergent shoot) treatment: 0.5% v/v solution (2 qt/100 gal water) **Timing:** Postemergence foliar treatment from spring to early summer is optimal. Repeat treatments may be needed in mid-summer. **Remarks:** Contact herbicide that is inactivated in turbid water; use only clean water to mix and spray.

RECOMMENDED CITATION: DiTomaso, J.M., G.B. Kyser et al. 2013. *Weed Control in Natural Areas in the Western United States*. Weed Research and Information Center, University of California. 544 pp.

Control of *Ludwigia hexapetala* at Delta Ponds

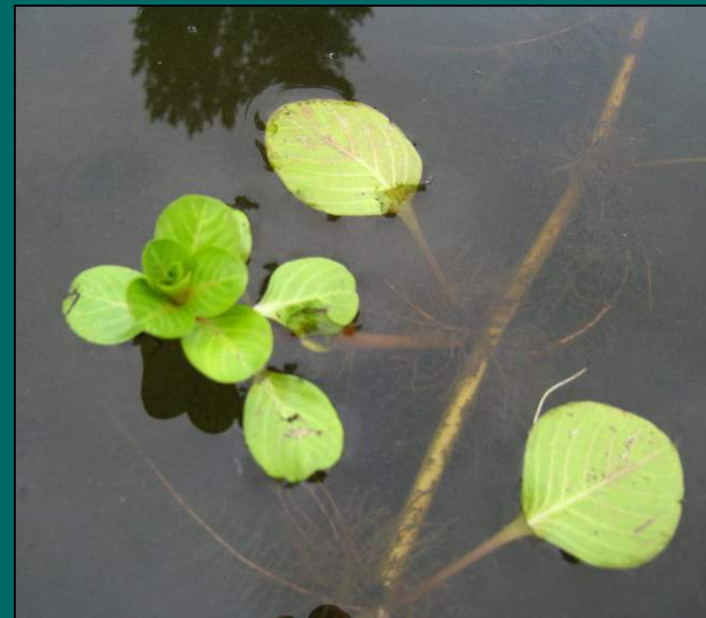
Lauri Holts
City of Eugene
Parks and Open Space

Ludwigia hexapetala
Uruguayan primrose-willow



- Native to South America
- Introduced to U.S. via ornamental trade
- One of several invasive Ludwigia in the Pacific Northwest

Ludwigia is extremely well adapted to spread and persist



Leaf & stem fragments have the ability to sprout roots

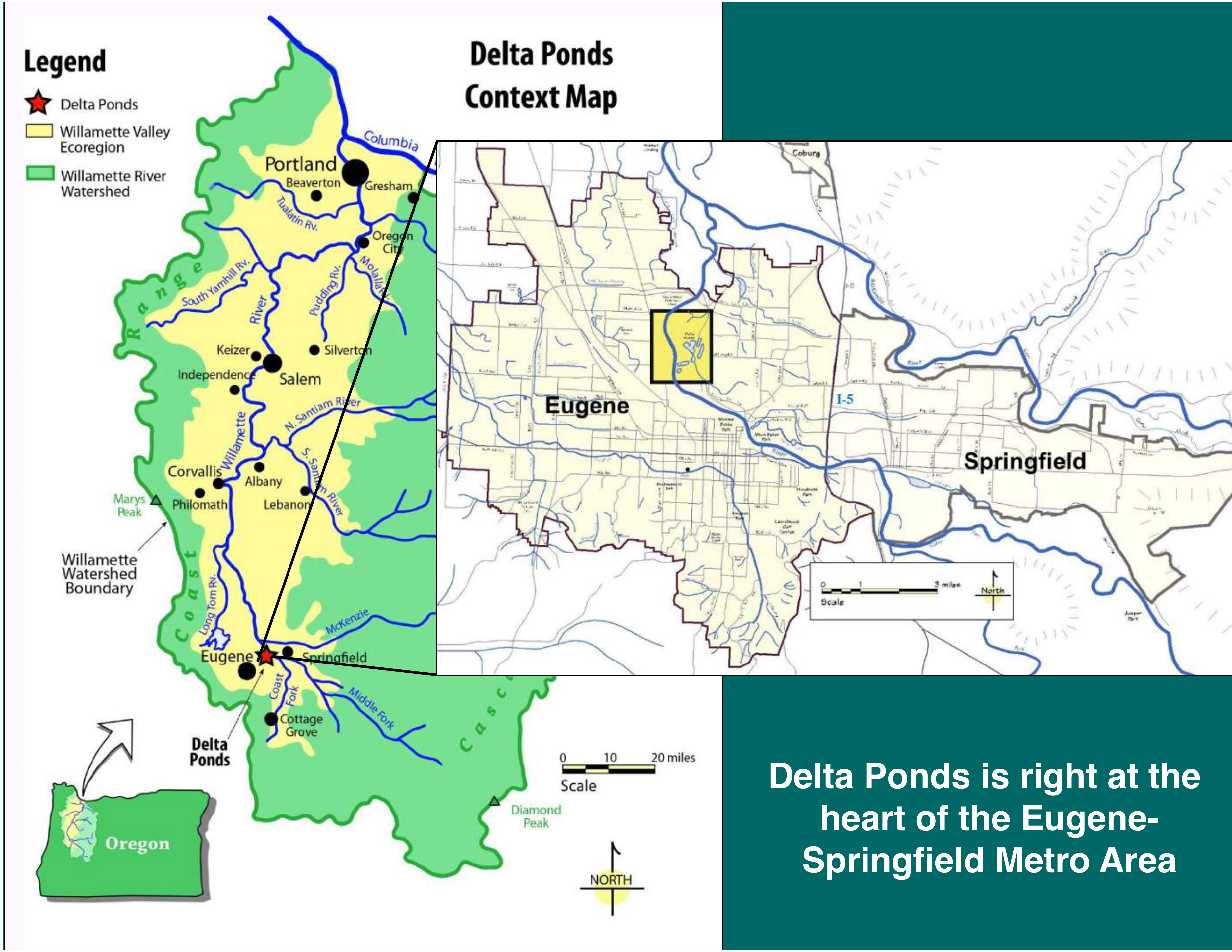
Aerenchymous roots absorb nutrients from air

Ludwigia will persist and grow along shorelines

…and we now know that it produces highly viable seed

Impacts of *Ludwigia hexapetala*

- Clogs waterways
- Decreases flood retention
- Degrades water quality
- Decreases open water habitat
- Displaces native vegetation
- Facilitates secondary invasion
- Impacts threatened species



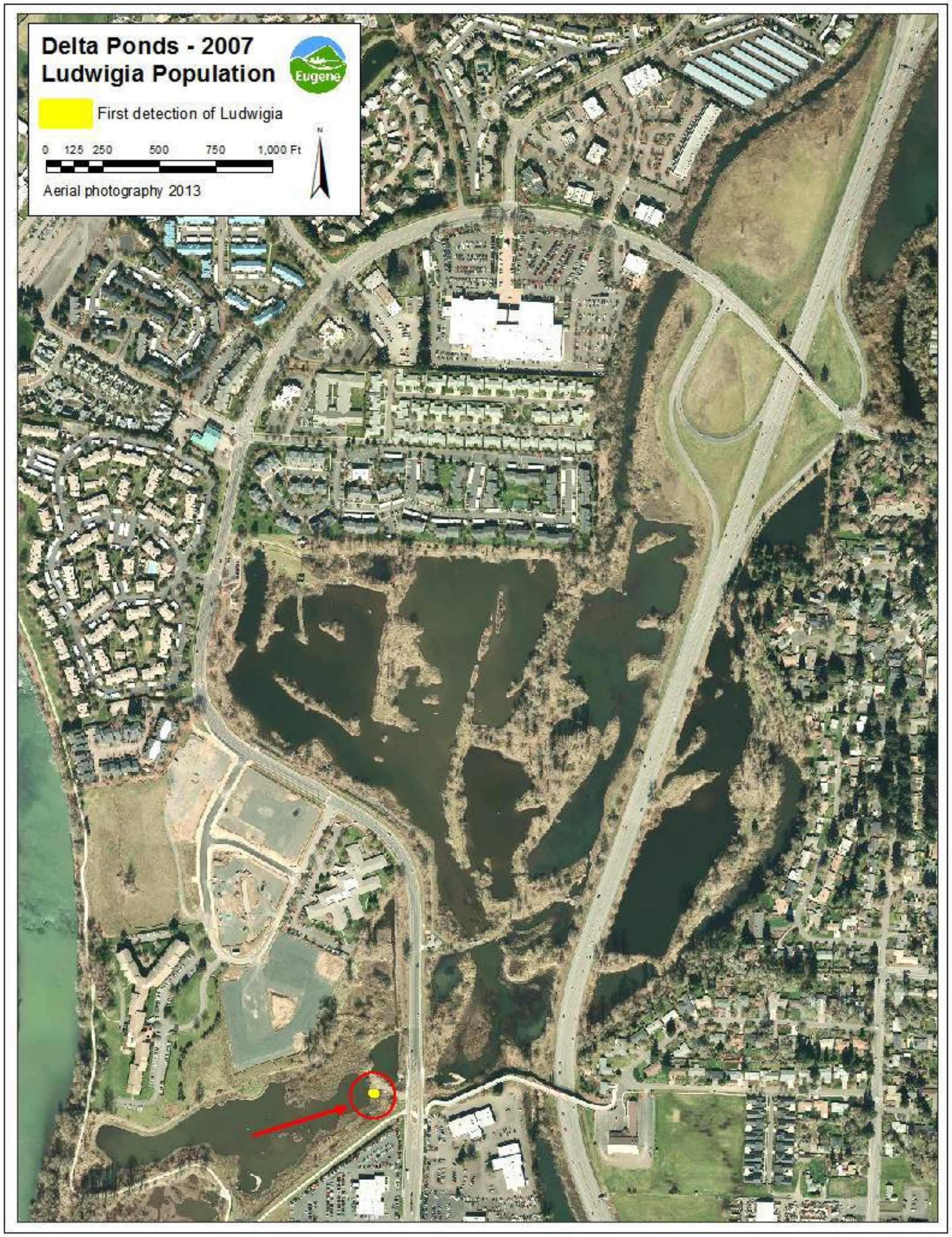
Delta Ponds is right at the heart of the Eugene-Springfield Metro Area

Ludwigia hexapetala at Delta Ponds

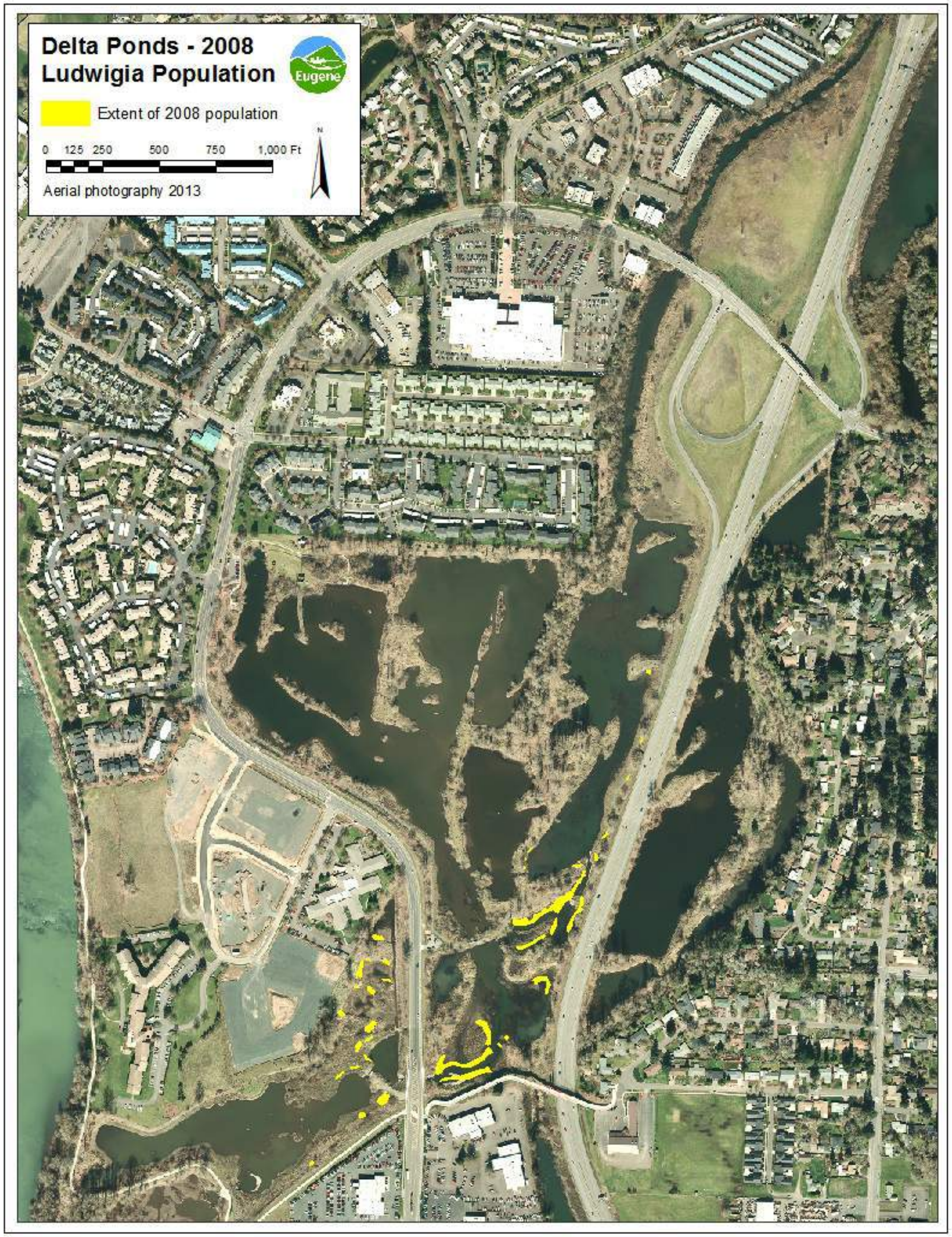
Ludwigia showed up in 2007 at an old boat ramp …

and within just a few years it had overtaken some of the ponds

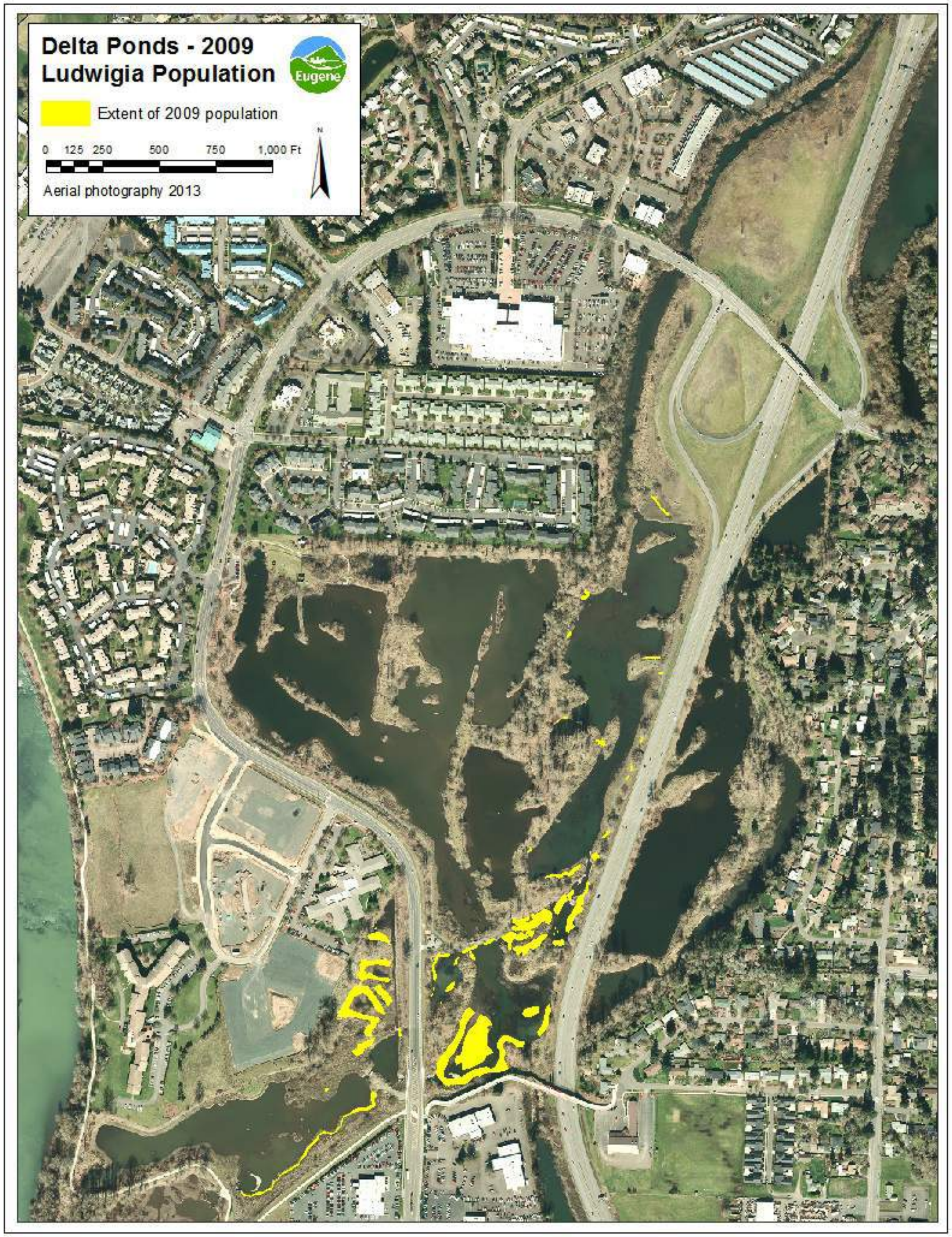
Photopoint photos from long-term Delta Ponds project monitoring


Delta Ponds - 2007
Ludwigia Population
Eugene
First detection of Ludwigia
0 125 250 500 750 1,000 Ft
N
Aerial photography 2013

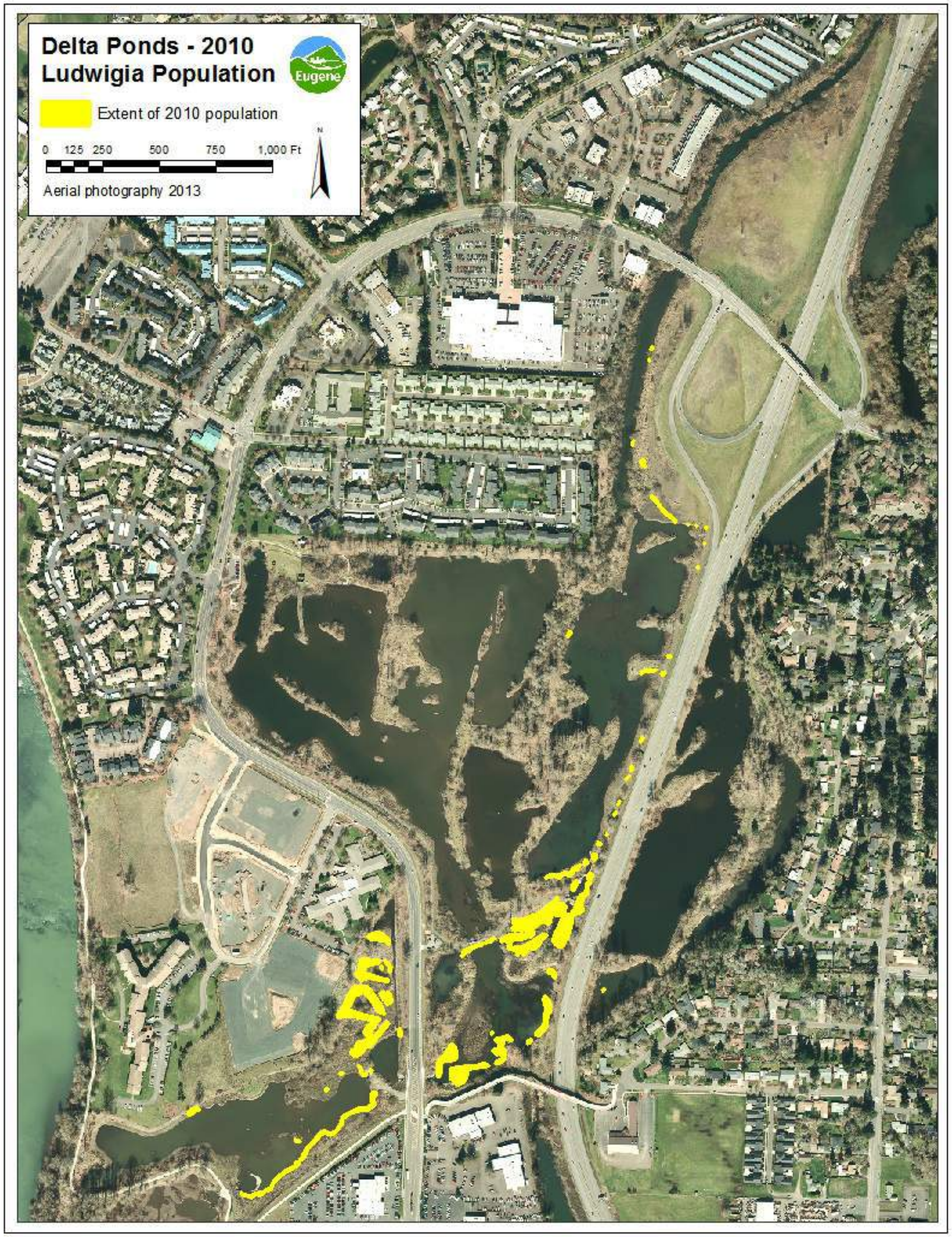
2007


Delta Ponds - 2008
Ludwigia Population
Eugene
Extent of 2008 population
0 125 250 500 750 1,000 Ft
Aerial photography 2013

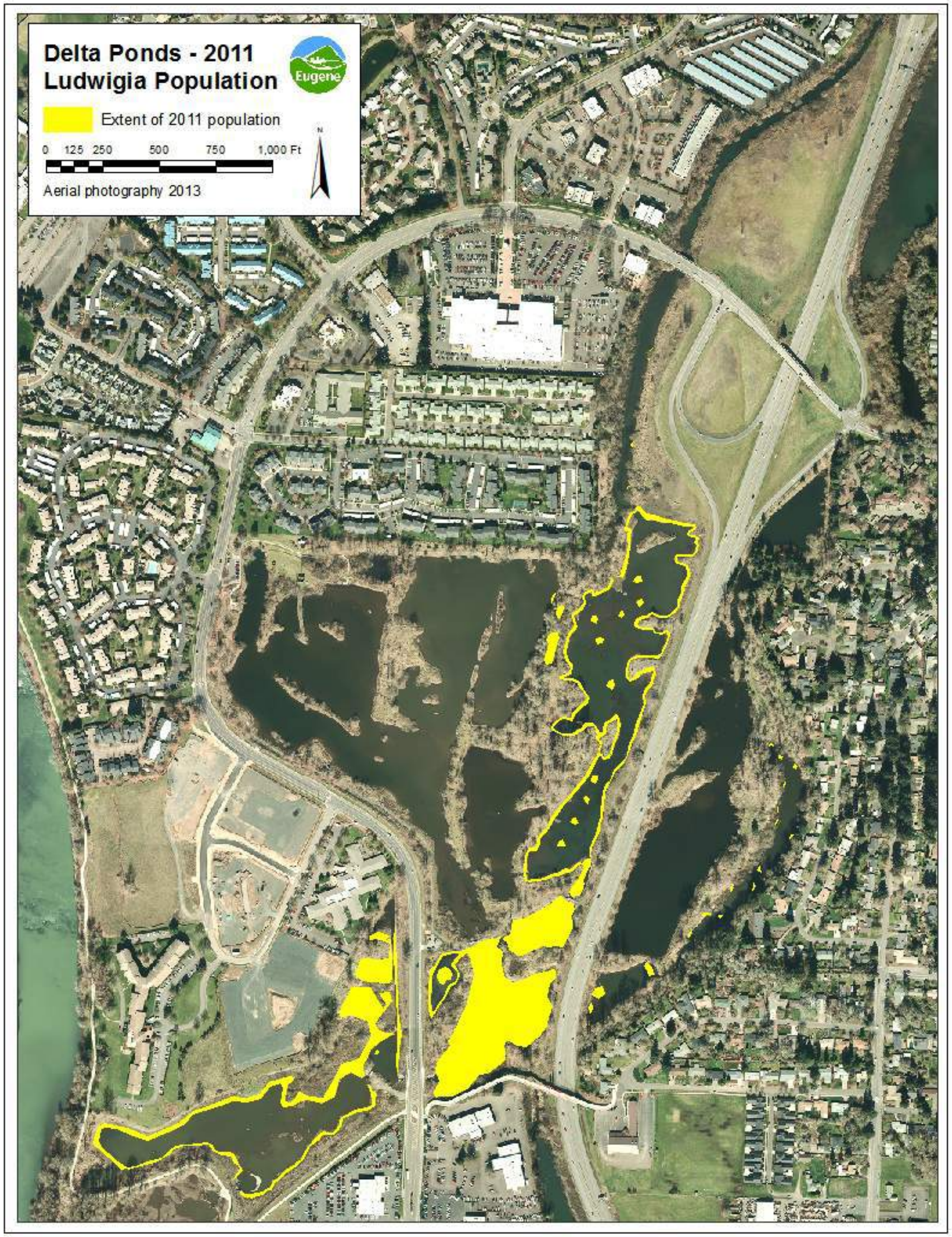
2008


Delta Ponds - 2009
Ludwigia Population
Eugene
Extent of 2009 population
0 125 250 500 750 1,000 Ft
N
Aerial photography 2013

2009

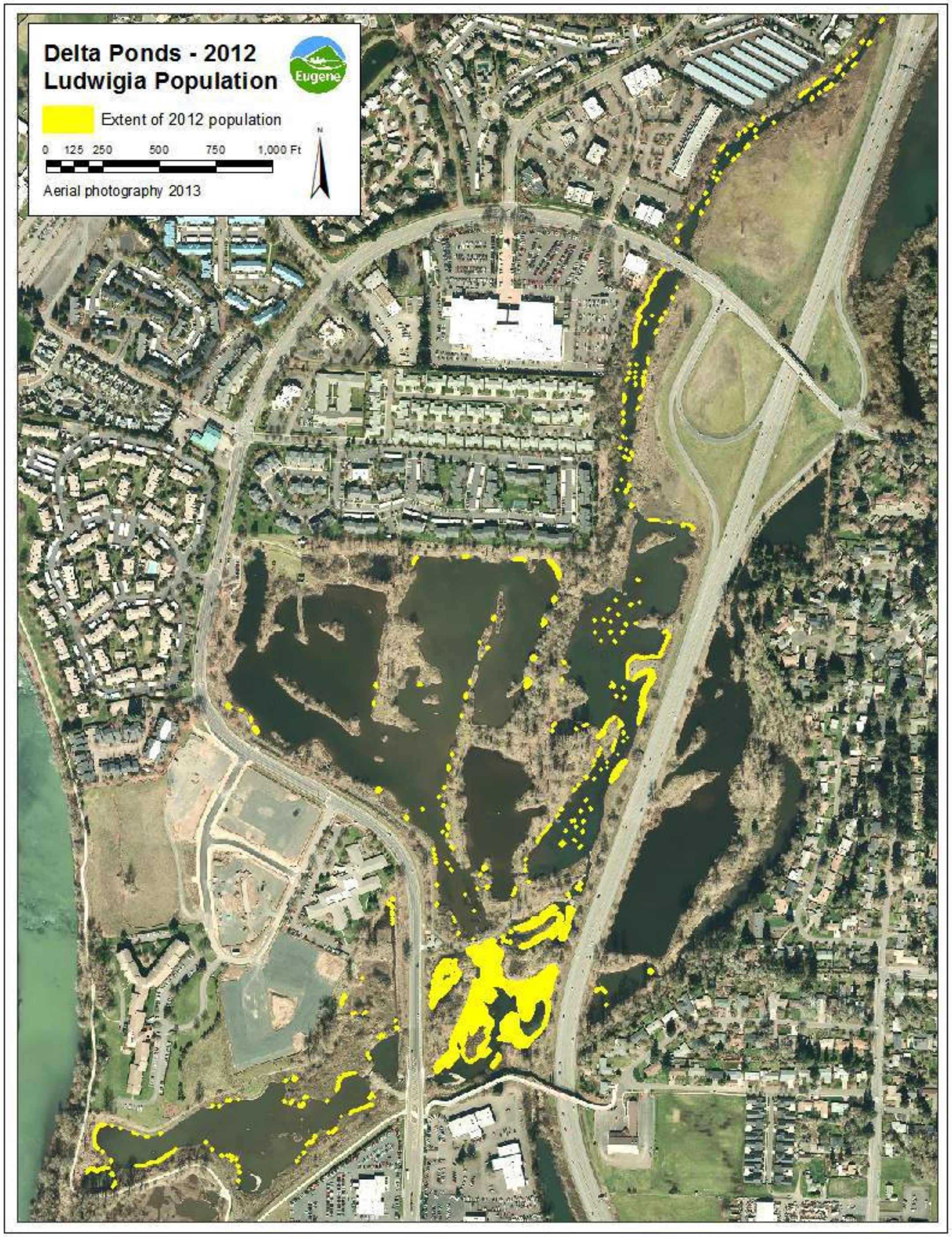

Delta Ponds - 2010
Ludwigia Population
Eugene
Extent of 2010 population
0 125 250 500 750 1,000 Ft
Aerial photography 2013

2010



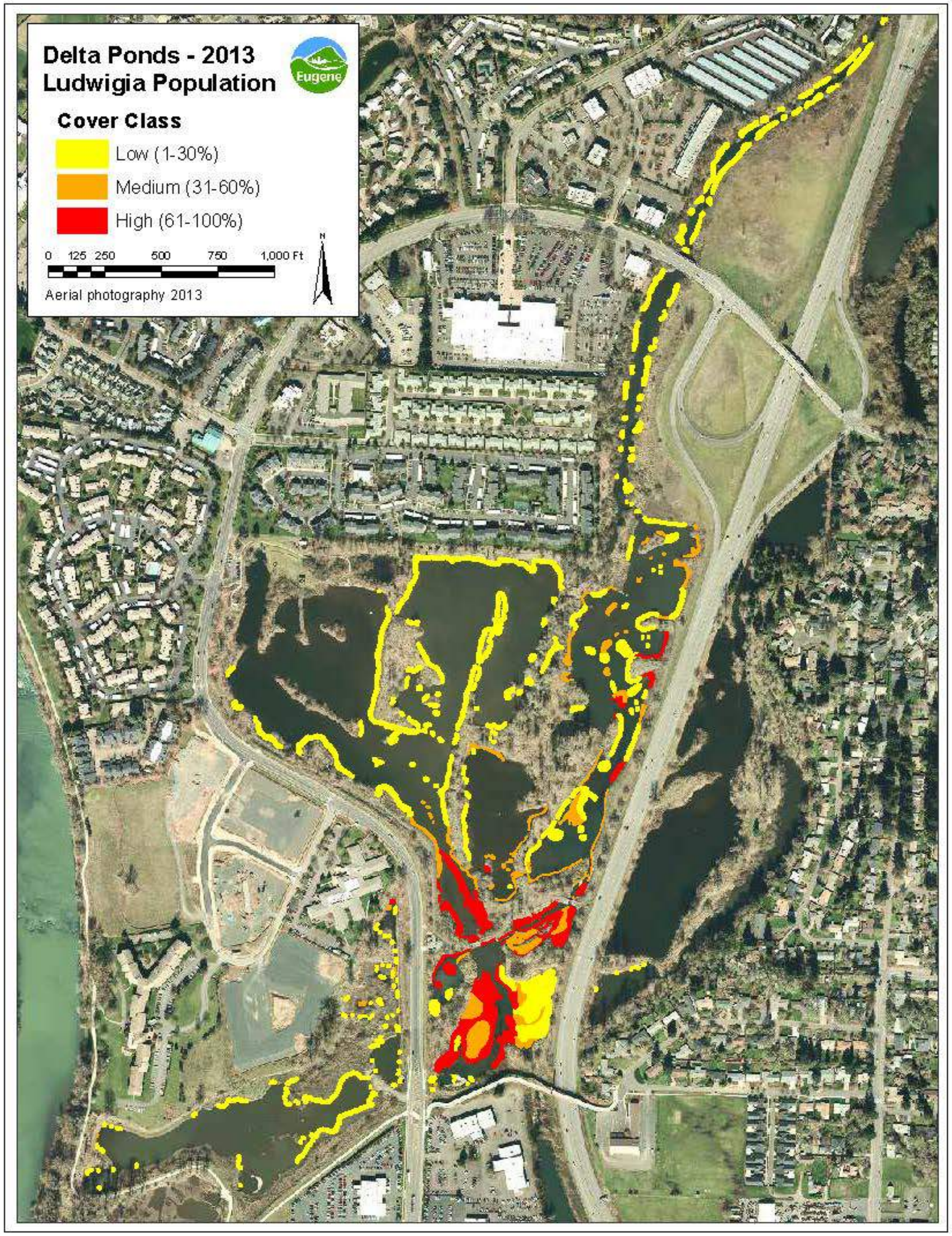
Delta Ponds - 2011
Ludwigia Population
Eugene
Extent of 2011 population
0 125 250 500 750 1,000 Ft
N
Aerial photography 2013

2011

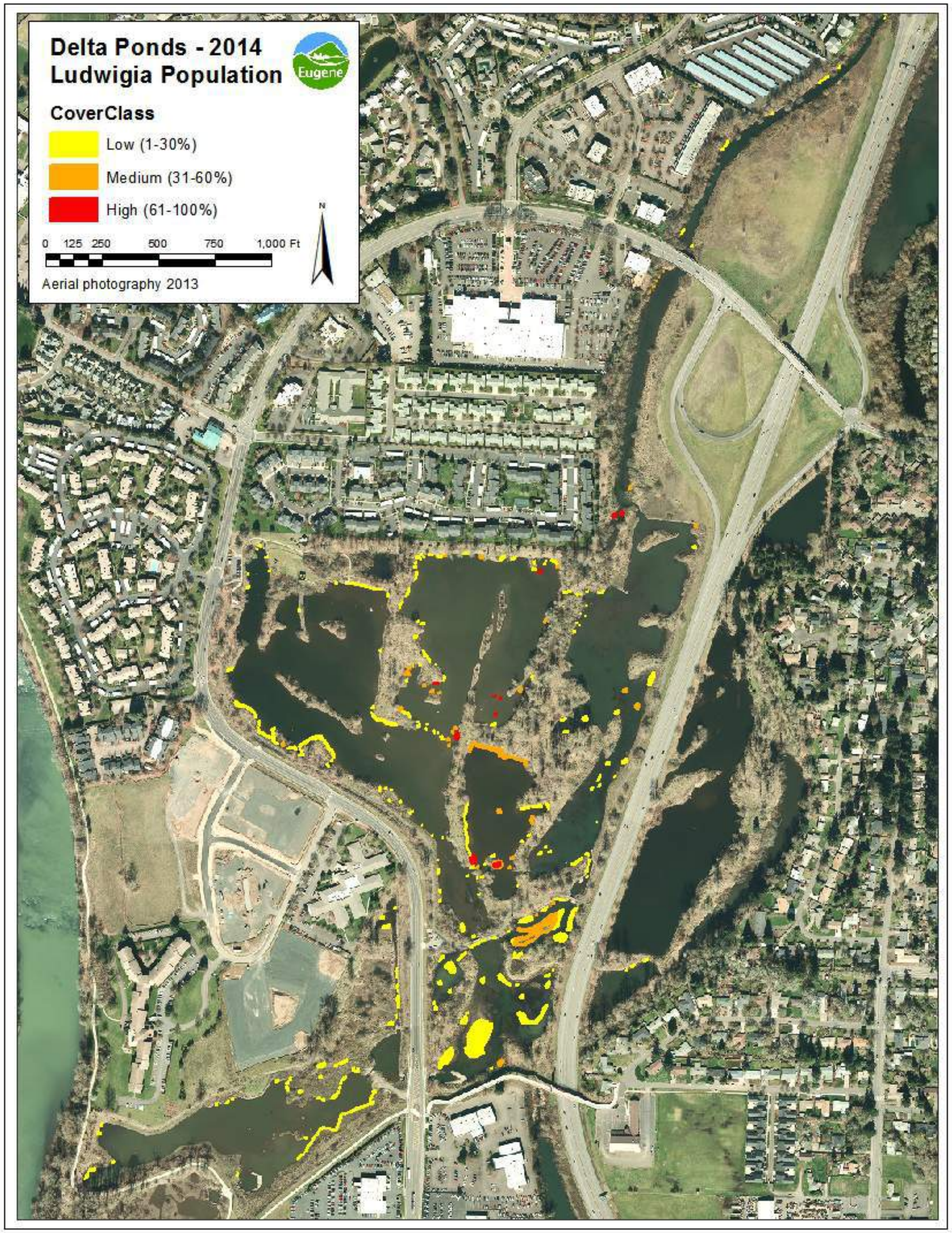


Delta Ponds - 2012
Ludwigia Population
Eugene
Extent of 2012 population
0 125 250 500 750 1,000 Ft
N
Aerial photography 2013

2012


Delta Ponds - 2013
Ludwigia Population
Eugene
Cover Class
Low (1-30%)
Medium (31-60%)
High (61-100%)
0 125 250 500 750 1,000 Ft
N
Aerial photography 2013

2013

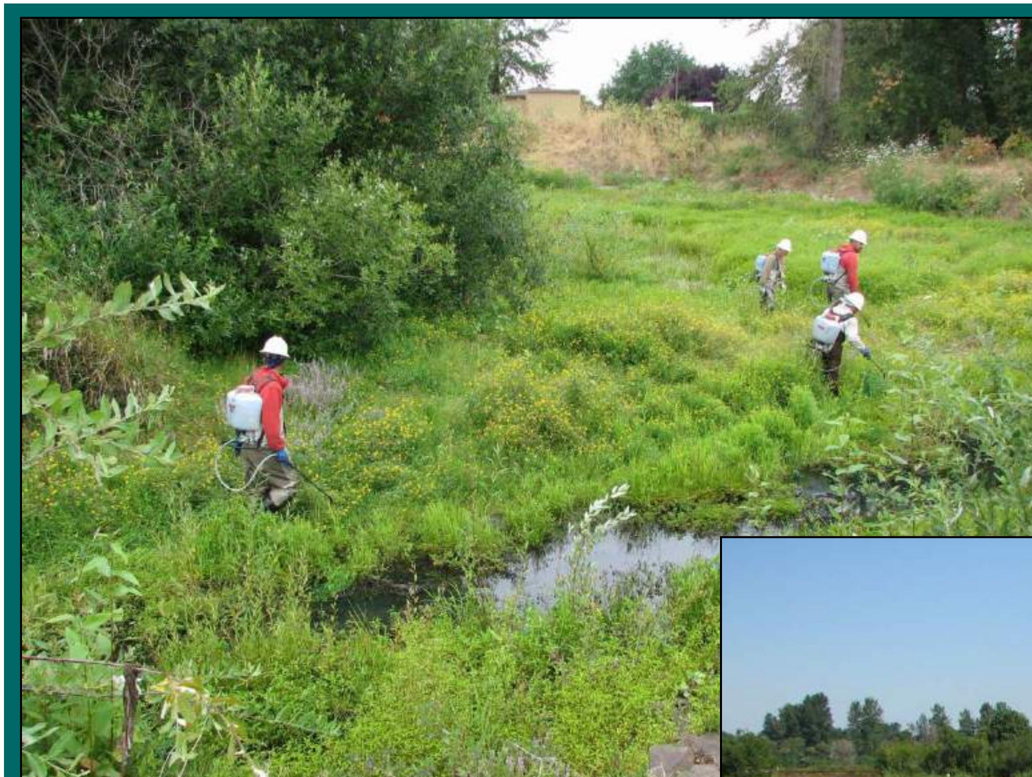

Delta Ponds - 2014
Ludwigia Population
Eugene
CoverClass
Low (1-30%)
Medium (31-60%)
High (61-100%)
N
0 125 250 500 750 1,000 Ft
Aerial photography 2013

2014

Manual control

(June/July and Sept/Oct)

Hand pulled:
- sparse plants
- plants intermixed with natives



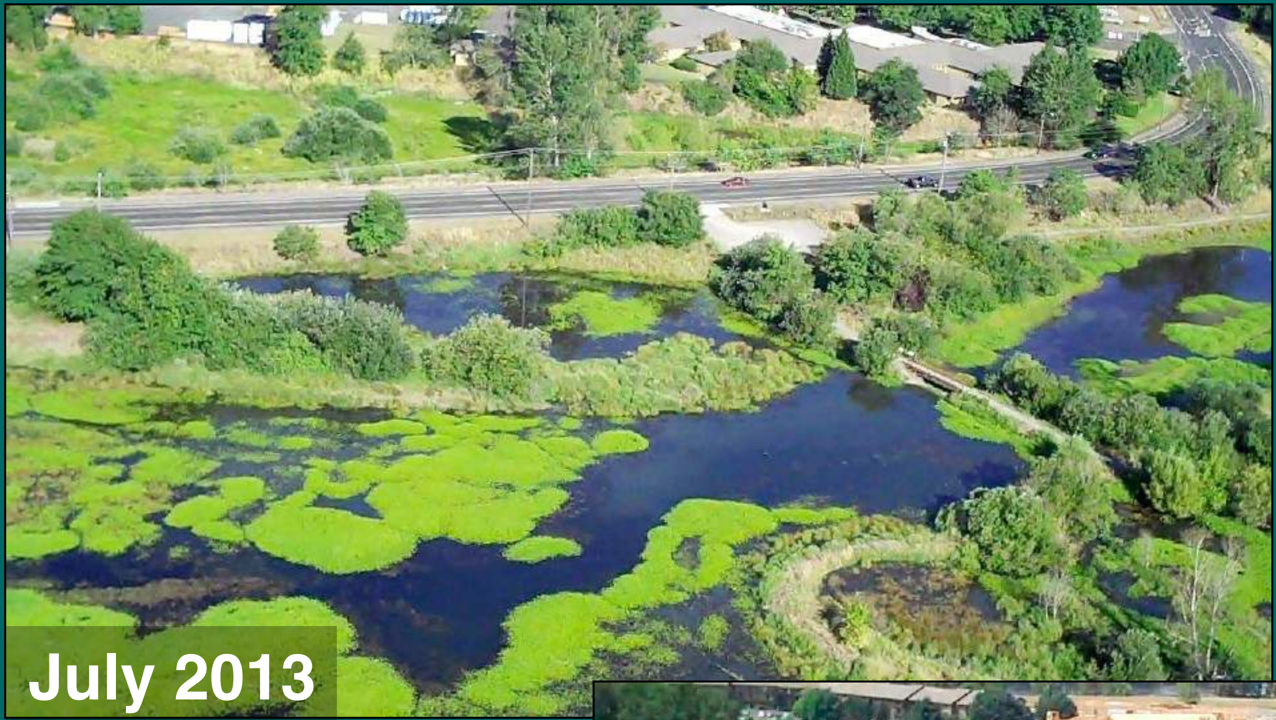
Chemical control

(late July/August)

Treated:

- plants growing on land
- dense aquatic patches

Chemical mixture:
3% glyphosate
0.5% Agridex surfactant
blue dye



Before chemical treatment

…and shortly after

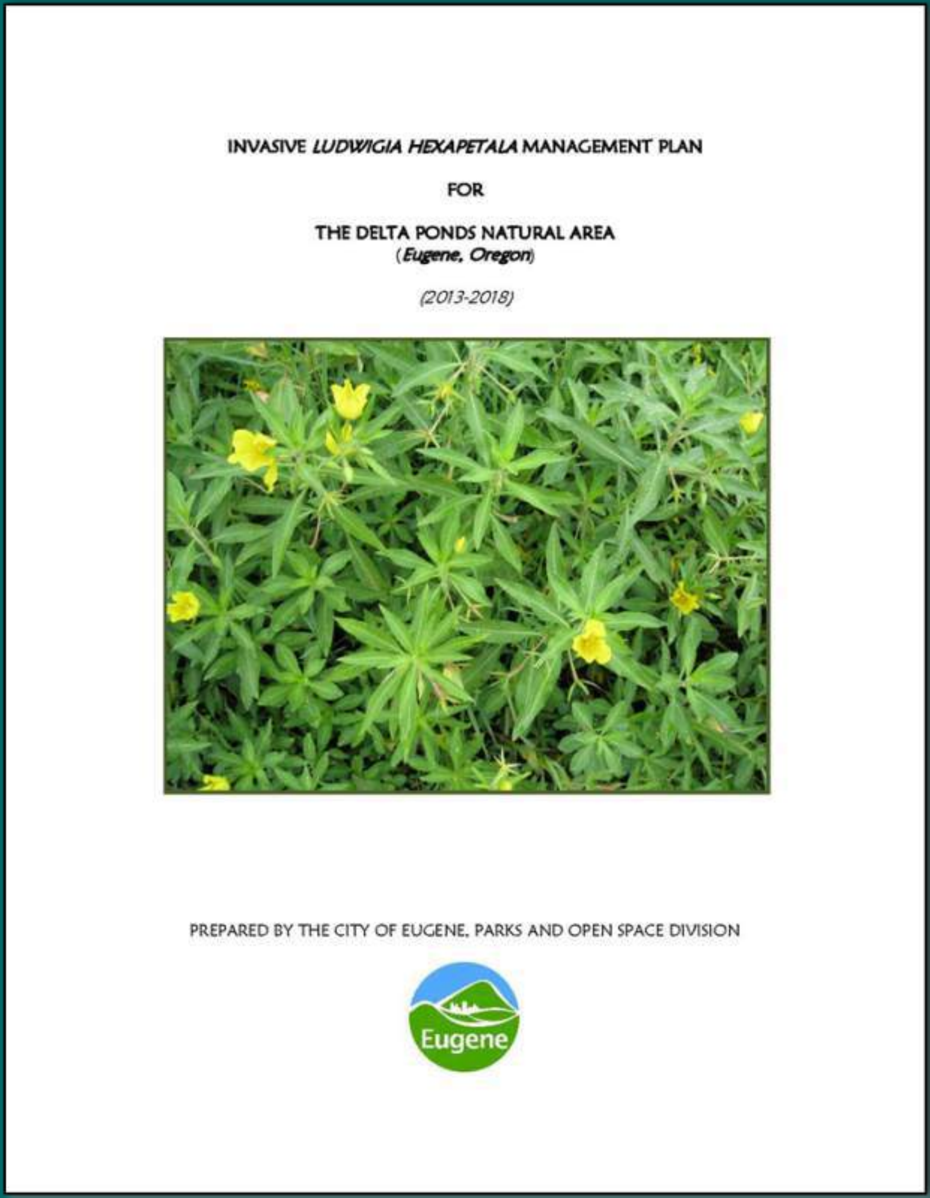
Images by Philip Bayles
psb@efn.org
www.raptorviews.com

Photopoint monitoring just before Phase I chemical treatment

…and one year later before Phase II control

Recommendations

- EDRR
- Consult with others
- Develop a Plan
- Commit to long-term vegetation management
- Adaptive Management



INVASIVE *LUDWIGIA HEXAPETALA* MANAGEMENT PLAN

FOR

THE DELTA PONDS NATURAL AREA
(*Eugene, Oregon*)

(2013-2018)

PREPARED BY THE CITY OF EUGENE, PARKS AND OPEN SPACE DIVISION


Questions?
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Establishing Research and Management Priorities for Invasive Water Primroses (Ludwigia spp.)

TECHNICAL REPORT · FEBRUARY 2016

DOI: 10.13140/RG.2.1.5020.6482

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ERDC/EL TR-16-2

Environmental Laboratory

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Engineer Research and Development Center

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Aquatic Plant Control Research Program

Establishing Research and Management Priorities for Invasive Water Primroses (*Ludwigia* spp.)

Brenda J. Grewell, Michael D. Netherland, and Meghan J. Skaer Thomason

February 2016

Aquatic Plant Control Research Program

ERDC/EL TR-16-2
February 2016

Establishing Research and Management Priorities for Invasive Water Primroses (*Ludwigia* spp.)

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Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Abstract

Creeping water primroses and water primrose-willows are among the most aggressive aquatic invasive plant invaders in the world. These aquatic Ludwigia species can impart severe ecological, economic, and human health impacts in aquatic ecosystems and threaten critical ecosystem functions. The authors expect these impacts to increase with greater global trade and projected climate change. This technical report presents an overview of the biology and ecology of these invasive plant species, along with select management case studies and research efforts. While the need for management approaches has become an important topic, little is known about the distribution of Ludwigia species and how they respond to varying environmental conditions in the U.S. Life history strategies and responses to environmental conditions vary among water primrose species. Therefore, species-specific management approaches may be required, and prevention and control strategies should be customized to the specific phase of the local invasion. This information is important for predicting further spread. Likewise, it is the foundation for risk assessments and effective management. This technical report proposes research priorities to improve understanding of the complexity of the biology and ecological invasion process of water primroses, and it provides resource managers with substantive recommendations for how to prevent and prioritize management of these aquatic weeds.

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Figures

Figures

Preface

This study was a joint effort between the U.S. Army Engineer Research and Development Center (ERDC) and the U.S. Department of Agriculture (USDA), Agriculture Research Service (ARS) under the Aquatic Plant Control Research Program (APCRP). The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to ERDC under the purview of the Environmental Laboratory (EL), Vicksburg, Mississippi. The APCRP is managed under the Civil Works Environmental Engineering and Sciences Office, Dr. Alfred F. Cofrancesco, Technical Director. Dr. Linda S. Nelson is Program Manager of the APCRP.

Principal Investigator for this study was Dr. Michael D. Netherland of the Environmental Processes Branch (EPP) of the Environmental Process and Effects Division (EP), U.S. Army Engineer Research and Development Center, Environmental Laboratory. At the time of publication, Dr. Brandon Lafferty was Chief, CEERD-EPP; Warren Lorentz was Chief, CEERD-EP; the Deputy Director of ERDC-Environmental Laboratory was Dr. Jack Davis (CEERD-EZB), and the Director was Dr. Beth Fleming (CEERD-EZA). This work was conducted and the report prepared by Dr. Brenda Grewell and Meghan J. Skaer Thomason, USDA-ARS (Davis, CA), and Dr. Netherland, EPP.

Conduct of this study would have been impossible without the participation of multiple personnel with a common interest in protecting aquatic habitat from the spread of invasive plant species. The authors wish to express their gratitude to various academicians, local, state, and Federal agencies, and non-governmental organizations that have contributed information for this study.

COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters

1 Purpose

The purpose of this technical report is to:

- Provide resource managers with background information on invasive, aquatic *Ludwigia* species, especially those located in Pacific States and Florida,
- Inform resource managers and policymakers why the current aggressive spread of *Ludwigia* should be a matter of concern,
- Supply resource managers with a list of research and management priorities that will serve to address information gaps on water primroses, guide actions required to prevent further introductions, effectively respond to invasions, and encourage innovative approaches to this problem.

As aquatic *Ludwigia* species increasingly invade and displace critical habitat and degrade a range of aquatic and riparian ecosystems, we suggest a comprehensive research approach to develop and demonstrate relevant management strategies to counter this growing problem.

While water primroses have been present in the United States (U.S.) for decades, the recent rate of spread in crucial water bodies in states such as California and Florida, and the longer-term experience in France, is of significant concern. How should we respond to a rapidly emerging problem in the midst of numerous other invasive plant priorities? The timely answer to these questions is of paramount importance to resource managers, policy makers, and stakeholders throughout Pacific, Gulf, and Atlantic coastal states.

2 Problem

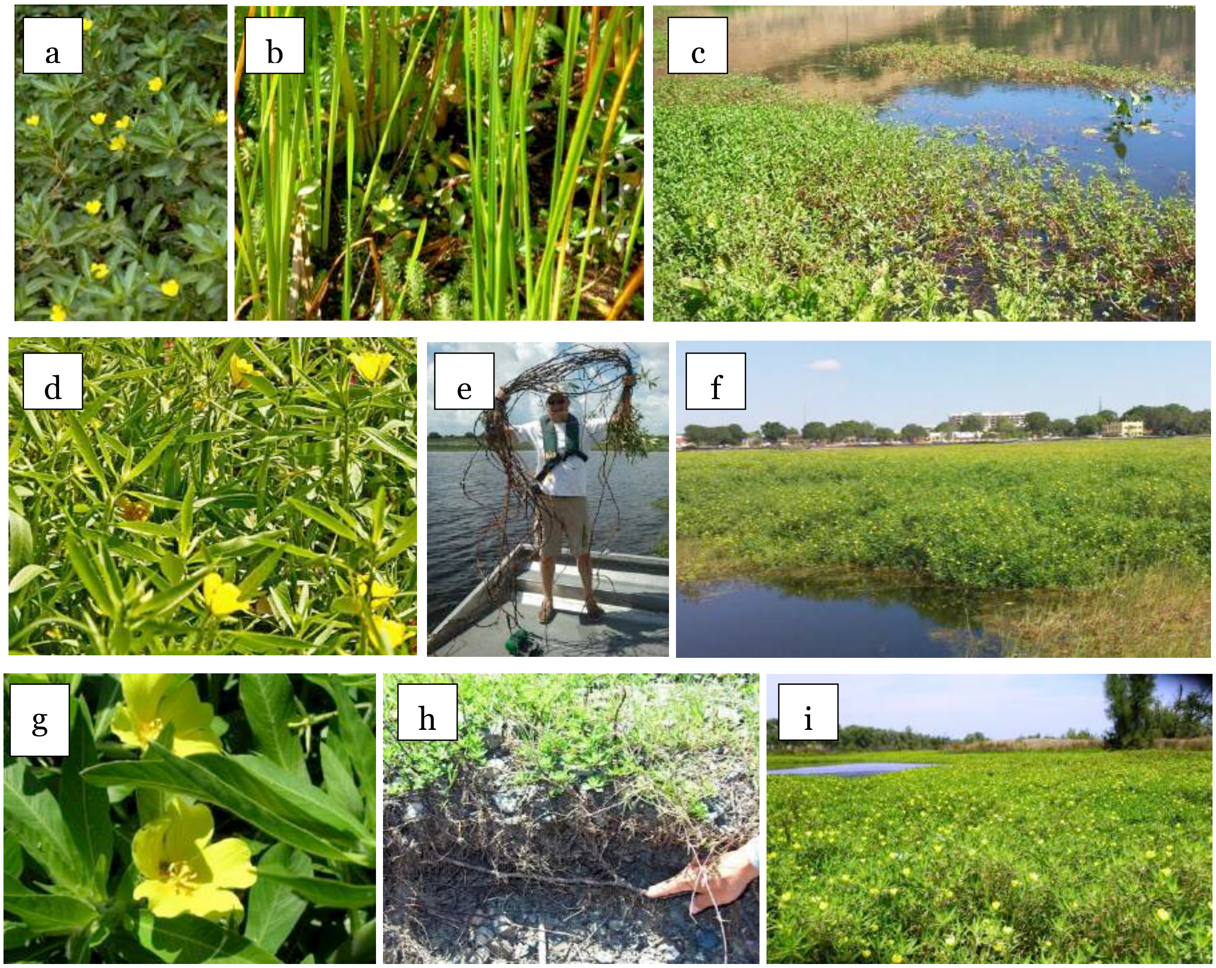
The increased spread of invasive plant species is a significant aspect of human-induced global change (Vitousek et al. 1997). In aquatic ecosystems, increases in the numbers of invasive weed species and their abundance have been linked to global trade, eutrophication of water, and changing climate (Lodge et al. 1998, Hussner 2009). Creeping water primroses and water primrose-willows are among the most aggressive, aquatic, invasive plants in the world. (Thiébaut and Dutartre 2009, Thouvenot et al. 2013a). Epidemic populations are increasingly problematic in the south Atlantic, Gulf, and Pacific west coastal United States, making for significant economic and ecological impacts. While the need for management approaches has become an important topic, the distribution of different species and their response to varying environmental conditions in the U.S. is limited. This biological and ecological information is the foundation for risk assessments and effective management. Likewise, it is important for predicting additional spread of invasive aquatic plants.

3 Background

Aquatic and riparian ecosystems are highly susceptible to invasion by non-indigenous, aquatic plants. Uruguayan primrose-willow (*Ludwigia hexapetala*), large-flowered primrose-willow (*Ludwigia grandiflora*), and creeping water primroses (*Ludwigia peploides*) are aggressive weeds in the evening primrose family Onagraceae. These species are degrading major watersheds in California and Florida as well as aquatic and riparian ecosystems in the Pacific Northwest, Atlantic, and Gulf coastal states by clogging lakes, ponds, irrigation canals, flood control channels, riverine, and other sensitive wetlands, and invading rice fields. These same *Ludwigia* species are also a problem in Australia, New Zealand, Turkey, and throughout Europe; in France they are now by far the most invasive alien, aquatic plant species (Thouvenot et al. 2013a). These three emergent macrophytes in the *Ludwigia* genus are commonly called “creeping water primroses” given their tendency for rooted, buoyant shoots that quickly grow to the water surface and form impenetrable mats with floating leaves (Figure 1a-c). Some species, such as *L. grandiflora* (Figure 1d - f) and *L. hexapetala* (Figure 1g-i), develop woody, willow-like stems (Figure 1e) and woody rhizomes (Figure 1h) in their tall emergent forms and are commonly known as “water primrose-willows.”

Exploration and import of ornamental plants for estate gardens and ponds dates to the early 17th century in Europe, late 17th century in the U.S., leading to many plant species that naturalized and became invasive (Reichard and White 2001). In 1733, English colonists established a plant introduction station and botanical gardens in Savannah, Georgia. They also imported seeds and exotic plants from Central and South America to test as medicinal plants, use as natural dyes, and plant crops for production and for export to England. In 1737, colonists established the first commercial nursery in New York to conduct international trade of ornamental plants. The establishment of botanical gardens in eastern states soon followed. Seeds and extractions from plants were often exchanged and sold to nurseries. By the early 1800’s, global exploration and trade in ornamental and aquarium plants had grown, and plant importation was common and quite popular (Reichard and White 2001). Carl Linnaeus, the father of plant taxonomy, was the first to classify *Ludwigia* specimens in the 18th century. He named the genus in honor of Christian Gottlieb Ludwig, an 18th century botanist and professor of medicine at the University of Leipzig, Germany (Linnaeus 1737).

Figure 1. *Ludwigia peploides* (Top row: a. Putah Creek, b. Lake Cleone and c. Lake Hennessey, California), *Ludwigia grandiflora* (Middle row: d-f. Lake Tohopekaliga, Kissimmee Chain of Lakes, Florida); and *Ludwigia hexapetala* (Bottom row: g-h. Russian River, California and i. Oroville Wildlife Area, California).



In 19th century France, legacy horticultural introductions of *L. hexapetala* (syn. *L. grandiflora* subsp. *hexapetala*) as an ornamental plant were documented with an intentional introduction in 1830 to the Lez River at Montpellier (Martins 1866) and naturalization from a botanical garden near Bordeaux in 1882 (Guillaud 1883, Dandelot et al. 2005b). While some thought these aquatic species may be native to Florida and other south Atlantic states, legacy horticultural introductions of aquatic *L. hexapetala* in South Carolina in 1844 and in Georgia in 1864 may be an alternate explanation, given their disjunct distribution from the putative native range of the genus in southern South America and the popularity of ornamental introductions for water gardens and aquaria during the 19th century. There is great uncertainty regarding native vs. non-native status of *Ludwigia* species in the southeastern U.S. Although molecular analyses of the *Ludwigia* family are incomplete, they are needed to keep managers abreast of the growing concerns with this species and resolve phylogenetic and taxonomic questions (Wagner et al. 2007). There has never been any question that the early 19th century horticultural introductions formed naturalized populations in the south of France that persisted locally and then spread into south and western France. In the 20th century, increased use for ornamental plantings accelerated their spread in Europe (Dandelot et al. 2005b). In fact, it is highly likely that multiple introductions occurred. In the last three or four decades, *L. hexapetala* has aggressively spread northward throughout France and more recently into the UK, Ireland, Belgium, the Netherlands, Italy, Spain, and Greece (Thouvenot et al. 2013a). It is interesting to note that a substantial time lag in invasiveness has been noted for *L. hexapetala* in south Atlantic states. An aggressive spread of *L. grandiflora* has recently affected sensitive wildlife habitats in the Kissimmee Chain of Lakes of Central Florida (Jacono 2014). Cytogenetic evaluation has confirmed *L. hexapetala* (chromosomes 2n=80) in Lake Harney on the Saint Johns River, while *L. grandiflora* (2n=48) has been confirmed in Lake Tohopekaliga and Lake Poinsett (Grewell and Netherland, unpublished data).

Ludwigia hexapetala is a relatively recent invader in Pacific western states with the earliest records dating back to the 1940's in Tiburon and San Diego, California. A voucher specimen collected near Corvallis, Oregon documented an introduction in 1940 when a "fish bowl" was emptied into a slough connected to the Willamette River. Intentional introduction via emptying of aquaria into flood control channels near Longview also explains the 1955 introduction to Washington. As previously mentioned for the southeast, there was a lag of 50 to 60 years before these populations spread to the extent that they were recognized as aggressive weeds that displace native plant communities.

In the 20th century, *Ludwigia peploides* was introduced as an ornamental plant in southern France, and it has since spread northwest to the Loire River; however, the distribution is scattered and more geographically limited than the more widely spread *L. hexapetala* in France (Dandelot 2005b). In the western U.S., *L. peploides* was the first to arrive. The earliest herbarium specimens were collected from 1863-1893 from scattered sites in northern California. During the 20th century, they spread into the San Joaquin Valley and southern California. Although invasive populations are being managed in Portland, *Ludwigia peploides* is still rare in Oregon, with only a few confirmed records. There is a single disjunct record of *L. peploides* in Washington from invasion of a wetland restoration site near Seattle. *L. peploides* was observed as a naturalized invasive weed in the Peconic River, New York in 2003 and became the target of a successful education and eradication effort. *L. peploides* is a weed in rice fields of Australia, California (McIntyre and Barrett 1985), Chile (Ramirez et al. 1991), and Argentina (Sabattini et al. 1998). Movement of rice seeds for cultivation could possibly be a pathway for introductions of *L. peploides* from South America.

During the 20th century, increased use of *Ludwigia* spp. as ornamental aquatic plants accelerated their spread in Europe (Dandelot et al. 2005b) and in the U.S. Recently, international focus has sharpened on the critical need for effective management approaches due to the exponential growth and spread of aquatic water primroses to nuisance proportions in near-coastal regions of the U.S. and Europe. Unfortunately, aquatic water primroses and primrose-willows are still sold as decorative plant species for water gardens and aquaria. While some states regulate their sale and transport, others sale live *Ludwigia* plants in their local garden centers. Likewise, national and international internet sources make live plants and seeds readily available.

4 Taxonomic Confusion

Management of invasive water primrose species, like other invasive plants, must be grounded in basic knowledge of the biology and ecology of the species and their responses to environmental conditions. These important factors can vary tremendously among related taxa and may require different management approaches. Therefore, the first step in an invasive species management program requires accurate identification. The morphology of aquatic water primrose species can be highly variable in response to local environmental conditions, making proper identification difficult and further perpetuating taxonomic confusion in both the U.S. and Europe (Harper 1904, Munz 1942, Dandelot et al. 2005b). The nomenclature herein follows Wagner et al. (2007) and Hoch and Grewell (2012).

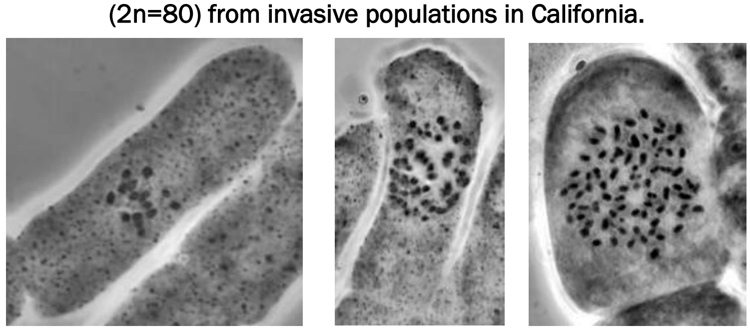
Ludwigia is an ancient genus of plants that originated between 93 and 80 million years ago in the Cono Sur of South America (Wagner et al. 2007). The pantropical *Ludwigia* genus includes 82 species (with subspecies, 87 taxa) that are taxonomically divided into 23 major sections (Zardini et al. 1991b). *Ludwigia* is the center of origin and basal lineage of the entire monophyletic evening primrose family, Onagraceae. The greatest diversity of species are found in southern South America (Wagner et al. 2007). *Ludwigia* species in section *Jussiaea* (Hoch et al. 2015) are largely aquatic, morphologically similar, but vary in ploidy levels. There has been a long history of taxonomic revisions of these three focal *Ludwigia* species. Species in this section are all perennial herbs with terete stems, floating, emergent, or erect leaves that ascend through spongy, arenchymous bases (Wagner et al. 2007). The plants root in sediment, form spongy white pneumatophores (aerial roots) in shallow water that supply oxygen to the plant allowing it to survive anoxic conditions (Ellmore 1981), and root extensively in the water column from floating stem nodes. Leaves are alternate, and leaf blades have a sub-marginal vein. The plants flower through summer The diurnal flowers typically have five to six yellow petals and twice as many stamens as sepals. The sepals are persistent after flower petals have dropped. Reproduction is by both seeds and asexual fragments. While they share these traits, the morphology of the three introduced *Ludwigia* species is extremely plastic in response to environmental conditions. Nearly all species of *Ludwigia* in section Jussiaea can be crossed with one another and produce vigorous F_1 hybrids (Zardini et al. 1991b). New hybrids can be expected in nature.

Hybridization between invasive weeds can improve performance and vigor, thus further increasing invasiveness (Gaskin and Schaal 2002, Ellstrand and Schierenbeck 2006). Some species in the section, including *L. hexapetala*, *L. grandiflora*, and *L. peploides*, have become major invasive weeds in their non-native, naturalized range.

5 Ploidy Levels

The base number of chromosomes in *Ludwigia* is n=8. Chromosome numbers in the polyploid Jussiaea section include n = 8, 16, 24, 40, and 48 (Zardini et al. 1991a). Differentiation of *L. hexpetala* and *L. grandiflora*, previously known as the *L. uruguayensis* complex, must be based on a combination of field observations of growth characteristics, morphological evaluation of fresh specimens, and chromosome numbers (Zardini et al. 1991a). Nesom and Kartesz (2000) evaluated voucher specimens in two herbaria, compared these with Zardini's herbarium specimens, observed overlapping characters, and proposed to recognize *L. hexapetala* as a subspecies, *L. grandiflora* subsp. *hexapetala* (Hook. & Arn.) . More recently, others have utilized numerous voucher specimens from throughout the native and invasive range, extensively observed populations in the field, and conducted morphometric evaluations of fresh specimens, chromosome counts, and genetic studies to distinguish *L. hexapetala*, *L. grandiflora*, *L. peploides* (Wagner et al. 2007, Hoch and Grewell 2012), and new aggressive hybrids (Okada et al., unpublished data). Ploidy level refers to the number of sets of chromosomes in the nucleus of a biological cell. Evolutionary events that increase *Ludwigia* chromosome sets can lead to new species. Ploidy levels of *Ludwigia* invaders vary by species. *Ludwigia peploides*, and recognized subspecies, is diploid (2n=16 chromosomes), *L. grandiflora* is hexaploid (2n=48 chromosomes), *L. hexpetala* is decaploid (2n=80 chromosomes) as shown in Figure 2.

Figure 2. Photomicrographs (1,000x) of mitotic chromosome preparations of floating root tip cells from *Ludwigia peploides* (2n=16), *Ludwigia grandiflora* (2n=48), and *Ludwigia hexapetala* (2n=80) from invasive populations in California.



Why Should Resource Managers Be Concerned about Ploidy Levels?

Aside from use for identification purposes, why should resource managers be concerned about the chromosomal data and ploidy levels of these species? There is increasing evidence that fitness (i.e., increased biomass production and reproductive output) and the adaptive ability of plants increase with increasing ploidy levels. Recent analyses have produced strong evidence that there is a positive relationship between chromosome numbers and ploidy levels of plant species and their degree of invasiveness through increased speed of cell division, gene redundancy, and increased phenotypic variation (te Beest et al. 2012, Pandit et al. 2014). For example, some polyploid species have increased ion uptake rates and are more tolerant of salinity and drought than related diploid species (Hollister 2014). In a practical sense, higher phenotypic plasticity of polyploids suggests that *L. hexapetala* may be better equipped to adjust to changing climate and environmental conditions, which may explain its superior ability to spread as compared to *L. peploides*. In a management context, this also suggests that integrated approaches to management of polyploid species of *Ludwigia* will be more challenging than management of *L. peploides*, and managers will need to know what species they are targeting in order to recommend the appropriate management technique.

Ludwigia peploides (Kunth) P. H. Raven

(synonyms (syn.): Jussiaea repens, J. r. var. montevidensis, J. r. var. glabrescens, J. californica, J. r. var. californica, J. r. var. peploides, J. diffusa; creeping water primrose) includes at least three subspecies that have been somewhat defined morphologically and geographically. Ludwigia peploides is diploid and can be distinguished from other Ludwigia species by chromosome numbers (2n = 16). Taxonomic distinction by morphology is also possible during the reproductive stage of the life cycle. The flowers of L. peploides are smaller than those of the polyploid species and usually have 10 stamens. The yellow, upturned petals of the flowers are typically 7-16 mm (~0.3 –0.6 inches) long and fruit capsules can be ~ 10-30 mm (0.4-1.2 inches) long. Sepals are persistent on capsules after petal drop. For comparison, petals of *L. grandiflora* may be 15-20 mm (0.6 – 0.8 inches) long, while petals of *L. hexapetala* are typically much larger. Petals of *L. hexapetala* are the largest, often measuring 20-29 mm (0.8-1.1 inches) long. *Ludwigia peploides* plants are self-compatible, and pollinating bees are frequent floral visitors. Bracteoles (or “bractlets”) near the base or up to the middle of the ovary are usually dark green, deltoid-squamate, and 0.5-1 mm (0.02-0.04 inches) long. These bracteoles, as well as other distinguishing characters, are best examined on fresh specimens, as they often shrivel, break easily, and are often missing on dry voucher specimens. The buoyant shoots of plants float on the water or on stolons root from nodes as they creep across wet soil. By comparison, the canopy height of populations is much less than observed in *L. hexapetala* or *L. grandiflora* populations. Plants can form dense colonies in standing water and slightly above the water line.

Ludwigia peploides Subspecies

L. peploides (Kunth) Raven subsp. *peploides* is found in Argentina, Paraguay, and Brazil where it is native. Specimens document the taxa in Nicaragua and Australia where it has been reported as introduced. It is also found in the western U.S. from California to Texas where it was long thought to be native; however, the existence of hybrids between other subspecies and molecular evidence from naturalized California specimens suggest a South American origin (Okada et al. unpublished data). This taxon is typically glabrous, and the leaf apex is not mucronate or glandular-mucronate. *Ludwigia peploides* (Kunth) Raven subsp. *glabrescens* (Kuntze) Raven occurs disjunctly in the U.S. and Eastern Asia and has long been considered native in the eastern, southeastern, and western U.S. including Texas where its range overlaps with *L. p.* subsp. *peploides*. However, we have observed *L. p.* subsp. *glabrescens* in Argentina, purchased live specimens from internet sellers, and suspected its disjunct presence in the U.S. may be a naturalized occurrence. The *L. p.* subsp. *glabrescens* has glossy or shiny green leaves with a glabrous upper surface, while the underside of the leaf is glabrous to sparsely pubescent. *Ludwigia peploides* (Kunth) Raven subsp. *montevidensis* (Spreng.) Raven is known to southern South America (Argentina, Uruguay, and southern Brazil) where it is native. It is widely recognized as introduced in disjunct, naturalized populations found in California, Louisiana, Oregon, and also in Cuba, Belgium, France, Italy, the Netherlands, Portugal, Spain, Switzerland, the United Kingdom (UK), Australia, and New Zealand. In South America and California, *L. p.* subsp. *montevidensis* is densely pubescent, while it is described as glabrous in Australia. The leaf apex is commonly mucronate. Recent molecular analyses confirm that naturalized populations of *L. p.* subsp. *montevidensis* in California are closely related to a native genotype in Uruguay, and hybrids between *L. peploides* subspecies that are present in California (Okada et. al, in prep.) likely occur elsewhere. Differences in environmental tolerances among the subspecies are unknown, but the three diploid taxa are predicted to be ecologically more similar to each other than to the polyploid invaders.

Ludwigia grandiflora (Michx.) Greuter & Burdet

(syn. *Ludwigia uruguayensis*, *Jussiaea uruguayensis, J. michauxiana*, *J. grandiflora*; large-flowered primrose-willow), occurs in the southeastern United States from the piedmont and coastal plain of southern South Carolina to coastal Georgia and northern Florida. It is also found in western Louisiana and appears in coastal and central Texas as well. The species is native to central and southern South America from south of the Amazon basin in Brazil to Uruguay, with most collections spotted in Brazil and Paraguay. Disjunct populations have been collected three times in Guatemala and once in Missouri (Wagner and Hoch 2005). The perennial herb to woody sub-shrub can be floating or creeping in water although the emergent shoot can be quite erect and ascending. The plants have been described as densely villous, but at times they are sparsely pubescent to near glabrous. Green triangular-shaped bracteoles are observed at the base of petioles in some populations, and lanceolate-shaped bractioles are found on the ovary. Leaves are highly variable in shape, and leaf apices are often mucronate. Capsules are villous to densely villous with hairs up to 1 mm long. Capsules are highly variable in size (11-25 mm; ~0.4-1 inches long), truncate at the apex, and narrowed towards the pedicel. There are 8-15 seeds per locule in a wedge shaped piece of endocarp embedded in the woody capsule. Chromosome numbers of the hexaploid species are 2n=48, and interploid hybrids between *L. grandiflora* and *L. hexapetala*, and *L. grandiflora* and *L. hookeri* are also reported where the range of the species overlap (Zardini et al. 1991b).

Ludwigia hexapetala (Hook. & Arn.) Zardini, H. Y. Gu & P. H. Raven

(syn. *Ludwigia grandiflora* subsp. *hexapetala*, *L. uruguayensis*, *L. u.* var. *major*, *Jussiaea uruguayensis* var. *major, J. michauxian*, *J. repens* var. *major*, *J. hexapetala*; Uruguayan primrose-willow) is native to southern South America (southern Brazil, eastern Paraguay, Argentina, and Uruguay). Morphological characters suggest *L. hexapetala* may be the product of hybridization between *L. grandiflora* and *L. hookeri* in the native range, but molecular studies are needed for confirmation (Zardini et al. 1991a,b). Populations in Costa Rica, west of the Andes in Chile, and in Peru are considered introduced (likely by shipping commerce) and naturalized, while introductions to Ecuador and Columbia are documented (Wagner et al. 2007, Wagner and Hoch 2005). *Ludwigia hexapetala* is also naturalized in coastal states of the U.S. In the Atlantic region, it has been collected at a few locations in Pennsylvania, New York, and Alabama, but the primary range is the southeast Atlantic states from the Carolinas to Florida. *Ludwigia hexapetala* is also naturalized and highly invasive in France, Belgium, Spain, and the UK.

Like *L. grandiflora*, *L. hexapetala* can be a creeping perennial herb in shallow water, or it can be a woody sub-shrub becoming more ascending and erect near and above the water's edge. Shoots can be >2 meters tall in eutrophic areas, and sometimes twine up the trunks of woody shrubs and trees at water's edge. It roots from buoyant stem nodes and has the ability to produce thick masses of adventitious roots. All parts of the shoot can be strongly villous, though submersed portions of stems tend to be glabrous. Leaf shapes are not diagnostic and vary tremendously with environmental conditions and life stage. Pre-reproductive leaves are often rounded and in clusters, while mature leaves and emergent leaves vary widely from oblanceolate to narrowly elliptic. Mucronate tips at leaf apex can often be observed without magnification. Many flowers are produced on shoots. Petals (5-6) are typically yellow, but can be light orange and are usually >25 mm long (> 1 inch), but can be 20 mm (0.8 inches) long and even as short as 11 mm (0.4 inches) in rocky dry areas where entire plants grow and flower in stunted form. Sepals can be green to reddish, and are pubescent and persistent after petal drop. Woody capsules are irregularly or tardily dehiscent as described for the other species and are typically 14-26 mm (0.6 – 1 inch) long and sparsely pubescent. Capsule shape is variable from straight to slightly curved-terete, truncate at the apex, and narrows toward the base. Bracteoles at the base of the ovary or part way up the pedicel are lanceolate, narrow or wide obovate, acute in shape or sometimes acuminate or attenuate at the apex, persistent, 1-1.8 mm (0.04-0.07 inches) long, 0.7-0.8 mm (~0.03 inches) wide, and color ranges from green to dark brown. Chromosome numbers of the decaploid species are 2n=80 (Zardini et al. 1991b).

Ecology

Studies of aquatic plant species in the native South American range of water primroses have largely focused on floristic surveys, composition, structure, and successional dynamics of vegetation that includes *Ludwigia* spp. in wetland areas of southern Brazil (Rolon et al. 2008, Maltchik et al. 2010) and in the Paraná River watershed (Sabattini and Lallana 2007). In southern Brazil, *L. peploides* is a member of wetland plant communities with high diversity of macrophyte and -macroinvertebrate species (Maltchik et al. 2010). The expansive Paraná River watershed is a dynamic, lentic system characterized by recurring flood pulses over short temporal scales that reset successional processes in the river system (Sabattini and Lallana 2007). Aquatic *Ludwigia* spp. have been reported from flowing rivers, low flow backwater channels of rivers, lagoons isolated from the primary river channel, perennial and seasonal wetlands, temporary ponds and lakeshores to the marginal high water line with distribution and abundance highly related to the hydrological regime (Sabattini and Lallana 2007). They are also reported from "baceiros, verdolagales, embalsados and camalotes" which are associations of aquatic plants that form floating islands that drift with flood pulses and spatially rearrange the associated ecological system in rivers and lakes (Pivari et al. 2008). Similar patterns of invasive *L. grandiflora* growth have been observed in the Kissimmee Chain of Lakes, Florida.

To date, the bulk of published scientific studies on the ecological and economic impacts of naturalized water primrose populations have come from France and nearby European countries with a long history of invasion. In France, *L. hexapetala* has colonized slow-flowing aquatic ecosystems, gravel and mud river banks, peat soils, ditches, sand bars, natural and artificial lakes and ponds, flooded gravel pits, oxbow channels, and wet meadows (Lambert et al. 2010, Thouvenot et al. 2013a). This tolerance to a wide range of environmental conditions has also been observed in the U.S. and suggests that the species has high phenotypic and morphological plasticity that allows it to survive, colonize, and invade novel habitats (Figure 3).

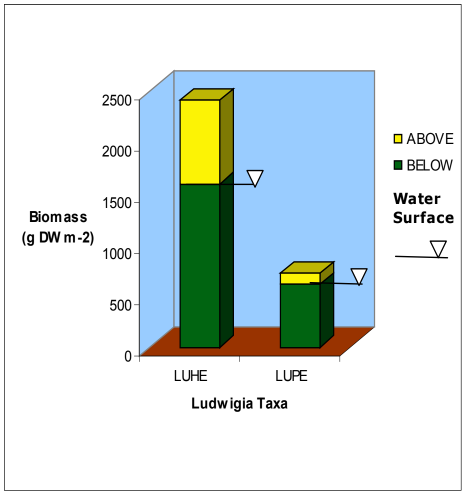
In France, *L. peploides* is self-compatible and produces many seed capsules and seeds; *L. hexapetala*, on the other hand, outcrosses, has variable capsule production, and contains sterile populations. (Dandelot et al. 2005a). High seed output of 10,000 seeds/m^2 is reported for *L. peploides* and *L. hexapetala* from the Loire River, France (Dandelot 2004). Clonal spread through asexual reproduction is the primary regeneration mode of *L. hexapetala* and *L. grandiflora* in California. Floating ramets (stem fragments with rooted nodes) can rapidly spread over great distances and establish new populations throughout watersheds (Okada et al. 2009). Sexual reproduction is another mode utilized by all three taxa in California with *L. hexapetala* and *L. grandiflora* being predominantly outcrossers. To date, managers in western states have not observed sterile populations of any of the species, however, hybrids are present (Okada et al. unpublished data).

Figure 3. The invasive *Ludwigia hexapetala* in California: a) Russian River; b) spring growth, Laguna de Santa Rosa floodplain; c) Feather River floodplain at Oroville Wildlife Area; d) as a submersed aquatic plant in swift current, Russian River; e) seasonal wetland, Colusa National Wildlife Refuge; f) Oxbow (Packer Lake), Sacramento River National Wildlife Refuge; and *Ludwigia grandiflora* in: g) floating island in Kissimmee Chain of Lakes, Florida; h) Kumeyaay Lake (flooded gravel pit), San Diego River, California.

The primary drivers of aquatic plant growth are hydrology, nutrient and light regimes, temperature, and biological interactions. These are all spatially variable factors throughout the native and naturalized range of the plants. In addition, researchers know very little about the degree to which each species can adjust or has genetically adapted to variation in climate and other environmental conditions. *Ludwigia* spp. have preferentially colonized slow and stagnant water habitats in France (Thouvenot et al. 2013a), and researchers and resource managers have observed similar patterns in Pacific west states. However, *L. hexapetala* has also persisted and spread below cold-water reservoir release points into the Russian River where currents can be swift. In these cases, the plants adjust their growth form, grow closer to the riverbank, and grow more erect to resemble hedgerows where they are less impacted by the fast current. If flow rates are reduced during the active growing season, they again grow long buoyant shoots that creep across the still to slow moving water surface. Managers have also observed *L. hexapetala* as a submersed aquatic plant in both still and moving river water (Figure 3d). Water depth is another ecological variable that influences growth of *Ludwigia* spp. *Ludwigia hexapetala* and *L. peploides* are most often found from 0.6 m (2 feet) above standing water to 1 m (3.3 feet) deep, but they tolerate depths up to 3 m (9.8 feet) and are also found at greater distances upslope from standing water (Lambert et al. 2010). In Germany, studies show that biomass production and allocation vary with water depth (Hussner 2010). Mesocosm experiments, conducted with a genotype of *L. hexapetala* that has invaded northern France, suggest that morphological plasticity of growth varies seasonally, and the species has a high tolerance for a range of water levels and light environments though growth was highest in full sunlight and in 30 cm (11.8 inches) of water (Thouvenot et al. 2013b). Studies are underway in California to quantify seasonal biomass production, allocation, and carbohydrate storage reserves of *L. hexapetala* across nutrient and water depth gradients to better understand life cycle dynamics for improved management. Recently a synoptic sampling survey of replicated plots was conducted in ten shallow California lakes to compare the growth and impact of *L. hexapetala* and *L. peploides*. The above water impact of the infestations was readily observed (see photographs, Figure 1) and showed that the biomass production and accumulation below the water surface greatly exceeded that of the above water growth of both species. In fact, *L. hexapetala* produced more than three times the biomass of *L. peploides* (Figure 4).

In general, water primroses have high growth rates. Biomass doubling times between 15-90 days under field conditions have been reported in France (Thouvenot et al. 2013a). Rejmánková (1992) demonstrated that *L. peploides* from California could regenerate 67% of its biomass within 45 days after 95% of it was experimentally cut and removed. In the same study, the species was able to maintain biomass production within a wide range of nitrogen availability (Rejmánková 1992). In the Russian River watershed, *L. hexapetala* adapted to both high and low nutrient environments where it grew well and spread in sandy, low nutrient soils and in highly eutrophic conditions in the Laguna de Santa Rosa floodplain where the highest biomass production was observed. *L. hexapetala* harvesting has been useful for phosphorous removal from wastewater and for production of biogas as an energy source to power vehicles (Cohen et al. 2013).

Figure 4. Summer biomass (g DW m^{-2}) of *Ludwigia hexapetala* (LUHE) and *L. peploides* (LUPE) sampled in 50 cm deep water above and below the water surface of ten shallow lakes in northern California.



6 Ecological Impacts

Perennial *Ludwigia* species can form very dense, nearly impenetrable mats that extend below the water surface (Figure 4), across the surface, and can become herbaceous or woody thickets over the water surface. These mats intercept incoming sunlight that drives photosynthetic processes and growth and greatly decrease subsurface light conditions, thereby limiting ecologically important submersed macrophytes and algal species resulting in a change in aquatic food web structure. Once established, *Ludwigia* species tolerate a wide range of nutrient conditions, and local spread can be rapid due to the high growth rates of the species. When disturbed, buoyant shoots break off easily from established plants and disperse rapidly with water flow throughout watersheds to colonize downstream sites.

In the invaded range, *Ludwigia* spp. often competitively displace native plants, degrade water quality, and reduce or eliminate available open water habitat that is critical foraging and rafting areas for water birds and other wildlife. Greenhouse experiments suggest a complex range of intra- and interspecific interactions (which vary between life stage and environmental conditions) exist between invasive *L. hexapetala* (reported as *syn. L. grandiflora* subsp. *hexapetala*) and native and other exotic plant species (Thouvenot et al. 2013c). For example, *L. hexapetala* had little impact on experimental plantings of native plant species during the early stages of *L. hexapetala* establishment. In fact, *L. hexapetala* actually facilitated the establishment of exotic *Egeria densa* proving that *L. hexapetala* and exotic *Myriophyllum aquaticum* could coexist under certain experimental conditions (Thouvenot et al. 2013c). These results agree with observations made in California, in settings where *L. hexapetala* is found at low to moderate densities within plant communities. Studies in France, Belgium, and Switzerland have quantified reductions in native plant diversity, macroinvertebrate, and fish populations because of competitive exclusion by *Ludwigia* species (EPPO 2011a, Nehring and Kolthoff 2011). Their alteration of plant community composition and physico-chemical characteristics of aquatic ecosystems fundamentally changed and impacted critical habitat and resident flora and fauna (Stiers et al. 2011, Thouvenot et al. 2013a). In the Sacramento National Wildlife Refuge Complex in northern California, *L. hexapetala* *has* invaded whole-pond systems, which are managed as seasonal wetlands, resulting in degradation of habitat quality for migratory waterfowl and other water-dependent wildlife by displacing desirable wildlife, food plants, and open water habitat.

In general, dense infestations of emergent macrophytes can dramatically reduce the dissolved oxygen (DO) concentrations in water by reducing water circulation and increasing biological oxygen demand from high biomass production and subsequent in situ decomposition of organic matter. Impacts to DO can vary with plant community composition and hydrologic conditions. When DO is reduced to low levels, the hypoxic environment may support some tolerant fish species, but many valued fish species such as bass in lakes and salmonids in coastal riverine systems experience a reduction in habitat quality. Regulation of water levels and flows in lake and river systems can provide important societal services such as flood control and water supply, but they also affect aquatic community composition and food web functions. Data from the Russian River suggests that high-density *Ludwigia* stands slow the flow of water, leading to increased sedimentation in the plant beds. Dense stands also reduce oxygen exchange between the atmosphere and water column and reduce light that supports important native submersed aquatic plants and aquatic food webs (EPPO 2011a). Dandelot et al. (2005a) report much lower DO levels and reduced pH levels associated with water primrose stands in France due to suppression of photosynthetic processes of submersed aquatic vegetation. The density of macroinvertebrates recorded in nature reserve ponds of Belgium was negatively related to the percent cover of *L. grandiflora* mats, likely due to anoxic conditions that limit diffusion of oxygen (Stiers et al. 2009, Stiers et al. 2011). Studies also suggest that *L. peploides* and *L. grandiflora* produce and release allelopathic chemicals that were shown to impact germination, survival, and growth of two native aquatic plants (Dandelot et al. 2008). Likewise, these compounds could negatively affect other organisms in aquatic food webs including fish and invertebrates (Schultz and Dibble 2012).

7 Economic and Human Health Impacts

The European and Mediterranean Plant Protection Organization (EPPO) risk analysis for *L. peploides* and *L. grandiflora* report that these species interfere with agricultural production, ecosystem services, and human use of water bodies. These impacts include deterioration of dams and other water management infrastructure, loss of recreation areas, increase in flood risk due to reduction of channel carrying capacity, and high economic consequences incurred for control of the weeds (EPPO 2011b, 2011c). The negative ecological and economic impacts and overall risks associated with the establishment of these species in aquatic environments have prompted measures to prevent their spread. In several cases, *Ludwigia* spp. are regulated as noxious weeds or quarantine species, and management costs for government agencies in Europe and several U.S. states are substantial.

The high biomass production of water primrose species displaces the volumetric water capacity of important water conveyance systems including water supply canals for agricultural irrigation (Figure 5a) and wetland preserves dually managed for fish and wildlife habitat (Figure 5b) and urban and industrial water use. Invasions of flood control reservoirs and flood drainage channels (Figure 5c) pose great risks to urban areas and agricultural lands and may decrease waterfront property values and economic viability of marinas. Dense infestations of the weeds during the summer growing season also impede water movement in canals at critical times for crop and wildlife needs. The plants can also cause hyper-accumulation of sediments that impacts water quality and the water capacity of natural and artificial channels (Dandelot et al. 2008).

Water primroses can affect the cost of food crop production. *L. peploides* is reported as a weed in rice fields in Argentina, Australia, California, Chile, and Columbia. Rice production in the Sacramento Valley of California is a successful $500 million a year industry, due in part to effective efforts to manage aquatic weeds that otherwise decrease yields. Recently, *L. hexapetala* has invaded rice fields in California (Figure 5d); and the problem appears to be growing in areas where organically grown rice is produced, thus leading to increased production costs.

Figure 5. Examples of economic and societal problems caused by invasive water primroses: a) flood control channels at Rohnert Park, California. High-density infestation of *L. hexapetala i*s bright green, and it reduces flood retention capacity; b) *Ludwigia peploides,* irrigation canal San Joaquin Valley, CA; c) federal water supply canal pre-treatment of *L. hexapetala,* Colusa National Wildlife Refuge, CA; d) *L. hexapetala* in rice, Butte County, CA; e) mosquito monitoring at Laguna de Santa Rosa, CA; f-g) costly mechanical removal at Kissimmee Lakes, FL; and h) herbicide application in a water conveyance canal in CA.

The dense mats formed by noxious growth of water primroses lead to an increased risk in mosquito-vectored diseases such as the West Nile Virus. The mats may provide a habitat and a safe refuge for mosquito larvae because they inhibit the effective application of larvicides for mosquito control. In the Laguna de Santa Rosa sub-basin of California's Russian River watershed, a record number of adult mosquitoes were trapped adjacent to the highest density patches of *L. hexapetala* (Figure 5e) at the time the West Nile Virus was first perceived as a public health threat, hence prompting a multi-million dollar control effort (Meisler 2009).

Invasive water primrose also impacts public recreational opportunities. Dense stands reduce access to water and block waterways, interfering with human activities such as boating, fishing, hunting, and swimming.

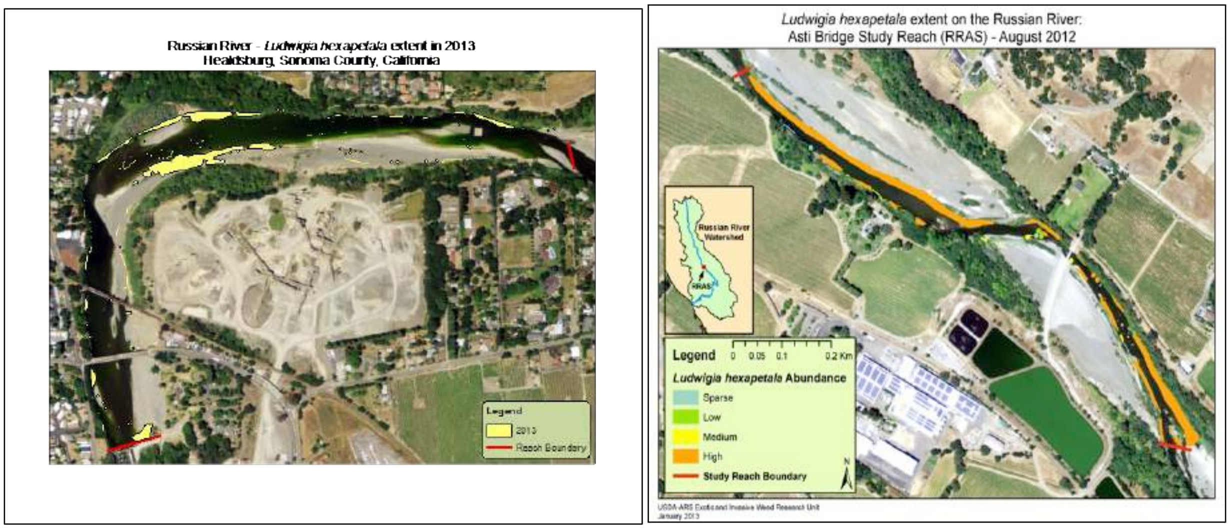
8 Impacted Ecosystems

Several aquatic ecosystems in the U.S. that are impacted by invasive water primroses represent unique resources from a global perspective. Select examples follow.

Russian River Watershed, California

The main channel of the Russian River is 177 km (110 mi) long, and the watershed drains 3,846 km^{-2} (1,485 square miles) to the Pacific Ocean in northern California. The river is the primary drinking water supply for Sonoma and Marin counties and provides irrigation water to support high value agricultural crops (primarily premium wine grapes). The Russian River is a federally managed river system with reservoir releases controlling river flows, especially throughout most of the summer and fall, to provide adequate flows for water supply, flood protection, and recreation and aquatic habitats. *L. hexapetala* has heavily invaded the river, which supports endangered coho salmon, threatened Chinook salmon, and steelhead trout (Figure 6). The Laguna de Santa Rosa Wetland Complex in the Russian River watershed is a RAMSAR designated wetland of international importance that includes seasonal and perennial freshwater wetlands such as creeks, ponds, marshes, vernal pools, swales, floodplains, riparian forest, and grasslands. The site has high conservation value as a habitat for fish, wildlife, and rare endemic plant and salamander species. The wetlands and waterways also provide irrigation, flood control, recreation, and aesthetic functions to the people of the Sonoma wine and dairy region. Changes to hydrology and increased nutrient loads from urban and agricultural wastewater are considered threats to this wetland, as is a major invasion of *L. hexapetala*.

Figure 6. Spatial distribution of invasive *Ludwigia hexapetala* on the Healdsburg (patchy) and Asti (continuous bands) reaches of the Russian River, approximately 120 km (75 miles) north of San Francisco, California.



Kissimmee Chain of Lakes, Florida

The Kissimmee Chain of Lakes is the northern watershed and headwaters of Lake Okeechobee and the Everglades ecosystem. This unique ecosystem supports high biological diversity including endemic, temperate, and subtropical species and a widely shifting mosaic of habitats (USFWS 1999). The Kissimmee watershed includes numerous lakes, tributary streams, floodplains, and marshes distributed over 8,498 hectares (21,000 acres) in south Florida. The Kissimmee River historically meandered 166 km (103 miles) between Lake Kissimmee and Lake Okeechobee. Because of increased urbanization since the 1960s, the river has been extensively straightened and modified to regulate water levels for water supply and flood control purposes, and these changes are thought to contribute to persistent infestations of invasive, submersed, aquatic macrophytes (Allen and Tugend 2002). A large ecological restoration effort has been underway to restore historic flows and native plant, fish, and wildlife populations, and for this reason, a high degree of hydrologic connectivity is retained in the system. Recently, *L. grandiflora* invaded the Kissimmee Lakes. The reasons for this spread are poorly understood, but the hydrochorous dispersal of these weeds put the entire Everglades ecosystem at risk. Local environmental impacts of the *L. grandiflora* stands have been investigated along with other aquatic macrophytes. Bunch et al. (2010) evaluated DO concentrations in water within stands of five emergent macrophyte species in Lake Istokpoga, Florida. The most favorable or highest DO concentrations for aquatic life were found in cattail stands. Hypoxia in summer and fall was 48.6 times more likely in areas invaded by water primrose (unidentified *Ludwigia* spp.) where conditions were likely uninhabitable for many low DO-intolerant fish (Bunch et al. 2010). Low hydrologic exchange and high accumulation of organic sediments characterized environmental conditions in the dense floating islands of the water primrose. Although it merits further investigation, observations suggest patches of native grass and macrophyte stands within the lakes may play a facilitative role in the initial establishment and subsequent dominance of *L. grandiflora*.

Santee Cooper Lakes, South Carolina

Much of the flow of the Santee River, originating in the Blue Ridge Mountains, has long been diverted into Santee Cooper Lakes and the Cooper River. These lakes, connecting rivers, and associated tidal marshes provide hydropower, support agriculture and urban needs, and epitomize the South Carolina low country. Water primrose-willow, reported as *Ludwigia uruguayensis* by the South Carolina Department of Natural Resources (DNR) in 2008, is a management problem in the Santee Cooper lakes. Here, the plants grow to one meter (~ three feet) tall in thickets along shorelines, where they have proven difficult to control due to extensive underground rhizomes (South Carolina DNR 2008). The water primrose-willow stands were initially restricted to the shoreline of Lake Marion, but when submersed *Hydrilla verticillata* infestations became quite dense in the lake, the *Ludwigia* sp. rooted in, and thrived on top of the buoyant *Hydrilla* beds (Davis 1997). This is apparently one way the primrose-willows establish free-floating mats and extend far from the shore in the lakes. The water primrose invasion has restricted boating and public access to waterways and shoreline areas, restricted water flow, degraded water quality, clogged water intakes, and affected power production.

American Heritage River: St. Johns River, Florida

One of the 14 rivers designated by the United States Environmental Protection Agency (EPA) to receive special attention towards natural resource and environmental protection and historic and cultural preservation is now in the early stages of invasion by *L. hexapetala*. The St. Johns River is the longest river in the state of Florida. The river flows slowly north across a low gradient giving it notoriety as one of the laziest rivers in the world extending 500 km (310 miles) from broad marshes south of Cape Canaveral in Indian River County to the estuary at the Atlantic Ocean near Jacksonville. The St. Johns slowly drains a basin of

22,900 km^{-2} (8,840 square miles) and includes one of the major interior lake and wetland ecosystems of Florida. It is a blackwater system supported by its swamps and marshes receiving flow from both natural springs and urban storm water runoff. The river was named an American Heritage River in 1998, and in 2008 was included on a list of America's ten most endangered rivers. The earliest European reference to Florida is a map drawn by Alberto Cantino in 1502 that describes unique vegetation rafts in the St. Johns River, prompting the early name Rio de las Almadias (River of Rafts) (Molander 2012). Today, the water primrose-willow impacts Lake Harney and Lake Monroe, two of the largest in a chain of lakes created by the river.

American Heritage River: Willamette River, Oregon

The Willamette River is also an EPA-designated American Heritage River that is impacted by invasion of *L. hexapetala*. From headwaters among the volcanoes of the Cascade Mountains, the cold water Willamette River flows north 301 km (187 miles) to join the Columbia River and discharge to the Pacific Ocean near Astoria, OR. The river was the terminus of the Oregon Trail, and since early pioneer days, it has been vital to the economy of the Willamette Valley and state of Oregon. *Ludwigia hexapetala* has been present in the Willamette watershed of Oregon since the 1940's, but did not become a problem until recently when it flooded historic gravel mining pits that are now operated as parks. Now, *L. hexapetala* patches occur along river shorelines of the mainstream of the Willamette River from Eugene downstream towards Portland. The river supports migrations of endangered salmonid fish. It is a spawning habitat for coho salmon, spring and fall run chinook (king) salmon, and steelhead and cutthroat trout. Protection and restoration of the river, wetlands, and floodplains are a high priority in Oregon, and local government agencies and environmental organizations have quickly responded to the threats imposed by water primrose.

9 Management Measures

Resource managers must tailor effective management measures for the *Ludwigia* species to the particular species of concern, the environmental conditions of each invasion site, and the options and resources available. However, basic tenets of invasive aquatic weed management, coupled with knowledge of the ecology of the species, can be adapted to mitigate the problem at a range of sites. The first and most effective management strategy is prevention of new invasions. To be effective, prohibitions of sales and transport of aquatic *Ludwigia* species in nurseries, garden centers, and e-commerce sites must be implemented and coupled with a comprehensive, public targeted education program to reduce movement of plant material from existing to uninvaded sites. Restoration plans for invaded sites should include details of the distribution and abundance of water primrose species on a watershed scale. Thiébaut (2007a) suggests that manual removal is usually a practical alternative for rapid response to new or low-density invasions, but mechanical removal with carefully managed transport and disposal is necessary where plants are well established. Chemical treatment can replace or be integrated with manual or mechanical removal approaches, but in many areas herbicides have only been used as a last resort where water use, environmental conditions, and permits make them a viable option (Thiébaut 2007a). Since 2009, France has not allowed herbicide use for any applications in aquatic habitats due to perceived risks and indirect effects on reduced DO concentrations in water (Haury et al. 2010). However, managers in the UK and the U.S. have used herbicides with some success. Several aquatic-registered herbicide options are available in the U.S. varying by state and region. Some water resource managers still seek alternatives to herbicide use, particularly in public drinking water supplies and in sensitive fish and wildlife habitats. In an ecological and socio-economic assessment of potential environmental weed targets for classical biological control, *L. grandiflora* and *L. peploides* were recognized as a top priority for biological control in Europe (Gassmann et al. 2006, Sheppard et al. 2006). Interest for biological control is also high in the U.S. This approach could be especially useful as a component of integrated management in large lake systems and could reduce biomass and the extent of other costly actions.

Regardless of the method used to remove or suppress biomass, it is important to recognize the species' recruitment potential from dormant seed banks that can generate new growth following management disturbance. Therefore, the timing of treatment or removal of biomass should occur before the flowering stage (Kelly and Maguire 2009) or during flowering, but before seed capsules expand and replenish sediment seed banks. For this reason, fall treatments are not advisable in areas with moist soil or drawdown zones where seed bank recruitment is most likely. Regardless of methodology, it is important to remove all plant material and use floating booms to contain fragments generated from management actions because water primroses can regenerate from small shoot fragments (Thiébaut 2007a) that quickly spread and establish throughout watersheds (Okada et al. 2009). Post-treatment monitoring for detection of reemergence is important. Resprouting capacity from rhizomes and/or continued emergence from persistent seed banks suggest managers must plan for a long-term effort.

10 Select Management Case Studies

Peconic River, New York

Current management efforts to control aquatic *Ludwigia* species are limited, and there is no consensus on best management practices. Management for water primroses has resulted in successes and failures, and there is still much to be learned about the best management practices for each. One of the best success stories comes from the Peconic River of Long Island, New York where *L. peploides* was first observed in 2003 (Stephenson 2008). By 2006, the Peconic Estuary Program formed a stakeholder partnership which included the Nature Conservancy, Freshwater Anglers of Long Island, Long Island Bassmasters, and others to eradicate the new invasion. The partnership also initiated an eradication and monitoring program that mobilized 438 volunteers who spent 2,360 hours hand-pulling 99 cubic meters (130 cubic yards) of *L. peploides* from the Peconic River (Peconic Estuary Program 2009). The group installed educational signage and developed a program to prevent introduction of non-native plants from aquaria and water gardens into natural lakes and rivers. By 2009, the group held "paddle the river" events to celebrate the successful containment of the weed, and vigilant monitoring and maintenance pulls continue to prevent resurgence.

Laguna de Santa Rosa, Sonoma County, California

A major invasion of *L. hexapetala* reached high levels of infestation in the Laguna de Santa Rosa tributary to the Russian River, associated floodplain, wetlands, and flood control channels before a local Ludwigia Task Force was formed to address the problem. Largely spurred by the potential threat of public health risk from mosquito-vectored West Nile Virus, a multi-million dollar effort was implemented over three years, using an integrated approach combining mechanical removal with glyphosate and trichlopyr herbicide applications. The short-term results achieved the objective of opening the waterways, but results were temporary and quite variable (Meisler 2009). Areas with the greatest water depths retained effects of management for two years, but regrowth to pre-project levels occurred in shallow wetland areas three to four years after treatment (Meisler 2009). Sustainable control was not achieved, but the nonprofit group who managed the effort learned important lessons that may improve future projects (Meisler 2009). For example, it is advisable to remove as much biomass as possible prior to use of herbicides to avoid extreme and unacceptable oxygen depletion levels that occur when sprayed biomass is left to decompose in the water column (Meisler 2009). Mechanical excavation of the flood control channels resulted in complete regrowth to pre-project or worse conditions within three years. Based on success of *L. hexapetala* control in canals elsewhere, this could have been avoided with minimal annual maintenance management. Management of a pernicious, perennial weed like *L. hexapetala* should not be approached as a short-term precursor to wetland restoration. The outcome of the project could have been improved by directly involving a collaborative team of experts in invasive aquatic weed ecology and management, and a commitment to long-term management of *L. hexapetala* as a component of comprehensive ecological restoration.

Colusa West Lateral Canal, Sacramento Valley, California

Concurrent with the Laguna de Santa Rosa project, a federal interagency team of biologists from the Sacramento National Wildlife Refuge Complex and plant ecologists from the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) implemented an effort to achieve control of *Ludwigia hexapetala* in federal water project canals at Colusa National Wildlife refuge.

The team used an experimental framework to test and evaluate control efforts to learn about effects and implement adaptive management as needed. Integrated methods using mechanical removal with a long arm excavator and fork attachment, coupled with hydrologic manipulation and a glyphosate herbicide with aquatic-approved surfactant application with and without follow-up spot spraying were compared to overwater spraying of the herbicide mix with and without follow-up spot spraying. The goal of these treatments was to determine the most effective strategy while minimizing herbicide use. Both methods that included maintenance touch up herbicide treatments were successful, and without follow-up management, the treated areas returned to conditions comparable to experimental controls within 3 years. The integrated method was more costly in the short term, given mechanical removal costs, but preferable to chemical treatment alone that resulted in severe oxygen depletion in the water for extended periods.

Delta Ponds, City of Eugene, Willamette River Watershed, Oregon

Invasive *L. hexapetala* invaded fish and wildlife habitats for western pond turtles and threatened juvenile Chinook salmon at restored gravel ponds, known as Delta Ponds, that have been reconnected to the Willamette River in Eugene, Oregon. In 2011 and 2012, the city initiated control efforts using contractors to manually pull low-density patches of the weed in aquatic areas upstream and downstream to successfully contain the worst infested area at the site, and to spot spray (2% glyphosate, 2% trichlopyr, and Agridex crop oil surfactant) *L. hexapetala* in terrestrial areas adjacent to the ponds (Figure 7). In 2013, the city of Eugene ramped up their efforts with a comprehensive Delta Ponds Invasive *Ludwigia* Control Project supported by the Oregon Weed Board, Oregon Department of Agriculture, and reviewed and advised by scientists with USDA-ARS, University of Oregon, and Oregon Department of Fish and Wildlife. The project continues the successful manual removal of low to moderate density patches and adds aquatic herbicide applications (glyphosate + crop oil surfactant) to the high infestation area of the site to minimize impacts to aquatic organisms (City of Eugene 2012). Photopoint monitoring and population mapping are used to assess plant community response to management in an adaptive framework (City of Eugene 2012). To date, three years after containment treatment and one year following herbicide treatment of the primary area, results of the effort have been very successful.

Figure 7. Pretreatment conditions, hand removal and spot herbicide applications to invasive *Ludwigia hexapetala* at Delta Ponds Natural Area, Eugene, Oregon. Photo credit: Lauri Holts

11 Current Research Activities

Rapid expansion of *L. hexapetala* on the Russian River, and continued expansion in the Sacramento-San Joaquin Delta as well as numerous other sites in California, Oregon, and Washington have resource managers concerned. A similar rapid expansion of two *Ludwigia* polyploids has been observed in Florida on the St. Johns River and Kissimmee Chain of Lakes. Continued expansion of invasive water primroses into key resources such as the Sacramento Delta, the Kissimmee River restoration projects, and acquired lands under the Comprehensive Everglades Restoration Program looks to be inevitable. Current management efforts are limited, partially due to taxonomic confusion, and there is no consensus on best management practices. There are few published studies regarding invasion, biology, and management of *Ludwigia* species present in the United States.

As pressure increases to manage a variety of *Ludwigia* polyploids, there is also a need to develop baseline biological and ecological data on populations present in the U.S. to optimize control efforts in a variety of lotic and lentic sites.

To address these concerns, the initial approach was to undertake biosystematics studies in the Pacific western states, update taxonomic treatments, and provide accurate information on the distribution of problematic *Ludwigia* taxa. Cytological and morphometric analyses of 80 populations from California to Washington, as well as molecular analyses of a subset of these populations have been completed. In addition, an updated taxonomic treatment of the genus *Ludwigia* in California was published (Hoch and Grewell 2012), and a taxonomic treatment for the Oregon Flora is nearly completed. Results of molecular analyses from populations in California detected very little genetic variation in *L. hexapetala* populations throughout California indicating the primary mode of reproduction is clonal (Okada et al. 2009). Final analyses of molecular samples from *Ludwigia* plant tissue collected in the South American native range are complete, and a manuscript is being finalized on this work to support research on potential biological control agents.

On-going studies on the biology and ecology of the *Ludwigia* species include research on seed bank recruitment under various hydrologic conditions, variation in decomposition of *L. hexapetala* with phenological stage and nutrient availability, plasticity of *L. hexapetala* in response to hydrologic regimes, and physiological integration of *L. hexapetala* across experimental light gradients. Multi-year studies to evaluate integrated management methods for control of *L. hexapetala* in water supply canals are being completed. The frequency and timing of tillage and an integrated approach using sheep grazing to remove biomass prior to tillage in managed wetland habitat during the summer dry season at Colusa National Wildlife Refuge is under investigation.

New collaborative work is also underway by USDA-ARS and the U.S. Army Corps of Engineers (USACE) to expand the geographic and management focus of APCRP research efforts. The objectives of current studies in progress are to: 1) evaluate the response of diploid, hexaploid, and decaploid species of *Ludwigia* to environmental conditions such as available nutrient gradients; 2) improve understanding of dispersal and colonization dynamics of *L. hexapetala*; 3) evaluate the spatial dynamics of invasive *L. hexapetala* patches in the Russian River, California, and determine mechanism(s) and environmental factors driving their spatial expansion; and 4) determine seasonal patterns in production and allocation of biomass and carbohydrate storage reserves in *L. hexapetala* along water quality and depth gradients in the Russian River watershed.

12 Identifying Research Priorities

Multiple invasive *Ludwigia* species are a threat to native biological diversity and ecosystem function. Resource managers expect this to increase with greater global trade and projected climate change. Research is needed to improve understanding of the complexity of the biology and ecological invasion process of water primroses and to provide water resource managers with substantive recommendations for methods to prevent and prioritize management of these aquatic weeds. Life history strategies and responses to environmental conditions vary among water primrose species. Therefore, species-specific management approaches may be required, and prevention and control strategies should be customized to the specific phase of the local invasion.

1. **Knowledge to Prevent and Contain Invasions.** Prevention of introduction and invasive spread are considered the most cost-effective weed management strategies. Dispersal of *Ludwigia* species with water flow within watersheds is evident, but little is known about the provenance of *Ludwigia* introductions into new areas or among discrete watersheds. Potential pathways may include continued, intentional, and accidental introductions from horticultural or aquaria trade sources, movement by waterfowl and other vertebrates, and movement among watersheds by boat trailers. It is important to determine where invasive water primroses are coming from, evaluate methods to prevent introduction, and limit spread from existing invasion sites.
2. **Identify and Determine Distribution of Complicated *Ludwigia* Species.** Accurate identification and understanding of the distribution of the species and potential hybrids is an essential first step in the development of prioritization and management strategies. Accurate identification of an invasive plant in its native and introduced range is also an important prerequisite for the success of any biological control project (Gaskin et al. 2013). Despite long-standing taxonomic confusion surrounding aquatic *Ludwigia* species, recent ecological risk assessments point to the need for further study of the biosystematics of the genus (Nehring and Kolthoff 2011). Work is well underway to solve this problem in the Pacific west states, but there is still considerable confusion regarding invasive taxa in Florida and elsewhere in eastern states. A comprehensive approach is needed that utilizes morphometric and cytogenetic evaluations

of chromosome numbers to determine ploidy levels present at invasion sites, differentiate species, and improve taxonomic treatments. There is a need to evaluate molecular markers to assess local population structure, genetic diversity, and identify invasive genotypes. Phylogenetic and other molecular studies are also needed to compare local invasive genotypes with those in the native range to determine their degree of relatedness and to determine origin of locally invasive species.

3. **Improve Understanding of the Ecology of Dispersal and Colonization Phases.** Integrative studies that link demographic processes and key plant traits (e.g., propagule availability, survival, growth, reproduction, and fitness) with dispersal, colonization, and proliferation phases of spread of plants are needed (Ibáñez et al. 2014), as is the need to know how these key processes affect water primroses in a range of environmental conditions. Studies of colonization dynamics should include an evaluation of the competitive ability of *Ludwigia* spp. and competitive interactions with native or other desirable plant species in the context of historical watershed changes (DeGasperis and Motzkin 2007) to prevent conditions that would allow the invasive *Ludwigia* species to dominate native communities. Research to understand how these processes operate at individual, population, watershed, and regional scales are needed to guide management at multiple phases of ongoing invasions and across habitat types. This comprehensive approach can also identify vulnerable areas and inform predictions for different interacting management scenarios such as climate change, hydrologic change, and resource (light, nutrients, etc.) availability.
4. **Mechanisms Driving Invasive Spread.** There is a need to understand what triggers expansion of *L. hexapetala* as it moves from a patchy distribution following colonization to expansive colonies that cover large areas. To better understand patterns of distribution and abundance of *L. hexapetala*, more detailed information is needed regarding yearly changes. Field observations suggest that not all invaded areas support continued, unabated patch colonization and expansion. Rather, some patches reduce their extent in some locations under some hydrologic conditions. Initial hypotheses for what drives these differences are factors such as hydrologic status (water depth relative to the rooting zone and temporal variability in water depth), as well as degree of disturbance during winter, when large floods can substantially rearrange river morphology. Improved understanding of what drives or limits expansion is important to water project managers who control timing and rates of flow for desired outcomes.

5. **What Management Strategies Show Promise for Specific Species and for Specific Habitat Types? Is Biological Control an Option?** Published literature on the efficacy of herbicides to control water primroses is lacking, and anecdotal accounts often omit essential details for relevant, local manager decision-making. In addition, information is needed regarding the best treatment timing in different hydrological settings and for specific *Ludwigia* species. Likewise, information concerning non-target effects of management options is also desired. These evaluations should be assessed in an ecological restoration context. There are a growing number of managers who desire alternatives to chemical control where *Ludwigia* species have invaded rivers and lakes that serve as public drinking water supplies and/or support to endangered fish species. Herbivorous insects associated with *L. peploides* have been identified in the southern U.S. (Harms and Grodowitz 2012). *Lysathia* and *Altica* water flea beetle species have been reported to feed on *Ludwigia* species and reduce biomass of invasive populations in Alabama (McGregor et al. 1996), California (Carruthers et al. 2011), Texas (Campbell and Clark 1983), and Argentina (Cordo and DeLoach 1982). Further work is needed to determine if these insect populations can be augmented to reduce *Ludwigia* biomass in field settings at critical times in the life stage of *Ludwigia*. Recent studies on potential biological control agents for *L. hexapetala* and *L. peploides* have been completed in South America, and potential insect herbivores that merit further testing have been identified. Biosystematic studies are needed to clarify the origin and specific genotypes of invasive *Ludwigia* species in the U.S. Clarification will help support future host specificity testing of potential insect herbivores, particularly in the South Atlantic and Gulf states where multiple *Ludwigia* species exist and are thought to be native; however, molecular studies are needed for confirmation.
6. **Weed Management and Restoration Implications of Seed Banks**. *Ludwigia* species maintain sediment seed banks. Recruitment from these seed banks can perpetuate infestations following management actions. Recruitment from seed banks are expected along rivers and in other aquatic systems with fluctuating water levels, since drawdown conditions promote recruitment. Seed banks even play a role in floating islands of vegetation where patches of sediment are less inundated than surrounding deeper water areas of marshes and lakes (Cherry and Gough 2006). Allocation to sexual reproduction is expected to vary with ploidy level. Studies are needed to assess germination requirements, ecology of the seed life stage of *Ludwigia* species with different ploidy levels, and

seed bank dynamics under changing environmental conditions to support management techniques that deplete seed banks and improve restoration of desirable plant communities.

7. **What Restoration Actions Can Reduce Negative Effects?** In an assessment regarding the impact of invasive *L. grandiflora* and other macrophytes on hypoxia in Kissimmee Lakes, researchers suggested that selective removal of macrophytes and sediment to provide pathways for water movement inside dense stands could mitigate or increase aqueous DO concentrations and improve and expand habitat for fish and wildlife (Bunch et al. 2010). The merits of innovative solutions such as this should be experimentally tested and could be implemented as low-cost interim solutions while improvements to management methods for challenging sites are developed and improved. Herbicides were applied to *L. grandiflora* in floating islands within lakes. Following application of the herbicides, effective control of the target weed was observed; however, the native vegetation was also affected and recruitment of native species was limited. Studies are needed to evaluate treatment methods for *L. grandiflora,* recruitment requirements of desirable plant species, and methods to restore open native grass communities in Florida lakes.
8. **How Invasive Will *Ludwigia* Species be with Climate Change, and How Can We Prepare and Respond?** Invasive *Ludwigia* species likely include different, sometimes locally adapted, species and populations that may differ in their ability to adjust (plasticity) to changing climate and other environmental conditions. Phenotypic plasticity and local adaptation are interacting factors that are generally not considered in models of species responses to climate change, but can greatly influence persistence and range expansion (Reed et al. 2011, Schwartz 2012). Simple climate matching models that rely on distribution of these species in their native range and project potential distribution outside of this range are not sufficient for *Ludwigia* species, since they have already invaded climate envelopes quite different from their area of origin. Research is needed to evaluate genetic adaptation vs. the degree of plasticity of regional populations to identify patterns of population differentiation, and how these factors affect the niche breadth of the invasive species. In turn, this information can provide resource managers with alternative environmental conditions and process management methods to control the spread of invasive *Ludwigia* weeds as it relates to climate change and new areas at risk for invasion. This research requires local population-level data on genetic and phenotypic variation, observational and experimental studies on local adaptation and phenotypic plasticity of multiple cytotypes

of aquatic *Ludwigia* species across large spatial scales, and common garden experiments to evaluate traits that will be important for species persistence or demise. In general, herbivore-inflicted damage to plants can decrease plant fitness and can potentially decrease the ability of the plant species to adjust to environmental change (Gianoli et al. 2009). Using the framework described, experiments to test invasive *Ludwigia* traits and population responses to changing environments while under herbivore pressure could inform future biological control practices while remaining sustainable with climate change.

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED *July 2013 to September 2014*
February 2016	TR	

4. TITLE AND SUBTITLE

Establishing Research and Management Priorities for Invasive Water Primroses (*Ludwigia* spp.)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Brenda J. Grewell, Michael D. Netherland, Meghan J. Skaer Thomason

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

USDA-Agricultural Research Service
University of California-Davis, Dept. of Plant Sciences MS-4. One Shields Avenue, Davis, CA 95616
US Army Engineer Research and Development Center
Environmental Laboratory

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/EL TR-16-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Engineer Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Creeping water primroses and water primrose-willows are among the most aggressive aquatic invasive plant invaders in the world. These aquatic Ludwigia species can impart severe ecological, economic, and human health impacts in aquatic ecosystems and threaten critical ecosystem functions. We expect these impacts to increase with greater global trade and projected climate change. This technical report presents an overview of the biology and ecology of these invasive plant species, along with select management case studies and research efforts. While the need for management approaches has become an important topic, little is known about the distribution of Ludwigia species and how they respond to varying environmental conditions in the U.S. Life history strategies and responses to environmental conditions vary among water primrose species. Therefore, species-specific management approaches may be required, and prevention and control strategies should be customized to the specific phase of the local invasion. This information is important for predicting further spread. Likewise, it is the foundation for risk assessments and effective management. This technical report proposes research priorities to improve understanding of the complexity of the biology and ecological invasion process of water primroses, and it provides resource managers with substantive recommendations for how to prevent and prioritize management of these aquatic weeds.

15. SUBJECT TERMS

Invasive aquatic plants, Aquatic Plant Control, Aquatic Plant Management, Invasive plant biology and ecology, water primrose management, aquatic herbicide, biological control

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Michael D. Netherland
U	U	U	UU	53	19b. TELEPHONE NUMBER *(Include area code)* 352-392-0335

WATER WEEDS

Guide to Aquatic Weeds in Benton County

BENTON
SOIL AND WATER
CONSERVATION
DISTRICT

BENTON COUNTY
Cooperative Weed
Management Area

Cover photos:
Brazilian elodea on boat motor (center)
Floating primrose-willow (top right)
Purple loosestrife (middle right)
Eurasian watermilfoil (lower right)

PUBLICATION DATE: June 2014

PRODUCTION CREDITS:

Content: Sasha Shaw and Katie Messick, King County Noxious Weed Control Program

Additional Content: Holly Crosson, Crystal Durbecq, Heath Keirstead & Emily Platt, Benton Soil & Water Conservation District

Design: Sandra Kraus, King County IT GIS, Visual Communications & Web Group

Photographs: most provided by King County staff and the Washington State Noxious Weed Board

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Other photos courtesy of:

Photographer	Affiliation	Website	Species
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CONTENTS

INTRODUCTION

WEED IDENTIFICATION PAGES

EMERGENT

FLOATING LEAF

FLOATING MAT

SUBMERGED

To see the complete Benton County CWMA weed list,
visit www.bentonswcd.org/programs/invasive-species/weed-profiles/

What are aquatic plants?

Native Pond-lily

Plants that grow in water are called aquatic plants. They grow in a variety of forms. Emergent plants are rooted in the soil and grow along shorelines. Floating plants grow in shallow to deep water and either have floating leaves or form floating mats on the surface of the water. Unlike free-floating plants, which are not rooted, floating-leaved plants have roots. Submerged plants grow mostly under water. Many native aquatic plants grow in Oregon, and they are very beneficial to the environment and generally do not cause significant problems. These native aquatic plants developed in the area naturally and usually are kept in check by natural controls such as herbivores, insects and competition from other plants. Native aquatic plants provide food and habitat for fish, birds, and other wildlife. They protect shorelines from erosion and often clean excess nutrients and pollution from the water.

What are invasive aquatic weeds?

Invasive aquatic weeds are plants that are introduced to a new area without the natural checks and balances of their home waters. They can sometimes grow out of control, creating dense monocultures and overwhelming lakes and streams. This guide describes some of these invasive aquatic plants that are a concern for Benton County, Oregon. They are all highly aggressive and create significant ecological and economic damage when they are not controlled. These invasive aquatic plants are called noxious weeds when they are identified by the Oregon State Noxious Weed Board as having a significant negative impact on the state's natural and economic resources.

Impacts of invasive aquatic weeds

- loss of native plants
- disruption of fish and wildlife habitat
- damage to commercial and sport fishing
- reduced recreational activities like boating and swimming
- clogged irrigation and drinking water structures
- decreased water quality
- increased mosquito habitat

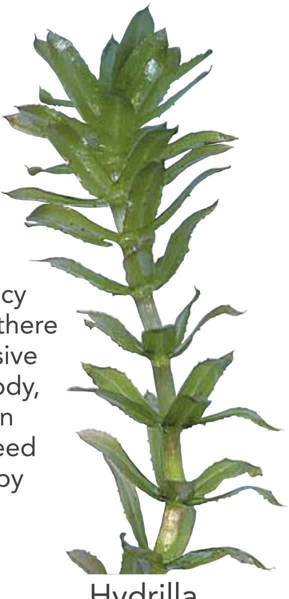
Garden Loosestrife

How to use this guide

This guide describes 12 aquatic noxious weeds to look out for in Benton County. The weeds are grouped by growth form: emergent, floating mat, floating leaves, and submerged. Some of the weeds in this guide are already present in Benton County, but some of them have only been found in a few locations or have not been found here yet. The guide does not include any native aquatic plants, some of which closely resemble these weeds. If you find a plant that looks like one of the weeds in this guide, we suggest you consult the more detailed references listed at the back of this guide or ask an expert for help with identification.

What can we do about invasive aquatic weeds?

Everyone can help prevent new introductions by cleaning boats, trailers and other equipment, by never dumping aquariums into lakes and creeks, and by not planting invasive aquatic plants. Also, early detection of an invasive aquatic weed greatly increases the opportunity for preventing damage. If you find an invasive aquatic weed in a new area, it is important that the responsible agency or landowner is alerted as soon as possible, while there is still a chance to stop its spread. Even when invasive weeds are already widely established in a water body, it is still possible to reduce their impact and contain their spread. For instance, it can help to remove seed heads before they mature or to contain the weed by controlling new populations.



Hydrilla

What should I do if I find an invasive aquatic weed?

Mark a map with the location of the plant and carefully collect a specimen including stems, leaves and any flowers or seed pods. Place the specimen in a sealed container with water and store in a cool, dark place. Contact the Oregon Invasives Hotline at OregonInvasivesHotline.org or 1-866-INVADER to make arrangements for getting the specimen identified. If this is not possible, contact BSWCD's Invasives Program and we can help determine if a site visit is needed to identify the plant.

Purple Loosestrife

What does the State Noxious Weed Law require when it comes to aquatic noxious weeds?

Oregon's noxious weed law (ORS 569) provides authority to the Oregon Department of Agriculture and to county Weed Control Districts to implement an integrated weed management approach to prevent the introduction and spread of noxious weeds throughout the state, which includes terrestrial, aquatic or marine plants designated by the State Weed Board. Priority is given to the prevention of new infestations of noxious weeds and then to the control and, where feasible, eradication of noxious weeds in infested areas. The noxious weeds are classified by distribution: A listed weeds are the highest priority statewide because they are highly limited in distribution; B listed weeds may be regionally abundant with limited state-wide distribution, and are recommended for intensive control on a case-by-case basis; and T listed weeds are a target list of weeds that are prioritized for focused prevention and control, and are designated on an annual basis.

How do I know which weeds have to be controlled?

The Benton County and Oregon State noxious weed lists are available online at http://www.bentonswcd.org/programs/invasive-species or by calling the Benton SWCD at 541-753-7208. In this guide, the weed classification and any control requirement is provided for each weed described.

CIR 707

UNIVERSITY OF FLORIDA
IFAS EXTENSION

Weed Control in Florida Ponds[1]

D.D. Thayer, K. A. Langeland, W.T. Haller, and J.C. Joyce[2]

Ponds are often built to supplement farm income via fish production, for personal enjoyment, or for stormwater management. Soon after the pond is constructed, unforeseen problems often arise. One major problem that occurs is that the pond becomes clogged with aquatic plants. The level at which an aquatic plant becomes a weed problem depends on the pond's intended use. A farm pond used primarily for weekend fishing can tolerate considerably more vegetation than a pond constructed specifically for fish production and/or irrigation. Shoreline grasses can help stabilize and prevent bank erosion, but out of control grasses may encroach into the water, where they restrict access and usability. This circular provides information on aquatic weed identification and control for farm and aquaculture ponds.

Prevention is the best technique for reducing takeover by aquatic weeds. It's easier and more economical to prevent weed problems than it is to cure them. Preventive measures include proper pond location and construction.

Site Selection

Where you dig a pond can be an important decision when it comes to preventive control. Proper location can help minimize erosion and nutrient enrichment from the runoff of silt and inorganic and organic fertilizers that decrease the lifespan of the pond and limit its usefulness.

Whether you fertilize your pond for fish production or avoid intentional nutrient enrichment, sites near fertilized fields, feedlots, barnyards, septic tanks, gardens, roadways, or other sources of runoff should be avoided. Agricultural and domestic runoff such as from parking lots and roadways may also contribute heavy metals, oils, and pesticide contaminants. If an “ideal” pond location cannot be found, a berm to divert runoff away from the pond can be constructed (Figure 1).

Avoid building a pond with a flowing stream unless excessive water can be diverted. When a fertilization program is being used for algae production, the continual flushing action of a flowing

1. This document is CIR 707, one of a series of the Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date October 1986. Revised June 2003. Cir 707 is also available from the IFAS Extension Bookstore at http://ifasbooks.ufl.edu. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.
2. D.D. Thayer, director, South Florida Water Management District, Aquatic Plant Management Division; K.A. Langeland, professor, Agronomy Department, Center for Aquatic and Invasive Plants; W.T. Haller, professor, Agronomy Department, Center for Aquatic and Invasive Plants; J.C. Joyce, professor, Executive Associate Vice President, Office of Vice President for Agriculture and Natural Resources; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, 32611.

stream would be counterproductive, resulting in the use of much more fertilizer to maintain an algae bloom. Herbicide effectiveness may also be diminished when a long contact period is required for underwater plants. Aquatic plants growing in the stream itself are much more difficult to control, even with the faster acting contact-type herbicides. Without control of water input, water quality in general will suffer and become difficult to manage.

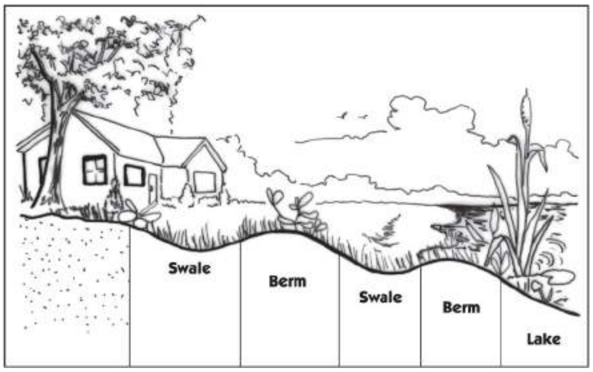


Figure 1. A swale and berm system slows down stormwater runoff and traps pollutants before they reach the pond.

After considering the factors mentioned above, select locations that have recommended watershed-to-pond ratios if you don't have a well or other water source. The USDA Natural Resources Conservation Service (NRCS) recommends that, based on Florida's annual rainfall, an excavated pond should be no less than 6 to 8 feet deep (Figure 2), and that a drainage area of 2 to 3 acres is necessary to maintain one foot of water in a one-acre pond (Figure 3). Experience with farm ponds in North Florida indicates that deeper ponds (10 to 20 feet deep) have fewer aquatic weed problems than shallower ponds. If a properly balanced fish population is to be maintained, then at least one surface acre of water is required. So, to build a one-acre pond with an average depth of 8 feet, an average 16 to 24 acres of watershed would be required. The surrounding vegetation cover, soil type, land slope, and other land use characteristics will have an effect on the degree of drainage. If the surrounding vegetation is primarily woodlands, then more watershed is required than if the surrounding land is primarily in pasture.

If possible, choose a location that maximizes use of prevailing winds. Good water circulation is essential for increasing dissolved oxygen in the water

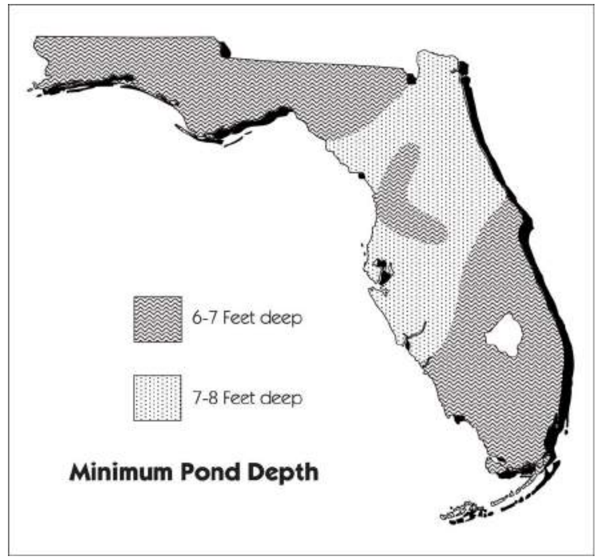


Figure 2. Based on probable seepage and evaporation losses, Florida ponds shoudl have a minimum depth of 6 to 8 feet.

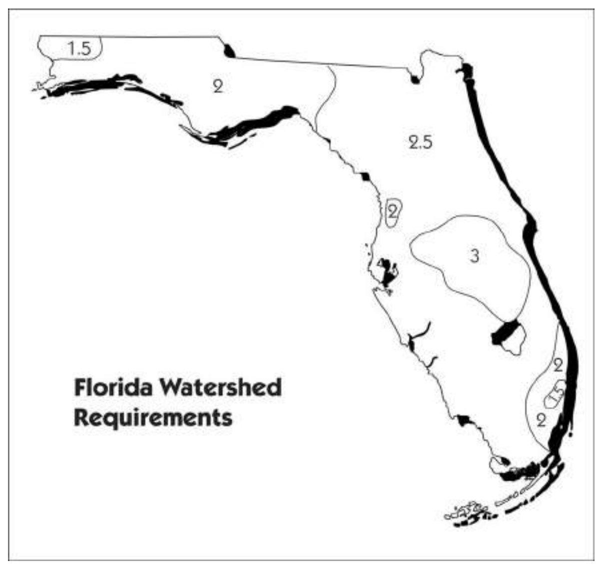


Figure 3. The watershed required for most of Florida would be 2 to 3 acres of watershed to 1 acre-ft of water.

column, cycling nutrients, increasing bacterial populations in the hydrosoil, and restraining floating plants from covering the pond.

If at all possible, avoid a location that will have heavy livestock usage. If the pond is going to be used primarily for watering livestock, divert water to a watering trough or section off a portion of the pond in order to prevent the livestock from wading in at will (Figure 4). Livestock increase erosion, levee destruction, organic pollution, and turbidity, as well as disturb fish spawning areas. Restricting livestock provides cleaner drinking water and will increase the life of the pond. The cost of fencing will be more than offset by the lowered cost of pond maintenance.

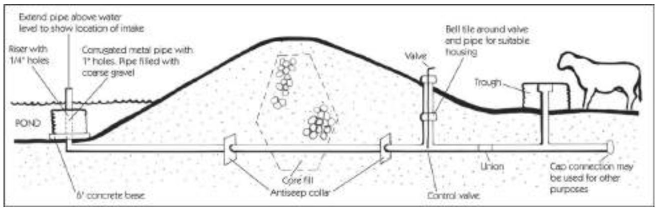


Figure 4. Water is piped through the dam's drainpipe to a stockwater trough.

Pond Construction

Pond banks should be as steep as possible along the edges to a depth of several feet to avoid shoreline vegetation from becoming established. They should then gradually slope to a depth of 6 to 8 feet to the pond center. Removal of brush and trees along the edge will increase berm stability and reduce leaf and branch litter. Grass species should be encouraged to grow along the banks to prevent erosion and washouts.

The construction of a small berm (Figure 1) around the entire pond can be helpful in trapping rainwater runoff that may be rich in nutrients and suspended solids (leaf litter, trash, etc.). The water that percolates through the berm into the pond will be filtered rather than flowing directly into the pond itself. Terracing adjacent fields can also be a valuable method of decreasing both field erosion and sedimentation. If your future plans include water drawdown for pond reconstruction, now is the time to plan for drainpipes, risers, valves, etc.

Stormwater Ponds

Urban stormwater ponds, technically called *wet detention areas*, have the primary purpose of flood control. Secondarily, surface water detention ponds are hoped to protect receiving waters from pollutants and may also be used in part or in total to mitigate destruction of wetlands. Wet detention ponds are often constructed with shallow sloping areas, called *littoral shelves*. The purpose of the littoral shelf is to provide habitat for rooted plant life. Stormwater ponds often have permits associated with them that require management of aquatic plants in the pond, including maintaining a certain amount and type of plants. Before attempting any weed control measures in stormwater ponds, the Water Management District in which you are located should be contacted. It is advisable to contact a professional pond managment company to manage weed problems in stormwater ponds. For additional information on stormwater pond management see "Stormwater Ponds--A Citizen's Guide to Their Purpose and Management," available from Southwest Florida Water Management District: 352/796-7211 or 800/423-1476.

Methods of Aquatic Weed Control

Fertilization

The principle behind a pond fertilization program is that phytoplankton (microscopic algae) populations increase as a result of the controlled addition of fertilizer nutrients until light penetration is reduced below the level required for growth of submersed weeds.

Before you decide on fertilization for weed control, consider the following. 1) Once a fertilization program has begun, you must always continue the program or face possible severe weed problems. 2) Particular weeds, such as hydrilla (see “Submersed Plants” in Appendix 1), have been shown in Florida to outcompete phytoplankton communities for nutrients, thereby making the weed problem worse. It is therefore imperative that fertilization should not be initiated until current weed infestations have been totally controlled. 3) If the fertilization of a pond is intended to be used to stimulate food production in an aquaculture pond, then additional weed control with herbicides or with weed-eating carp *Ctenopharyngodon idella* (see page 6, “Herbivorous Fish”) may be beneficial (Figure 5).

Phytoplankton is the base of the food chain. Increases in phytoplankton will increase the production of zooplankton, which ultimately increases fish production. Most fertilization recommendations suggest adding inorganic fertilizer every 2 weeks until a shiny object placed 18 inches below the surface is no longer visible (Figure 6). Once this level of phytoplankton is obtained, maintain that level with periodic fertilization. The optimum pH should be at least 6.5 or higher, and liming may be required prior to fertilization. The best time of year to begin a fertilization program is in the

Figure 5. The grass carp provides effective weed control for most submersed and many floating weeds.

spring before aquatic weeds have begun growth. Once established, submersed vegetation must be controlled either with chemicals or grass carp or must be physically removed in order to ensure good algae production. Fertilization shortly after an herbicide application may speed decomposition resulting in oxygen depletion and should be avoided. Remember, if you desire clear water for swimming or other recreational purposes, do not fertilize your pond. **NEVER** add fertilizer to a permitted stormwater retention pond.

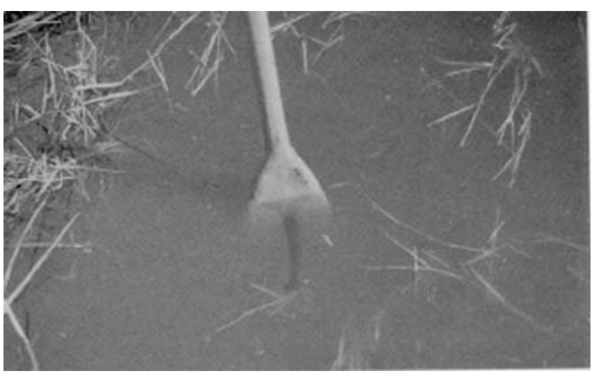


Figure 6. Fertilization encourages production of phytoplankton that reduces light penetration into the water.

Nutrient Reduction

The converse of fertilization is reduction of fertilizer nutrients into your pond. While most Florida ponds will have sufficient naturally occuring nutrients to support problem levels of plant growth, decreasing the amount of nutrients going into a pond can minimize some problems, especially the growth of algae and floating plants, which derive their nutrients from the water, not the pond bottom. Sources of nutrients that can be decreased include: the amount of food provided to fish, fertilizer (especially those that contain high nitrogen) applied to landscapes in the watershed, livestock and domestic ducks.

Drawdown

Water level fluctuation or pond draining can be used very effectively if the conditions are favorable. Exposing the bottom of your pond to the atmosphere will solidify suspended mud and consolidate bottom sediments to a watertight condition. Excessive nutrients suspended in the water column will be diluted as a result of the water exchange. In order to have a successful drawdown, you must leave the water level down long enough to desiccate and kill submersed plants. An incomplete drawdown may have little to no effect, and some plant species that are not susceptible to drawdown may spread into the de-watered lake bottom more easily. Cattails are often opportunistic and may establish during extended drawdowns (Figure 7). The consolidation of bottom muck by drying should also improve fish spawning and nursery areas. Drawdowns also increase options for chemical weed control. Some herbicides are only labeled for use on drained pond bottoms, and treatments at this time often provide several years of weed control because the herbicides are bound in the bottom sediments.

Figure 7. Cattails flourish in a pond that has been drown down to kill weeds.

Mechanical Control

Mechanical control involves the physical harvesting of vegetation by hand or with specifically engineered equipment. For the owner of a small pond, mechanical control can be helpful for removing small populations of nuisance plants. For example, a small population of duckweed (see "Floating Plants" in Appendix 1) can be netted when plants form windrows against the shoreline. Brush species, cattails, and other shoreline vegetation can be cut with a sickle or pulled by hand while still immature. Booms or barriers extended across an incoming creek or stream can often keep plants such as waterhyacinths (see "Floating Plants" in Appendix 1) from entering the pond. When confined, these plants can easily be hand removed or sprayed with herbicide. While the simplest mechanical harvesting devices for weed control are often the cheapest, and often highly effective, commercially made mechanical harvesters (Figure 8) designed specifically for aquatic weed management are available. These harvesters vary in size from simple hydraulic sickle-bar cutters powered by a 5-H.P. engine and mounted on the front of a pontoon boat to 10,000-pound capacity harvesters which convey cut vegetation on board for transport to shoreline dumping sites. In general, large mechanical harvesting equipment can be difficult to maneuver in a smaller pond, and weed control cost would be exorbitant for the private pond owner.

Figure 8. Aquatic plant harvester clears weeds from a lake surface.

Biological Control

Ideally, the best weed control agent is one that keeps weed pests restrained naturally. Many native plants have biological restraints that keep them from growing prolifically. The major aquatic weed problems in Florida are caused by nonnative plants that were introduced from foreign lands without their natural pests and controlling organisms. In the absence of natural enemies, these nonnative plants grow uncontrolled and rapidly invade new areas. To provide some insight into biological control for these nuisance plants, research scientists travel to their foreign habitat searching for insects, disease, or other organisms that may aid in controlling their growth. In theory, this concept sounds ideal; however, years of research are required to insure that the introduced organism does not become another dangerous pest. Once it has been determined that the biocontrol agent will not be a pest, and the control agent will exist under the environmental conditions of the pest host, the organism is released. Most biological organisms will not eradicate the host plant, but will instead reduce the plant s potential to become a serious pest.

Several biocontrol agents have been released in Florida or occur naturally; however, others must be added to the pond and are presently available for release in Florida.

Insects and Plant Pathogens

Over the years, insects have proven to be the most popular biological control agents due to their high degree of host specificity. The insect is generally effective at destroying only the host plant because of its parallel evolutionary development with the plant's taxonomic characteristics. Plant pathogens such as viruses, bacteria, fungi, or nematodes are already present in the aquatic environment and may limit the growth of aquatic weeds by invading weak or wounded plant tissue.

The alligatorweed flea beetle (*Agasicles hygrophila*), discovered in South America and introduced into the United States in 1964, is the best example of an extremely successful biocontrol program using insects for aquatic weed control. In regions of the country where the flea beetle can overwinter, as it does in Florida, alligatorweed is no longer considered a major weed problem.

The waterhyacinth has had several biocontrol agents introduced to it over the years that help in reducing the prolific growth that it is capable of; however, unlike alligatorweed, these biocontrol agent don't appear capable of quickly controlling the plant. Two waterhyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*), the waterhyacinth mite (*Orthagalumna terebrantis*), and fungus (*Cercospora rodmanii*) have been imported to Florida and can often be found associated with the plant. Because one requirement of a successful biological control program utilizing insects is self-dissemination, locating sources of insects for introduction should not be necessary.

Herbivorous Fish

Numerous nonnative fishes around the world are reported to consume aquatic vegetation. However, because of the concern for potential damage in Florida's diverse lakes and rivers, only a few of these fish have been investigated and even fewer show promise for weed control. Many of these species may not be suitable for weed control because the individual has insufficient consumption (high stocking rates needed), they are prolific spawners (often cause overcrowding), or they are restricted to warm climates (must be overwintered in controlled environments).

Of the fishes examined to date, the grass carp (Figure 5) is the best candidate for aquatic plant control in a variety of situations and climates and may provide the only practical control method for water bodies where herbicides cannot be used. This fish has provided excellent control of submersed plants, filamentous algae, and small floating plants such as duckweeds. The grass carp is used by Arkansas and other states for this purpose in natural lakes and has been researched by a number of other states. Florida has conducted research and has approved the use of the triploid grass carp, which has three sets of chromosomes compared to the normal two sets and is thus sterile.

As stated previously, the grass carp does consume vegetation and if stocked in sufficient numbers is likely to remove all submersed plants from pond systems. Before stocking ponds that have heavy vegetation cover, it is often advantageous to treat with herbicides. In order to determine proper stocking rates for a given pond, a competent fish biologist should be consulted and a permit obtained from a Florida Wildlife Conservation Commission office.

There are three possible management strategies utilizing grass carp: 1) complete vegetation removal within one to two years with a heavy stocking rate; 2) winter stocking, before the spring growth of weeds begins, using fewer fish to maintain a lesser amount of vegetation in the system and increasing the grass carp population as needed; and 3) integrated control using herbicide treatments to obtain desired levels quickly and stocking grass carp to maintain this level. Again, the grass carp population should be adjusted as needed. A word of caution is in order: it is much easier to stock additional grass carp than to remove unwanted fish from the system.

Herbicides

Controlling aquatic plants with herbicides is the most commonly used method of weed control. Chemical weed control has several advantages.

- Herbicides may be directly applied to undesirable vegetation, offering a high degree of selectivity and leaving desirable levels of vegetation.
- Pre-emergence application of appropriate herbicides can provide early weed control. This may be used to promote desirable vegetation without competition during critical early growth stages.
- Herbicides reduce the need for mechanical control which can increase turbidity and affect fish populations.
- Erosion may be reduced by promoting the lower growing grass species for cover.
- Many weeds, especially perennials, that cannot be effectively controlled by other methods are generally susceptible to herbicides.
- Routine use of herbicides under a maintenance program usually reduces the cost of weed control.

Herbicide Selectivity

Herbicides may be placed into two general categories: selective and nonselective. Selective herbicides are used to control weeds without damaging nearby plants, crops, lawns, and ornamentals. Nonselective herbicides are chemicals that kill all plants that are sprayed at an adequate rate. Herbicides in this latter category are used where no plant growth is wanted such as fencerows, ditchbanks, driveways, etc. Factors that influence selectivity include application rate, time and method of application, environmental conditions, stage of plant growth, and the biological characteristics of the plant.

Mode of Action

Herbicide activity can be divided into contact and systemic types. Contact herbicides only kill the parts of the plant that they physically contact; therefore, the entire plant must be sprayed. They usually cause rapid die-back of the vegetation they come in contact with and are generally more effective on annuals. Systemic herbicides are absorbed by both roots and foliage and translocated within the plant s vascular system. Systemics are particularly effective against deep rooted perennial weeds, providing long term control, and do not need uniform coverage of the entire plant.

Herbicide Formulation

The active ingredient of a herbicide is rarely 100 percent of the formulation. Instead, the herbicide is mixed with water or an oil blend and often includes inert adjuvants that facilitate the spreading, sticking, wetting, and other modifying characteristics of the spray solution. These special ingredients usually improve the safe handling, measuring, and application of the active ingredient.

The majority of liquid herbicide formulations are liquid (L). Each gallon of formulation usually contains 2 to 8 pounds of active ingredient. The high concentration generally means easier handling, transport, and storage. Liquids require little agitation and are considered to be nonabrasive. Liquids are usually mixed with water at a ratio of 1:50 or 1:100 prior to use.

Many of the aquatic herbicides have not only liquid but dry formulations as well. The vast majority of these dry formulations are sold as granules (G) or pellets (P). The active ingredient is generally adsorbed onto clay particles with the amount of active ingredient ranging from 1 to 15 percent. Granules are convenient for spot treatments, are ready to use and require no mixing, reduce drift hazards, and can be applied easily. The disadvantages of granules are their high expense per pound of active ingredient and their ineffectiveness as a treatment on the foliage of emergent plants.

Another common dry formulation is the wettable powder (WP). WP formulations resemble a fine dust and generally contain greater than 50 percent active ingredient. When mixed with water, agitation is required to keep the insoluble particles in suspension. The advantages of a WP are the lower cost, ease of handling, and ease of measuring. Some disadvantages of WP are the abrasion of suspended particles on spray equipment and the requirement for constant tank agitation.

Adjuvants

An adjuvant is an inert ingredient added to the spray solution in order to facilitate or modify the action of the herbicide. Spray tank additives may include surfactants, thickening agents, spreaders, stickers, wetting agents, penetrants, anti-foaming agents or many other modifiers. Many herbicides contain adjuvants in their formulation and may not need any additional material added to the spray tank; however, many of these same herbicide labels may suggest that additional surfactant be added. Most of the adjuvants are strictly optional and may be added to help modify the spray solution. For instance, a spreader-sticker may be added to the herbicide mix for spraying a contact type of herbicide, because covering as much of the leaf surface as possible would increase the percentage of weed control. Additional surfactant for wetting may be necessary when target weeds have dense leaf hairs. The best source of information for deciding on adjuvant addition is the herbicide label or the chemical manufacturer s representative.

The Label

All herbicide containers must have attached to them a label that provides instructions for storage and disposal, use of the product, and precautions for the user and the environment. The label is the law. It is unlawful to alter, detach, or destroy the label. It is also unlawful to use a pesticide in a manner that is inconsistent with or not specified on the label. For example, herbicides that are sold for use in the garden should never be used in ponds unless the label specifies this use. Misuse of a herbicide is not only a violation of federal and state law; herbicides used contrary to label directions may seriously contaminate water, rendering it unfit for fish, irrigation, and swimming, and as a source of potable water. Herbicides sold for use in water have been state and EPA approved and have undergone years of costly and extensive research to ensure their environmental safety.

The herbicide label contains a great deal of information about the product and should be read thoroughly and carefully before each use. Before purchasing a herbicide, read the label to determine:

- whether the weed species can be controlled with the product
- whether the herbicide can be used safely under particular application conditions
- what herbicide formulation best suits your needs and application equipment
- how much herbicide is needed
- where the herbicide can be used and what restrictions apply if you are also watering livestock, fishing, swimming, consuming as potable water, watering crops, etc.
- what the toxicity is to various fish species
- when to apply the pesticide (time of year, stage of plant growth, etc.)
- whether there are any restrictions for use of the pesticide (certified applications only, ditchbanks only, ponds only, etc.)
- what safety equipment is needed
- signal word that indicates the acute toxicity to humans, i.e., danger, warning or caution.

Precautions with Herbicides

When a large percentage of a water body is infested with weeds, care is needed when fish safety is a concern. Several herbicides act on contact, killing the weeds in a matter of hours. When aquatic plants die and begin to decay, they remove oxygen from the water, creating what is known as a biological oxygen demand. If too large an area in a pond volume is controlled, dissolved oxygen levels in the pond may drop below the concentration necessary to sustain fish. Here are several general rules to keep in mind when treating aquatic plants.

1) Avoid treating on cloudy days when dissolved oxygen levels will naturally be lower.

2) If a large portion of the pond is covered with plants, treat no more than one-third to one-half of the plants at once, leaving time between applications for oxygen recovery.

3) Treat early in the spring before plants get out of control.

4) In order to get maximum performance from your herbicide, treat when the water temperature is above 60°F and plants are actively growing.

The majority of EPA and state approved aquatic herbicides have a wide range of safety with nontarget organisms. The level at which some herbicides become toxic to fish is several hundred times higher than field application rates. However, herbicides like copper sulfate ($CuSO_4$) may be toxic to several fish species at label use rates and require extra precaution when large treatments are to be made, especially in soft water. Appendix 3 lists the 96-hour LC_{50} (lethal concentration to 50 percent of any particular population) in ppm and also the pounds of various aquatic herbicides needed per acre-foot of water to be toxic to bluegill, channel catfish, rainbow trout, crawfish, and freshwater shrimp.

How to Use Herbicides

When using herbicides, as with any toxic material, it is important that personal exposure be kept to an absolute minimum. Most accidents result from careless handling and a general lack of label knowledge. Herbicides are categorized into four groups based on their oral, dermal, and inhalation toxicity. Every label contains a signal word (Danger, Warning, or Caution) that indicates level of toxicity.

While mixing and spraying herbicides, protective clothing and equipment such as long-sleeved shirts and long-legged pants, gloves, rubber boots, and goggles or a face shield should be used. Most labels will suggest you wear protective clothing and will tell you the precautions to be taken when using the herbicide.

While mixing, loading, handling, and cleaning up, observe all safety recommendations on the label. When minor spills occur, use absorbent materials such as soil or sawdust to soak up the chemical. Place contaminated materials into a sealed container for disposal. Cleanup of a major spill may be too difficult for an untrained person to handle. Should there be a bad spill, call Chemtrec toll-free at 1 800 424 9300 for emergency assistance. For first aid information about herbicide poisoning, refer to the label for instructions and contact your physician.

If you choose herbicides as a means of control, refer to Appendix 2 and locate the herbicide listed as effective for your particular weed problem. Product tradenames, water systems labeled for use, mode of action, duration of herbicidal activity, and precautions are listed for herbicides.

Once you review the herbicides and decide which best suits your problem, review Appendix 3 to ensure that there will be no toxicity problems.

Appendices

Appendix 1. Aquatic Weed Identification

Aquatic plants are commonly classified into several categories depending on the location in the water column they inhabit. Aquatic plants may be free floating, emersed, submersed, or shoreline plants. Free floating plants are rarely if ever rooted into the soil and their leaves are located above the water. Emersed aquatic plants are rooted in the soil under water with their leaves on or above the water surface. Submersed aquatic plants are usually rooted in the soil with all or most of their leaves growing under water. Ditchbank plants are not true aquatic plants, but are often associated with the moist soils located around ponds and lakes and are therefore included here, as are common types of algaes.

Floating Plants

Common duckweed

(*Lemna minor*)

Description: Small, footprint-shaped leaves, no more than 1/8 inch long having one root. Leaves are pale green and float flat on the water surface. Reproduction occurs by seeds and rapidly through budding.

Control: Biological: grass carp. Herbicides: diquat, fluridone.

Figure 9. Common duckweed (*Lemna minor*)

Common salvinia

(*Salvinia minima*)

Description: Circular leaves 1/4-1/2 inch in diameter with dense leaf hairs on the upper leaf surface. Leaves are brownish green and float flat on the surface. Salvinia is a fern and reproduces by spores and fragmentation.

Control: Biological: partial control with grass carp. Herbicides: diquat.

Figure 10. Common salvinia (*Salvinia minima*)

Common watermeal

(*Wolffia* species)

Description: These are tiny, floating, rootless plants that are less than

1/32 inch long. The plant body is rounded and feels grainy when rolled between the fingertips. The plants are so small they appear to be merely green specks or dots. Often two to three are attached.

Control: Biological: none.

Herbicides: fluridone (marginal).

Figure 11. Common watermeal (*Wolffia* species)

Mosquito fern

(Azolla caroliniana)

Description: Free-floating fern less than 1/2 inch across, with branching stems. Leaves tiny, bilobed, in two ranks, usually reddish (especially in full sun), or green. Propagates vegetatively, rapidly forming large thick mats.

Control: Nutrient reduction. Biological: attacked by native insects, which are suppressed by predation from fire ants. Herbicides: diquat, flurodone.

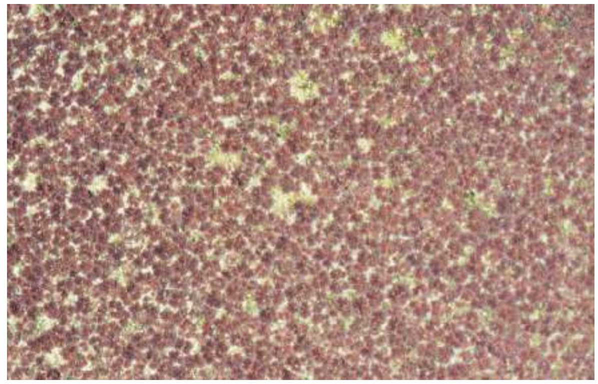


Figure 12. Mosquito fern (*Azolla caroliniana*)

Waterhyacinth

(*Eichhornia crassipes*)

Description: Plants several inches to two feet in height. Smooth leaves attached to spongy bulb-shaped stalks. Reproduction is primarily through the production of daughter plants.

Control: Biological: hyacinth weevil, partial control with fungus. Herbicides: 2,4-D, diquat, glyphosate, triclopyr.

Figure 13. Waterhyacinth (*Eichhornia crassipes*)

Waterlettuce

(*Pistia stratiotes*)

Description: Resembles a head of lettuce. Grows in a rosette with spongy, dense hairy leaves 6-8 inches in diameter. Daughter plants are the major means of reproduction.

Control: Biological: waterlettuce weevil. Herbicides: diquat, endothall liquid.

Figure 14. Waterlettuce (*Pistia statiotes*)

Emersed Plants

Pickerelweed

(*Pontederia lanceolata*)

Description: An erect plant with lance-shaped leaves up to 10 inches long. Each stem has violet-blue flowers at the top. Reproduction occurs by seed and creeping rootstalks.

Control: Herbicides: triclopyr, partial control with 2,4-D and glyphosate.

Alligatorweed

(*Alternanthera philoxeroides*)

Description: Hollow-stemmed perennial capable of forming dense mats. Leaves are opposite between 2 and 4 inches long, and football-shaped. Stems have a solitary white flower head at the tip. Reproduction by fragmentation.

Figure 15. Pickerelweed (*Pontederia lanceolata*)

Control: Biological: alligatorweed flea beetles and thrips. Herbicides: triclopyr, partial control with 2,4-D and glyphosate.

Figure 16. Alligatorweed (*Alternanthera philoxeroides*)

Cattail

(*Typha* species)

Description: Erect perennials (up to 9 feet) that can reproduce by seed or creeping rootstalk. Grass-like leaves are flat and smooth to the touch. Flowers look like a "cat's tail" and can be found in a tightly packed spike usually 6-8 inches long.

Control: Herbicides: diquat, glyphosate, fluridone.

Figure 17. Cattail (*Typha* species)

Pennywort

(*Hydrocotyle umbellata*)

Description: Dark green, shiny rounded leaves which are centrally attached to a long stalk. Leaves may lie flat on the water surface or be erect. Pennywort reproduces by seed and creeping stems.

Control: Herbicides: diquat, 2,4-D, glyphosate, triclopyr.

Figure 18. Pennywort (*Hydrocotyle umbellata*)

Smartweed

(*Polygonum species*)

Description: Leaves are alternate, lance-shaped, and attached to swollen joints on the stem. The flower stalk consists of many small pinkish white flowers in a single spike. Smartweed spreads by seed, and may form large floating mats.

Control: Herbicides: triclopyr, partial control with glyphosate (species dependent) and 2,4-D.

Figure 19. Smartweed (*Polygonum* species)

White water-lily

(*Nymphaea odorata*)

Description: Leaves are flat, rounded, and attached at the center to the stalk. Leaves are often 10 inches in diameter and split to the center on one side. The flower is sweet-scented, white and showy. Reproduction is by seed and branching stems.

Control: Herbicides: fluridone, 2,4-D liquid and granular, triclopyr, glyphosate.

Figure 20. White water-lily (*Nymphaea odorata*)

Spatterdock

(*Nuphar luteum*)

Description: Large heart-shaped leaves arising from a stalk attached to a thick creeping root system. The flower is yellow and about one inch in diameter. Reproduction is by seed and new sprouts.

Control: Herbicides: glyphosate, fluridone.

Figure 21. Spatterdock (*Nuphar luteum*)

Submerged Plants

Coontail

(*Ceratophyllum demersum*)

Description: Leaves grow in a whorl, are finely dissected, and have teeth on one side of the leaf margin. Leaves are 1/2-1 inch in length and crowded towards the stem tip giving the appearance of a raccoon's tail. Coontail is rootless and floats near the surface in the warmer months. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, endothall liquid and granular, fluridone, 2,4-D granular.

Hydrilla

(*Hydrilla verticillata*)

Description: Long stemmed, branching plant that is rooted to the bottom and often forms large surface mats. Leaves grow in a whorl with toothed margins that feel rough. Hydrilla can spread by plant fragments, underground stems, seed, leaf buds, or buds located on the underground stems.

Figure 22. Coontail (*Ceratophyllum demersum*)

Control: Biological: grass carp. Herbicides: copper, diquat, endothall (liquid and granular), fluridone.

Figure 23. Hydrilla (*Hydrilla verticillata*)

Bladderwort

(*Utricularia* species)

Description: A submersed, free floating plant, having a variety of growth forms. Although leaf shapes and flowers differ, all species bear small urnlike bladders which are used to trap small aquatic animals. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, fluridone, 2,4-D granular.

Figure 24. Bladderwort (*Utricularia* species)

Southern naiad

(*Najas guadalupensis*)

Description: Bottom-rooted, slender-leaved, dark green to greenish purple plant with branching stems. Leaves are less than 1 inch in length and narrow. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, endothall liquid and granular, fluridone, 2,4-D granular.

Figure 25. Southern naiad (*Najas guadalupensis*)

Fanwort

(*Cabomba caroliniana*)

Description: Leaves of fanwort are finely dissected and fan-shaped. Leaves are opposite and generally no more than 1-1 1/2 inches wide. The flower is white or cream colored, about 1/2 inch in diameter and blooms above the water surface. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, fluridone, 2,4-D granular.

Figure 26. Fanwort (*Cabomba caroliniana*)

Pondweed

(*Potamogeton* species)

Description: Several species of pondweed are found in Florida; Illinois pondweed (*P. illinoensis*) is most frequently encountered. It has both floating and submersed leaf forms. The football-shaped floating leaves are not always present, but are easily distinguishable from the lance-shaped submersed leaves. The flowers are clustered together on a spike 1-2 inches long located just above the water surface at the stem tip. Reproduction is by seed and from underground stems.

Control: Biological: grass carp. Herbicides: diquat, endothall (Hydrothal) liquid and granular, fluridone, 2,4-D granular.

Grasses and Sedges

Torpedograss

(*Panicum repens*)

Description: Narrow leaved (less than 1/4-inch wide), with stems often several feet in length. Torpedograss creeps horizontally by underground

Figure 27. Pondweed (*Potamogeton* species)

stems and forms large floating mats. Reproduction is by seed and creeping stems.

Control: Biological: partial control with grass carp. Herbicides: partial control with glyphosate, fluridone.

Figure 28. Torpedograss (*Panicum repens*)

Maidencane

(*Panicum hemitomon*)

Description: Maidencane leaves usually grow at 90o angles from the stem and generally 1/2-inch in width. An extensive creeping root system allows maidencane to form dense floating mats with stems often several feet in length. Reproduction is by seed and creeping root stalk.

Control: Biological: partial control with grass carp. Herbicides: partial control with glyphosate.

Figure 29. Maidencane (*Panicum hemitomon*)

Paragrass

(*Brachiaria purpurascens*)

Description: Paragrass often forms stems several yards in length which often fall on the ground. Paragrass can be easily identified by the dense hairs located at the stem joints. Dense floating mats often form. Reproduction is by seed and stem joints forming roots.

Control: Biological: partial control with grass carp. Herbicides: glyphosate, fluridone.

Figure 30. Paragrass (*Brachiaria purpurascens*)

Proliferating spikerush

(roadgrass, hairgrass)

(*Eleocharis baldwinii*)

Description: Proliferating spikerush has two growth forms. When it occurs on moist soils at the edge of ponds or lakes it is erect and the leafless stems are 1-4 inches tall. When submersed, the stems become long and proliferate throughout the water column. Leaves occur only as bladeless sheaths at stem bases.

Control: Biological: grass carp. Herbicides: fluridone (repeat applications).

Figure 31. Spikerush (roadgrass, hairgrass) (*Eleocharis baldwini*)

Sedge

(*Cyperus* species)

Description: Many sedges are found in Florida and are generally difficult to identify by species. In general, sedges can be identified by the triangular stem and leaf blades, which are generally rough to the touch. Flower stalks arise from the center forming a compact group or headlike cluster of flower spikes. Reproduction is by seed.

Control: Herbicides: partial control with glyphosate.

Figure 32. Sedge (*Cyperus* species)

Ditchbank Brush

(*Myrica cerifera*)

Description: Shrub or small tree usually 10 feet tall. Leaves are alternate, pale green, and lance-shaped. When crushed, leaves emit a pleasant aroma. Close inspection of the leaves will reveal numerous small dark scales on top and bright orange scales below. Reproduction is by seed.

Control: Herbicides: imazapyr,* triclopyr.*

Wax myrtle

Figure 33. Wax Myrtle (*Myrica cerifera*)

Willow

(*Salix* species)

Description: Fast growing shrub which can become a tree in a short period of time. Leaves are alternate and lance-shaped with finely toothed margins. The fruit capsule contains many small hairy seeds which drift in air currents.

Control: Herbicides: partial control with 2,4-D, glyphosate, imazapyr,* triclopyr.

Brazilian pepper

(*Schinus terebinthifolius*)

Description: An extremely fast growing shrub found predominantly in disturbed areas of south

Figure 34. Willow (*Salix* species)

Florida. This aggressive nonnative species produces large quantities of seeds contained in a red fruit usually about 1/4-inch in diameter. Reproduction is by seed.

Control: Herbicides: glyphosate, 2,4-D, imazapyr,* triclopyr.

Figure 35. Brazilian pepper (*Schinus terebinthifolius*)

Water primrose

(*Ludwigia* species)

Description: Small shrub attaining height of up to 6 feet with multiple branching stems. Leaves are lance-shaped with small soft hairs on both sides. Flowers are yellow with four symmetrical petals. Reproduction is by seed and underground stems.

Control: Herbicides: 2,4-D, imazapyr.*

Figure 36. Water primrose (*Ludwigia* species)

Algae

Macrophytic algae

Description: Macro, meaning large, describes a type of algae that looks more like a submersed plant. Capable of attaining several feet in length, muskgrass (*Chara* species), is the most common of these algae found in Florida. The algae appear to have a whorl of spined leaves, grey-green in color, resembling the submersed plant coontail. However, algae have no true leaves. When crushed, Chara emits a musky odor.

Control: Biological: grass carp. Herbicides: copper, diquat, endothall (Hydrothrol) liquid and granular.

Figure 37. Macrophytic algae

Filamentous algae

Description: Many species of filamentous algae are frequently a problem in Florida ponds. These threadlike filaments are often called "pond scum" or "pond moss" when they are seen floating on the pond surface. Although many species of filamentous algae can frequently become a problem to pond owners, most species can be controlled in a similar manner. A few species, especially some of the blue-green algae (e.g., *Pithophora* and *Lyngbya*), are difficult to control and would require special recommendations from a qualified biologist.

Control: Biological: partial control with grass carp. Herbicides: copper, endothall (Hydrothol).

Figure 38. Filamentous algae

Planktonic algae

Description: Microscopic (planktonic) algae are small plants that cannot be identified without magnification. They occur in all ponds and, after fertilization, give the pond its green color. Most of the microscopic algae are beneficial to ponds, converting nutrients into a source of food in the food chain. There is rarely a need to control microscopic algae; however, when large blooms occur, oxygen depletion, foul odors, off-flavor fish, and even fish kills may occur.

Control: Herbicides: copper.

Appendix 2. Herbicides

Figure 39. Planktonic algae

Copper Products

Copper sulfate (cupric sulfate pentahydrate)

Tradenames: Tennessee, Chem One, Noranda, Old Bridge Copper Sulfate, and others.

Copper chelate (alkanolamine complex)

Tradenames: CUTRINE-PLUS, Captain

Copper chelate (triethanolamine complex)

Tradenames: K-TEA.

Copper chelate (ethylenediamine complex)

Tradenames: Komeen, Nautique, Clearigate

Water systems labeled for use:

Copper sulfate: impounded waters, lakes, ponds, reservoirs, and irrigation systems. Copper chelates: ornamental, fish, and fire ponds; potable water reservoirs; freshwater lakes and fish hatcheries.

Mode of action: Contact herbicide, often used in combination with other contact herbicides.

Duration of herbicidal activity: Copper sulfate may persist up to 7 days before the free copper is precipitated to insoluble forms and remains an inactive precipitate in bottom sediments. As the hardness of the water increases, the persistence of the free copper decreases. The chelated coppers can be used where hard water may precipitate uncomplexed forms of copper too rapidly.

Precautions: Copper sulfate can be very corrosive to steel and galvanized pipe. Chelated coppers are virtually noncorrosive. Contact with skin and eyes may be irritating. As water hardness decreases, toxicity to fish increases. Copper sulfate may be toxic to fish species at recommended dosages. Generally, the chelated coppers are nontoxic to trout, tropical fish, ornamental fish, and other sensitive fish at recommended dosages.

2,4-D Products

2,4-D Granular

Tradenames: Aqua-Kleen, AQUACIDE, Navigate.

2,4-D Amine

Tradenames: 2,4-D Amine No. 4, Riverside 2,4-D amine (Pro Source), WEEDAR 64, A-4D.

Diquat

Tradenames: Reward, Landscape and Aquatic Herbicide.

Water systems labeled for use: May be used in slowly moving bodies of water, ponds, lakes, rivers, drainage and flood control canals, ditches, and reservoirs.

Mode of action: Contact herbicide.

Duration of herbicidal activity: Diquat is rapidly and completely inactivated by soil.

Precautions: Do not apply to muddy water because the diquat will be inactivated. Never treat more than 1/3 1/2 of a densely vegetated pond at any one time because rapidly decaying vegetation will deplete oxygen, thereby suffocating fish. Skin contact may cause irritation. Avoid drift.

Diuron

Tradenames: Direx 4L, DIURON 80, KARMEX, Nautilus.

Water systems labeled for use: Irrigation and drainage ditches that have been drained of water for a period of 72 hours. After 72 hours diuron is fixed to the soil and the ditch may then be used.

Nautilus is registered for the control of macroalgae in commercially operated freshwater ponds, used only for ornamental fish production; discharge from ponds within 30 days of application is not allowed.

Mode of action: Diuron is readily absorbed through the root system, less so through foliage, and translocated upward toward plant foliage.

Duration of herbicidal activity: Control duration will vary with amount of chemical applied, soil type, rainfall and other conditions. Usually control will last for a period of 10-12 months.

Precautions: May irritate eyes, nose, throat, and skin. Avoid breathing dust. Apply before expected seasonal rainfall. Do not treat any ditch with desirable tree roots extended into them or injury may result. Prevent drift of dry powder to desirable plants. Do not contaminate any body of water.

Endothall

Tradenames: Granular: AQUATHOL, Super K, HYDROTHOL 191. Liquid: AQUATHOL K, HYDROTHOL 191.

Water systems labeled for use: Irrigation and drainage canals, ponds and lakes.

Mode of action: Contact herbicide.

Duration of herbicidal activity: Microbiological break down is fairly rapid in water and soil with a short herbicidal duration.

Precautions: Hydrothol 191 liquid + granular should not be used where fish are an important resource. Fish may be killed by dosages necessary to kill weeds. Skin contact may cause irritation. May be corrosive to application equipment.

Fluridone

Tradenames: Sonar AS, Sonar SRP, Avast!, Avast! SRP.

Water systems labeled for use: Lakes, ponds, ditches, canals, and reservoirs.

Mode of action: Fluridone is foliage absorbed and translocated into the actively growing shoots where destruction of the chlorophyll pigments occurs, resulting in white growing points.

Duration of herbicidal activity: Depending upon application and vegetation being controlled, control may last 1 year.

Precautions: Do not use treated water for irrigation of agronomic crops or turf for 7 to 30 days following treatment. Trees or shrubs growing in treated water may be injured. Higher treatment rates will be required if there is a large turnover in water volume in treated water.

Glyphosate

Tradenames: Rodeo, Aquamaster, Aquaneat, Eagre, Aquapro, GlyPro.

Water systems labeled for use: Lakes, ponds, streams, rivers, ditches, canals, reservoirs, and any other freshwater bodies.

Mode of action: Glyphosate is foliage absorbed and translocated throughout the plant and root system, killing the entire plant.

Duration of herbicidal activity: Only effective at the time of treatment.

Precautions: Not to be used for submersed or pre- emergence vegetation. Floating mats of vegetation will require treatment. A rain-free period of 6 hours after application is required. May be corrosive to galvanized steel. Avoid drift to desirable vegetation as glyphosate is nonselective and will affect contacted vegetation.

Imazapyr

Tradename: ARSENAL.

Water systems labeled for use: Nonirrigation ditchbanks and similar areas. Environmental use permit for aquatics.

Mode of action: Both foliage and root absorbed and translocated throughout the entire plant.

Duration of herbicidal activity: Provides control of existing and germinating seedlings throughout the growing season.

Precautions: Do not contaminate any water supply. Do not apply on ditches used for irrigation. Do not treat in areas where desirable tree roots are visible. Prevent drift to desirable plants. Should not be mixed or stored in unlined steel containers or spray tanks.

Triclopyr

Tradenames: Renovate 3.

Water systems labeled for use: Aquatic sites such as ponds, lakes, reservoirs, non-irrigation canals and ditches which have little or no continuous outflow, marshes and wetlands, including broadleaf and woody vegetation on banks and shores within or adjacent to these and other aquatic sites.

Mode of action: Triclopyr induces characteristic auxin-type responses in growing plants. It is absorbed by both leaves and roots, and it is readily translocated throughout the plant. Foliage applications have achieved maximum plant response to treatment when the treatment has been applied soon after full leaf development and soil moisture is adequate for normal plant growth.

Duration of herbicidal activity: Time required for 50 percent breakdown in soil is between 10 and 46 days depending on environmental conditions and soil type. At label rates, phytotoxic residues in soils should cause no problems. Triclopyr has a 6- to 8-hour half-life in water.

Precautions: Irrigation: Do not use treated water for irrigation for 120 days following application. As an alternative to waiting 120 days, treated water may be used for irrigation once the triclopyr level in the intake water is determined to be non-detectable by laboratory analysis (immunoassay). There is no restriction on use of water from the treatment area to irrigate established grasses.

Do not apply Renovate 3 directly to, or otherwise permit it to come into direct contact with grapes, tobacco, vegetable crops, flowers, or other desirable broadleaf plants, and do not permit spray mists containing it to drift into them.

- Do not apply to salt water bays or estuaries.
- Do not apply directly to un-impounded rivers and streams.
- Do not apply on ditches or canals used to transport irrigation water. It is permissible to treat non-irrigation ditch banks.
- Do not apply where runoff water may flow onto agricultural land, as injury to crops may result.
- When making applications to control unwanted plants on banks or shorelines of moving water sites, minimize overspray to open water.
- The use of a mistblower is not recommended.
- See label setbacks for potable water intakes.

Appendix 3. Toxicity of Aquatic and Ditchbank Herbicides to Selected Aquatic Organisms

	TREATMENT RATE [1]	TOXICITY [2] 96-HR LC_{50}, ppm		
	ppm	Bluegill Sunfish	Rainbow Trout	Invertebrates
Copper Sulfate	0.1-1.0			17.0[3]
Soft Water		0.9	0.01	
Hard Water		7.3	--	
Copper Chelate	0.1-1.0			19.0[4]
Soft Water		1.2	<0.2	
Hard Water		7.5	4.0	
2, 4-D Amine	negligible[5]	524	377	184[6]
2,4-D BEE	1.25-2.5[7]	0.61	2.0	7.2[3]
Diquat	0.12-0.72	>115	21	>100[8]
Diuron	negligible (0.25-1.0)[10]	8.2	16	0.16[4]
Imazapyr	negligible	>100	>100	>100[3]
Endothall (Aquathol)	1.0-5.0	501	529	320[9]
Endothall (Hydrothol)	0.1-3.0	1.2	1.3	0.36[5]
Fluridone	0.01-0.15	14.3	11.7	6.3[5]
Glyphosate (Rodeo)	negligible	>1000	>1000	930[5]
Triclopyr	0.75-2.5	891	552	775[9]

[1]Estimated concentration in water after application according to label instructions.

[2]Toxicity varies according to experimental conditions.Values are typical from varous sources.

[3]Freshwater shrimp

[4]Blue shrimp

[5]Labeled only for foliar or ditchbank application, therefore concentrations in water are negligible.

[6]Daphnia

[7]Calculated for label rates of 26.7% G.

[8]*Gammarus fasciatus*

[9]Daphnia, 48 hr

[10]Nautilus

Appendix 4. Formulas for Herbicide Calculations

Formulas for Active Ingredient

(1) Gallons of liquid formulation required = lb ai* required ÷ lb ai per gal of concentrate

(2) Pounds of dry formulation required = lb ai required ÷ % ai in formuation expressed as decimal

Formulas for Herbicide Application to Ponds or Lakes

(3) Volume of pond in cu ft = surface area in sq ft x average depth in ft

(4) Volume of pond in ac† ft = surface area in ac ft x average depth in ft

(5) Volume of pond in ac ft = volume of pond in cu ft ÷ 43,560 ft^2 per ac

(6) Total gal of chem required = ac ft x ppmv** x 0.33

(7) ppmw‡ = (lb ai of chem applied ÷ volume in ac ft) x 2.72

(8) Total lb ai required = ac ft x 2.72 x ppmw desired

(9) Total gal of liquid formulation required = ac ft x 2.72 x ppmw desired ÷ lb ai per gal of concentrate

Acre-feet Calculation

(10) Acre-feet = acres x average depth in feet

Acreage Calculations

(11a) Rectangular shape: Acres = width in ft x length in ft ÷ 43,560 ft^2 per ac

(11b) Circular shape: Acres = 3.14 x $(\text{radius in ft})^2$ ÷ 43,560 ft^2 per ac

Herbicide Application Coverage

(12) Acres/min = (swath width in ft x speed in mph) ÷ 495

Volume of Herbicide Concentrate Required

(13) Gallons of herbicide concentrate required = weight of active ingredient required in spray mixture ÷ weight of active ingredient required in spray mixture ÷ weight of active ingredient per gallon of herbicide.

*ai = active ingredient; †ac = acre; **ppmv = parts per million by volume; ‡ppmw = parts per million by weight

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Acres	0.405	Hectares
Acres	4,047	Square meters
Acres	4,840	Square yards
Acres	43,560	Square feet
Acre-feet	1,233	Cubic meters
Acre-feet	43,560	Cubic feet
Acre-feet	325,900	Gallons
Centimeters	0.394	Inches
Centimeters	0.01	Meters
Centimeters	10.0	Millimeters
Cubic feet	0.0283	Cubic meters
Cubic feet	0.0370	Cubic yards
Cubic feet	0.804	Bushels
Cubic feet	7.48	Gallons(fluid)
Cubic feet	25.7	Quarts (dry)
Cubic feet	28.3	Liters
Cubic feet	29.9	Quarts (fluid)
Cubic feet	51.4	Pints (dry)
Cubic feet	59.8	Pints (fluid)

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Cubic feet	62.4	Pounds of water
Cubic feet	1,728	Cubic inches
Cubic feet	28,320	Cubic centimeters
Cubic inches	0.000016	Cubic meters
Cubic inches	0.0006	Cubic feet
Cubic inches	0.0037	Gallons (dry)
Cubic inches	0.0043	Gallons (fluid)
Cubic inches	0.0149	Quarts (dry)
Cubic inches	0.0164	Liters
Cubic inches	0.0173	Quarts (fluid)
Cubic inches	0.0298	Pints (dry)
Cubic inches	0.0346	Pints (fluid)
Cubic inches	0.0361	Pounds of water
Cubic inches	0.5540	Ounces (fluid)
Cubic inches	16.39	Cubic centimeters
Cubic yards	0.765	Cubic meters
Cubic yards	21.7	Bushels
Cubic yards	27.0	Cubic feet
Cubic yards	202.0	Gallons (fluid)
Cubic yards	807.9	Quarts (fluid)
Cubic yards	1,620	Pints (fluid)
Cubic yards	7,646	Liters
Cubic yards	46,656	Cubic inches
Cups	0.25	Quarts (fluid)
Cups	0.5	Pints (fluid)
Cups	8.0	Ounces (fluid)
Cups	16.0	Tablespoons
Cups	48.0	Teaspoons
Cups	236.5	Milliliters
Feet	0.3048	Meters
Feet	0.3333	Yards
Feet	12.0	Inches
Feet	30.48	Centimeters
Feet per minute	0.01136	Miles per hour
Feet per minute	0.01667	Feet per second
Feet per minute	0.01829	Kilometers per hour
Feet per minute	0.3048	Meters per minute
Feet per minute	0.3333	Yards per minute
Feet per minute	60.0	Feet per hour
Gallons (dry)	269.0	Cubic inches (dry)
Gallons (fluid)	0.00378	Cubic meters
Gallons (fluid)	0.1337	Cubic feet
Gallons (fluid)	3.785	Liters
Gallons (fluid)	4.0	Quarts (fluid)
Gallons (fluid)	8.0	Pints (fluid)
Gallons (fluid)	8.337	Pounds
Gallons (fluid)	128.0	Ounces (fluid)

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Gallons (fluid)	3,785	Cubic centimeters
Gallons of water	3.785	Kilograms
Gallons of water	8.345	Pounds of water
Gallons of water	3,785	Grams
Grains	0.0648	Grams
Grams	0.001	Kilograms
Grams	0.0022	Pounds
Grams	0.0353	Ounces
Grams	15.53	Grains
Grams	1,000.	Milligrams
Grams per liter	10.0	Percent
Grams per liter	1,000.	Parts per million
Hectares	2.47	Acres
Hectares	10,000.	Square meters
Hectares	11,950	Square yards
Hectares	107,600	Square feet
Inches	0.0254	Meters
Inches	0.0278	Yards
Inches	0.0833	Feet
Inches	2.54	Centimeters
Kilograms	0.0011	Tons
Kilograms	2.205	Pounds
Kilograms	35.28	Ounces
Kilograms	1,000.	Grams
Kilometers	0.6214	Miles
Kilometers	1,000.0	Meters
Kilometers	1,093.	Yards
Kilometers	3,281.	Feet
Kilometers per hour	0.6214	Miles per hour
Kilometers per hour	16.67	Meters per minute
Kilometers per hour	18.23	Yards per minute
Kilometers per hour	54.68	Feet per minute
Liters	0.001	Cubic meters
Liters	0.0353	Cubic feet
Liters	0.2642	Gallons (fluid)
Liters	1.0	Kilograms of water
Liters	1.057	Quarts (fluid)
Liters	2.113	Pints (fluid)
Liters	33.81	Ounces (fluid)
Liters	61.02	Cubic inches
Liters	1,000.	Cubic centimeters
Liters	1,000.	Grams of water
Meters	0.001	Kilometers
Meters	1.094	Yards
Meters	3.281	Feet
Meters	39.37	Inches
Meters	100.0	Centimeters

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Meters	1,000.	Millimeters
Metric tons	1.1	Tons (U.S.)
Metric tons	1,000.	Kilograms
Metric tons	2,205.	Pounds
Metric tons	1,000,000.	Grams
Miles	1.609	Kilometers
Miles	1,609.	Meters
Miles	1,760.	Yards
Miles	5,280.	Feet
Miles per hour	1.467	Feet per second
Miles per hour	1.609	Kilometers per hour
Miles per hour	26.82	Meters per minute
Miles per hour	29.33	Yards per minute
Miles per hour	88.0	Feet per minute
Miles per minute	26.82	Meters per second
Miles per minute	29.33	Yards per second
Miles per minute	88.0	Feet per second
Milliliters	0.00105	Quarts (fluid)
Milliliters	0.0021	Pints (fluid)
Milliliters	0.0042	Cups (fluid)
Milliliters	0.0338	Ounces (fluid)
Milliliters	0.0676	Tablespoons
Mililiters	0.2029	Teaspoons
Milliliters	1.0	Cubic centimeters of water
Milliliters	1.0	Grams of water
Ounces (dry)	0.0625	Pounds
Ounces (dry)	28.35	Grams
Ounces (dry)	437.5	Grains
Ounces (fluid)	0.00781	Gallons (fluid)
Ounces (fluid)	0.03125	Quarts (fluid)
Ounces (fluid)	0.0625	Pints (fluid)
Ounces (fluid)	0.125	Cups (fluid)
Ounces (fluid)	1.805	Cubic inches
Ounces (fluid)	2.0	Tablespoons
Ounces (fluid)	6.0	Teaspoons
Ounces (fluid)	29.57	Milliliters
Parts per million (ppm)	0.0001	Percent
Parts per million	0.001	Liters per cubic meter
Parts per million	0.001	Grams per liter
Parts per million	0.001	Milliliters per liter
Parts per million	0.013	Ounces per 100 gallons of water
Parts per million	0.0584	Grains per US gallon
Parts per million	0.330	Gallons per acre-foot of water
Parts per million	1.0	Milligrams per liter
Parts per million	1.0	Milligrams per kilogram
Parts per million	1.0	Milliliters per cubic meter
Parts per million	2.72	Pounds per acre-foot of water

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Parts per million	8.35	Pounds per million gallons
Percent (%)	1.33	Ounces (dry) per gallon of water
Percent	8.34	Pounds per 100 gallons of water
Percent	10.00	Grams per kilogram
Percent	10.00	Grams per liter
Percent	10,000.	Parts per million
Pints (dry)	0.0156	Bushels
Pints (dry)	0.0625	Pecks
Pints (dry)	0.5	Quarts (dry)
Pints (dry)	33.6	Cubic inches
Pints (fluid)	0.125	Gallons (fluid)
Pints (fluid)	0.474	Liters
Pints (fluid)	0.5	Quarts (fluid)
Pints (fluid)	2.0	Cups
Pints (fluid)	16.0	Ounces (fluid)
Pints (fluid)	28.88	Cubic inches
Pounds	0.0005	Tons
Pounds	0.454	Kilograms
Pounds	16.0	Ounces
Pounds	453.6	Grams
Pounds	7,000.	Grains
Quarts (dry)	0.03125	Bushels
Quarts (dry)	0.0389	Cubic feet
Quarts (dry)	0.125	Pecks
Quarts (dry)	2.0	Pints (dry)
Quarts (dry)	67.20	Cubic inches
Quarts (fluid)	0.00094	Cubic meters
Quarts (fluid)	0.0012	Cubic yards
Quarts (fluid)	0.0334	Cubic feet (fluid)
Quarts (fluid)	0.25	Gallons (fluid)
Quarts (fluid)	0.946	Liters
Quarts (fluid)	2.0	Pints (fluid)
Quarts (fluid)	2.087	Pounds of water
Quarts (fluid)	4.0	Cups
Quarts (fluid)	32.0	Ounces (liquid)
Quarts (fluid)	57.75	Cubic inches
Square feet	0.000009	Hectares
Square feet	0.000023	Acres
Square feet	0.0929	Square meters
Square feet	0.111	Square yards
Square feet	144.0	Square inches
Square miles	2.590	Square kilometers
Square miles	259.	Hectares
Square miles	640.	Acres
Square miles	2,590,000	Square meters
Square miles	3,098,000	Square yards
Square miles	27,880,000	Square feet

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Square yards	0.00008	Hectares
Square yards	0.00021	Acres
Square yards	0.8361	Square meters
Square yards	9.0	Square feet
Square yards	1,296.	Square inches
Tablespoons	0.0625	Cups
Tablespoons	0.5	Ounces (fluid)
Tablespoons	3.	Teaspoons
Tablespoons	15.0	Milliliters
Teaspoons	0.0208	Cups
Teaspoons	0.167	Ounces (fluid)
Teaspoons	0.333	Tablespoons (fluid)
Teaspoons	5.0	Milliliters
Tons	0.907	Metric ton
Tons	907.	Kilograms
Tons	2,000.	Pounds
Tons	32,000.	Ounces (dry)
Yards	0.000568	Miles
Yards	0.914	Meters
Yards	3.	Feet
Yards	36.	Inches

How do I find out more about permit requirements for aquatic weed control?


Yellow Flag Iris

Since aquatic plants are by definition growing in an easily disturbed, sensitive environment, any work done to remove them is regulated by federal, state and local agencies. If you are planning to use herbicides, you should consult with the Oregon Department of Environmental Quality and follow the stipulations outlined in the National Pollutant Discharge Elimination System general permit (2300-A). Ensure that any herbicides used are registered for aquatic use and always read and follow the label carefully. Rules regarding aquatic herbicide use are administered by the Oregon Department of Agriculture. Often, in-water work in waters of the state requires a removal-fill permit administered through the Department of State Lands. Other permits from state and local agencies may be required for work involving bottom barriers, mechanical equipment or manual control of aquatic weeds. For assistance, contact the Benton SWCD at 541-753-7208 and/or your local city government permitting office. Refer to the State Water-Related Permits Guide for more information on permits that may be required for aquatic weed control activities.

What help does the SWCD provide for invasive aquatic weed control?

The Benton SWCD Invasives Program will provide information and advice on aquatic weeds and guide property owners through the complex permit regulations that exist when working in aquatic environments. In addition, because of the challenges involved with controlling aquatic weeds, the Invasives Program will help landowners find out about additional resources and may be able to provide direct assistance in some cases for the highest priority aquatic weeds. Call the program for more information at 541-753-7208 or email us at office@bentonswcd.org.

Japanese Knotweed
Polygonum cuspidatum

Identification: A woody perennial with hollow stems that form a zig-zag pattern. In late summer they form clusters of white flowers in drooping clusters from leaf axils. Leaves rounded with flat base. Plants die back in the winter.

Impacts: Spreads quickly and forms dense thickets that displace native vegetation. Creates bank erosion problems. Lowers quality of riparian habitat for fish and wildlife. Extremely vigorous rhizomes form deep, dense mat. Plants resprout from stem or root fragments creating new infestations downstream.

Habitat: Most commonly found in the flood zone along rivers and creeks, it also grows in roadside ditches, railroad rights-of-way, unmanaged lands, wetlands, neglected gardens, and other moist areas.

Control: Cut stems close to ground twice a month or more between April and August, then once a month or more for the rest of the year for three to five years. Stem fragments can easily resprout so allow to dry out completely or bag, seal and send to landfill. See King County BMPs for Knotweed for chemical control info.

Look-alikes: Bamboo, common pokeweed

Legal Status:
ODA Class B,
contractor and volunteer response recommended in Benton County.

Purple Loosestrife
Lythrum salicaria

Identification: Tall perennial wetland plant with showy, compact spikes of magenta flowers. Stem is square and leaves are opposite, smooth edged and narrow. Blooms mid-July through August.

Impacts: Has up to 2.5 million seeds per plant and also spreads by rhizomes. Outcompetes native plants and provides little habitat for native animals.

Habitat: Wetlands, streams, lakeshores and wet pastures. Occurs sporadically along the Willamette.

Control: Dig or pull plants in soft soil or cut plants at base to prevent seed formation. Herbicide should only be applied by a licensed aquatic herbicide applicator unless the plants are growing away from the water. Always throw this plant in the trash, never in compost or yard waste.

Look-alikes: Hardhack *(Spiraea douglasii)* is a native woody shrub with spikes of fuzzy pink flowers and wider, alternate leaves. Fireweed *(Epilobium angustifolium)* is a tall upland native perennial with more open spikes of flowers and alternate leaves. Plants in the mint family have square stems, but the leaves are usually toothed.

Legal Status: ODA Class B, volunteer or contractor response recommended in Benton Co.

Yellow Flag Iris
Iris pseudacorus

Identification: Large yellow iris that grows in water. Bright showy flower, tall leaves in folded, fan-like clusters. Dense rhizomes. Blooms late April through June.

Impacts: Forms impenetrable clumps. Outcompetes native plants and degrades habitat of native animals. Accumulates sediment and fills in waterways.

Habitat: Lakeshores, wetlands, creeks and canals. Common in the north part of Benton County.

Control: Difficult to control by hand. Often requires repeated use of heavy tools such as pick-axes or hatchets to remove sections of rhizome. Herbicide should only be applied by a licensed aquatic herbicide applicator unless the plants are growing away from the water. Spray or wipe actively growing plants with a systemic herbicide.

Look-alikes: Cattail *(Typha latifolia)* leaves are not flattened and folded like iris. Nothing else that grows in water looks like it in bloom.

Legal Status:
ODA Class B, volunteer response recommended in Benton County.

European Waterchestnut
Trapa natans

Identification: Annual plant that grows rooted to the substrate with a floating rosette of leaves. Leaves are shaped like a wide, rounded diamond with teeth along the margins. Submerged leaves along stem are feather like. Seed is a nut-like structure with four curved horns and a tough covering that is green when fresh and brown when dried. Flowers are small and inconspicuous and have four white petals.

Impacts: Forms dense surface mats that crowd out native vegetation and reduce oxygen and light levels in the water below. Plants have very little nutritional value for native wildlife.

Habitat: Prefers placid, nutrient rich lakes and rivers with a pH of 6.7-8.2. Plants have also been found in freshwater regions of estuaries and exposed mud flats. Has not been found in Benton County.

Control: Complete removal of plants is critical to successful eradication. Seeds may lay dormant for up to 12 years. Manual, mechanical and chemical techniques are used to control this plant.

Look-alikes: Not easily confused with other aquatic plants.

Legal Status:
ODA Class A. If found in Benton County, report to OregonInvasivesHotline.org immediately.

Smooth Frogbit or South American Spongeplant
Limnobium spongia

Identification: A floating to rooted stoloniferous perennial. Floating rosettes send runners out into the water, the ends of which form juvenile plants. Juvenile form has thick, spongy, floating ovate to spatulate leaves, usually with rounded tips and on an inflated stalk. Juvenile leaves and sometimes mature leaves have a patch of spongy tissue (aerenchyma) on lower surfaces.

Impacts: Dense stands can impede the flow of water.

Habitat: Lakes, ponds and slow rivers. Has not been found in Benton County.

Control: Physical removal may work with very small, early populations. Be sure to minimize off-site dispersal. For chemical control recommendations, google "UC Davis' Weed Control in Natural Areas in the Western United States Smooth Frogbit".

Look-alikes: Water hyacinth

Legal Status:
Not listed by ODA. If found in Benton County, report to OregonInvasivesHotline.org immediately.

Yellow Floating Heart
Nymphoides peltata

Identification: Floating, bottom-rooted perennial with several leaves per stem. The small (3-10 cm) floating leaves are nearly round to heart-shaped with wavy leaf margins and purplish undersides. One to five flowers per stalk are held above the water surface. Flowers are bright yellow with five distinctly fringed petals. Blooms June through August.

Impacts: Forms dense mats on the water surface that impede recreation, create ideal mosquito breeding areas, and can alter water quality by increasing water temperature and decreasing dissolved oxygen.

Habitat: Wetlands, lakes, ponds, slow-moving water up to 12-feet deep, also can grow in wet mud.

Control: Hand pulling can work with small infestations, but plant fragments will form new plants. Herbicide is effective and can be applied by a licensed aquatic herbicide applicator.

Look-alikes: The native yellow pond-lily (*Nuphar lutea)* has ball-shaped yellow flowers and large, heart-shaped leaves that are held out of the water as the water recedes. The native watershield (*Brasenia schreberi*) has oval leaves with no slit, stem attached at the center of leaf, and lower leaf surface and stem covered in a slippery gelatinous substance.

Legal Status: ODA Class A, if found report to OregonInvasivesHotline.org.

Floating Primrose-willow & Uruguayan Primrose-willow
Ludwigia peploides, Ludwigia hexapetala

Identification: Low-growing perennial that forms mats in water up to 10 feet deep. Showy, yellow five-petalled flowers in leaf axils, smooth-margined alternate leaves, prostrate stems float on water. Blooms late July to August.

Impacts: Clogs waterways, impedes recreation. Ecological pest that outcompetes native plants.

Habitat: Freshwater wetlands, drainage ditches and ponds. Known infestations in side channels of the Willamette River.

Control: Hand pull or rake up small infestations, being sure to get as many roots as possible (roots will resprout). Herbicide can only be applied by a licensed aquatic herbicide applicator.

Look-alikes: The native water purslane *(Ludwigia palustris)* has inconspicuous green flowers and opposite leaves. No wetland native has showy yellow flowers like this.

Legal Status: ODA Class B, if found report to OregonInvasivesHotline.org.

Parrotfeather
Myriophyllum aquaticum

Identification: Spikes of feathery leaves emerging up to a foot above the water. Looks like miniature pine trees or horsetails growing on the water's surface. Emerges in late May and persists into October.

Impacts: Clogs irrigation canals and slow-flowing streams and rivers, filling entire water column. Harms recreation, wildlife habitat and native plants.

Habitat: Freshwater waterbodies and streams. Still sold as a water garden plant on the internet but illegal to buy or sell it in Oregon.

Control: Very difficult to eradicate. Pull or rake, being very careful to remove all fragments from the water. Manual control requires persistence over many years. Herbicide can only be applied by a licensed aquatic herbicide applicator.

Look-alikes: Underwater stems resemble other milfoil species, but above-water stems are very distinctive and hard to confuse with anything else. Horsetail (*Equisetum*) is similar but larger and doesn't grow in water.

Legal Status: ODA Class B, control only in priority habitats in Benton County.

Brazilian Waterweed (Elodea)
Egeria densa

Identification: Long-stemmed submerged perennial with non-toothed leaves in whorls of four (up to six) and small white, three-petalled floating flowers. Can top out and form mats on the surface. Blooms in summer.

Impacts: Spreads rapidly by fragmentation, clogs waterways, impedes recreation, outcompetes native species, reduces fish habitat, alters water quality.

Habitat: Lakes, ponds, slow-moving water up to 30 feet deep. Commonly found in side channels and on the banks of the Willamette River.

Control: Clean fragments from boats, motors and trailers to prevent spread. Small areas can be cleared by hand-pulling, taking care to remove all plant fragments from the water. Contact a licensed aquatic herbicide applicator for assistance with herbicide use.

Look-alikes: Hydrilla *(Hydrilla verticillata)* has visibly toothed leaves in whorls of five and grows from tubers. The native American waterweed *(Elodea canadensis)* has smaller leaves in whorls of three.

Legal Status: ODA Class B, control suggested only in areas where
it is not already well established.

Curlyleaf Pondweed
Potamogeton crispus

Identification: Perennial submerged plant with oblong leaves with curled edges. Leaves resemble skinny green lasagna noodles. Forms modified buds called turions along the stems. Turions can break off and form new plants.

Impacts: Can form dense mats of vegetation that inhibit the growth of native aquatics and interfere with boating and other water recreation. When the plants die off and go dormant in the summer, the decaying plant matter can make the water extremely eutrophic.

Habitat: Widespread in ponds, lakes, streams, rivers, reservoirs, irrigation ditches and marshes.

Control: Clean fragments from boats, motors and trailers to prevent spread. Can be partially controlled with mechanical and chemical methods. Reduce spread by cutting plants at sediment level early in growing season. Contact a licensed aquatic herbicide applicator for assistance with herbicide use.

Look-alikes: Richardson's pondweed (P. *richardsonii*)

Legal Status: ODA Class B, control in areas where it is not already well established.

Eurasian Watermilfoil
Myriophyllum spicatum

Identification: Feathery underwater leaves, long reddish or green stems and small emergent spikes of tiny flowers. Can top out and form mats on the surface. Leaf "feathers" have more than 14 leaflet pairs and leaves collapse against stem when plant is removed from water. Blooms in summer.

Impacts: Spreads rapidly by fragmentation, clogs waterways, impedes recreation, outcompetes native species, reduces fish habitat, can alter water quality.

Habitat: Lakes, ponds, slow-moving rivers up to 20-feet deep.

Control: Clean fragments from boats, motors and trailers to prevent spread. Hand pull small infestations, taking care to remove all plant fragments from the water. Dense, whole-lake infestations can be mowed with a mechanical harvester to maintain open water (not recommended for partially infested water bodies). Herbicide can be applied by a licensed aquatic herbicide applicator.

Look-alikes: Native milfoil species, which generally have fewer than 14 leaflet pairs and hold their shape out of water, and variable-leaf milfoil (*Myriophyllum heterophyllum*), a Class A noxious weed not known in Benton County. All milfoils can be difficult to tell apart. If you think you have an invasive milfoil, contact the Benton SWCD Invasives Program for verification.

Legal Status: ODA Class B, control in areas where not yet well-established in Benton County.

Hydrilla
Hydrilla verticillata

Identification: Long-stemmed, submerged, perennial with visibly toothed leaves in whorls of five. Flowers inconspicuous. Grows from small tubers in the sediment.

Impacts: One of the top 10 federally listed noxious weeds. Spreads rapidly by fragmentation, clogs waterways, impedes recreation, outcompetes native species, reduces fish habitat, alters water quality. Extremely aggressive and persistent.

Habitat: Lakes, ponds, ditches, slow-moving water up to 30 feet deep. Not known to occur in Benton County.

Control: If you find this plant, contact the Oregon Invasives Hotline immediately. Very difficult to eradicate.

Look-alikes: Brazilian waterweed or elodea (*Egeria densa*) has smooth-edged leaves in whorls of four. American waterweed (*Elodea canadensis*) has smooth-edged leaves in whorls of three.

Legal Status:
ODA Class A, if found report to OregonInvasivesHotline.org

What services does the Conservation District provide to county residents?

- Early detection and eradication of pioneering infestations of high-priority noxious weeds
- Weed surveys and consultations
- Best Management Practices and fact sheets for noxious weeds in the county
- Cooperative Weed Management Area coordination
- Advice on the appropriate use of weed control methods and tools
- Training and coordination of Weed Spotter volunteers
- Presentations and slide shows on weed identification and control

What can you do?

Prevent weed infestations:

- Follow noxious weed laws and quarantines
- Never put non-native plants or aquarium contents into a natural water body
- Choose non-invasive species for gardens
- Clean boats, trailers, boots, and other equipment before moving between water bodies
- Become a Weed Spotter and help find new invaders

Control weed infestations:

- Obtain necessary permits before working in water
- Use integrated pest management and control weeds safely and appropriately
- Follow Best Management Practices for aquatic weeds
- Properly dispose of noxious weeds and weed seeds
- Monitor the area and follow up as needed to keep the weeds out after the first year of control
- Contact Benton SWCD if you are unsure what to do

Resources for additional information

Benton Soil & Water Conservation District Invasive Plants Database, www.bentonswcd.org/programs/invasive-species/weed-profiles/

King County Noxious Weed Control Program, www.kingcounty.gov/weeds

On The Lookout for Aquatic Invaders: Identification Guide by Oregon Sea Grant, http://seagrant.oregonstate.edu/sgpubs/H14001-on-the-lookout

Oregon Department of Agriculture Noxious Weed Control Program, www.oregon.gov/ODA/PLANT/WEEDS/Pages/index.aspx

Oregon Invasive Species Council, oregoninvasivespeciescouncil.org

Washington State Department of Ecology, Aquatic Plants, Algae and Lakes, http://wdfw.wa.gov/licensing/aquatic_plant_removal

Washington State Department of Fish and Wildlife: Aquatic Plants and Fish, http://wdfw.wa.gov/publications/00713/wdfw00713.pdf

Center for Aquatic and Invasive Plants, University of Florida, http://plants.ifas.ufl.edu/

An Aquatic Plant Identification Manual for Washington's Freshwater Plants, Washington State Department of Ecology, June 2001, Publication 01-10-032, www.ecy.wa.gov/programs/wq/plants/plantid2/

A Field Guide to the Common Wetland Plants of Western Washington and Northwestern Oregon, Sarah Spear Cooke, Editor, Seattle Audubon Society, 1997.

Aquatic and Riparian Weeds of the West, Joseph M. DiTomaso and Evelyn A. Healy, University of California Agriculture and Natural Resources, 2003, Publication 3421.

Contact Benton SWCD with questions and concerns: office@BentonSWCD.org or 541-753-7208.

The Quarantine List

Wetland and aquatic plants whose sales are prohibited in the State of Oregon and are state-listed noxious weeds.

Common Name	Scientific Name
Brazilian Waterweed (Elodea)	*Egeria densa*
Common Reed	*Phragmites australis*
Cordgrass	*Spartina spp.*
Eurasian Watermilfoil	*Myriophyllum spicatum*
European Waterchestnut	*Trapa natans*
Flowering Rush	*Butomus umbellatus*
Hydrilla	*Hydrilla verticillata*
Knotweeds	*Polygonum and Fallopia spp.*
Parrotfeather	*Myriophyllum aquaticum*
Poison Hemlock	*Conium maculatum*
Purple Loosestrife	*Lythrum salicaria*
Purple Nutsedge	*Cyperus rotundus*
Water Primrose	*Ludwigia peploides, L. hexapetala, L. grandiflora*
Yellow Flag Iris	*Iris pseudacorus*
Yellow Floating Heart	*Nymphoides peltata*
Yellow Nutsedge	*Cyperus esculentus*

Current quarantine list and more information and photos can be found at Oregon State Weed Board, www.oregon.gov/ODA/PLANT/WEEDS/pages/oswb_index.aspx

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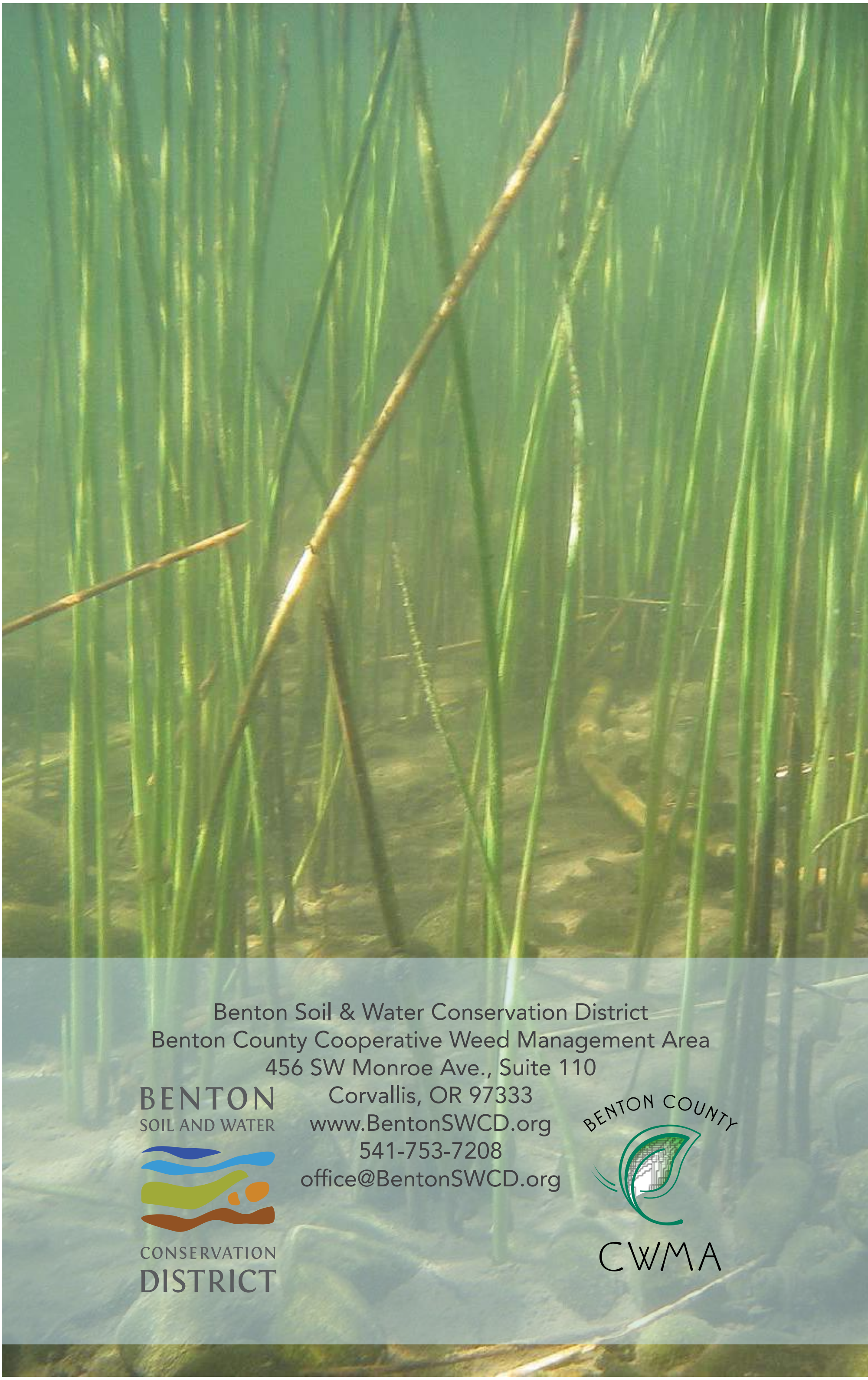
Common and *Scientific* Names



Benton Soil & Water Conservation District
Benton County Cooperative Weed Management Area
456 SW Monroe Ave., Suite 110
Corvallis, OR 97333
www.BentonSWCD.org
541-753-7208
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BENTON SOIL AND WATER CONSERVATION DISTRICT

BENTON COUNTY CWMA

UNIVERSITY OF FLORIDA

IFAS EXTENSION

Weed Control in Florida Ponds[1]

D.D. Thayer, K. A. Langeland, W.T. Haller, and J.C. Joyce[2]

Ponds are often built to supplement farm income via fish production, for personal enjoyment, or for stormwater management. Soon after the pond is constructed, unforeseen problems often arise. One major problem that occurs is that the pond becomes clogged with aquatic plants. The level at which an aquatic plant becomes a weed problem depends on the pond's intended use. A farm pond used primarily for weekend fishing can tolerate considerably more vegetation than a pond constructed specifically for fish production and/or irrigation. Shoreline grasses can help stabilize and prevent bank erosion, but out of control grasses may encroach into the water, where they restrict access and usability. This circular provides information on aquatic weed identification and control for farm and aquaculture ponds.

Prevention is the best technique for reducing takeover by aquatic weeds. It's easier and more economical to prevent weed problems than it is to cure them. Preventive measures include proper pond location and construction.

Site Selection

Where you dig a pond can be an important decision when it comes to preventive control. Proper location can help minimize erosion and nutrient enrichment from the runoff of silt and inorganic and organic fertilizers that decrease the lifespan of the pond and limit its usefulness.

Whether you fertilize your pond for fish production or avoid intentional nutrient enrichment, sites near fertilized fields, feedlots, barnyards, septic tanks, gardens, roadways, or other sources of runoff should be avoided. Agricultural and domestic runoff such as from parking lots and roadways may also contribute heavy metals, oils, and pesticide contaminants. If an "ideal" pond location cannot be found, a berm to divert runoff away from the pond can be constructed (Figure 1).

Avoid building a pond with a flowing stream unless excessive water can be diverted. When a fertilization program is being used for algae production, the continual flushing action of a flowing

1. This document is CIR 707, one of a series of the Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date October 1986. Revised June 2003. Cir 707 is also available from the IFAS Extension Bookstore at http://ifasbooks.ufl.edu. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.

2. D.D. Thayer, director, South Florida Water Management District, Aquatic Plant Management Division; K.A. Langeland, professor, Agronomy Department, Center for Aquatic and Invasive Plants; W.T. Haller, professor, Agronomy Department, Center for Aquatic and Invasive Plants; J.C. Joyce, professor, Executive Associate Vice President, Office of Vice President for Agriculture and Natural Resources; Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, 32611.

stream would be counterproductive, resulting in the use of much more fertilizer to maintain an algae bloom. Herbicide effectiveness may also be diminished when a long contact period is required for underwater plants. Aquatic plants growing in the stream itself are much more difficult to control, even with the faster acting contact-type herbicides. Without control of water input, water quality in general will suffer and become difficult to manage.

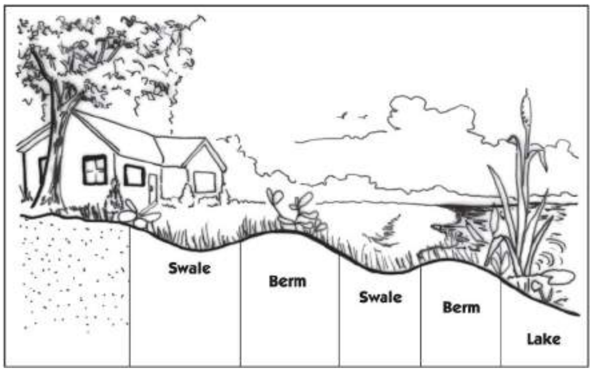

Figure 1. A swale and berm system slows down stormwater runoff and traps pollutants before they reach the pond.

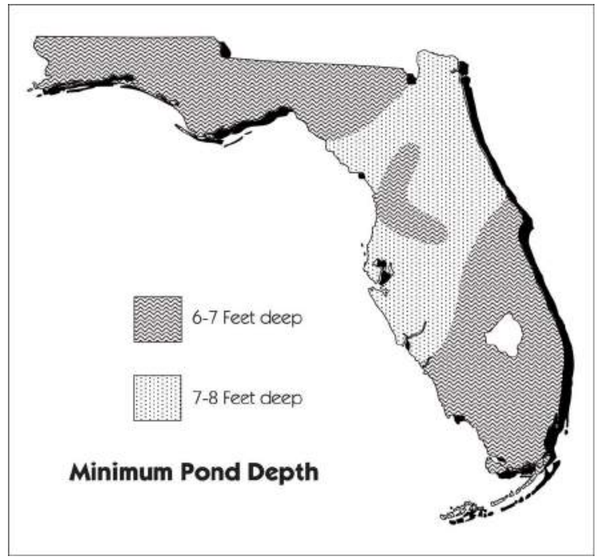

Figure 2. Based on probable seepage and evaporation losses, Florida ponds shoudl have a minimum depth of 6 to 8 feet.

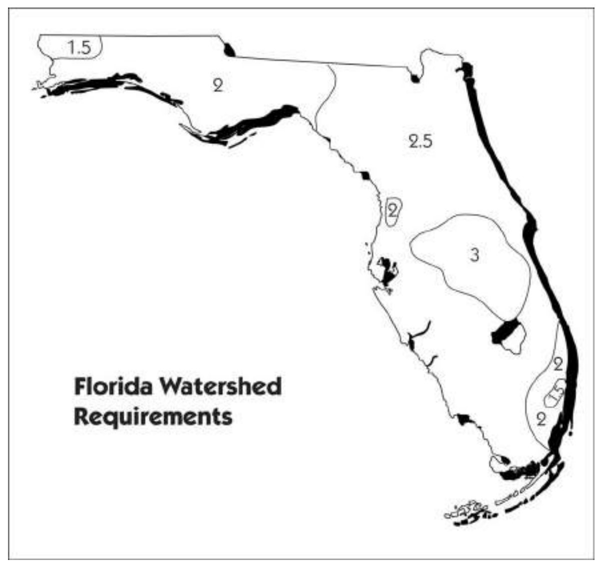

Figure 3. The watershed required for most of Florida would be 2 to 3 acres of watershed to 1 acre-ft of water.

After considering the factors mentioned above, select locations that have recommended watershed-to-pond ratios if you don't have a well or other water source. The USDA Natural Resources Conservation Service (NRCS) recommends that, based on Florida's annual rainfall, an excavated pond should be no less than 6 to 8 feet deep (Figure 2), and that a drainage area of 2 to 3 acres is necessary to maintain one foot of water in a one-acre pond (Figure 3). Experience with farm ponds in North Florida indicates that deeper ponds (10 to 20 feet deep) have fewer aquatic weed problems than shallower ponds. If a properly balanced fish population is to be maintained, then at least one surface acre of water is required. So, to build a one-acre pond with an average depth of 8 feet, an average 16 to 24 acres of watershed would be required. The surrounding vegetation cover, soil type, land slope, and other land use characteristics will have an effect on the degree of drainage. If the surrounding vegetation is primarily woodlands, then more watershed is required than if the surrounding land is primarily in pasture.

If possible, choose a location that maximizes use of prevailing winds. Good water circulation is essential for increasing dissolved oxygen in the water column, cycling nutrients, increasing bacterial populations in the hydrosoil, and restraining floating plants from covering the pond.

If at all possible, avoid a location that will have heavy livestock usage. If the pond is going to be used primarily for watering livestock, divert water to a watering trough or section off a portion of the pond in order to prevent the livestock from wading in at will (Figure 4). Livestock increase erosion, levee destruction, organic pollution, and turbidity, as well as disturb fish spawning areas. Restricting livestock provides cleaner drinking water and will increase the life of the pond. The cost of fencing will be more than offset by the lowered cost of pond maintenance.

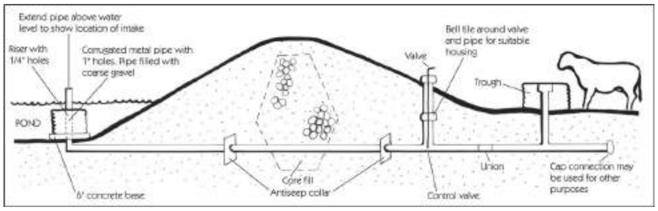

Figure 4. Water is piped through the dam's drainpipe to a stockwater trough.

Pond Construction

Pond banks should be as steep as possible along the edges to a depth of several feet to avoid shoreline vegetation from becoming established. They should then gradually slope to a depth of 6 to 8 feet to the pond center. Removal of brush and trees along the edge will increase berm stability and reduce leaf and branch litter. Grass species should be encouraged to grow along the banks to prevent erosion and washouts.

The construction of a small berm (Figure 1) around the entire pond can be helpful in trapping rainwater runoff that may be rich in nutrients and suspended solids (leaf litter, trash, etc.). The water that percolates through the berm into the pond will be filtered rather than flowing directly into the pond itself. Terracing adjacent fields can also be a valuable method of decreasing both field erosion and sedimentation. If your future plans include water drawdown for pond reconstruction, now is the time to plan for drainpipes, risers, valves, etc.

Stormwater Ponds

Urban stormwater ponds, technically called *wet detention areas*, have the primary purpose of flood control. Secondarily, surface water detention ponds are hoped to protect receiving waters from pollutants and may also be used in part or in total to mitigate destruction of wetlands. Wet detention ponds are often constructed with shallow sloping areas, called *littoral shelves*. The purpose of the littoral shelf is to provide habitat for rooted plant life. Stormwater ponds often have permits associated with them that require management of aquatic plants in the pond, including maintaining a certain amount and type of plants. Before attempting any weed control measures in stormwater ponds, the Water Management District in which you are located should be contacted. It is advisable to contact a professional pond managment company to manage weed problems in stormwater ponds. For additional information on stormwater pond management see "Stormwater Ponds--A Citizen's Guide to Their Purpose and Management," available from Southwest Florida Water Management District: 352/796-7211 or 800/423-1476.

Methods of Aquatic Weed Control

Fertilization

The principle behind a pond fertilization program is that phytoplankton (microscopic algae) populations increase as a result of the controlled addition of fertilizer nutrients until light penetration is reduced below the level required for growth of submersed weeds.

Before you decide on fertilization for weed control, consider the following. 1) Once a fertilization program has begun, you must always continue the program or face possible severe weed problems. 2) Particular weeds, such as hydrilla (see “Submersed Plants” in Appendix 1), have been shown in Florida to outcompete phytoplankton communities for nutrients, thereby making the weed problem worse. It is therefore imperative that fertilization should not be initiated until current weed infestations have been totally controlled. 3) If the fertilization of a pond is intended to be used to stimulate food production in an aquaculture pond, then additional weed control with herbicides or with weed-eating carp *Ctenopharyngodon idella* (see page 6, “Herbivorous Fish”) may be beneficial (Figure 5).

Phytoplankton is the base of the food chain. Increases in phytoplankton will increase the production of zooplankton, which ultimately increases fish production. Most fertilization recommendations suggest adding inorganic fertilizer every 2 weeks until a shiny object placed 18 inches below the surface is no longer visible (Figure 6). Once this level of phytoplankton is obtained, maintain that level with periodic fertilization. The optimum pH should be at least 6.5 or higher, and liming may be required prior to fertilization. The best time of year to begin a fertilization program is in the

Figure 5. The grass carp provides effective weed control for most submersed and many floating weeds.

spring before aquatic weeds have begun growth. Once established, submersed vegetation must be controlled either with chemicals or grass carp or must be physically removed in order to ensure good algae production. Fertilization shortly after an herbicide application may speed decomposition resulting in oxygen depletion and should be avoided. Remember, if you desire clear water for swimming or other recreational purposes, do not fertilize your pond. **NEVER** add fertilizer to a permitted stormwater retention pond.

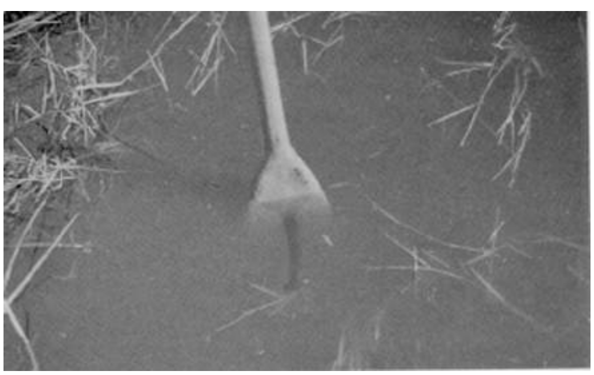

Figure 6. Fertilization encourages production of phytoplankton that reduces light penetration into the water.

Nutrient Reduction

The converse of fertilization is reduction of fertilizer nutrients into your pond. While most Florida ponds will have sufficient naturally occuring nutrients to support problem levels of plant growth, decreasing the amount of nutrients going into a pond can minimize some problems, especially the growth of algae and floating plants, which derive their nutrients from the water, not the pond bottom. Sources of nutrients that can be decreased include: the amount of food provided to fish, fertilizer (especially those that contain high nitrogen) applied to landscapes in the watershed, livestock and domestic ducks.

Drawdown

Water level fluctuation or pond draining can be used very effectively if the conditions are favorable. Exposing the bottom of your pond to the atmosphere will solidify suspended mud and consolidate bottom sediments to a watertight condition. Excessive nutrients suspended in the water column will be diluted as a result of the water exchange. In order to have a successful drawdown, you must leave the water level down long enough to desiccate and kill submersed plants. An incomplete drawdown may have little to no effect, and some plant species that are not susceptible to drawdown may spread into the de-watered lake bottom more easily. Cattails are often opportunistic and may establish during extended drawdowns (Figure 7). The consolidation of bottom muck by drying should also improve fish spawning and nursery areas. Drawdowns also increase options for chemical weed control. Some herbicides are only labeled for use on drained pond bottoms, and treatments at this time often provide several years of weed control because the herbicides are bound in the bottom sediments.

Figure 7. Cattails flourish in a pond that has been drown down to kill weeds.

Mechanical Control

Mechanical control involves the physical harvesting of vegetation by hand or with specifically engineered equipment. For the owner of a small pond, mechanical control can be helpful for removing small populations of nuisance plants. For example, a small population of duckweed (see “Floating Plants” in Appendix 1) can be netted when plants form windrows against the shoreline. Brush species, cattails, and other shoreline vegetation can be cut with a sickle or pulled by hand while still immature. Booms or barriers extended across an incoming creek or stream can often keep plants such as waterhyacinths (see “Floating Plants” in Appendix 1) from entering the pond. When confined, these plants can easily be hand removed or sprayed with herbicide. While the simplest mechanical harvesting devices for weed control are often the cheapest, and often highly effective, commercially made mechanical harvesters (Figure 8) designed specifically for aquatic weed management are available. These harvesters vary in size from simple hydraulic sickle-bar cutters powered by a 5-H.P. engine and mounted on the front of a pontoon boat to 10,000-pound capacity harvesters which convey cut vegetation on board for transport to shoreline dumping sites. In general, large mechanical harvesting equipment can be difficult to maneuver in a smaller pond, and weed control cost would be exorbitant for the private pond owner.

Figure 8. Aquatic plant harvester clears weeds from a lake surface.

Biological Control

Ideally, the best weed control agent is one that keeps weed pests restrained naturally. Many native plants have biological restraints that keep them from growing prolifically. The major aquatic weed problems in Florida are caused by nonnative plants that were introduced from foreign lands without their natural pests and controlling organisms. In the absence of natural enemies, these nonnative plants grow uncontrolled and rapidly invade new areas. To provide some insight into biological control for these nuisance plants, research scientists travel to their foreign habitat searching for insects, disease, or other organisms that may aid in controlling their growth. In theory, this concept sounds ideal; however, years of research are required to insure that the introduced organism does not become another dangerous pest. Once it has been determined that the biocontrol agent will not be a pest, and the control agent will exist under the environmental conditions of the pest host, the organism is released. Most biological organisms will not eradicate the host plant, but will instead reduce the plant s potential to become a serious pest.

Several biocontrol agents have been released in Florida or occur naturally; however, others must be added to the pond and are presently available for release in Florida.

Insects and Plant Pathogens

Over the years, insects have proven to be the most popular biological control agents due to their high degree of host specificity. The insect is generally effective at destroying only the host plant because of its parallel evolutionary development with the plant's taxonomic characteristics. Plant pathogens such as viruses, bacteria, fungi, or nematodes are already present in the aquatic environment and may limit the growth of aquatic weeds by invading weak or wounded plant tissue.

The alligatorweed flea beetle (*Agasicles hygrophila*), discovered in South America and introduced into the United States in 1964, is the best example of an extremely successful biocontrol program using insects for aquatic weed control. In regions of the country where the flea beetle can overwinter, as it does in Florida, alligatorweed is no longer considered a major weed problem.

The waterhyacinth has had several biocontrol agents introduced to it over the years that help in reducing the prolific growth that it is capable of; however, unlike alligatorweed, these biocontrol agent don't appear capable of quickly controlling the plant. Two waterhyacinth weevils (*Neochetina eichhorniae* and *N. bruchi*), the waterhyacinth mite (*Orthagalumna terebrantis*), and fungus (*Cercospora rodmanii*) have been imported to Florida and can often be found associated with the plant. Because one requirement of a successful biological control program utilizing insects is self-dissemination, locating sources of insects for introduction should not be necessary.

Herbivorous Fish

Numerous nonnative fishes around the world are reported to consume aquatic vegetation. However, because of the concern for potential damage in Florida's diverse lakes and rivers, only a few of these fish have been investigated and even fewer show promise for weed control. Many of these species may not be suitable for weed control because the individual has insufficient consumption (high stocking rates needed), they are prolific spawners (often cause overcrowding), or they are restricted to warm climates (must be overwintered in controlled environments).

Of the fishes examined to date, the grass carp (Figure 5) is the best candidate for aquatic plant control in a variety of situations and climates and may provide the only practical control method for water bodies where herbicides cannot be used. This fish has provided excellent control of submersed plants, filamentous algae, and small floating plants such as duckweeds. The grass carp is used by Arkansas and other states for this purpose in natural lakes and has been researched by a number of other states. Florida has conducted research and has approved the use of the triploid grass carp, which has three sets of chromosomes compared to the normal two sets and is thus sterile.

As stated previously, the grass carp does consume vegetation and if stocked in sufficient numbers is likely to remove all submersed plants from pond systems. Before stocking ponds that have heavy vegetation cover, it is often advantageous to treat with herbicides. In order to determine proper stocking rates for a given pond, a competent fish biologist should be consulted and a permit obtained from a Florida Wildlife Conservation Commission office.

There are three possible management strategies utilizing grass carp: 1) complete vegetation removal within one to two years with a heavy stocking rate; 2) winter stocking, before the spring growth of weeds begins, using fewer fish to maintain a lesser amount of vegetation in the system and increasing the grass carp population as needed; and 3) integrated control using herbicide treatments to obtain desired levels quickly and stocking grass carp to maintain this level. Again, the grass carp population should be adjusted as needed. A word of caution is in order: it is much easier to stock additional grass carp than to remove unwanted fish from the system.

Herbicides

Controlling aquatic plants with herbicides is the most commonly used method of weed control. Chemical weed control has several advantages.

- Herbicides may be directly applied to undesirable vegetation, offering a high degree of selectivity and leaving desirable levels of vegetation.
- Pre-emergence application of appropriate herbicides can provide early weed control. This may be used to promote desirable vegetation without competition during critical early growth stages.
- Herbicides reduce the need for mechanical control which can increase turbidity and affect fish populations.
- Erosion may be reduced by promoting the lower growing grass species for cover.
- Many weeds, especially perennials, that cannot be effectively controlled by other methods are generally susceptible to herbicides.
- Routine use of herbicides under a maintenance program usually reduces the cost of weed control.

Herbicide Selectivity

Herbicides may be placed into two general categories: selective and nonselective. Selective herbicides are used to control weeds without damaging nearby plants, crops, lawns, and ornamentals. Nonselective herbicides are chemicals that kill all plants that are sprayed at an adequate rate. Herbicides in this latter category are used where no plant growth is wanted such as fencerows, ditchbanks, driveways, etc. Factors that influence selectivity include application rate, time and method of application, environmental conditions, stage of plant growth, and the biological characteristics of the plant.

Mode of Action

Herbicide activity can be divided into contact and systemic types. Contact herbicides only kill the parts of the plant that they physically contact; therefore, the entire plant must be sprayed. They usually cause rapid die-back of the vegetation they come in contact with and are generally more effective on annuals. Systemic herbicides are absorbed by both roots and foliage and translocated within the plant s vascular system. Systemics are particularly effective against deep rooted perennial weeds, providing long term control, and do not need uniform coverage of the entire plant.

Herbicide Formulation

The active ingredient of a herbicide is rarely 100 percent of the formulation. Instead, the herbicide is mixed with water or an oil blend and often includes inert adjuvants that facilitate the spreading, sticking, wetting, and other modifying characteristics of the spray solution. These special ingredients usually improve the safe handling, measuring, and application of the active ingredient.

The majority of liquid herbicide formulations are liquid (L). Each gallon of formulation usually contains 2 to 8 pounds of active ingredient. The high concentration generally means easier handling, transport, and storage. Liquids require little agitation and are considered to be nonabrasive. Liquids are usually mixed with water at a ratio of 1:50 or 1:100 prior to use.

Many of the aquatic herbicides have not only liquid but dry formulations as well. The vast majority of these dry formulations are sold as granules (G) or pellets (P). The active ingredient is generally adsorbed onto clay particles with the amount of active ingredient ranging from 1 to 15 percent. Granules are convenient for spot treatments, are ready to use and require no mixing, reduce drift hazards, and can be applied easily. The disadvantages of granules are their high expense per pound of active ingredient and their ineffectiveness as a treatment on the foliage of emergent plants.

Another common dry formulation is the wettable powder (WP). WP formulations resemble a fine dust and generally contain greater than 50 percent active ingredient. When mixed with water, agitation is required to keep the insoluble particles in suspension. The advantages of a WP are the lower cost, ease of handling, and ease of measuring. Some disadvantages of WP are the abrasion of suspended particles on spray equipment and the requirement for constant tank agitation.

Adjuvants

An adjuvant is an inert ingredient added to the spray solution in order to facilitate or modify the action of the herbicide. Spray tank additives may include surfactants, thickening agents, spreaders, stickers, wetting agents, penetrants, anti-foaming agents or many other modifiers. Many herbicides contain adjuvants in their formulation and may not need any additional material added to the spray tank; however, many of these same herbicide labels may suggest that additional surfactant be added. Most of the adjuvants are strictly optional and may be added to help modify the spray solution. For instance, a spreader-sticker may be added to the herbicide mix for spraying a contact type of herbicide, because covering as much of the leaf surface as possible would increase the percentage of weed control. Additional surfactant for wetting may be necessary when target weeds have dense leaf hairs. The best source of information for deciding on adjuvant addition is the herbicide label or the chemical manufacturer s representative.

The Label

All herbicide containers must have attached to them a label that provides instructions for storage and disposal, use of the product, and precautions for the user and the environment. The label is the law. It is unlawful to alter, detach, or destroy the label. It is also unlawful to use a pesticide in a manner that is inconsistent with or not specified on the label. For example, herbicides that are sold for use in the garden should never be used in ponds unless the label specifies this use. Misuse of a herbicide is not only a violation of federal and state law; herbicides used contrary to label directions may seriously contaminate water, rendering it unfit for fish, irrigation, and swimming, and as a source of potable water. Herbicides sold for use in water have been state and EPA approved and have undergone years of costly and extensive research to ensure their environmental safety.

The herbicide label contains a great deal of information about the product and should be read thoroughly and carefully before each use. Before purchasing a herbicide, read the label to determine:

- whether the weed species can be controlled with the product
- whether the herbicide can be used safely under particular application conditions
- what herbicide formulation best suits your needs and application equipment
- how much herbicide is needed
- where the herbicide can be used and what restrictions apply if you are also watering livestock, fishing, swimming, consuming as potable water, watering crops, etc.
- what the toxicity is to various fish species
- when to apply the pesticide (time of year, stage of plant growth, etc.)
- whether there are any restrictions for use of the pesticide (certified applications only, ditchbanks only, ponds only, etc.)
- what safety equipment is needed
- signal word that indicates the acute toxicity to humans, i.e., danger, warning or caution.

Precautions with Herbicides

When a large percentage of a water body is infested with weeds, care is needed when fish safety is a concern. Several herbicides act on contact, killing the weeds in a matter of hours. When aquatic plants die and begin to decay, they remove oxygen from the water, creating what is known as a biological oxygen demand. If too large an area in a pond volume is controlled, dissolved oxygen levels in the pond may drop below the concentration necessary to sustain fish. Here are several general rules to keep in mind when treating aquatic plants.

1) Avoid treating on cloudy days when dissolved oxygen levels will naturally be lower.

2) If a large portion of the pond is covered with plants, treat no more than one-third to one-half of the plants at once, leaving time between applications for oxygen recovery.

3) Treat early in the spring before plants get out of control.

4) In order to get maximum performance from your herbicide, treat when the water temperature is above 60°F and plants are actively growing.

The majority of EPA and state approved aquatic herbicides have a wide range of safety with nontarget organisms. The level at which some herbicides become toxic to fish is several hundred times higher than field application rates. However, herbicides like copper sulfate ($CuSO_4$) may be toxic to several fish species at label use rates and require extra precaution when large treatments are to be made, especially in soft water. Appendix 3 lists the 96-hour LC_{50} (lethal concentration to 50 percent of any particular population) in ppm and also the pounds of various aquatic herbicides needed per acre-foot of water to be toxic to bluegill, channel catfish, rainbow trout, crawfish, and freshwater shrimp.

How to Use Herbicides

When using herbicides, as with any toxic material, it is important that personal exposure be kept to an absolute minimum. Most accidents result from careless handling and a general lack of label knowledge. Herbicides are categorized into four groups based on their oral, dermal, and inhalation toxicity. Every label contains a signal word (Danger, Warning, or Caution) that indicates level of toxicity.

While mixing and spraying herbicides, protective clothing and equipment such as long-sleeved shirts and long-legged pants, gloves, rubber boots, and goggles or a face shield should be used. Most labels will suggest you wear protective clothing and will tell you the precautions to be taken when using the herbicide.

While mixing, loading, handling, and cleaning up, observe all safety recommendations on the label. When minor spills occur, use absorbent materials such as soil or sawdust to soak up the chemical. Place contaminated materials into a sealed container for disposal. Cleanup of a major spill may be too difficult for an untrained person to handle. Should there be a bad spill, call Chemtrec toll-free at 1 800 424 9300 for emergency assistance. For first aid information about herbicide poisoning, refer to the label for instructions and contact your physician.

If you choose herbicides as a means of control, refer to Appendix 2 and locate the herbicide listed as effective for your particular weed problem. Product tradenames, water systems labeled for use, mode of action, duration of herbicidal activity, and precautions are listed for herbicides.

Once you review the herbicides and decide which best suits your problem, review Appendix 3 to ensure that there will be no toxicity problems.

Appendices

Appendix 1. Aquatic Weed Identification

Aquatic plants are commonly classified into several categories depending on the location in the water column they inhabit. Aquatic plants may be free floating, emersed, submersed, or shoreline plants. Free floating plants are rarely if ever rooted into the soil and their leaves are located above the water. Emersed aquatic plants are rooted in the soil under water with their leaves on or above the water surface. Submersed aquatic plants are usually rooted in the soil with all or most of their leaves growing under water. Ditchbank plants are not true aquatic plants, but are often associated with the moist soils located around ponds and lakes and are therefore included here, as are common types of algaes.

Floating Plants

Common duckweed

(*Lemna minor*)

Description: Small, footprint-shaped leaves, no more than 1/8 inch long having one root. Leaves are pale green and float flat on the water surface. Reproduction occurs by seeds and rapidly through budding.

Control: Biological: grass carp. Herbicides: diquat, fluridone.

Figure 9. Common duckweed (*Lemna minor*)

Common salvinia

(*Salvinia minima*)

Description: Circular leaves 1/4-1/2 inch in diameter with dense leaf hairs on the upper leaf surface. Leaves are brownish green and float flat on the surface. Salvinia is a fern and reproduces by spores and fragmentation.

Control: Biological: partial control with grass carp. Herbicides: diquat.

Figure 10. Common salvinia (*Salvinia minima*)

Common watermeal

(*Wolffia* species)

Description: These are tiny, floating, rootless plants that are less than

1/32 inch long. The plant body is rounded and feels grainy when rolled between the fingertips. The plants are so small they appear to be merely green specks or dots. Often two to three are attached.

Control: Biological: none.

Herbicides: fluridone (marginal).

Figure 11. Common watermeal (*Wolffia* species)

Mosquito fern

(Azolla caroliniana)

Description: Free-floating fern less than 1/2 inch across, with branching stems. Leaves tiny, bilobed, in two ranks, usually reddish (especially in full sun), or green. Propagates vegetatively, rapidly forming large thick mats.

Control: Nutrient reduction. Biological: attacked by native insects, which are suppressed by predation from fire ants. Herbicides: diquat, flurodone.

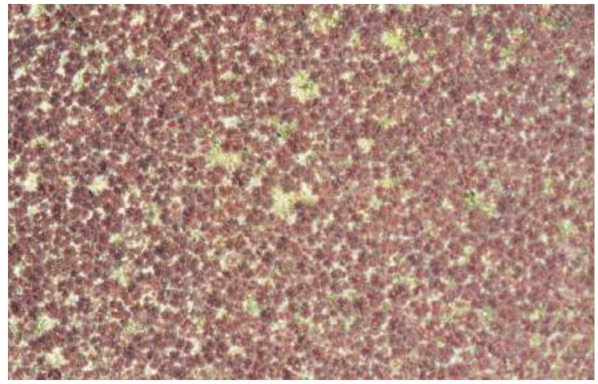

Figure 12. Mosquito fern (*Azolla caroliniana*)

Waterhyacinth

(*Eichhornia crassipes*)

Description: Plants several inches to two feet in height. Smooth leaves attached to spongy bulb-shaped stalks. Reproduction is primarily through the production of daughter plants.

Control: Biological: hyacinth weevil, partial control with fungus. Herbicides: 2,4-D, diquat, glyphosate, triclopyr.

Figure 13. Waterhyacinth (*Eichhornia crassipes*)

Waterlettuce

(*Pistia stratiotes*)

Description: Resembles a head of lettuce. Grows in a rosette with spongy, dense hairy leaves 6-8 inches in diameter. Daughter plants are the major means of reproduction.

Control: Biological: waterlettuce weevil. Herbicides: diquat, endothall liquid.

Figure 14. Waterlettuce (*Pistia statiotes*)

Emersed Plants

Pickerelweed

(*Pontederia lanceolata*)

Description: An erect plant with lance-shaped leaves up to 10 inches long. Each stem has violet-blue flowers at the top. Reproduction occurs by seed and creeping rootstalks.

Control: Herbicides: triclopyr, partial control with 2,4-D and glyphosate.

Figure 15. Pickerelweed (*Pontederia lanceolata*)

Alligatorweed

(*Alternanthera philoxeroides*)

Description: Hollow-stemmed perennial capable of forming dense mats. Leaves are opposite between 2 and 4 inches long, and football-shaped. Stems have a solitary white flower head at the tip. Reproduction by fragmentation.

Control: Biological: alligatorweed flea beetles and thrips. Herbicides: triclopyr, partial control with 2,4-D and glyphosate.

Figure 16. Alligatorweed (*Alternanthera philoxeroides*)

Cattail

(*Typha* species)

Description: Erect perennials (up to 9 feet) that can reproduce by seed or creeping rootstalk. Grass-like leaves are flat and smooth to the touch. Flowers look like a "cat's tail" and can be found in a tightly packed spike usually 6-8 inches long.

Control: Herbicides: diquat, glyphosate, fluridone.

Figure 17. Cattail (*Typha* species)

Pennywort

(*Hydrocotyle umbellata*)

Description: Dark green, shiny rounded leaves which are centrally attached to a long stalk. Leaves may lie flat on the water surface or be erect. Pennywort reproduces by seed and creeping stems.

Control: Herbicides: diquat, 2,4-D, glyphosate, triclopyr.

Figure 18. Pennywort (*Hydrocotyle umbellata*)

Smartweed

(*Polygonum species*)

Description: Leaves are alternate, lance-shaped, and attached to swollen joints on the stem. The flower stalk consists of many small pinkish white flowers in a single spike. Smartweed spreads by seed, and may form large floating mats.

Control: Herbicides: triclopyr, partial control with glyphosate (species dependent) and 2,4-D.

Figure 19. Smartweed (*Polygonum* species)

White water-lily

(*Nymphaea odorata*)

Description: Leaves are flat, rounded, and attached at the center to the stalk. Leaves are often 10 inches in diameter and split to the center on one side. The flower is sweet-scented, white and showy. Reproduction is by seed and branching stems.

Control: Herbicides: fluridone, 2,4-D liquid and granular, triclopyr, glyphosate.

Figure 20. White water-lily (*Nymphaea odorata*)

Spatterdock

(*Nuphar luteum*)

Description: Large heart-shaped leaves arising from a stalk attached to a thick creeping root system. The flower is yellow and about one inch in diameter. Reproduction is by seed and new sprouts.

Control: Herbicides: glyphosate, fluridone.

Figure 21. Spatterdock (*Nuphar luteum*)

Submerged Plants

Coontail

(*Ceratophyllum demersum*)

Description: Leaves grow in a whorl, are finely dissected, and have teeth on one side of the leaf margin. Leaves are 1/2-1 inch in length and crowded towards the stem tip giving the appearance of a raccoon's tail. Coontail is rootless and floats near the surface in the warmer months. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, endothall liquid and granular, fluridone, 2,4-D granular.

Hydrilla

(*Hydrilla verticillata*)

Description: Long stemmed, branching plant that is rooted to the bottom and often forms large surface mats. Leaves grow in a whorl with toothed margins that feel rough. Hydrilla can spread by plant fragments, underground stems, seed, leaf buds, or buds located on the underground stems.

Figure 22. Coontail (*Ceratophyllum demersum*)

Control: Biological: grass carp. Herbicides: copper, diquat, endothall (liquid and granular), fluridone.

Figure 23. Hydrilla (*Hydrilla verticillata*)

Bladderwort

(*Utricularia* species)

Description: A submersed, free floating plant, having a variety of growth forms. Although leaf shapes and flowers differ, all species bear small urnlike bladders which are used to trap small aquatic animals. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, fluridone, 2,4-D granular.

Figure 24. Bladderwort (*Utricularia* species)

Southern naiad

(*Najas guadalupensis*)

Description: Bottom-rooted, slender-leaved, dark green to greenish purple plant with branching stems. Leaves are less than 1 inch in length and narrow. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, endothall liquid and granular, fluridone, 2,4-D granular.

Figure 25. Southern naiad (*Najas guadalupensis*)

Fanwort

(*Cabomba caroliniana*)

Description: Leaves of fanwort are finely dissected and fan-shaped. Leaves are opposite and generally no more than 1-1 1/2 inches wide. The flower is white or cream colored, about 1/2 inch in diameter and blooms above the water surface. Reproduction is by seed and fragmentation.

Control: Biological: grass carp. Herbicides: diquat, fluridone, 2,4-D granular.

Figure 26. Fanwort (*Cabomba caroliniana*)

Pondweed

(*Potamogeton* species)

Description: Several species of pondweed are found in Florida; Illinois pondweed (*P. illinoensis*) is most frequently encountered. It has both floating and submersed leaf forms. The football-shaped floating leaves are not always present, but are easily distinguishable from the lance-shaped submersed leaves. The flowers are clustered together on a spike 1-2 inches long located just above the water surface at the stem tip. Reproduction is by seed and from underground stems.

Control: Biological: grass carp. Herbicides: diquat, endothall (Hydrothal) liquid and granular, fluridone, 2,4-D granular.

Grasses and Sedges

Torpedograss

(*Panicum repens*)

Description: Narrow leaved (less than 1/4-inch wide), with stems often several feet in length. Torpedograss creeps horizontally by underground

Figure 27. Pondweed (*Potamogeton* species)

stems and forms large floating mats. Reproduction is by seed and creeping stems.

Control: Biological: partial control with grass carp. Herbicides: partial control with glyphosate, fluridone.

Figure 28. Torpedograss (*Panicum repens*)

Maidencane

(*Panicum hemitomon*)

Description: Maidencane leaves usually grow at 90o angles from the stem and generally 1/2-inch in width. An extensive creeping root system allows maidencane to form dense floating mats with stems often several feet in length. Reproduction is by seed and creeping root stalk.

Control: Biological: partial control with grass carp. Herbicides: partial control with glyphosate.

Figure 29. Maidencane (*Panicum hemitomon*)

Paragrass

(*Brachiaria purpurascens*)

Description: Paragrass often forms stems several yards in length which often fall on the ground. Paragrass can be easily identified by the dense hairs located at the stem joints. Dense floating mats often form. Reproduction is by seed and stem joints forming roots.

Control: Biological: partial control with grass carp. Herbicides: glyphosate, fluridone.

Figure 30. Paragrass (*Brachiaria purpurascens*)

Proliferating spikerush

(roadgrass, hairgrass)

(*Eleocharis baldwinii*)

Description: Proliferating spikerush has two growth forms. When it occurs on moist soils at the edge of ponds or lakes it is erect and the leafless stems are 1-4 inches tall. When submersed, the stems become long and proliferate throughout the water column. Leaves occur only as bladeless sheaths at stem bases.

Control: Biological: grass carp. Herbicides: fluridone (repeat applications).

Figure 31. Spikerush (roadgrass, hairgrass) (*Eleocharis baldwini*)

Sedge

(*Cyperus* species)

Description: Many sedges are found in Florida and are generally difficult to identify by species. In general, sedges can be identified by the triangular stem and leaf blades, which are generally rough to the touch. Flower stalks arise from the center forming a compact group or headlike cluster of flower spikes. Reproduction is by seed.

Control: Herbicides: partial control with glyphosate.

Figure 32. Sedge (*Cyperus* species)

Ditchbank Brush

(*Myrica cerifera*)

Description: Shrub or small tree usually 10 feet tall. Leaves are alternate, pale green, and lance-shaped. When crushed, leaves emit a pleasant aroma. Close inspection of the leaves will reveal numerous small dark scales on top and bright orange scales below. Reproduction is by seed.

Control: Herbicides: imazapyr,* triclopyr.*

Wax myrtle

Figure 33. Wax Myrtle (*Myrica cerifera*)

Willow

(*Salix* species)

Description: Fast growing shrub which can become a tree in a short period of time. Leaves are alternate and lance-shaped with finely toothed margins. The fruit capsule contains many small hairy seeds which drift in air currents.

Control: Herbicides: partial control with 2,4-D, glyphosate, imazapyr,* triclopyr.

Brazilian pepper

(*Schinus terebinthifolius*)

Description: An extremely fast growing shrub found predominantly in disturbed areas of south

Figure 34. Willow (*Salix* species)

Florida. This aggressive nonnative species produces large quantities of seeds contained in a red fruit usually about 1/4-inch in diameter. Reproduction is by seed.

Control: Herbicides: glyphosate, 2,4-D, imazapyr,* triclopyr.

Figure 35. Brazilian pepper (*Schinus terebinthifolius*)

Water primrose

(*Ludwigia* species)

Description: Small shrub attaining height of up to 6 feet with multiple branching stems. Leaves are lance-shaped with small soft hairs on both sides. Flowers are yellow with four symmetrical petals. Reproduction is by seed and underground stems.

Control: Herbicides: 2,4-D, imazapyr.*

Figure 36. Water primrose (*Ludwigia* species)

Algae

Macrophytic algae

Description: Macro, meaning large, describes a type of algae that looks more like a submersed plant. Capable of attaining several feet in length, muskgrass (*Chara* species), is the most common of these algae found in Florida. The algae appear to have a whorl of spined leaves, grey-green in color, resembling the submersed plant coontail. However, algae have no true leaves. When crushed, Chara emits a musky odor.

Control: Biological: grass carp. Herbicides: copper, diquat, endothall (Hydrothrol) liquid and granular.

Figure 37. Macrophytic algae

Filamentous algae

Description: Many species of filamentous algae are frequently a problem in Florida ponds. These threadlike filaments are often called "pond scum" or "pond moss" when they are seen floating on the pond surface. Although many species of filamentous algae can frequently become a problem to pond owners, most species can be controlled in a similar manner. A few species, especially some of the blue-green algae (e.g., *Pithophora* and *Lyngbya*), are difficult to control and would require special recommendations from a qualified biologist.

Control: Biological: partial control with grass carp. Herbicides: copper, endothall (Hydrothol).

Figure 38. Filamentous algae

Planktonic algae

Description: Microscopic (planktonic) algae are small plants that cannot be identified without magnification. They occur in all ponds and, after fertilization, give the pond its green color. Most of the microscopic algae are beneficial to ponds, converting nutrients into a source of food in the food chain. There is rarely a need to control microscopic algae; however, when large blooms occur, oxygen depletion, foul odors, off-flavor fish, and even fish kills may occur.

Control: Herbicides: copper.

Appendix 2. Herbicides

Figure 39. Planktonic algae

Copper Products

Copper sulfate (cupric sulfate pentahydrate)

Tradenames: Tennessee, Chem One, Noranda, Old Bridge Copper Sulfate, and others.

Copper chelate (alkanolamine complex)

Tradenames: CUTRINE-PLUS, Captain

Copper chelate (triethanolamine complex)

Tradenames: K-TEA.

Copper chelate (ethylenediamine complex)

Tradenames: Komeen, Nautique, Clearigate

Water systems labeled for use:

Copper sulfate: impounded waters, lakes, ponds, reservoirs, and irrigation systems. Copper chelates: ornamental, fish, and fire ponds; potable water reservoirs; freshwater lakes and fish hatcheries.

Mode of action: Contact herbicide, often used in combination with other contact herbicides.

Duration of herbicidal activity: Copper sulfate may persist up to 7 days before the free copper is precipitated to insoluble forms and remains an inactive precipitate in bottom sediments. As the hardness of the water increases, the persistence of the free copper decreases. The chelated coppers can be used where hard water may precipitate uncomplexed forms of copper too rapidly.

Precautions: Copper sulfate can be very corrosive to steel and galvanized pipe. Chelated coppers are virtually noncorrosive. Contact with skin and eyes may be irritating. As water hardness decreases, toxicity to fish increases. Copper sulfate may be toxic to fish species at recommended dosages. Generally, the chelated coppers are nontoxic to trout, tropical fish, ornamental fish, and other sensitive fish at recommended dosages.

2,4-D Products

2,4-D Granular

Tradenames: Aqua-Kleen, AQUACIDE, Navigate.

2,4-D Amine

Tradenames: 2,4-D Amine No. 4, Riverside 2,4-D amine (Pro Source), WEEDAR 64, A-4D.

Diquat

Tradenames: Reward, Landscape and Aquatic Herbicide.

Water systems labeled for use: May be used in slowly moving bodies of water, ponds, lakes, rivers, drainage and flood control canals, ditches, and reservoirs.

Mode of action: Contact herbicide.

Duration of herbicidal activity: Diquat is rapidly and completely inactivated by soil.

Precautions: Do not apply to muddy water because the diquat will be inactivated. Never treat more than 1/3 1/2 of a densely vegetated pond at any one time because rapidly decaying vegetation will deplete oxygen, thereby suffocating fish. Skin contact may cause irritation. Avoid drift.

Diuron

Tradenames: Direx 4L, DIURON 80, KARMEX, Nautilus.

Water systems labeled for use: Irrigation and drainage ditches that have been drained of water for a period of 72 hours. After 72 hours diuron is fixed to the soil and the ditch may then be used.

Nautilus is registered for the control of macroalgae in commercially operated freshwater ponds, used only for ornamental fish production; discharge from ponds within 30 days of application is not allowed.

Mode of action: Diuron is readily absorbed through the root system, less so through foliage, and translocated upward toward plant foliage.

Duration of herbicidal activity: Control duration will vary with amount of chemical applied, soil type, rainfall and other conditions. Usually control will last for a period of 10-12 months.

Precautions: May irritate eyes, nose, throat, and skin. Avoid breathing dust. Apply before expected seasonal rainfall. Do not treat any ditch with desirable tree roots extended into them or injury may result. Prevent drift of dry powder to desirable plants. Do not contaminate any body of water.

Endothall

Tradenames: Granular: AQUATHOL, Super K, HYDROTHOL 191. Liquid: AQUATHOL K, HYDROTHOL 191.

Water systems labeled for use: Irrigation and drainage canals, ponds and lakes.

Mode of action: Contact herbicide.

Duration of herbicidal activity: Microbiological break down is fairly rapid in water and soil with a short herbicidal duration.

Precautions: Hydrothol 191 liquid + granular should not be used where fish are an important resource. Fish may be killed by dosages necessary to kill weeds. Skin contact may cause irritation. May be corrosive to application equipment.

Fluridone

Tradenames: Sonar AS, Sonar SRP, Avast!, Avast! SRP.

Water systems labeled for use: Lakes, ponds, ditches, canals, and reservoirs.

Mode of action: Fluridone is foliage absorbed and translocated into the actively growing shoots where destruction of the chlorophyll pigments occurs, resulting in white growing points.

Duration of herbicidal activity: Depending upon application and vegetation being controlled, control may last 1 year.

Precautions: Do not use treated water for irrigation of agronomic crops or turf for 7 to 30 days following treatment. Trees or shrubs growing in treated water may be injured. Higher treatment rates will be required if there is a large turnover in water volume in treated water.

Glyphosate

Tradenames: Rodeo, Aquamaster, Aquaneat, Eagre, Aquapro, GlyPro.

Water systems labeled for use: Lakes, ponds, streams, rivers, ditches, canals, reservoirs, and any other freshwater bodies.

Mode of action: Glyphosate is foliage absorbed and translocated throughout the plant and root system, killing the entire plant.

Duration of herbicidal activity: Only effective at the time of treatment.

Precautions: Not to be used for submersed or pre- emergence vegetation. Floating mats of vegetation will require treatment. A rain-free period of 6 hours after application is required. May be corrosive to galvanized steel. Avoid drift to desirable vegetation as glyphosate is nonselective and will affect contacted vegetation.

Imazapyr

Tradename: ARSENAL.

Water systems labeled for use: Nonirrigation ditchbanks and similar areas. Environmental use permit for aquatics.

Mode of action: Both foliage and root absorbed and translocated throughout the entire plant.

Duration of herbicidal activity: Provides control of existing and germinating seedlings throughout the growing season.

Precautions: Do not contaminate any water supply. Do not apply on ditches used for irrigation. Do not treat in areas where desirable tree roots are visible. Prevent drift to desirable plants. Should not be mixed or stored in unlined steel containers or spray tanks.

Triclopyr

Tradenames: Renovate 3.

Water systems labeled for use: Aquatic sites such as ponds, lakes, reservoirs, non-irrigation canals and ditches which have little or no continuous outflow, marshes and wetlands, including broadleaf and woody vegetation on banks and shores within or adjacent to these and other aquatic sites.

Mode of action: Triclopyr induces characteristic auxin-type responses in growing plants. It is absorbed by both leaves and roots, and it is readily translocated throughout the plant. Foliage applications have achieved maximum plant response to treatment when the treatment has been applied soon after full leaf development and soil moisture is adequate for normal plant growth.

Duration of herbicidal activity: Time required for 50 percent breakdown in soil is between 10 and 46 days depending on environmental conditions and soil type. At label rates, phytotoxic residues in soils should cause no problems. Triclopyr has a 6- to 8-hour half-life in water.

Precautions: Irrigation: Do not use treated water for irrigation for 120 days following application. As an alternative to waiting 120 days, treated water may be used for irrigation once the triclopyr level in the intake water is determined to be non-detectable by laboratory analysis (immunoassay). There is no restriction on use of water from the treatment area to irrigate established grasses.

Do not apply Renovate 3 directly to, or otherwise permit it to come into direct contact with grapes, tobacco, vegetable crops, flowers, or other desirable broadleaf plants, and do not permit spray mists containing it to drift into them.

- Do not apply to salt water bays or estuaries.
- Do not apply directly to un-impounded rivers and streams.
- Do not apply on ditches or canals used to transport irrigation water. It is permissible to treat non-irrigation ditch banks.
- Do not apply where runoff water may flow onto agricultural land, as injury to crops may result.
- When making applications to control unwanted plants on banks or shorelines of moving water sites, minimize overspray to open water.
- The use of a mistblower is not recommended.
- See label setbacks for potable water intakes.

Appendix 3. Toxicity of Aquatic and Ditchbank Herbicides to Selected Aquatic Organisms

	TREATMENT RATE [1]	TOXICITY [2] 96-HR LC_{50}, ppm		
	ppm	Bluegill Sunfish	Rainbow Trout	Invertebrates
Copper Sulfate	0.1-1.0			17.0[3]
Soft Water		0.9	0.01	
Hard Water		7.3	--	
Copper Chelate	0.1-1.0			19.0[4]
Soft Water		1.2	<0.2	
Hard Water		7.5	4.0	
2, 4-D Amine	negligible[5]	524	377	184[6]
2,4-D BEE	1.25-2.5[7]	0.61	2.0	7.2[3]
Diquat	0.12-0.72	>115	21	>100[8]
Diuron	negligible (0.25-1.0)[10]	8.2	16	0.16[4]
Imazapyr	negligible	>100	>100	>100[3]
Endothall (Aquathol)	1.0-5.0	501	529	320[9]
Endothall (Hydrothol)	0.1-3.0	1.2	1.3	0.36[5]
Fluridone	0.01-0.15	14.3	11.7	6.3[5]
Glyphosate (Rodeo)	negligible	>1000	>1000	930[5]
Triclopyr	0.75-2.5	891	552	775[9]

[1]Estimated concentration in water after application according to label instructions.

[2]Toxicity varies according to experimental conditions.Values are typical from varous sources.

[3]Freshwater shrimp

[4]Blue shrimp

[5]Labeled only for foliar or ditchbank application, therefore concentrations in water are negligible.

[6]Daphnia

[7]Calculated for label rates of 26.7% G.

[8]*Gammarus fasciatus*

[9]Daphnia, 48 hr

[10]Nautilus

Appendix 4. Formulas for Herbicide Calculations

Formulas for Active Ingredient

(1) Gallons of liquid formulation required = lb ai* required ÷ lb ai per gal of concentrate

(2) Pounds of dry formulation required = lb ai required ÷ % ai in formuation expressed as decimal

Formulas for Herbicide Application to Ponds or Lakes

(3) Volume of pond in cu ft = surface area in sq ft x average depth in ft

(4) Volume of pond in ac† ft = surface area in ac ft x average depth in ft

(5) Volume of pond in ac ft = volume of pond in cu ft ÷ 43,560 ft^2 per ac

(6) Total gal of chem required = ac ft x ppmv** x 0.33

(7) ppmw‡ = (lb ai of chem applied ÷ volume in ac ft) x 2.72

(8) Total lb ai required = ac ft x 2.72 x ppmw desired

(9) Total gal of liquid formulation required = ac ft x 2.72 x ppmw desired ÷ lb ai per gal of concentrate

Acre-feet Calculation

(10) Acre-feet = acres x average depth in feet

Acreage Calculations

(11a) Rectangular shape: Acres = width in ft x length in ft ÷ 43,560 ft^2 per ac

(11b) Circular shape: Acres = 3.14 x $(\text{radius in ft})^2$ ÷ 43,560 ft^2 per ac

Herbicide Application Coverage

(12) Acres/min = (swath width in ft x speed in mph) ÷ 495

Volume of Herbicide Concentrate Required

(13) Gallons of herbicide concentrate required = weight of active ingredient required in spray mixture ÷ weight of active ingredient required in spray mixture ÷ weight of active ingredient per gallon of herbicide.

*ai = active ingredient; †ac = acre; **ppmv = parts per million by volume; ‡ppmw = parts per million by weight

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Acres	0.405	Hectares
Acres	4,047	Square meters
Acres	4,840	Square yards
Acres	43,560	Square feet
Acre-feet	1,233	Cubic meters
Acre-feet	43,560	Cubic feet
Acre-feet	325,900	Gallons
Centimeters	0.394	Inches
Centimeters	0.01	Meters
Centimeters	10.0	Millimeters
Cubic feet	0.0283	Cubic meters
Cubic feet	0.0370	Cubic yards
Cubic feet	0.804	Bushels
Cubic feet	7.48	Gallons(fluid)
Cubic feet	25.7	Quarts (dry)
Cubic feet	28.3	Liters
Cubic feet	29.9	Quarts (fluid)
Cubic feet	51.4	Pints (dry)
Cubic feet	59.8	Pints (fluid)

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Cubic feet	62.4	Pounds of water
Cubic feet	1,728	Cubic inches
Cubic feet	28,320	Cubic centimeters
Cubic inches	0.000016	Cubic meters
Cubic inches	0.0006	Cubic feet
Cubic inches	0.0037	Gallons (dry)
Cubic inches	0.0043	Gallons (fluid)
Cubic inches	0.0149	Quarts (dry)
Cubic inches	0.0164	Liters
Cubic inches	0.0173	Quarts (fluid)
Cubic inches	0.0298	Pints (dry)
Cubic inches	0.0346	Pints (fluid)
Cubic inches	0.0361	Pounds of water
Cubic inches	0.5540	Ounces (fluid)
Cubic inches	16.39	Cubic centimeters
Cubic yards	0.765	Cubic meters
Cubic yards	21.7	Bushels
Cubic yards	27.0	Cubic feet
Cubic yards	202.0	Gallons (fluid)
Cubic yards	807.9	Quarts (fluid)
Cubic yards	1,620	Pints (fluid)
Cubic yards	7,646	Liters
Cubic yards	46,656	Cubic inches
Cups	0.25	Quarts (fluid)
Cups	0.5	Pints (fluid)
Cups	8.0	Ounces (fluid)
Cups	16.0	Tablespoons
Cups	48.0	Teaspoons
Cups	236.5	Milliliters
Feet	0.3048	Meters
Feet	0.3333	Yards
Feet	12.0	Inches
Feet	30.48	Centimeters
Feet per minute	0.01136	Miles per hour
Feet per minute	0.01667	Feet per second
Feet per minute	0.01829	Kilometers per hour
Feet per minute	0.3048	Meters per minute
Feet per minute	0.3333	Yards per minute
Feet per minute	60.0	Feet per hour
Gallons (dry)	269.0	Cubic inches (dry)
Gallons (fluid)	0.00378	Cubic meters
Gallons (fluid)	0.1337	Cubic feet
Gallons (fluid)	3.785	Liters
Gallons (fluid)	4.0	Quarts (fluid)
Gallons (fluid)	8.0	Pints (fluid)
Gallons (fluid)	8.337	Pounds
Gallons (fluid)	128.0	Ounces (fluid)

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Gallons (fluid)	3,785	Cubic centimeters
Gallons of water	3.785	Kilograms
Gallons of water	8.345	Pounds of water
Gallons of water	3,785	Grams
Grains	0.0648	Grams
Grams	0.001	Kilograms
Grams	0.0022	Pounds
Grams	0.0353	Ounces
Grams	15.53	Grains
Grams	1,000.	Milligrams
Grams per liter	10.0	Percent
Grams per liter	1,000.	Parts per million
Hectares	2.47	Acres
Hectares	10,000.	Square meters
Hectares	11,950	Square yards
Hectares	107,600	Square feet
Inches	0.0254	Meters
Inches	0.0278	Yards
Inches	0.0833	Feet
Inches	2.54	Centimeters
Kilograms	0.0011	Tons
Kilograms	2.205	Pounds
Kilograms	35.28	Ounces
Kilograms	1,000.	Grams
Kilometers	0.6214	Miles
Kilometers	1,000.0	Meters
Kilometers	1,093.	Yards
Kilometers	3,281.	Feet
Kilometers per hour	0.6214	Miles per hour
Kilometers per hour	16.67	Meters per minute
Kilometers per hour	18.23	Yards per minute
Kilometers per hour	54.68	Feet per minute
Liters	0.001	Cubic meters
Liters	0.0353	Cubic feet
Liters	0.2642	Gallons (fluid)
Liters	1.0	Kilograms of water
Liters	1.057	Quarts (fluid)
Liters	2.113	Pints (fluid)
Liters	33.81	Ounces (fluid)
Liters	61.02	Cubic inches
Liters	1,000.	Cubic centimeters
Liters	1,000.	Grams of water
Meters	0.001	Kilometers
Meters	1.094	Yards
Meters	3.281	Feet
Meters	39.37	Inches
Meters	100.0	Centimeters

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Meters	1,000.	Millimeters
Metric tons	1.1	Tons (U.S.)
Metric tons	1,000.	Kilograms
Metric tons	2,205.	Pounds
Metric tons	1,000,000.	Grams
Miles	1.609	Kilometers
Miles	1,609.	Meters
Miles	1,760.	Yards
Miles	5,280.	Feet
Miles per hour	1.467	Feet per second
Miles per hour	1.609	Kilometers per hour
Miles per hour	26.82	Meters per minute
Miles per hour	29.33	Yards per minute
Miles per hour	88.0	Feet per minute
Miles per minute	26.82	Meters per second
Miles per minute	29.33	Yards per second
Miles per minute	88.0	Feet per second
Milliliters	0.00105	Quarts (fluid)
Milliliters	0.0021	Pints (fluid)
Milliliters	0.0042	Cups (fluid)
Milliliters	0.0338	Ounces (fluid)
Milliliters	0.0676	Tablespoons
Mililiters	0.2029	Teaspoons
Milliliters	1.0	Cubic centimeters of water
Milliliters	1.0	Grams of water
Ounces (dry)	0.0625	Pounds
Ounces (dry)	28.35	Grams
Ounces (dry)	437.5	Grains
Ounces (fluid)	0.00781	Gallons (fluid)
Ounces (fluid)	0.03125	Quarts (fluid)
Ounces (fluid)	0.0625	Pints (fluid)
Ounces (fluid)	0.125	Cups (fluid)
Ounces (fluid)	1.805	Cubic inches
Ounces (fluid)	2.0	Tablespoons
Ounces (fluid)	6.0	Teaspoons
Ounces (fluid)	29.57	Milliliters
Parts per million (ppm)	0.0001	Percent
Parts per million	0.001	Liters per cubic meter
Parts per million	0.001	Grams per liter
Parts per million	0.001	Milliliters per liter
Parts per million	0.013	Ounces per 100 gallons of water
Parts per million	0.0584	Grains per US gallon
Parts per million	0.330	Gallons per acre-foot of water
Parts per million	1.0	Milligrams per liter
Parts per million	1.0	Milligrams per kilogram
Parts per million	1.0	Milliliters per cubic meter
Parts per million	2.72	Pounds per acre-foot of water

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Parts per million	8.35	Pounds per million gallons
Percent (%)	1.33	Ounces (dry) per gallon of water
Percent	8.34	Pounds per 100 gallons of water
Percent	10.00	Grams per kilogram
Percent	10.00	Grams per liter
Percent	10,000.	Parts per million
Pints (dry)	0.0156	Bushels
Pints (dry)	0.0625	Pecks
Pints (dry)	0.5	Quarts (dry)
Pints (dry)	33.6	Cubic inches
Pints (fluid)	0.125	Gallons (fluid)
Pints (fluid)	0.474	Liters
Pints (fluid)	0.5	Quarts (fluid)
Pints (fluid)	2.0	Cups
Pints (fluid)	16.0	Ounces (fluid)
Pints (fluid)	28.88	Cubic inches
Pounds	0.0005	Tons
Pounds	0.454	Kilograms
Pounds	16.0	Ounces
Pounds	453.6	Grams
Pounds	7,000.	Grains
Quarts (dry)	0.03125	Bushels
Quarts (dry)	0.0389	Cubic feet
Quarts (dry)	0.125	Pecks
Quarts (dry)	2.0	Pints (dry)
Quarts (dry)	67.20	Cubic inches
Quarts (fluid)	0.00094	Cubic meters
Quarts (fluid)	0.0012	Cubic yards
Quarts (fluid)	0.0334	Cubic feet (fluid)
Quarts (fluid)	0.25	Gallons (fluid)
Quarts (fluid)	0.946	Liters
Quarts (fluid)	2.0	Pints (fluid)
Quarts (fluid)	2.087	Pounds of water
Quarts (fluid)	4.0	Cups
Quarts (fluid)	32.0	Ounces (liquid)
Quarts (fluid)	57.75	Cubic inches
Square feet	0.000009	Hectares
Square feet	0.000023	Acres
Square feet	0.0929	Square meters
Square feet	0.111	Square yards
Square feet	144.0	Square inches
Square miles	2.590	Square kilometers
Square miles	259.	Hectares
Square miles	640.	Acres
Square miles	2,590,000	Square meters
Square miles	3,098,000	Square yards
Square miles	27,880,000	Square feet

Appendix 5. Convenient Conversion Factors

Multiply	By	To get
Square yards	0.00008	Hectares
Square yards	0.00021	Acres
Square yards	0.8361	Square meters
Square yards	9.0	Square feet
Square yards	1,296.	Square inches
Tablespoons	0.0625	Cups
Tablespoons	0.5	Ounces (fluid)
Tablespoons	3.	Teaspoons
Tablespoons	15.0	Milliliters
Teaspoons	0.0208	Cups
Teaspoons	0.167	Ounces (fluid)
Teaspoons	0.333	Tablespoons (fluid)
Teaspoons	5.0	Milliliters
Tons	0.907	Metric ton
Tons	907.	Kilograms
Tons	2,000.	Pounds
Tons	32,000.	Ounces (dry)
Yards	0.000568	Miles
Yards	0.914	Meters
Yards	3.	Feet
Yards	36.	Inches