DRAFT: WRITTEN FINDINGS OF THE
WASHINGTON STATE NOXIOUS WEED CONTROL BOARD
August 2013

Scientific name: *Arundo donax* L.

Synonyms: *Arundo donax* var. *versicolor* (Mill.) Stokes, *Arundo versicolor* Mill.

Common name: giant reed, elephant grass, giant cane grass, Spanish reed, bamboo reed, donax reed, reed cane, reed grass, Danubian reed, Italian reed

Family: Poaceae

Legal Status: *Arundo donax* was not listed as a noxious weed in 2014; instead it was added to the Washington State Department of Agriculture's Prohibited Plant List, also known as the quarantine list, WAC 16-752, with the exclusion of variegated cultivars. Being added to the quarantine list means it is prohibited to transport, buy, sell, offer for sale or distribute plants or plant parts of the regulated species (*Arundo donax*) within the state of Washington. *Arundo donax* is still on the state noxious weed board's monitor list.

Images: Left, plant habit, image Eric Coombs, Oregon Department of Agriculture, Bugwood.org; Center, leaf blade width similar at the middle and at its base, image WSNWCB; Right, leaf base and auricle, image WSNWCB.

<u>Description and Variation:</u>

Arundo donax is a large perennial grass with stems that can resemble bamboo. Plants are mostly glabrous and generally grow up to a height of 8 meters (DiTomaso and Healy 2003), though sometimes noted as tall as 10 meters (Lambert et al. 2010).

<u>Stems</u>:

Arundo donax stems, also called culms, grow up to 10 meters tall in large tussocks or hedges (Allred 2007). The culms grow 1-4 cm (0.4 to 1.6 inches) in diameter and have long hollow internodes of varying lengths, generally 12-30 cm (5 to 12 inches) (McWilliams 2004, Allred 2007). First year culms are unbranched and then commonly branch the second year and may only have leaves on the branches (McWilliams 2004, DiTomaso and Healy 2003).

Roots:
Arundo donax has well-developed, creeping rhizomes that are typically more than 1 cm thick and often form a dense network, and rhizomes are firm and knotty at stem bases (DiTomaso and Healy 2003). Tough, fibrous roots grow from the rhizomes deep into the soil (Perdue 1958).

Leaves:

Image: Leaf blade pulled back to show ligule (arrow) and coloring at the base of the leaf blade, image WSNWCB.

Leaves are alternately arranged, conspicuously 2-ranked (in one plane) and are pale green to blue-green in color (Dudley 2000). Leaf blades are 5-8 cm (2 to 3.2 inches) broad at the base by 30-100 cm (11.8 inches to 3.28 feet) long (Allred 2007, McWilliams 2004). The blades are flat and taper to a fine point, with the middle and base of blade about equal in width (Allred 2007, DiTomaso and Healy 2003). Leaf margins are rough to the touch (scabrous) (DiTomaso and Healy 2003). Blade bases (region of auricles) light to dark brown, more or less broadly rounded to heart-shaped, clasping the stem, often with long, wavy hairs along the margins (Allred 2007, DiTomaso and Healy 2003). The leaf ligule is membranous, shortly ciliate and 0.4-2 mm long (Allred 2007, DiTomaso et al. 2013). Leaf sheaths are tightly wrapped around the stem and can often remain long after the leaf blades have fallen (Perdue 1958).

Flowers:
Arundo donax flowers (florets) are in large, terminal, plume-like panicles, 30-60 cm long by 30 cm wide (Allred 2007). Panicles are open with ascending branches or contracted with more or less erect branches. Spikelets are 10-15 mm and comprised of 2-4 florets (Allred 2007). Floret stalks (rachilla) are glabrous (DiTomaso and Healy 2003). Glumes at the base of spikelets are subequal in length, as long as the spikelets, thin and brownish-purplish, 3-veined and long acuminate (Allred 2007). Floret lemmas are 8-12 mm, 3-5-veined, have hairs that are 4-9 mm long, and with bifid tips having a short awn (Allred 2007). Paleas are 3-5 mm long and have hairs at the base (Allred 2007).

Arundo donax flowers mostly March through November but can occur at other times and nearly year-round in some areas (DiTomaso and Healy 2003). In California desert populations, *A. donax* has been observed flowering from August to October, but in coastal habitats, flowering occurs irregularly among years and sites (A. Lambert, personal observation in Saltonstall et al. 2010).

Images: Left, upright inflorescence, image credit Joseph M. DiTomaso, University of California - Davis, Bugwood.org; Center, inflorescence showing scale, image credit Chris Evans, Illinois Wildlife Action Plan, Bugwood.org; Right, illustration of *Arundo donax* spikelet (left) and floret (right) from Allred (2007), illustration by Linda A. Vorobik and Hana Pazdírková.

<u>Fruits and Seeds:</u>
Arundo donax fruit is a single-seeded dried fruit (a caryopsis) that is light brown and 3-4 mm long (Allred 2007). North American populations are not known to produce viable seeds (DiTomaso and Healy 2003), and no seeds have been found in Europe (Lewandowski et al. 2003 in Saltonstall et al. 2010). Some populations in Asia have been said to produce viable seed (DiTomaso and Healy 2007).

<u>Cultivars</u>
There are a number of cultivars of *Arundo donax*. Any cultivar of *A. donax* is included in this noxious weed listing. Cultivars of *A. donax*, which are primarily variegated and smaller than the species, include:

- *Arundo donax* 'Variegata': leaves striped, edge off-white
- *Arundo donax* 'Peppermint Stick': Cream and green stripes, holds color all season, inflorescence bronze-colored in fall
- *Arundo donax* 'Golden Chain': gold and green variegated leaves, smaller than *A. donax* 'Versicolor'
- *Arundo donax* 'Macrophylla': a more compact version than the species with larger leaves
- *Arundo donax* 'Versicolor': green and white variegated leaves

Images: Left, *Arundo donax* 'Variegata' leaf close up, image credit David J. Moorhead, University of Georgia, Bugwood.org; Right, *Arundo donax* 'Variegata' plants image credit John Ruter, University of Georgia, Bugwood.org.

Look-alikes:

Phragmites australis, common reed

Arundo donax is similar to, but usually larger than, *Phragmites australis*, another large grass in Washington. *Phragmites australis* has a native and non-native strain, of which the non-native strain is a Class B noxious weed and somewhat common in parts of Washington (WSDA 2011). Generally *A. donax* is taller with thicker stems, thicker rhizomes and wider leaves than *P. australis,* but there is some overlap (Allred 2007). *Arundo donax* has a wedge-shaped, broad, round-lobed or clasping leaf base while *P. australis* leaf bases gradually taper or narrow (Allred 2007, DiTomaso and Healy 2007). *Arundo donax* leaves are arranged in one plane (2 ranked), while *P. australis* leaves are not arranged in one plane. Also, *A. donax*'s floret stems (rachilla) are glabrous while *P. australis* rachilla have hairs that are (4) 6-10 mm long and *A. donax*'s lemma are hairy while *P. australis*'s lemma are glabrous (DiTomaso and Healy 2007).

Table of key characteristics between *Arundo* and *Phragmites* adapted from Nelle (2007).

Characteristic	Arundo	Phragmites
Total height	10 – 24 (30) feet	6 – 12+ feet
Leaf width	1.5 – 3 inches	.5 – 1.5 inches
Stem diameter	1 – 2 inches	.25 - .5 inches

Images: Left, *Arundo donax* with leaves arranged in one plane (2 ranked), image credit Leslie J. Mehrhoff, University of Connecticut, Bugwood.org; Center, *Phragmites australis* leaves extending from stems in many directions, image credit Greg Haubrich, WSDA; Right, *Phragmites australis* (above) with a much smaller diameter stem and narrower leaves than *Arundo donax* (below), image WSNWCB.

Habitat:

Arundo donax can sustain populations in different regions in the United States, suggesting it tolerates a wide variety of environmental conditions (Quinn and Holt 2008). *Arundo donax* grows in moist places in a variety of soils, from heavy clays to loose sands, but grows best in moist, well-drained soils (DiTomaso et al. 2013). It is typically terrestrial but tolerates flooding (DiTomaso and Healy 2003). Plants establish in riparian areas, floodplains, ditches, culverts, and roadsides. It can often be found along drainage ditches, where it was planted for bank stabilization (Dudley 2003). It is more likely to establish in field conditions that provide bare ground and ample soil moisture (Quinn and Holt 2008).

Plants tolerate some salinity and extended periods of drought but not in areas with prolonged or regular periods of freezing temperatures (DiTomaso and Healy 2003). Its ability to survive and grow in drought conditions is due to its coarse, drought-tolerant rhizomes and deep growing roots that reach deep-seated sources of moisture (Perdue 1958). *Arundo donax* can also colonize marine islands after flooding that has transported rhizome fragments from rivers across ocean waters (Lambert et al. 2010).

Arundo donax grows in full sun to part shade and can survive in low light levels. Spencer (2012) found that *A. donax* tolerated significant shading, surviving in 90% reduction of full sun.

Images: Left, *Arundo donax* growing in a community garden in South Seattle, image credit WSNWCB; Right, *Arundo donax* growing on the edge of stream in California, image credit Joseph M. DiTomaso, University of California - Davis, Bugwood.org.

<u>Geographic Distribution:</u>

<u>Native Distribution:</u>
The USDA ARS (2013) GRIN database lists *Arundo donax* native to:

- Temperate parts of Asia (Saudi Arabia, Afghanistan, Iran, Iraq, Syria, Kazakhstan, Turkmenistan, Uzbekistan, China and Japan)
- Tropical parts of Asia (Bhutan, India, Nepal, Pakistan, Cambodia, Laos, Myanmar, Thailand, Vietnam, Indonesia and Malaysia)

According to the USDA ARS (2013) GRIN database, *Arundo donax* has naturalized in many parts of the world:

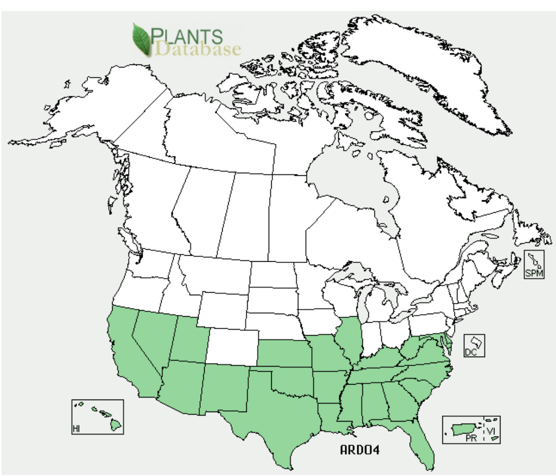
- Africa (Macaronesia and Northern Africa)
- Temperate Asia outside of its native range (western Asia: Cyprus, Israel, Jordan, Lebanon, Turkey, Azerbaijan and Georgia)
- Australia
- New Zealand

- Europe (Hungary, Switzerland, Ukraine, Albania, Croatia, Greece, Italy, Romania, France, Portugal and Spain)
- South America (West Indies, Costa Rica, El Salvador, Guatemala, Nicaragua, Suriname, Venezuela, Brazil, Bolivia, Ecuador, Peru, Argentina, Chile and Uruguay)
- North America (Canada, United States and Mexico)

Distribution in North America:
Though it may have been originally introduced to North America for musical instrument reed production and for soil stabilization, it is more commonly cultivated today as an ornamental species, with increasing interest of it being used as a biofuel (Leighton 1976, Hitchcock 1950, Isaacson 1996, all in Mack 2008, Barney and DiTomaso 2008).

Arundo donax has been documented in Canada, the United States and Mexico (McWilliams 2004). Currently *A. donax* is not known to have escaped into any natural systems in Canada (Brouillet et al. 2010 in USDA 2012). It is only known to grow in botanic gardens and is available from some nurseries in southern Ontario and southern British Columbia (CNLA 2008, Isaacson and Allen 2007 in USDA 2012). At least four provinces in Mexico have escaped *A. donax* populations and it is likely to be present in other areas of Mexico as well (McWilliams 2004).

The PLANTS database (USDA NRCS 2013) lists escaped *Arundo donax* growing in the United States, specifically:
Hawaii, California, Nevada, Utah, Arizona, New Mexico, Texas, Kansas, Oklahoma, Missouri, Arkansas, Louisiana, Illinois, Kentucky, Tennessee, Alabama, Georgia, Mississippi, West Virginia, Maryland, Delaware, Virginia, North Carolina, South Carolina, Florida, Puerto Rico and also in the Virgin Islands. Though not listed in PLANTS, Oregon has recently had at least one escaped population of *A. donax*, though it has since been controlled (Miller and Forney 2011). Southern California and along the Rio Grande in Texas and Mexico have been noted to have experienced the greatest negative impacts from *A. donax* invasion (Bell 1997, Dudley and Collins 1995, Dudley 2000 all in Lambert et al. 2010).




Images: Left, *Arundo donax* distribution map from USDA NRCS PLANTS database (2013); Right, map predicting the potential spread of *Arundo donax* in the United States and Canada based on suitable habitat, map insets for Hawaii, and Puerto Rico are not to scale (USDA 2012).

Arundo donax has the following noxious weed and/or quarantine listings in the United States:

- Texas: listed as a noxious weed, it is an offense to sell, distribute or import
- California: noxious weed list
- Colorado: list A noxious weed designation
- Nebraska: listed as an aquatic invasive species—unlawful to possess, import, export, purchase, sell transport or release into the waters of the state
- Nevada: category A noxious weed, and actively eradicated from nursery stock dealer premises
- Oregon: quarantined except for variegated cultivars (effective December 31, 2013); permit required for planted populations over ¼ acre for biofuel or other economic purposes (National Plant Board 2013, OAR 603-052-1211 2012).

California:
In California, from the late 1700s to early 1800s, *Arundo donax* was planted for erosion control in flood channels and as wind breaks (DiTomaso et al. 2013) and was also harvested for roofing material and fodder (Dudley 2000). Currently *A. donax* is listed as a noxious weed and the California Invasive Plant Council Inventory categorized it as being highly invasive. More recently it has become problematic in riparian corridors in many areas of the state (DiTomaso and Healy 2007).

Oregon:
In Oregon, *Arundo donax* has been sold as an ornamental plant in the nursery trade and cultivated for the production of reeds for musical instruments. It was placed on Oregon's Watch List in 2007 with only one escaped population found so far in the state, growing in Jackson County along Bear Creek in Medford (Miller and Forney 2011). Recently, *A. donax* has been undergoing trials for its possible use as a biofuel. To accommodate this potential new biofuel crop, the Oregon Legislature passed a rule with the intent of balancing the goals of developing new agricultural crops and supporting renewable energy development while protecting natural resources and preventing the establishment of *A. donax* in riparian areas, where it could cause major negative impacts to natural resources (OAR 603-052-12 2012).The rule allows commercial production under a permit with an assessment fee to cover the cost of monitoring and a bond to cover the cost of eradication if needed (OAR 603-052-1211 2012). Also under this rule, *A. donax* cannot be planted, grown, or stored in riparian areas, wetlands, or special flood hazard areas (100-year flood plains) or in a 100 ft. buffer beyond the edge of riparian areas, wetlands, or flood hazard areas. Additionally, beginning in 2014, only variegated cultivars of *A. donax* can be sold for ornamental plantings, to lower the risk of ornamental or woodwind reed plants becoming feral. It is still possible to plant variegated cultivars of *A. donax* for ornamental purposes and to cultivate *A. donax* for woodwind reeds totaling less than ¼ acre without a permit (OAR 603-052-1211 2012).

In Oregon, a five-acre plantation established near Junction City grew poorly in clay soil and after a few years of growth, was removed in 2009 (Miller and Forney 2011). Portland General Electric (PGE) is presently conducting trials in Boardman to see if *A. donax* can be used as an alternative to coal for production of electricity.

<u>History and Distribution in Washington:</u>

Currently, no significant escaped populations of *Arundo donax* are known of in Washington State. There are no herbarium records of *A. donax* in online records for Washington State or the Pacific Northwest (Consortium of PNW Herbaria 2013).

Plantings of *A. donax* were established in Prosser in 2003 and 2006 to study its vigor growing east of the Cascades Mountains in the Pacific Northwest (Miller and Forney 2011). According to Miller and Forney (2011) the 2006 planting diminished in vigor and density and had a high mortality rate (83%) during the winter of 2008. It is theorized that the high mortality rate may have been due to the shallow planting of the rootstocks or insufficient water in the winter. Currently there is at least one known commercial planting of *A. donax* in Walla Walla County.

Arundo donax occurs in some landscape plantings throughout the state due to its availability in the nursery trade. For example, there is an ornamental planting of *A. donax* in a city park in Yakima (Dick Jacobson pers. comm.) and one in Tacoma on the waterfront (Dave Heimer pers. comm.). There are a couple of known ornamental plantings of *A. donax* in King County. One such planting is by a community garden in south Seattle that may have some new patches forming around the site, but it is unknown if the spread is intentional by the local gardeners.

Biology:

Growth and Development:

Arundo donax produces new culms in the spring from its rhizomes and continues until fall, when the deposition of photosynthate reserves into the rhizome ceases (Motamed and Wijte 1999 in Wijte et al. 2005). During the growing season, new stems grow from nodes near the tips of the rhizomes (Wijte et al. 2005). The rhizome length between nodes is rarely more than 5-10 cm (Wijte et al. 2005). Expansion of plants by rhizome growth was measured in a flood zone of the Tijuana River Valley over a two year period and found to be significantly faster in the flood zone (mean = 0.41 +/- 0.05m 2 yr^{-1}) than outside of the flood zone (mean = 0.18 +/- 0.04m 2yr^{-1}) (Boland 2006). In a dense clump, there may be up to 80 stems per square meter in favorable conditions (Wijte et al. 2005). The growth rate of *A. donax* may vary depending on site conditions. Under optimal conditions, *A. donax* can grow rapidly, with rates noted of 0.3 to 0.7 meters of stem growth per week (Perdue 1958) to over 5 cm a day (Bell 1997 in Balogh et al. 2012). The first year culms are unbranched and photosynthetic while branching normally occurs after the first growing season, with first season stems losing their green color and becoming lignified during the fall (Decruyenaere and Holt 2011).

When dormant, *Arundo donax* can survive low temperatures but it is subject to damage when frost occurs after the initiation of spring growth (Perdue 1958). Dead culms lose their leaves, are grayish in color, become brittle, splintery, and fall over, typically remaining until the next flood or fire (DiTomaso and Healy 2003).

Reproduction:

Arundo donax is currently known to spread only by vegetative means in North America, since it does not produce pollen or viable seed (Balogh et al. 2012). Genetic fingerprinting indicates a single genetic clone of *A. donax* in the United States (Balogh et al. 2012), though Giessow et al. (2012) report several phenotypes present along the Santa Ana River in California and that moderate levels of genetic diversity are present. Plants vegetatively reproduce from rhizomes, rhizome and stem fragments (DiTomaso et al. 2013), and layering (Boland 2006). Layering occurs when a stem develops adventitious roots and shoots where it contacts the soil (Grace 1993 in Boland 2006). It is common for the layering stem to be buried and it typically dies within a few months, resulting in fully independent young plants several meters from the original clump (Boland 2006).

Rhizome and stem fragments with a node can develop into a new plant under suitable moist conditions (DiTomaso and Healy 2003). Vegetative reproduction by rhizome fragments appears to be more common than by stem fragments (Boland 2008). Wijte et al. (2005) found in controlled environments that stem fragments ranging in size from 1 to 10 cm long (and even if split lengthwise) could successfully regenerate as long as the fragment had an axillary bud. If the axillary bud is damaged the stem fragment will not develop shoots or roots (Wijte et al. 2005). Stem fragments with a bud can sprout when buried less than 10 cm and rhizome fragments readily develop new shoots from a depth of 25 cm (Boose and Holt 1999). Intact rhizomes buried under 1-3 meters of silt can develop new shoots as well (DiTomaso and Healy 2007). Stem fragments are salt tolerant and can still regenerate at water salinities of 15 g NaCl per liter (Peck and Wijte 1997 in Wijte et al. 2005).

Vegetative reproduction may vary depending on site conditions and events. Boland (2006) only found stems layering from existing populations in a flood zone and not from new introductions of plants from outside of the flood zone. Layers were formed when flooding caused stems to bend, their tips became embedded in wet mud, and within a few weeks stems and roots had sprouted (Boland 2006). Boland (2006) proposed that fragments provide the initial long distance dispersal of *A. donax*, rhizomes maintain the clump, and layers carry out the fast spread into open space. Stem and rhizome fragments commonly disperse with water, mulch and human activities (DiTomaso et al. 2013, Boland 2008). Riverbanks can be undercut by flooding, which breaks off or scours out rhizome fragments (Brinke 2010 in Giessow et al. 2011). Flash flooding events both aid in break up and dispersal of plant fragments and create open habitat for establishment (Saltonstall et al. 2010).

Images: Left, *Arundo donax* layering, image by Joseph M. DiTomaso, University of California-Davis, Bugwood.org; Right, second year new growth from first year stems in Seattle, image WSNWCB.

<u>Control:</u>
Controlling large infestations of *Arundo donax* is an expensive endeavor (USDA 2012). In a cost benefit analysis by Giessow et al. (2011) examining all the control costs of *A. donax* in coastal California (Monteray to San Diego), control costs averaged out to $25,000 per acre. Control costs using herbicide have also been noted to reach up to $20,000 per hectare (Mack 2008 in Miller and Forney 2011). *Arundo donax* should be monitored for and controlled as soon as possible to reduce population spread and subsequent increases in management costs. In order to prevent reestablishment of *A. donax* after control, rhizomes must be removed or killed to eradicate infestations (DiTomaso and Healy 2003).

After controlling *Arundo donax*, it is important to plant areas with desirable plants. Deliberate plantings on site could help delay *A. donax*'s initial re-establishment into managed areas, but community resistance may not be sustainable, depending on the species used (Quinn and Holt 2009). In one study, Quinn and Holt (2008) found plots containing the shrub seepwillow (*Baccharis salicifolia*) seemed to resist establishment by *A. donax* for one year but it may have also have resisted colonization by other native species. Careful planning of the vegetation community to be planted—with consideration of species recruitment capabilities and planting densities—are important steps in restoration after *A. donax* control. Monitoring sites after *A. donax* control and restoration will be needed to rapidly respond to any rhizome or stem resprouts.

<u>Mechanical Methods:</u>
DiTomaso et al. (2013) note that small infestations of *Arundo donax* can be hand pulled or dug out of the ground, making sure to remove all rhizomes. These methods work well when sensitive native plants or wildlife might be damaged by other control methods (DiTomaso et al. 2013). It is best to pull plants in loose or moist soil before they reach 6 feet tall (Dudley 2000). The earlier *A. donax* can be controlled, the less plant materials there will be to dispose of or compost. Also, stems can be cut back to the base of the plant (with pruning shears, machete, or chainsaw) and then followed up with the removal of rhizomes from the soil (with a pick-ax, mattock and/or shovel) (Dudley 2000).

Chopping, cutting or mowing (e.g., rotary brush cutter, tractor-mounted mower) can also be used to reduce the infestation, although the fibrous nature of *A. donax* can make using these techniques challenging (DiTomaso et al. 2013).Though cutting or mowing generally causes less soil disturbance, it is non-selective and doesn't impact the plant's rhizomes. Make sure to properly dispose of cut stems after treatment. Even with several cuttings, larger stands will be able to survive years of treatment (DiTomaso et al. 2013).

Mechanized equipment, such as a backhoe, is commonly used to remove *Arundo donax* (DiTomaso et al. 2013). Again, all rhizomes will need to be removed as any left in the ground will resprout. With rhizomes being able to establish from deep in the soil, this method may not eradicate *A. donax* as fragments could be easily buried or left behind, and other methods will be needed in combination.

Like mowing, prescribed burning of *Arundo donax* will remove the culms but will not kill the plant's rhizomes (DiTomaso and Healy 2003) so other management methods would also be needed. Fire can also damage other desirable plants in the plant community. A weed burner device can be used as a spot treatment to heat girdle stems at the base (DiTomaso et al. 2013). This technique is less costly than basal and stem herbicide treatments and is suitable for use during wet weather when wildfire hazard is low (DiTomaso et al. 2013). Effectiveness is comparable to manual cutting. Burning is best followed by herbicide treatment of resprouting plants (DiTomaso et al. 2013). Stems and roots should be removed, chipped or burned on site to prevent resprouting (DiTomaso et al. 2013). While a chipper can be used, the fibrous nature of the material may cause clogging and make chipping difficult (R. Dale, pers. comm. in Dudley 2000). Chipping of dried plant material poses no threat for regeneration or forming debris dams (Bell 1997). Make sure to clean all equipment of plant parts to prevent introducing *A. donax* to new areas.

<u>Cultural Methods:</u>
Starving the *Arundo donax* of light by using tarps is a control option. Circuit Rider Productions (2007) developed a protocol for tarping *Arundo donax*. It states to first cut the *A. donax* stems to a standard height as close to the ground as possible. Make sure the stem cuts are level to avoid holes in the tarp and injury if a fall occurs. Next, use tarp pieces that are as large as possible to minimize edges and make sure to overlap edges to prevent *A. donax* from growing out. Then, secure the tarp with staples and/or other

heavy objects. After tarp installation, it is important to monitor the tarp every two weeks and patch any holes that occur. The timing of tarp installation is important—begin the treatment during the active growing season when there is minimal risk of tarps being dislodged by floodwaters. If tarps are installed out of a flood area then the installation time is more flexible. Tarps may need to be reapplied the following season to allow for complete kill and areas should be monitored after tarp removal to ensure roots masses will not resprout.

Biological Control:
Grazing animals can assist in the control of *Arundo donax*. The most successful grazers of *A. donax* are goats, particularly Angora and Spanish goats (DiTomaso et. al 2013). Using goats is cost-effective and they can maneuver over difficult terrain, but desired plants need protection as grazing is non-selective (DiTomaso et al. 2013). *Arundo donax* is known to not be very palatable to cattle but they will graze on it during drier months (DiTomaso et al. 2013). Sheep also have potential as grazers and have been shown to survive for extended periods on strict diets of *A. donax* (DiTomaso et al. 2013). However, sheep must be properly managed to prevent soil compaction problems, particularly in wet areas (DiTomaso et al. 2013).

Currently there are no approved biological control agents for *Arundo donax*. Research is underway to determine if the Arundo wasp (*Tetramesa romana*), the Arundo scale, (*Rhizaspidiotus donacis*) and the Arundo fly, (*Cryptonevra* sp.) could be successful biological control agents (Hoddle 2010). So far, the Arundo wasp was found to be specific to *A. donax* and so it is unlikely it would harm native or cultivated plants here. Extensive testing still needs to be done before these biological control agents could be approved for use (DiTomaso et al. 2013).

Chemical methods:
Arundo donax is not listed in the Pacific Northwest Weed Management Handbook.

DiTomaso et al. (2013) provide the following herbicide recommendations for *Arundo donax*:

- Glyphosate: For broadcast spray treatment: 2.25 to 4.5 lb a.e./acre or 2 to 4 lb a.e./acre around aquatic sites. Spot treatment 2% v/v solution. Two to three years of treatment are necessary. Apply mid-summer to fall after flowering and before dormancy for the best timing to control plants and to prevent injury on many natives. A follow up application in spring may be necessary. For cut stump treatment: undiluted glyphosate can be applied with a paint brush within 1 to 2 minutes after cutting stems within 5-10 cm (2-4 inches) of the ground (DiTomaso et al. 2013, Dudley 2000). Results have shown that glyphosate can be used for cut stem treatment year round (if the conditions meet label requirements) but may be best in the fall (Dudley 2000).

- Imazapyr: Using 0.5-1 lb a.e. (1 to 2 qt. product) in a fall application. Since it does have soil residual activity, using this treatment may impact restoration efforts.

- Using a mix of Imazapyr +glyphosate: 1 pt imazapyr (Habitat) + 1 qt. glyphosate product/acre (0.25 +1 lb a.e./acre, respectively). Apply mix in the fall, using these two herbicides together is thought to provide better control at lower rates of each herbicide, making it more affordable compared to imazapyr alone.

Spencer et al. (2008) found that 3% or 5% foliar applications with glyphosate were the most effective and consistent treatments for killing *Arundo donax* with a single late-season application when plants are translocating nutrients to their rhizomes. Treatments with 1.5% concentrate resulted in significant decline of living stems but new stems were observed the following spring. This result is important if the goal of the treatment program is to minimize the number of treatments, thus reducing labor costs and minimizing impacts on sensitive habitat by reducing the number of site visits (Spencer et al. 2008).

In other trials by Spencer et al. (2010), plants treated with a 1.5% imazapyr foliar spray had reduced leaf chlorophyll content less than 30 days after treatment but recovered the following spring.

Using a combination of treatments can also be effective. Cutting or burning plants followed by a foliar treatment of glyphosate on the regrowth, when stems are 1-2 meters tall (3 weeks to 3 months later) can control *Arundo donax* (DiTomaso et al. 2013, Dudley 2000).

Economic Importance:

Detrimental:

Arundo donax is a highly invasive grass in riparian areas, especially in disturbed areas, crowding out native plants species. Bell (1997) estimates *A. donax* has successfully invaded tens of thousands of acres along the major coastal drainage systems of southern California. Where it invades, *A. donax* lowers diversity and creates monocultures. Cushman and Gaffney (2010) documented a significantly lower richness of native perennial plant species on stream banks and floodplains in northern California that had *A. donax* infestations. When *A. donax* was controlled, Cushman and Gaffney (2010) found a significant increase in native plant species richness and abundances of both established plants and seedlings. Additionally, McWilliams (2004) cites a study by Chadwick and Associates suggesting *A. donax* also lacks the canopy structure to provide shading of bank-edge river habitats, resulting in warmer water than would be found with native plants.

Where *Arundo donax* invades, it typically develops dense monocultures that diminishes wildlife habitat (DiTomaso and Healy 2003). It provides few to zero food sources or nesting habitat for native animals (Zembal 1998). *Arundo donax*'s most observed use as cover has been by invasive feral pigs (Zembal 1998). In California, *A. donax* competes with native woody species that provide nesting habitat for the federally endangered bird, the Least Bell's vireo (*Vireo bellii pusillus*), the federally threatened bird, the willow flycatcher (*Empidonax traillii eximus*) and other native species (Hendricks and Rieger 1989; Franzreb 1989; Zembal 1986 and 1990 all in Bell 1997).

Arundo donax consumes large amounts of water, taking this resource away from native plants, wildlife and other uses such as agriculture. Transpiration rates of *A. donax* are calculated to be 56,200 acre-feet of water per year on the Santa Ana River, compared to an estimated 18,700 acre-feet that would be consumed by native plants (Hoddle 2010). The Orange County Water District (2003) reports that this annual consumption of water by *A. donax* has an estimated value of $18 million (in Miller and Forney 2011). Watts and Moore (2011) studied stands of *A. donax* in south Texas and found they used approximately 8.8 +/- 0.9mm of water per day during a peak growing season and noted this rate of water use is high for plants. Another estimate of water use from Bell (1997) is that *A. donax* can use as much as 528 gallons of water per square meter. Large stands have also significantly increased water loss from underground aquifers in semiarid regions due to high evapotranspiration rates (DiTomaso and Healy 2003).

In addition, *Arundo donax* is adapted to a periodic fire regime (DiTomaso and Healy 2003). *Arundo donax* can dominate riparian woodlands after a fire and can allow the area to be more susceptible to future fires as it is readily flammable throughout much of the year (Coffman et al. 2010, DiTomaso and

Healy 2003). Within days after a fire, *A. donax* can resprout and has a higher growth rate and productivity compared to native riparian plants, growing 3 to 4 times faster than native woody riparian plants (Coffman et al. 2010). *Arundo donax* one year post fire was nearly 20 times higher and more productive, by 14-24 times, than four native woody species. Coffman et al. (2010) note three mechanisms appear to give *A. donax* an advantage over native species after a fire: fire adapted phenology, high growth rate and growth response to nutrient enrichment. Thus, fire events tend to help push riparian stands in the direction of pure *A. donax* (Bell 1997).

The displacement of a native plant community by *Arundo donax* can alter the use of critical riparian ecosystems by wildlife and intermediate trophic levels (Herrera and Dudley 2003). *Arundo donax* dominance reduces arthropod abundance and diversity (Herrera and Dudley 2003). Aerial arthropod assemblages associated with native riparian plant communities are significantly reduced when the system is dominated by *A. donax*. Herrera and Dudley (2003) found that in the spring where native wood plants dominate the riparian vegetation, the associated invertebrate assemblages were both more diverse and approximately double the abundance of those found in patches dominated by *A. donax*. Dominance of *A. donax* in riparian areas also leads to decline in avian diversity and abundance (Kisner 2004 in Lambert et al. 2010) and it is also noted to have led to the extinction of a rare fish species near Monterrey, Mexico (Flores and Wood 2009).

Arundo donax grows quickly and is well adapted to the dynamics of riparian systems (Bell 1997) making it difficult to control. Flood events can break up rhizomes and spread pieces downstream where they can establish new clones (Bell 1997). *Arundo donax* can also create large debris piles that threaten the structural integrity of bridges and other in-stream structures that require expensive debris removal and cleanup following flood events (Miller Forney 2011).

Arundo donax has been noted to have little use as livestock forage, its leaves quickly mature and become unpalatable (Ryan 2001). Though it is not very palatable to cattle, they will eat it during dry seasons (Hoshovsky 1986 and Wynd et al. 1948 in McWilliams 2004). Bell (1997) summarizes a number of the chemicals found in *A. donax* stems and leaves, including silica (Jackson and Nunez 1964), tri-terpines and sterols (Chandhuri and Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal *et al.* 1972), hydroxamic acid (Zuñiga *et al.* 1983), and numerous other alkaloids which, along with its high lignin content, may make it unpalatable and protect it from most native insects and other grazers (Miles et al. 1993, Zuñiga et al. 1983).

The high density of *Arundo donax* growth along the U.S. and Mexico border has caused safety and security problems for the border patrol (Goolsby 2007 in Seawright 2009).

Arundo donax is also noted by DiTomaso and Healy (2003) as an alternate host for beet western yellows virus, sugarcane mosaic virus, and maize dwarf mosaic virus.

<u>Beneficial:</u>
<u>Biofuel:</u>
Increasing energy demands have sparked interests in non-native plants as fuel sources. *Arundo donax* could be a promising bio-energy crop because of its high biomass yield, but there is concern of its use as a biofuel crop given it is a known invasive species in riparian areas (Mack 2008). Currently *A. donax* is under consideration internationally and in a number of places in the United States as a biofuel crop, including Boardman, Oregon where it is being test grown (Virtue et al. 2010, Barney and DiTomaso 2008).

The North American Weed Management Association (now called the North American Invasive Species Management Association) wrote a letter, dated September 27, 2012, opposing a proposal by the Environmental Protection Agency (EPA) to rule known invasive plants as potential biofuels in the United States, specifically mentioning *Arundo donax* and napiergrass. The EPA issued a supplemental final rule associated with the Renewable Fuel Standard (RFS) program in June 2013 determining that *A. donax* and napier grass qualify as cellulosic renewable fuel under the RFS program (EPA 2013). EPA is also adopting a set of new registration, recordkeeping, and reporting requirements to minimize the risk that these species should behave as invasive species and require remediation activities that may cause additional green house gas emissions (EPA 2013). For example, renewable fuel producers will be required to demonstrate that the growth of *A. donax* will not pose a significant likelihood of spreading beyond the planting area or that such a risk will be minimized through an EPA-approved Risk Mitigation Plan (EPA 2013).

Ceotto and Di Candilo (2010) note that floral sterility is beneficial for *Arundo donax* as a biofuel as it will not spread to neighboring fields by seed, but the lack of seeds makes propagation and planting more costly. They also point out that despite the successful yields that have been obtained in field plot experiments, large-scale cultivation of *A. donax* is still a challenge. Rhizome propagation, which is primarily used to plant fields, has high human labor needs, is expensive and requires a large number of parent plants to establish a crop. One drawback seen by Ceotto and Di Candilo (2010) is that in northern Italy, crops can live 15 years and farmers may not want to commit their fields for that period of time to the crop if the price for lignocellulosic biomass cannot be guaranteed.

There have been proposals for large plantations of *Arundo donax* in the United States, including plans in 2006 to build a 130,000 kW power plant in central Florida fueled by *A. donax* (Anonymous 2006 in Mack 2008). Given its growth traits and spread, Barney and DiTomaso (2008) concluded that *A. donax* would be rejected for introduction into Florida, if the state used the Australian Weed Risk Assessment protocol (Mack 2008). Due to economic issues, the plans for the Florida power plant have been delayed (Mack 2008). At the Seventeenth Australasian Weeds Conference, it was concluded that *A. donax* had potential as a highly productive biomass crop in non-riparian areas in Australia that should be carefully regulated under a permit in conjunction with a noxious weed legislative framework (Virtue et al. 2010).

While *Arundo donax* does have merits that may make it a source of biofuel, many features of this plant are commonly cited as traits of a plant invader (Daehler 2003 in Mack 2008). Containment of *A. donax* would need to be diligently maintained where it is planted as an economic crop (Mack 2008).

<u>Other Benefits:</u>
Arundo donax has been historically cultivated across Asia, southern Europe, North Africa, and the Middle East (Perdue 1958 in Lambert et al. 2010). Plantings of *A. donax* have been maintained in rural areas for fence material, roof thatching, construction of baskets and other artisanal products, and food preparation (Lambert et al. 2010, Perdue 1958). It is still used in many parts of the world for house construction, lattice-work, mats, screens, stakes, walking sticks, and fishing poles (Allred 2007). In the Mediterranean region, *A. donax* has been used for many garden purposes including lattices for drying fruit, baskets, fences, and trellises, and the leaves are used for tying up vines and other plants (Perdue 1958). At one location in South Seattle with a few small patches of *A. donax*, it appeared the stems were being used for some of these purposes such as for propping up plants and for lattices (W. DesCamp and G. Haubrich pers. obs. 2013).

Reeds for woodwind musical instruments are made from *Arundo donax* culms (Perdue 1958). Substitute products have been tested over the years but nothing has been found to be a suitable substitute to make reeds out of other than *A. donax*. The plant has also been used as a source of cellulose for rayon manufacture and it is also being used as a source of pulp to make paper (Duke 1983, Perdue 1958). At least one company is growing a test field of *A. donax* in Washington to be used as a tree pulp substitute for paper, as well as for other potential uses.

Arundo donax continues to be sold horticulturally throughout the U.S. including a variegated form that is known to have escaped in some areas (Dudley unpublished data in Lambert et al. 2010). It is promoted as a bold and attention-grabbing accent in large gardens (Christman 2003). The large, thick and fluffy flower plumes are noted to be excellent in dried arrangements (Christman 2003).

Medicinally, *Arundo donax* has been used for a number of purposes including a diaphoretic, a diuretic, an emollient, a galactofuge and a hypotensive (Plants for our Future 2013).

Arundo donax is also capable of taking up undesirable chemicals in soil. *Arundo donax* performs well in constructed wetlands treating dairy factory stormwater, removing biochemical oxygen demand, total nitrogen and total phosphorus (Idris et al. 2012). Some research has been conducted to show that *A. donax* may be used for the remediation of arsenic contaminated soils (Mirza et al. 2011).

Rationale for Listing:

Arundo donax is a highly invasive, non-native, perennial grass that forms dense monocultures of stems reaching 20+ feet tall. It readily invades riparian areas, where it causes erosion, damages bridges, alters channel morphology, increases costs for chemical and mechanical control along transportation corridors, and impedes law enforcement activities along international borders. Additionally, *A. donax* consumes excessive amounts of water, competing for water resources in arid regions where these resources are critical to the environment, agriculture, and municipal users. *Arundo donax* has escaped cultivation and naturalized in numerous countries including the United States and Mexico. It is particularly problematic in California, where it has formed pure stands over thousands of hectares of riparian habitat. These infestations have reduced natural biodiversity, pose a significant fire risk, and use substantial amounts of valuable ground-water in arid regions. In our region, given the course of climate change, *A. donax* may become as competitive here as in the southern states and could impact salmon recovery efforts.

Currently *A. donax* is being tested and grown for use as a biofuel crop due to its high biomass yield. It is also used for a variety of other purposes including ornamental, reeds for musical instruments, a building material and paper pulp. With its limited distribution in Washington*, A. donax* is a candidate for a Class B noxious weed listing (except where commercially grown) to be designated within riparian areas, wetlands, special flood hazard areas (100-year flood plains), irrigation waterways, or in a 100 ft. buffer beyond the edge of riparian, wetland, and special flood hazard areas in regions 1, 2, 3, 4, 5, and 6. This listing will require control in habitats susceptible to invasion while still allowing for its commercial planting.

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