Early Detection and Rapid Response Plan for Giant Reed (*Arundo donax* L.) in Oregon

Portland State
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2015

EXECUTIVE SUMMARY

Cultivation of Arundo (*Arundo donax* L.) for a variety of purposes dates back hundreds of years or more in many parts of the world. Unfortunately, it is also a highly invasive weed in riparian areas and other wet habitats in the United States. It is considered one of the worst invasive plants in California and Texas where it has spread extensively along river corridors and drainage canals. Arundo tolerates a wide range of environmental conditions and is naturalized in many states, ostensibly after escaping from intentional plantings for erosion control and ornamental purposes. In Oregon, Arundo is known to successfully over-winter west of the Cascade Mountains as ornamental plantings, but it is unclear how capable it is of surviving outside cultivation in eastern Oregon where cold and dry conditions predominate during the winter months.

Portland General Electric (PGE) operates the 585-megawatt capacity Boardman Power Plant, which came on line in 1980. In order to meet new federal and state rules focused on reducing regional haze, improving visibility in wilderness and scenic areas, and reducing CO_2 emissions, coal burning at Boardman will cease no later than December 31, 2020 (Pedersen 2010). The Boardman facility was originally planned to operate through 2040, so rather than shutting the plant, down PGE is investigating the possibility of converting it to run on renewable energy sources. Such a conversion would help meet targets in Oregon's Renewable Portfolio Standard, which calls for major energy providers to produce a minimum of 25% renewable energy by 2025. Additionally, a biofuel powered plant would complement intermittent energy sources such as wind farms already in place by providing a source of renewable base-load energy to help meet energy needs during peak demand periods or lulls in wind energy.

After considering a few alternatives to coal, PGE determined torrefied biomass to be the most suitable option for the Boardman facility. Torrefied biomass, sometimes referred to as biochar, is an energy-dense biofuel produced by the controlled roasting of biomass crops in the absence of oxygen. Large amounts of biomass would be needed to fire the Boardman plant. PGE has evaluated 27 potential biomass sources, including wheat straw, poplar, sorghum, hog fuel, and others and concluded that Arundo was a

viable option due to its reportedly high yields (potentially up to 35 dry tons per acre) and easily handled chips. Estimates suggest 1.25 million tons of torrefied Arundo would be required annually to produce the desired energy output (300 MW); that would require cultivating approximately 67,000 acres of Arundo (Lewis et al. 2012). Less acreage would be required if Arundo was used in combination with other viable biomass resources.

The Oregon Department of Agriculture placed Arundo on their watch list of potential weeds in 2004 (ODA 2013). When dialog began in 2011 regarding its potential large-scale cultivation by PGE, ODA revised their risk assessment and concluded that although their metrics suggest Arundo might qualify as a noxious weed, they would recommend it remain unlisted due to Arundo's "lack of seed production, lower risk of natural spread, limited economic impacts, lack of health impacts, capacity to control, and probability of detection". ODA developed a control area order which detailed measures aimed to mitigate chances of this potential weed escaping into the wild. The control area order (OAR 603-052-1206 to 603-052-1211), finalized in 2012, was drafted with input from a variety of agencies, organizations, tribal liaisons, and individuals involved with natural resources, many of whom held reservations about large-scale propagation or Arundo. PGE has contracted with growers in Morrow County to grow 90 acres of Arundo in compliance with the control area order; biomass from these fields will be torrefied and used for a test burn at the Boardman plant targeted for 2015.

Efforts in Oregon and elsewhere have demonstrated that the most effective weed management programs focus on prevention, early detection and a rapid, coordinated response to pioneer weed infestations. This EDRR Plan for Arundo in Oregon summarizes existing knowledge of Arundo biology (including current distribution, growth habits, anatomy, physiology, reproduction, and dispersal capacity) and outlines strategies to prevent naturalized populations through best management practices for cultivated stands, targeted surveys, increased awareness and effective control responses. **Arundo management in Oregon should remain focused on preventing the establishment and spread of feral Arundo populations in Oregon riparian areas, wetlands and other natural areas.** If feral Arundo is found in Oregon, a successful coordinated approach will hinge on the cooperation of preserve and refuge managers, agriculturists, private landowners, state and federal agencies. Management options include digging, cutting, fire, biological control agents and chemical methods. An integrated strategy that includes a combination of management methods is likely to be required.

Current detection efforts in Morrow County include regular (weekly and seasonal) visual inspections of all cultivated field perimeters by PGE and the Morrow County Weed Control Program. The Morrow Soil and Water Conservation District (SWCD) has completed two years of annual visual inspections and photo points at fixed points of interest and/or transportation crossings along the Umatilla River, Willow Creek and the south shore of the Columbia River (pers. comm., W. Lei, PGE). Should feral Arundo be detected in the Pacific Northwest, remote sensing using aerial or satellite imagery could also become a valuable tool.

The following actions are recommended for Arundo early detection and rapid response in Oregon.

1. Prevention
    a. Variegated varieties may be as invasive as the fully green varieties and should be prohibited for sale and cultivation
    b. Assess the effectiveness of the 100-foot buffer zone currently in rule
2. Detection
    a. Expand passive surveillance statewide, particularly in urban areas
    b. Expand active ground and boat surveillance in areas near and downstream from Umatilla County Arundo plantations, including the Columbia River
    c. Conduct delimiting surveys around all known feral and cultivated stands of Arundo in Oregon outside the Control Area
    d. Develop and apply remote sensing capabilities in Oregon
    e. Utilize helicopter and fixed-wing surveys when the opportunity arises
3. Outreach and Education
    a. Increase outreach to gardeners and natural resource personnel to enhance passive surveillance capability
    b. Identify and publicize horticultural alternatives to planting Arundo
    c. Institute an Arundo exchange program to encourage homeowners to report and remove Arundo in exchange for a native, or noninvasive plant
4. Management

a. Eradicate existing feral and cultivated populations of Arundo in Oregon outside the Control Area
b. Use scale appropriate management tools. Physical removal of small stands with care to contain rhizome fragments and herbicide applications for larger stands
c. Consult with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service on the use of herbicides near or over waters that may be habitat for threatened and endangered species to avoid long delays in implementation of eradication efforts
d. Conduct research on biocontrol agent efficacy in Oregon
e. Use integrated management that combines treatment options when appropriate, e.g., physical removal of canes followed by herbicide treatment

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INTRODUCTION AND PROBLEM DEFINITION

Giant reed (*Arundo donax* L.) is a tall, non-native, clumping grass with large bamboo-like culms (stems) and robust rhizomes. It has been cultivated for thousands of years for a wide variety of purposes including the production of paper fiber and reeds for woodwind instruments, as a windbreak, to prevent soil erosion in riparian areas, and as an ornamental garden plant (Perdue 1958). Arundo has been identified as a potential phytoremediation plant: targeting highly alkaline "red mud" residue from aluminum refining (Alshaal et al. 2013) and soils contaminated with heavy metals (Papazoglou 2007).

Power producers have also been evaluating Arundo as a source of biofuel. In Oregon, pending acceptable demonstration and regulatory approval, Portland General Electric (PGE) is testing the feasibility of converting their 585-megawatt coal-fired Boardman Power Plant to alternative fuels by no later than 2020 in order to meet federal air quality standards and Oregon's renewable energy standards under the Renewable Energy Act of 2007. Biomass-generated energy is considered a good compliment to wind-generated energy because it generates power during periods with low or no wind. PGE has evaluated a number of high-yield biomass crops including Arundo, hybrid poplar, reed canary grass, bamboo, wheat straw, corn stover, and willow. Arundo's rapid growth, high crop yields and energy content, low input needs and perennial growth form all point towards it as a unique energy crop (Ceotto and di Candilo 2010) and the most viable option for the Boardman Plant (Lewis et al. 2012). However, many of the same qualities that are desirable in biomass crops (perennial, rapid establishment, high density growth, tolerance to water stress and marginal soils, reallocation of nutrients to roots, lack of major pests and diseases) are considered indicators of potential invasiveness in plants.

Over its long history of use, Arundo has escaped cultivation numerous times. Naturalized populations are documented in 25 states across the U.S. as well as in tropical and temperate environments around the world. The Global Invasive Species Database notes Arundo as one of the world's 100 worst alien species (Lowe et al. 2000). Only two escaped populations have been found in Oregon despite numerous small-scale plantings by nurseries, homeowners and wind-instrument makers dating back as far as 30 years. The increased interest in growing Arundo at a large scale in Oregon, combined with its history of invasiveness elsewhere, has generated concern that this grass could escape cultivation, spread in riparian and wetland habitats and cause impacts in the Pacific Northwest similar to those seen in California, Texas and elsewhere. The Oregon Department of Agriculture (ODA) evaluated Arundo for its potential to become problematic within the state with formal risk assessments conducted in 2007 and in 2011 (ODA 2011). These assessments scored *Arundo* as in the noxious weed category, but a number of factors led the Oregon State Weed Board to keep Arundo on Oregon's 'Watch List' (a non-regulatory catalog of plants which are scrutinized for potential listing) rather than formally list it as a noxious weed. ODA subsequently developed a Control Area Order (OAR 603-052-1206 to 603-052-1211) regulating the cultivation of Arundo in Oregon to: "balance goals to develop new agricultural crops and support renewable energy development from agricultural feedstocks while protecting natural resources and preventing the establishment of giant reed in riparian areas where it could cause major negative impacts to the natural resources of the State of Oregon."

PGE estimates they will need 50,000 to 90,000 acres of Arundo in production, harvested once a year, in order to fuel the plant at capacity. They are not pursuing commercial biomass production of Arundo in nearby Washington counties (pers. comm. W. Lei, PGE).

The purpose of this document is to present a plan for monitoring for escaped populations and summarize available control measures. We describe existing and natural barriers to naturalization in Oregon; identify priority areas for early detection surveys; outline effective methods for finding escaped populations of Arundo and other large-statured grasses; and present rapid response options based upon extensive experience managing this plant elsewhere.

BIOLOGY OF *ARUNDO*

Taxonomy

Arundo donax L. is a true grass, belonging to the *Poeacea* family. The genus name *Arundo* is Latin for 'reed' and worldwide three species of Arundo are generally recognized: *A. plinii* Turra from the Mediteranean region, *A. formosana* Hack. from Taiwan and the cosmopolitan *A. donax* L.(Csurhes 2009). However, a revised systematics study by Hardion et al. (2012) asserts three distinct genetic and morphological clusters within *A. plinii*: *A. micrantha*, *A. donaciformis* and *A. plinii* (sensu stricto) indicating a total of five species within the genus. *A. donax* is the only naturalized species of *Arundo* in North America, although *A. formosana* is known in the Bay Area of California as an ornamental (Goolsby and Moran 2009). The native range of *A. donax* is a matter of speculation since this species has been cultivated for such a long period of time, but it is considered native to eastern Asia and long ago introduced to the Mediterranean region where it naturalized widely (Ahmad et al 2008, Saltonstall et al. 2010, Hardion et al. 2012).

Arundo donax has many common names including giant reed, carrizo, bamboo reed, donax cane, Italian or Spanish reed, or simply Arundo (Perdue 1958). The commercial name "Adx" is increasingly being used, typically in reference to Arundo biofuel or paper pulp production (Csurhes 2009, Jeon et al. 2010). In this document, we will use 'Arundo' to refer to *Arundo donax*. At least four variegated varieties of Arundo have been developed for their ornamental striped or spotted leaf patterns; these are sold under the names "Peppermint Stick," "Golden Chain," "Versicolor, and "Variegata".

Morphology & Anatomy

Arundo is a tall, perennial, clumping grass with cane-like, hollow culms (stems) up to 5 cm (2 in) in diameter. Mature stands may grow more than 6 m (20 ft) tall, but are typically 3.7 to 4.9 m (12 to16 ft) (Odero et al. 2011). Flat or folded blue-green leaves are 2.5 to 8 cm (1 to 3") wide and 60 to 90 cm (24 to 36") long and taper to a long point; they are stiff, but have a smooth surface and are conspicuously distichous (alternately arranged with successive leaves arising on opposite sides of the culm). Membranous ligules with small hairs along the margins are found at the junction of the leaf blade to the culm (Barkworth et al. 2007, Perdue 1958). Following the first year of growth, side shoots often form near the top of the stems (Barkworth et al. 2007). Ornamental varieties of Arundo are variegated, with either striped or spotted leaf patterns. Naturalized stands of variegated Arundo have been found in California, Georgia, Louisiana, Oklahoma and Texas suggesting repeated escape of ornamental plantings or frequent cell mutations (Ahmad et al. 2008).

Erect, terminal plume-like inflorescences are 20-60 cm long (0.6 to 2.0 ft) and their color may change from purplish-brown in to silvery white as they mature. Individual inflorescences contain hundreds of spikelets arranged as a panicle; each spikelet has one or more florets (typically between two to six) (Barkworth et al. 2007). Flowering phenology is not well understood and it is important to note that flowering does not imply seed production (see Reproduction and Dispersal). Inflorescences may be produced in the summer to autumn months, but flowering is infrequent especially at high latitudes. In desert populations, flowering occurs between August and October and in coastal areas of California it is highly variable across time and stands of Arundo (Saltonstall et al. 2010). In California, Johnson et al. (2006) suggest a possible link between flowering and low soil moisture levels, but this has not been experimentally documented. Experimental plantings in Eastern Washington and North Eastern Oregon have not flowered, and until recently it was thought that ornamental plants elsewhere in the Pacific Northwest were similarly nonflowering (pers. comm., T. Butler, ODA). An ornamental planting in Monmonth, Oregon (44.85 -123.23), however, was recently found flowering in mid-July (pers. comm., T. Forney, ODA).

Rhizomes are light brown, thick and stout, almost bulbous in appearance (Perdue 1958), and generally exhibit pachymorphic growth (Speck and Spatz 2004, Boland 2006), in which carbohydrate stores aid survival from frost, fire, grazers and desiccation (Cronk and Fennessy 2001). Leptomorphic rhizomes in comparison grow laterally near the soil surface and are optimized for rapid growth (ibid). Below-ground biomass is estimated to be 22% of above-ground growth in cultivated Arundo (Lewis et al. 2012).

Arundo's robust culms, large stature and stiffly held leaves often lead to comparisons to bamboo and common reed (Figure 1). Indeed, a few genera of bamboo (e.g., *Arundinaria* spp., *Bambusa* spp., *Phyllostachys* spp.) do resemble Arundo from a distance or without close inspection. The most notable difference between these grasses is that bamboo leaves generally attach to the stem by a constricted leaf base (pseudo-petiole) whereas Arundo leaves arise directly from the culm itself and have no true or pseudo-petiole (Barkworth et al. 2007). Comparisons are also drawn between Arundo and common reed (*Phragmites australis*). Arundo is typically taller, with longer leaves, has a hairy lemma and mature inflorescences are typically white (compared to common reed's light brown inflorescences and smooth lemmas). Additionally, branching off the main culm is typical in many *Bambusa* spp. and in second-year Arundo growth, but not common reed.

Habitat & Hardiness

Arundo is well suited to a variety of habitats including ditches, streams, rivers and arid and cismontane seeps in California (Robbins et al. 1951, cited in Hoshovsky 1986). Dudley (2011) notes it growing in "agricultural areas, coastland, desert, natural forests, planted forests, range/grasslands, riparian zones, ruderal/disturbed, scrub/shrublands, [and] urban areas." Because Arundo tolerates a wide range of ecological conditions, the factors that promote it's invasive behavior in certain areas are not entirely clear, however, disturbed soils, altered flow regimes, and elevated nutrient inputs may contribute to this plants invasive tendencies."

Figure 1. Line illustrations demonstrating differences between *Arundo donax* (left), *Phragmites australis* (middle) and *Arundinaria appalachiana* (right). Note second year branching on Arundo culms and *A. appalachiana's* pseudo-petiole.

<u>Soil, Salinity and Water</u>

Arundo's most robust growth is associated with low-gradient (<2%), well-drained soils with abundant moisture and nutrients (Dudley 2000). A variety of soils, including coarse sands, loose gravels, heavy clays and other alluvial sediments are widely considered suitable for Arundo (ibid, Hoshovsky 1986, Perdue 1958). Stephenson and Calcarone (1999) suggest "well-developed soils" are required for establishment, but no data is provided to support that claim, however, such soils might provide for more robust growth of Arundo. Lambert et al. (2013) experimented with Arundo in various soil types, as well as various moisture, nutrient, and light treatments, and found that soil type strongly influenced Arundo biomass production; plants grown in a mixture of clay, sand, and humus produced 65% more than those in pure sand or clay-sand mixtures.

Arundo tolerates soils with pH ranging between 5 to 8.7 (DiTomaso 1998), high levels of the heavy metals cadmium and nickel (Papazoglou 2007); and high salinity (Lambert et al. 2010, Perdue 1958). Lambert et al. (2013) noted that Arundo is known to grown in estuarine and even marine environments such as coastal strands and islands. In Australia, Arundo tolerates saline soils for months at concentrations up to 25 dS/m (16 ppt) and still grows robustly (Williams 2008). Ocean water salinity is approximately

52 dS/m (35 ppt). Stem fragments are capable of rooting in water with salinity as high as 15 ppt (Wijte et al. 2005), but may be able to survive brief periods at higher salinities (Peck 1998).

Arundo thrives where water is at or near the surface, but mature plants (more than one year old) are capable of surviving “extended periods of severe drought accompanied by low atmospheric-humidity or periods of excessive moisture” (Perdue 1958). In both California and Texas, Arundo has spread beyond the native riparian vegetation into areas with dry riverbanks that are far from permanent water (Dudley 2000). In Australia, Williams et al. (2008) found that Arundo could be grown as a dry-land crop in areas with more than 450 mm (17.7 in) rainfall, but suffered 70% reductions in biomass compared to irrigated fields in the same soils. Vegetative fragments are vulnerable to desiccation during establishment, but once rooted appear resilient (see Reproduction). Clones establish in areas with little water but the potential spread of stem or rhizome fragments from such sites might contribute to subsequent spread into more vulnerable areas.

Temperature

Low temperature limits the potential geographic range of Arundo in North America. USDA (2012) estimated that about 57 percent of the United States and two percent of Canada is suitable for establishment of Arundo (Figure 2) (USDA 2012), however, establishment does not necessarily correlate with invasiveness. Many areas within the predicted distribution already have naturalized populations. Arundo does not appear to go dormant in areas with mild winters (average minimum temperature of 9.9 °C (49.8 F) and high nutrient availability (Decruyenaere & Holt 2005).

Figure 2. Predicted distribution of *Arundo donax* in the United States and Canada as predicted by USDA Plant Hardiness Zones 6-13 and annual rainfall. (APHIS 2012)

Graziani and Steinmaus (2009) evaluated Arundo from invaded sites in coastal Southern California in both lab and field conditions to determine the base and optimal temperature and moisture needed for rhizomes to sprout. Their results suggest the lowest temperature for sprouting is 12.7 °C (54.9 F), with 94 degree days required to sprout at that temperature. Optimal temperatures for sprouting are 28 °C (82.4 F) (ibid) to 30 C (F) (Spencer and Ksander 2006).

Established plants at test plots in Morrow County, Oregon experienced a 15-20% winter-kill in 2012-2013, which may be attributed to a September harvest spurring tender new regrowth (pers. comm., W. Lei, PGE).

Growth

Arundo tends to establish on unvegetated to sparsely vegetated soils, growing rapidly in height and then spreading radially, crowding out other vegetation and forming large monocultures (Ambrose and Rundel 2007). Arundo is a C3 plant, but is comparable to C4 plants in terms of growth rates and biomass production (Decruyenaere & Holt 2005). Once rooted, Arundo can grow at a rapid pace: estimates suggest vertical growth of 10 cm (4 in) per day (Perdue 1958, Dudley 2000, Hoshovsky 1986) or 2.5 to 4.0 m in a single growing season (Rieger and Kreager 1989). Mature naturalized stands of Arundo can reach impressive heights ranging between 3 to 10 m (Saltonstall et al. 2010), but more often reaching 5-6 m. Culms will often grow unbranched in their first year, but then branch near the top in their second year (Hoshovsky 1986). This growth habit was observed in test plantings in eastern Oregon (pers. comm. W. Lei, PGE). Looking at 16 naturalized populations from California, Mississippi and Texas, Spencer et al. (2006) documented average shoot lengths of 3.37 m (±0.26 S.E.) with 74.5 shoots/m2 (± 7.8) and an extrapolated biomass of 17.12 kg/m2 (± 2.94). By way of contrast, established clones of smooth cordgrass (*Spartina alternflora*) - another introduced large-statured grass - produce between 0.1 and 1.1 kg/m2 (Castillo et al. 2010).

Wildfires promote the rapid growth of Arundo; shoots regenerate within days and can attain heights of 2.3 m in three months (Coffman 2010). An abundant reserve of carbohydrate in the rhizomes; an ability to uptake nutrients released by the fire, and the comparatively slow regrowth of native species like willow (*Salix* spp.) and black cottonwood (*Populus balsamifera*) may make Arundo's quick post-fire recovery possible (ibid). Boland (2006) showed that clonal expansion via rhizome growth inside the flood zone is significantly faster (mean of 0.41 ± 0.05 m^2/yr) than outside (mean of 0.81 ± 0.04 m^2/yr) in the Tijuana River Valley and that rapid, episodic spread by layering is 7.4 times faster than rhizome growth. Areas with enriched shallow groundwater, often from anthropogenic sources, may experience faster spread of Arundo (Ambrose and Rundel 2007).

Much of the data on Arundo growth is from areas warmer than Oregon, but test plots in eastern Oregon suggest irrigated plants are capable of ample growth and overwintering. Thornby et al. (2007) developed a growth model for Arundo that predicts shoot and biomass production based on outdoor experiments and invasive populations in California. Using this model they predicted a single rhizome fragment growing in

Siskiyou County (in Northern California) would produce 600 g of leaves and culms in its first year of growth – this is less than half the above-ground biomass than a fragment grown in warm Southern California climates, but still a substantial biomass for a single year of growth from a single rhizome fragment. Of course, the ability to produce biomass rapidly is the appeal of Arundo as a biofuel. Lewis et al. (2012) estimated Arundo could produce between 20 and 35 tons of biomass/acre under field conditions in the Pacific Northwest.

Nutrient availability in soils and shallow groundwater may influence establishment success and subsequent growth rates of Arundo. Arundo appears to prefer areas with elevated nitrogen and phosphorus (Decruyenaere and Holt 2005, Ambrose and Rundel 2007). Fenn et al. (2003) found that anthropogenic nutrient enrichment from agricultural and urban sources may be a contributing factor in the invasion of several Mediterranean grasses in the Mojave and Sonoran Deserts as well as coastal sage scrub habitats. Altered patterns of nutrient availability (typically linked to seasonal variations of temperature and soil moisture) may increase the chances for establishment and growth of escaped Arundo (Ambrose and Rundel 2007). In Southern California, Arundo showed higher lateral growth rates in areas with ample nitrogen compared to nitrogen-poor areas (Decruyenaere & Holt 2005). Experiments conducted by Quinn et al. (2007) showed that Arundo responded with 63% greater root tissue and 77% greater photosynthetic tissue when water was augmented with ammonium nitrate, and that added nitrogen allowed a significant increase in rhizome length and tiller production even when grown in competition with common three-square bulrush (*Schoenoplectus americanus*). Arundo's ability to more effectively utilize elevated nutrient concentrations may explain its ability to outcompete native plant communities in nutrient enriched sites.

Reproduction

<u>Sexual</u>

Although some clones produce conspicuous inflorescences, Arundo spreads by asexual means (Di Tomaso and Healy 2003, Saltonstall 2010). Perdue (1958) briefly notes viable seed in populations from Afghanistan, South Western Pakistan, and Iran, but this has never been observed in North American (Mack 2008, Johnson et al. 2006) or Europe (Lewandowski 2003) or Australia (Williams 2008). Low levels of genetic diversity or poor levels of pollen production have been proposed causes of this apparent seed sterility (Johnson et al. 2006). Indeed, genetic diversity of invasive Arundo populations in the United States is low, suggesting multiple introductions of one clonal lineage (Tarin et al. 2013, Saltonstall et al. 2010, Ahmad et al. 2008).

Balogh et al. (2012) examined Arundo pollen and enlarged caryopses – in what appeared to be matured seeds – but found both were defective and incapable of generating viable seed. They found that Arundo's male gametophytes fail to produce mature pollen grains and although 10 percent of the plants from one South Carolina population exhibited floret enlargement, no seeds were capable of germinating. Across North America, very few Arundo florets ever even enlarge to resemble mature caryopses. Johnson et al. (2006) showed that out of 36,666 florets collected from California, Nevada, Colorado, New Mexico, Texas, Nuevo Leon (northern Mexico), Georgia and Washington D.C, just 43 enlarged and only 0.5% of those showed any signs of respiration when tested with tetrazolium chloride. Arundo is therefore considered sterile due to both the failure of the megasporocyte to properly develop (Lewandowski 2003, Balough et al. 2012) and arrested pollen production (Johnson et al. 2006, Balough et al. 2012). This does not make Arundo difficult to propagate, however, due to its extensive mats of rhizomes and roots.

<u>Asexual</u>

Vegetative reproduction of Arundo can take one of three forms: clonal expansion, rhizome fragments, or layering. Clonal expansion - wherein new tillers form from established rhizomes - is relatively slow; estimates in southern California suggest 0.29 m growth over two years (Boland 2006). This slow clonal expansion is in keeping with Arundo's pachymorphic (clumping) rhizomes (Speck and Spatz 2004, Boland 2006).

Rhizome fragments are presumed to occur when flood events disturb clumps of Arundo and wash dislodged pieces downstream. Rhizome and stem fragments with a singe node are capable of resprouting (DiTomaso, et al. 2013). Furthermore, the use of heavy machinery in Arundo-infested areas is very likely to produce viable fragments and subsequent downstream recruitment (Boland 2008). In Southern California, areas downstream of areas where bulldozers were used for irrigation channel maintenance had densities of sprouting Arundo that were 61 times greater than the valley as a whole (ibid). Thus, both naturally occurring and anthropogenic disturbances are capable of producing rhizome fragments. Boland (2006) suggested that Arundo rhizome fragments are the primary means for establishment at new sites within flood zones, but that rapid subsequent expansion is more probably due to layering.

Layering is the formation adventitious roots from mature (typically second-year) stem tips or nodes. If stems are arching downwards to contact the soil due to wind, water, trampling or other disturbances, but are still attached to the 'parent' plant, this form of spread is a form of clonal expansion. Layering stems might alternatively be broken free from the rhizome, and thus categorized as asexual reproduction. Boland (2006) showed that layering is common in naturalized populations of the Tijuana River Valley, where it resulted in spread 7.4 times faster than clonal expansion and produced 25 times more propagules than rhizome fragmentation.

Decruyenaere and Holt (2001) found that Arundo establishment was a function of propagule type (horizontal stem, vertical stem, rhizome) and time of year the propagule was collected. A suite of environmental factors, including soil nitrogen availability, determined recruitment of new ramets in Southern California. Plants at a low-nitrogen site exhibited more shoot replacement that emphasized maintenance of the stand, whereas plants at a high-nitrogen site had greater lateral expansion through rhizome growth (Decruyenaere and Holt (2005).

Dispersal

<u>Intentional</u>

Humans were responsible for the initial intentional introduction of Arundo to California for the purposes of erosion control and to Oregon for woodwind instrument reed production, for ornamental purposes, and most recently for biomass production (ODA 2011).

Accidental

Equipment

As noted above, earthmoving equipment can fragment Arundo rhizomes and lead to widespread dispersal. In Oregon, commercial operations will be harvested once a year. The process will entail cutting (swathing), conditioning (crushing) and field curing (drying). During the 2011 test harvest, cut and conditioned material was cured for eight days (daytime high temperatures ranging between 70 and 85° F) and then baled prior to transport.

Water

The frequency and magnitude of flood events may dictate where Arundo is spread via disturbed rhizomes; in San Diego County, California Arundo was generally found less than 7.3 m (24 ft) from the river channel (Rieger and Kreager 1989).

Zoochory

The movement of propagules with animals is another possible mechanism for Arundo to increase its range. Fragments of aquatic macrophytes and seeds of large-statured grasses are likely moved in the feathers or feet of migratory birds (Vivian-Smith and Stiles 1994, Les et al. 2003). Since Arundo does not set viable seed, birds are unlikely to move propagules from infested areas. Feeding behavior of the non-native nutria (*Myocastor coypus*) appears to increase the spread of Arundo by way of layering. Jones-Lewey and Rios (2011) described abundant partially-eaten, sprouting stems of Arundo and multiple observations of rapid increase in Arundo within areas of the Nueces and Sabinal Rivers in Texas. Nutria could also disturb Arundo rhizome mats and/or cause bank erosion, which could feasibly contribute to spread of rhizomes with water currents. There are no known nutria populations in eastern Oregon, however, climate change could lead to nutria population expansion into the region (Jarnevich et al. in review)

Impacts

The dense stems and thick mat of roots and rhizomes of Arundo can lead to numerous floodplain modifications within riparian areas. Cane debris can lead to increased flood damage, including stressing the integrity of in-stream structures like bridges and require costly removal. In streams and smaller channels, Arundo can completely block the flow of water, causing the channel to shift course. Extensive populations of Arundo are known to transpire large amounts of water, thus reducing water availability for irrigation, drinking water, wildlife and native plants. In Southern California's Santa Ana River, Arundo uses 20,000-30,000 acre-feet of water each year, enough for 100,000 people (Glasser 2003). In irrigation ditches, Arundo may reduce water-carrying capacity (Hoshovsky 2003).

Arundo is well adapted to extreme fire events and is likely flammable throughout much of the year. Riparian areas with significant amounts of Arundo tend to burn more intensely due to the large amount of standing biomass, senesced leaf litter, and the tall stand structure with ample air flow (Giessow et al. 2011). In heavily infested areas, riparian ecosystems may lose their function as natural fire breaks (Ambrose and Rundel 2007, Coffman 2010) and may instead disperse fires through riparian corridors and potentially into urban areas (Giessow et al. 2011). Post-fire regeneration of native woody vegetation, such as cottonwood and willows, relies heavily on seed rather than resprouting from mature root crowns; Arundo is often capable of reaching higher densities and abundances following fires due to the lack of competition and the ability to rapidly re-sprout from rhizomes (Coffman et al. 2010). In this way, Arundo can alter a flood-based ecosystem to a fire-based one.

Arundo has a variety of physical and chemical impacts on riparian and lotic systems. It reduces native plant species richness (Cushman and Gaffney 2010), increases sediment accretion and alters channel morphometry (Dean and Schmidt 2011) and increases flood risk (Spencer et al. 2013), releases allelopathic compounds that inhibit algal productivity (Hong et al. 2011), facilitates the survival and persistence of cattle ticks that are a vector for bovine babesiosis (Racelis et al. 2012), and increases water loss through evapotranspiration (Watts and Moore 2011).

HISTORY OF *ARUNDO* IN THE WESTERN U.S.

Dubbed one of the 100 "world's worst" invaders (Lowe et al. 2013), Arundo has naturalized in 25 states, and in Puerto Rico and the Virgin Islands (Figure 3), although the level to which it has become problematic varies widely. Currently, five states (California, Colorado, Nebraska, Nevada, and Texas) have Arundo listed as a noxious weed (NPB 2014). It is on non-regulatory watch/monitor lists in New Mexico, Oregon, Utah and Washington and considered invasive in wildlands in Alabama, Arizona, Delaware, Georgia, Maryland, South Carolina, Tennessee and Virginia (Bargeron et al. 2013).

In a quantitative analysis of invasive riparian plants in western states Ringold et al. (2008) found that Arundo was present in 5.3%, 4.0%, and 2.3% of the riparian area on perennial streams in Arizona, California, and Nevada, respectively. Size of stream was not a factor in the distribution of Arundo, however, there was a highly significant association of Arundo with the presence of disturbance and large dams.

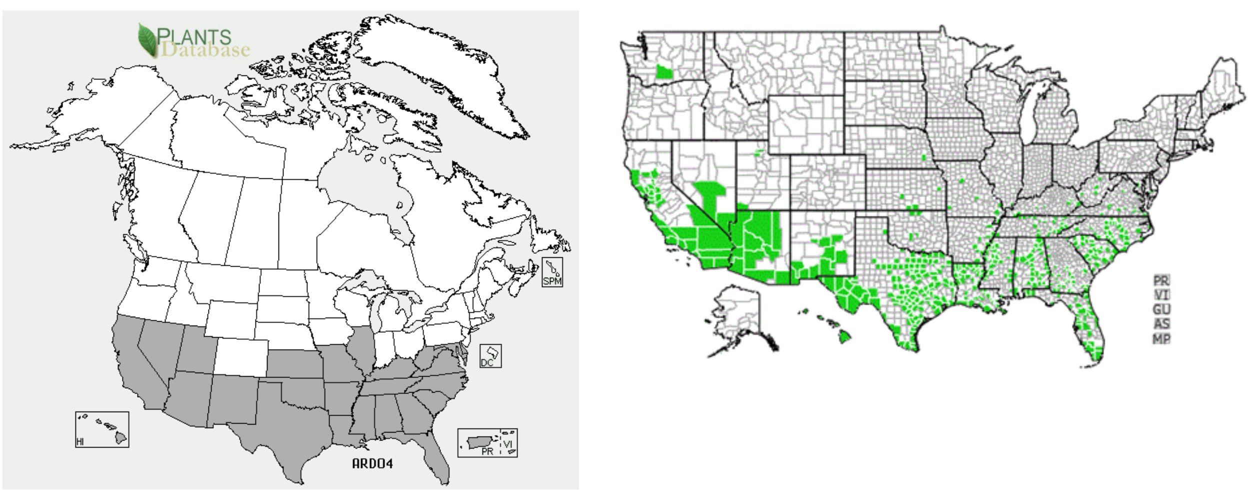

Figure 3. Distribution maps of Arundo by a) state (USDA-NRCS) and b) county (EDDMapS) level.

California

The earliest introductions of Arundo are thought to have been to California in the 1820’s when the plants were brought in for erosion control along drainage canals. Arundo has invaded central California river valleys along the coast and inland and is increasing in the North Coast. It is most problematic in southern California coastal rivers where it can occupy the entire river channel (California Invasive Plant Council 2014)

Washington

No known naturalized populations are known in the state, although a few intentional plantings are known from Sunnyside in Yakima County and at a community garden in the Seattle area (King County) (pers. comm., G. Haubrich, WSDA). Each of these intentional plantings illustrates Arundo's ability to overwinter in high latitudes where water is present as well as a potential vector. The Yakima County site is located near a seasonally wet irrigation ditch; disturbance to the clone or the bank area could potentially move rhizomes downstream. At the King County site where multiple distinct clones are growing, there is the potential that gardeners will propagate it for use off site. Experimental, field plantings to evaluate bioenergy potential were established at sites near Touchet, Prosser, and Walla Walla. Because Arundo is not a listed noxious weed the state is unable to enforce any control efforts.

Idaho

Naturalized populations of Arundo are currently unknown in Idaho (pers. comm. T. Woolf, IDA).

Oregon

Arundo has been introduced to Oregon for production of reeds for woodwind instruments (oboes, bassoons, bagpipes, etc); as an ornamental landscaping plant prized for providing a rapid screen; and, most recently, as a potential biofuel crop. In at least two cases, ornamental plantings have escaped into natural waterways. In one instance, Arundo was found in Bear Creek near Medford (Jackson County) in 2006. This single patch was treated chemically and is considered eradicated (ODA 2011); however, it is unclear when the site was last monitored for regrowth or how far downstream was surveyed for additional populations (pers. comm., T. Forney, Oregon Department of Agriculture).

Until recently, the Bear Creek population was the only confirmed escaped population. However, in 2013 multiple, lightly-rooted Arundo plants were discovered during restoration of the riparian area of Beaverton's Willow Creek, (pers. comm. R. Emanuel, Clean Water Services); they were removed manually and the source identified as a nearby homeowner who had trimmed ornamental Arundo patches and disposed of the stems in the adjacent riparian area. Clean Water Services worked with the homeowner to treat the ornamental plantings and clear vegetation in the immediate area to make detection of any additional Arundo easier (ibid).

Two additional populations have been discovered in other areas of Jackson County, both located adjacent to irrigation canals. There is some evidence that one of these patches is a remnant of one of the original sites for woodwind reed production (pers. comm., C. Pirosko, ODA), although none of the other woodwind reed growing sites have shown any signs of off-site growth. Local and state weed authorities began treating both these Jackson County patches in 2013. Additional Arundo plantings are known at a nursery in Monmouth (Polk County) and along the shore of Munsel Lake (Lane County); neither of these populations appear to be spreading from their original planting areas.

Currently, there are three commercial sites, all in northern Morrow County near Boardman, with a total of 90 acres in production; these fields were planted to provide material for a test burn at the Boardman power plant. Source material for these sites included rhizomes from the Santa Ana River riparian zone in California as well as plantlets from Indiana, Georgia and Washington State; rhizomes were planted 36" apart and 6-9" deep in May 2011 (pers. comm., W. Lei, PGE). Early and repeated freezing temperatures are believed to be the cause of an estimated 15-20% kill rate over the 2012-13 winter. One of these sites, known as the Greenwood site, is currently in the second year of monitoring to demonstrate chemical eradication of an abandoned Arundo field. The Lloyd field, north of Threemile Canyon Farm is in the first year of eradication via physical removal. Another 7 acres was planted in Umatilla Count at the Hermiston Agricultural Research & Extension Center, but competition from weeds resulted in very poor growth. This site is scheduled for eradication in the spring of 2015. PGE will retain one field to complete high-density planting trials (Wayne Lei, PGE, pers. comm.). Results of these test plots, as well as local input, have led PGE to consider mixing Arundo with other alternative biofuel crops such as Western Juniper, Russian Olive, hogfuel and hybrid sorghum, which would reduce the acreage of Arundo required to fuel the plant.

Nevada

Arundo has invaded ditches and wetlands primarily in Southern Nevada including Clark, Nye Counties. In 2006, Arundo was listed as a Category "A" noxious weed by the Nevada Department of Agriculture, subject to active eradication wherever it is found, including nursery stock dealers. In the Las Vegas area 30-40 patches of Arundo have been found and treated since it was first detected in 2001; one to two remain to be treated (pers. comm., N. Rice). Treatments have included cutting and spraying subsequent regrowth, as well as limited mechanical removal with a backhoe. Arundo reportedly has become established in very arid habitats outside of riparian areas, especially in the area of Pahrump, NV; this is possibly the result of it being used for windbreaks and as fencing (ibid). Recent reports of Arundo in Humboldt County, in Northern Nevada have not been confirmed (pers. comm., R. Little, NV Dept. of Ag.), but an infestation in a remote area of the La Madre Mountains near 1650 m (5413 ft) (US BLM 2013) suggests Arundo is capable of surviving freezing conditions in riparian areas.

RESPONSE PLAN

Goal of *Arundo* Management in Oregon

One of the best available predictors of a plant's potential invasiveness is a wide geographical range and a previous history of invasiveness (Wittenberg and Cock 2001). Given the history of Arundo in other regions, it is important that the state of Oregon assume that, even with the best prevention efforts, future escapes of Arundo are likely. Introductions might arise from agricultural cultivated stands (for biofuel or woodwind reed) or escaped ornamental plants. Movement with natural vectors like water currents will become of concern should Arundo become established in neighboring states where currents flow downstream to the Snake or Columbia Rivers. Given the potential negative impacts of Arundo invasion, rapid response to feral populations is imperative.

Lack of widespread establishment of Arundo in Oregon's riparian areas should not be construed as evidence of the lack of invasiveness. Invasive species follow a typical "invasion curve" that includes a lag phase assumed to be typically 50 years long for plants (Hobbs and Humphries 1995) and as long as 170 years for trees (Kowark, 1995, as cited in Daehler, 2009). The presence of lags in biological invasions is well-documented and illustrates that a long period of non-invasive behavior is a poor predictor of future behavior and invasiveness (Crooks, 2005).

Impacts and management costs are well known in states with Arundo infestations. Management costs are prohibitively expensive: removal of biomass combined with chemical treatments have been estimated at up to $25,000 per acre in heavily infested areas (Giessow et al. 2011). Therefore, early detection and rapid response to all existing and future escaped patches of Arundo are high priorities.

Arundo management in Oregon should focus on the eradication of all escaped populations in natural areas outside of cultivation for agricultural and/or ornamental purposes.

The four main efforts to attain the goal are to:

- encourage strict adherence of the Arundo Control Area Order in order to minimize large-scale, high-risk plantings of Arundo;
- inform agencies and the general public about Arundo and the need to report naturalized populations or high-risk plantings;
- detect and eradicate any pioneer infestations, preferably while they are still small; and
- coordinate local, state, and federal agencies and private interests to facilitate cost-effective and efficient implementation of Arundo management if naturalized populations are found.

Strategy

<u>Prevention</u>

ODA's Control Area Rule (603-052-1206) prohibits planting of Arundo in a floodplain and provides for a 100-foot buffer between riparian areas, wetlands and floodplains and areas where Arundo can be planted, grown, or stored. Only the variegated varieties of Arundo can be sold unless the State Weed Board designates Arundo as a noxious weed. Because Arundo relies upon vegetative reproduction exclusively, these restrictions reduce the risk of unintentional spread and establishment in natural areas. The 100-foot buffer area required under the Oregon rule is substantially less than the 500-m (0.3 mi) buffer suggested by Williams et al. (2008) for Australia.

Variegated plants produced less biomass and had more prostrate stems early in the growing season than fully green plants, but did not differ in other morphological aspects or in relative growth rate in a northern California common-garden study (Spencer et al., 2008). The relative growth rate (production of new stems) did not differ between varieties. The lower vigor of the variegated varieties suggests that they would be less invasive, however, as Spencer et al (2008) point out, the production of new stems is one method by which Arundo occupies space and invades. Because variegated varieties do not differ from fully green, wild-type plants in this important characteristic, similar invasion dynamics may be expected.

The highest risk of aggressive invasion by Arundo is in nutrient-rich riparian habitats (Ambrose and Rundel 2007) such as those near intensive agriculture, watersheds with ample agricultural and residential land use, and riparian terraces downstream of wastewater treatment facilities. Thus, limiting nutrient inputs into riparian systems may help reduce Arundo's spread in watersheds where its distribution is limited or not yet known (Ambrose and Rundel 2007).

In North Carolina, plans for a cellulosic ethanol plant call for growing 20,000 acres of energy grasses, of which a significant portion will be Arundo (Wall 2012). Concerns about Arundo's potential invasiveness there have led to a number of preventative measures, similar to some of those implemented in Oregon. These include voluntary best management practices developed collaboratively between the Cooperative Extension, Department of Agriculture, and the Biofuels Center of North Carolina as a condition of a federal loan guarantee; field setbacks of 25 feet or more; a monitoring program to identify any spread of Arundo; and annual reporting by producers on their crop sizes. Rules in North Carolina are generally more lax than those in Oregon: there is no permit program for commercial production, BMP's are voluntary and do not explicitly exclude planting Arundo in floodplains, and there are no bond requirements placed on growers to cover eradication costs (Preyer 2013, Cox 2013).

Detection

The best preventative efforts will not eliminate the risk of introduced populations of weedy plants in natural areas. The probability that any infestation can be successfully eradicated and the resources (effort and cost) required for eradication are inversely correlated with the size of an infestation. Therefore, early detection of small, pioneer infestations is required to minimize impacts of all weedy species, including Arundo.

Detection Methods

Oregon can increase the probability of successful detection by utilizing active search methods. "Active", in this sense, refers to searchers whose assigned duty is the detection of Arundo to the exclusion of any collateral assignments. Passive detection approaches can also be effective and efficient, especially where motivated and qualified personnel are involved. Passive detection involves searchers who have duties and interests other than searching for Arundo, but who might be in areas where it could become established and could sight a new infestation if they were appropriately informed. Except in areas near the Arundo plantation in eastern Oregon, Arundo detection in Oregon has occurred primarily by passive searchers. No systematic active search has been attempted in western Oregon.

Aerial searches from airplanes and helicopters, boat surveys and shore-based surveys have all been used in an effective *Spartina* detection effort in Oregon; each approach has its advantages and disadvantages. The area that can be covered, costs, and reliability vary considerably among these methods. Ground and boat searches are likely to be the most reliable because they usually offer the observer the opportunity to get closer to a suspect site. There are many areas, however, that cannot be easily accessed for ground and boat surveys. Helicopters can maneuver so that most of the areas at risk can be seen, and they often can bring observers close to any targets. Commercial rental of a helicopter is typically costly, however, and scheduling of flights can be difficult due to changing weather patterns and helicopter availability. The Bonneville Power Administration and the U.S. Coast Guard, have generously allowed the use of their helicopters and pilots for *Spartina* surveys on occasion. Fixed-wing aircraft are much less costly than helicopters, are widely available for hire, and can cover nearly all the areas considered at risk for invasion. However, they cannot maneuver as close to possible infestations and so are not as useful as helicopters for close inspection.

Remote sensing of Arundo infestations is a promising technique for early detection. Tidwell (2012) found that, although Arundo has a wide range of biophysical characteristics that complicate detection, patches as small as 3.5 m^2 could be detected by off-the-shelf multispectral sensors mounted on unmanned or light, sport aircraft. Everett et al. (2005) found that high-resolution (2.8 m), Quickbird satellite imagery provided 86-100% accuracy in distinguishing Arundo infestations in the Rio Grande Valley in Texas.

Response to Detection

Confirmation of Report

An Arundo sighting detected through passive or active surveys must be confirmed as quickly as possible to avoid the costs and redirection of resources that would result from responding to false reports. The Noxious Weed Program in the Oregon Department of Agriculture should be primary point of contact provide the definitive confirmation of any reported detection.

Ownership and Delimiting Survey

Following positive identification, ownership of the site needs to be determined. Local tax lot information can be used for determining ownership in most cases. Tax lot information is available from local county assessor's offices or from the Oremap project of the Oregon Department of Revenue. Oremap includes tax lot maps in PDF format on their website (www.ormap.net).

Response may occur more quickly and require less consultation to determine ownership and to evaluate treatment options if Arundo invades a site managed by a government agency or nongovernmental organization. It is imperative, however, that site managers inform ODA of new infestations, whether it is suspected Arundo or another species, to ensure that statutory requirements of Oregon weed law are met and adequate delimiting surveys are conducted on adjacent or nearby non-managed sites that are susceptible to infestation. Furthermore, the Oregon Department of Agriculture may be able to provide financial and personnel assistance for Arundo control efforts.

Notification

Several persons and or institutions need to be informed if there is a confirmed site that is infested with a Arundo. These include:

- site owners and owners of adjacent sites,
- lessees of the site or any person or organization managing the site,
- downstream site managers that may be impacted by Arundo
- local, state, and federal agencies with riparian management responsibilities, and
- the county Noxious Weed Program manager.

Landowners and lessees are especially important because the Oregon Department of Agriculture and other parties will need permission to access the site.

Delimiting survey

Upon confirmation of an Arundo infestation, a comprehensive, delimiting survey should be initiated. The purpose of this survey is to gain information needed to support several decisions, some of which may need to be made quickly – such as whether control efforts should begin immediately or whether they can be safely delayed. The Oregon Department of Agriculture, which is responsible for enforcement of noxious weed laws in Oregon, should have the primary responsibility for coordinating the delimiting survey although other agencies and organizations should be prepared to provide personnel and equipment assistance if needed. The Oregon Department of Agriculture may use its quarantine authority if Arundo is designated an “A” noxious weed in Oregon.

The delimiting survey should include estimates of net (area occupied if all plants in the infested area were a monoculture in one patch) and gross (area encompassed by lines connecting the outlying plants) infested area. Areas can be determined with GIS software using GPS coordinates of plants located in the field. The Oregon Departments of Agriculture, Fish and Wildlife, and Environmental Quality and the Division of State

Lands have GIS capabilities. In addition to the exact location and physical extent of the infestation, information necessary for effective control includes data on plant height, substrate type, presence or proximity to water. Other data, such as site history, would be useful in optimizing future prevention and detection efforts.

Access to a boat and qualified pilot may be critical for access to some sites. Portland State University, Oregon Department of Agriculture, and Oregon Department of Fish and Wildlife may be able to provide boats for the delimiting survey. Pickups, ATVs, and herbicide application equipment is available from the Oregon Department of Agriculture.

Management Options

Biological, physical, and chemical weed control methods have been applied to Arundo in other states with mixed success. A detailed description of various management options, their best use, timing, costs, and advantages and disadvantages is provided in Appendix C and summarized below. Given its physical characteristics, large stands of feral Arundo should be readily detected, even with only passive surveillance, and consequently feral stands in Oregon are likely to be small at this point. If aerial surveys are used, however, larger stands may be obscured from view by tree canopy. Small stands of feral and backyard Arundo could, in most cases, be eradicated using physical methods with care take to avoid dispersal of uprooted rhizomes. Larger stands, such as those in plantations may require repeated herbicide treatments for eradication.

Physical control

Manual

Digging may be suitable when targeting extremely small clones or individual plants situated near desirable trees or other plants. The complete removal of all rhizomes will be easiest in sandy or other loose soils, and where rain or irrigation has softened the soil. Cutting to simply removing Arundo canes will result in repeated regrowth. Although the frequency and duration required for eradication using only cutting of canes is not known, this method will eliminate the chance of layering or rooting from broken stems. All stems and rhizomes should be chipped before sending to the local landfill or burned on-site (in accordance with local fire regulations) (Hoshovsky 1986).

Tarping

Use of thick opaque tarps or geo-textile fabrics may be effective as a means to deprive Arundo plants of sunlight and/or water, but such barriers need to remain in place for 6 months or more (Appendix C). This method is labor intensive, requiring plants be cut to ground level and then tarps secured with staples, sand bags or heavy rock. When used on saltmarsh cordgrass (*Spartina patens*) covers are left in place for two years (Pickering 2009).

Mechanical

Cutting, mowing or chopping machinery mounted to tractors can be used to quickly eliminate above-ground growth and facilitate other control techniques, but mechanical equipment is not effective as a stand-alone method since rhizome carbohydrate reserves are difficult to deplete. In natural systems, mechanical removal of rhizome themselves is extremely difficult: in California, bulldozers have excavated the rootstock that is then ground on-site (Boland 2008). Finely ground material is unable to sprout, but removal of rootstock is invariably incomplete; some rhizomes are dropped en route to the grinder and others are ejected from the grinder uncut (Boland 2008) and small rhizome fragments buried as deep as 3 meters may resprout (Dudley 2000). A treatment summary from Team Arundo del Norte (2007) suggests that this method is best suited for areas with exposed rhizomes such as eroded river banks or cliffs, but cautions that heavily disturbed soils are often subject to secondary invasion by other unwanted plants. In agronomic sites physical removal is possible using commonly available disc and extraction farming equipment (pers. comm., W. Lei, PGE).

Prescribed fire

Used alone, prescribed fire is not considered a viable control method for Arundo because plants quickly resprout from rhizomes, producing up to four feet of growth in less than one month (Neill 2006), and fire increases Arundo's competitive edge over native plants (Coffman et al 2010). Additionally, getting flames to spread effectively in sparse or patchy stands of Arundo may be difficult, making this an even less practical technique. Burning may prove useful to eliminate standing biomass in order to begin another control method as part of an Integrated Pest Management strategy. Extreme caution must guide use of this method since spreading uncontrolled fires beyond the target areas can have dire consequences, especially in wildland-urban interface (WUI) areas. Controlled burns cannot take place during the fire season and require a burn permit from the local fire district. Other permits may be required from Oregon Department of Agriculture, Oregon Department of Forestry, and/or Oregon Department of Environmental Quality depending on land ownership, proximity to urban areas, air quality conditions, and the purpose of the burn.

Biological control of *Arundo*

Since Arundo has no close relatives in North America and reproduces asexually, it should make a model target for biological control. Biocontrol is usually not considered an eradication technique and is likely to be most effective on very large infestations as part of an integrated management strategy that also uses physical and chemical methods (Neill 2006). Few grasses have been the focus of biocontrol programs (Goolsby, Spencer and Whitehead 2009), but several potential biocontrol agents have been identified for Arundo and two have been approved for release (Goolsby et al. 2011). A cost-benefit analysis suggests $4.38 of benefits for each dollar spent on Arundo biocontrol programs in the Lower Rio Grande Valley of Texas (Seawright et al. 2009).

The larvae of the Arundo wasp (*Tetramesa romana*) and the Arundo scale (*Rhizaspidiotus donacis*), nonnative species found on Arundo in California, have been approved for release. The Arundo wasp causes stem galling and results in stunting and sometimes death of stems. When the Arundo wasp and the Arundo scale are both present Arundo plants are severely stressed and stunted and have virtually no leaf production (USDA 2010). There is no evidence that these biocontrol agents are present in Oregon or whether they would be effective under the environmental conditions present in Oregon.

Compounds in the leaves and stems of Arundo likely limit its palatability to both insects and grazers, however, cattle are known to browse young shoots and goats are being used in California (Hoshovsky 1986). Goats preferred other weed species over Arundo in a young Arundo field (pers. comm., W. Lei, PGE).

Herbicides

Imazapyr and glyphosate have proven effective on Arundo, particularly when used with some mechanical pretreatment of the stand (Table 1).

Table 1. Herbicide efficacy and cost.

Method	Cost (per acre)	Best use	
Low volume spray (imazapyr)	$2,000[1]	Accessible clumps < 60 ft diam. or linear strips, steep river banks where mowing isn't feasilbe	Pros: light/partial coverage of uncut Arundo sufficient; good control of spring/summer resprouts; 10 gal/acre (backpack sprayer) Cons: slow acting; soil residual for ~1 yr; inter-root transfer to trees; use restrictions within ½ mile of potable water intakes
High volume spray (glyphosate)	$5,000[1]		Pro: no soil residual, no restrictions on aquatic applications Cons: full coverage required; 100+ gal/acre requires crews & power pums Poor control of spring/summer resprouts
Mow + spray resprouts (imazapyr)	$7,000[1]		
Manual removal + cut stem application	$20,000-150,000[1]	Small, isolated patches or individual plants[2]	Pros: highly effective; requires less herbicide; precision (avoidance of desirable natives) Cons: time consuming; requires treatment within 1-2 minutes of cut to ensure uptake

[1.] Neill 2006

[2.] Bell 1997

Outreach and Education

Outreach and education are critical in all aspects of Arundo management. Prevention efforts depend upon an educated citizenry that understands the risk and horticultural alternatives to Arundo. Educated citizens, as well as natural resource agency staff, can also provide valuable passive detection assistance and facilitate early detection. Rapid response and eradication efforts would also benefit from widespread and thorough understanding of the impacts and management options for Arundo.

Rapid response events should be exploited as an outreach and education opportunity. Press coverage of management of existing, feral stands of Arundo, such as the stand at Munsel Lake, could serve as examples of effective response and result in additional reports. Other outreach opportunities include contacting Master Gardeners and various water resource and weed organizations with interest or management responsibilities (Table 2).

Table 2. Organizations and government agencies with resource management responsibilities that will be impacted by Arundo.

Agency/Organization	Responsibility
OR Department of Agriculture	Noxious weed control; herbicide registration; applicator licensing
Soil and Water Conservation Districts	Provide local conservation services including coordination, technical assistance, & outreach
OR Division of State Lands	Removal/fill permits in wetlands and waterways; maintenance of statewide wetland inventories (NWI and LWI)
OR Department of Environmental Quality	Clean Water Act; NPDES general permits for use of pesticides in, over or near surface water (2300-A) and in irrigation systems (2000-J) ;401 certification of US Corps of Engineers permitting; maintains 303(d) list of impaired waterbodies
OR Department of Fish and Game	Protection of fish and wildlife and their habitats
OR Parks & Recreation Department	Maintenance of state-owned park lands
OR State Marine Board	Boater education, Aquatic Invasive Species Prevention Program
Oregon Water Resources Department	
Oregon Watershed Enhancement Board	Provides grants for stream, river, wetland conservation/restoration
Center for Lakes and Reservoirs, PSU:	Implement Aquatic Invasives Species Management Plan
Oregon State University, Extension Service	Research; educational outreach
U.S. Environmental Protection Agency	Herbicide registration, implement Clean Water Act
NOAA Fisheries	Sustainable fisheries, Endangered Species Act, marine coastal ecosystem health

Table 2. Continued

Agency/Organization	Responsibility
U.S. Fish and Wildlife Service	Habitat conservation, Endangered Species Act, refuge management
U.S. Army Corps of Engineers	Navigation, dredging, wetlands fill permits (404 permitting)
Columbia Riverkeepers	Citizen coalition focused on restoration, pollution prevention, monitoring, and education
Willamette Riverkeeper	Monitoring Program, River Discovery Education Program and Habitat Restoration Program
Tualatin Riverkeepers	Restoration Tool Bank, river cleanup/restoration
Rogue Riverkeeper	Protection of waterquality Volunteer Riverwatch program (Rogue and Chetco Basins)
WaterWatch	Maintaining streamflows; policy
Waterkeeper Alliance	Oversees Waterkeeper programs worldwide; advocacy for wise-use of water resources
Network of Oregon Watershed Councils	Focus on building capacity and awareness of watershed councils, improving relationships between partnering organizations/agencies
Oregon Watershed Councils	Local, non-regulatory groups focused on improving watershed health
Oregon Association of Conservation Districts	

FUNDING

Adequate resources are critical to effective prevention and control efforts for any invasive organism. The Oregon Department of Agriculture Control Area Order (OAR 603-052-1206 to 603-052-1211) includes two funding provisions. The first is a $2/acre-fee required annually from permit holders to cover monitoring fields under cultivation and surveys for feral populations. As Arundo acreage under cultivation increases, this fee will become a viable funding mechanism for EDRR surveys. At a maximum, PGE projects between 30,000 to 60,000 acres, which would povide $60,000 to $120,000 annually. Until more Arundo is planted, existing budgets (PGE, County weed control programs, Coopertive Weed Management Areas, etc.) will need to cover monitoring efforts. The second provision is a surety bond for $100/acre (maximum of $1,000,000) for the duration of Arundo cultivation and for 3 years post-production to “cover any and all costs associated with the detection and eradication of giant reed inside or outside of production fields" if Oregon Department of Agriculture determines Arundo must be eradicated. In fields to be taken out of production, financial responsibility for eradication and monitoring costs remain with the permit holder. If the suspected source of a feral Arundo population is either an ornamental or woodwind reed planting, Oregon Department of Agriculture may request the landowner's cooperation in controlling, limiting spread or eradicating the population. Such work would be at no-cost to landowner, but rather would be covered by Oregon Department of Agriculture's general operating budget or by a collaborator through a State Weed Board grant (although these grant funds are limited to use on listed noxious weeds).

Additional funding sources may become necessary if Arundo becomes widespread and control costs exceed those funded through permit fees, surety bonds, and those available through Oregon Department of Agriculture's budget. Depending upon federal funding appropriation, some support for Arundo surveys may be available through the Oregon Aquatic Nuisance Species Management Plan or US Fish and Wildlife Service/Oregon Department of Fish and Wildlife Oregon Conservation Strategy Implementation Grants. Specific management tasks may be funded through the Oregon Watershed Enhancement Board, Oregon State Weed Board, or Oregon Department of Fish and Wildlife (Access and Habitat, Restoration and Enhancement, Bird Stamp Program or the Western Oregon Restoration Program). The Oregon Invasive Species Council may also declare an invasive species emergency, thereby allowing potential use of funds in the Oregon Invasive Species Control Account (OAR 609-010-0100 to 609-010-0140).

NEEDED ACTIONS

1. Prevention
    a. Variegated varieties may be as invasive as the fully green varieties and should be prohibited for sale and cultivation
    b. Assess the effectiveness of the 100-foot buffer zone currently in rule

2. Detection
    a. Expand passive surveillance statewide, particularly in urban areas
    b. Expand active ground and boat surveillance in areas near and downstream from Umatilla County Arundo plantations, including the Columbia River
    c. Conduct delimiting surveys around all known feral and cultivated stands of Arundo in Oregon outside the Control Area
    d. Develop and apply remote sensing capabilities in Oregon
    e. Utilize helicopter and fixed-wing surveys when the opportunity arises
3. Outreach and Education
    a. Increase outreach to gardeners and natural resource personnel to enhance passive surveillance capability
    b. Identify and publicize horticultural alternatives to planting Arundo
    c. Institute an Arundo exchange program to encourage homeowners to report and remove Arundo in exchange for a native, or noninvasive plant
4. Management
    a. Eradicate existing feral and cultivated populations of Arundo in Oregon outside the Control Area
    b. Use scale appropriate management tools. Physical removal of small stands with care to contain rhizome fragments and herbicide applications for larger stands
    c. Consult with the U.S. Fish and Wildlife Service and the National Marine Fisheries Service on the use of herbicides near or over waters that may be habitat for threatened and endangered species to avoid long delays in implementation of eradication efforts
    d. Conduct research on biocontrol agent efficacy in Oregon
    e. Use integrated management that combines treatment options when appropriate, e.g., physical removal of canes followed by herbicide treatment

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APPENDICES

Appendix A. Risk Assessment Summaries

Table 1. Oregon Department of Agriculture's Noxious Weed Qualitative Risk Assessment.

Category	Metric	Arundo/Total Possible	Comments (basis for score)
Geographical	Invasive in other areas	3 / 6	Arundo is well adapted to subtropical to warm temperate climates. The majority of Oregon is outside of the ideal climate zones. It has only been observed to grow vigorously in southwest Oregon. It does not survive in areas with prolonged or regular periods of freezing temperatures.
	Habitat availability	5 / 6	Prefers riparian habitats and there are many miles of this habitat in Oregon.
	Proximity to Oregon	3 / 6	California is the only boarding state with weedy populations and there are no populations adjacent to Oregon. It is most abundant in central (Sacramento Valley, San Joaquin Valley, South Coast Regions) and southern California.
	Current distribution	0 / 10	There are no known escaped populations in Oregon. The escaped population is from Bear Creek in Jackson County. It was controlled by ODA in 2006.
Biological	Environmental factors	2 / 4	Frost and freezing temperatures significantly impact the growth of Arundo. It is dependant on adequate soil moisture for establishment and spread.
	Reproductive traits	3 / 6	Viable seeds are not produced. Reproduction is by root fragments only.
	Biological factors	4 / 4	Arundo is highly resistant to herbivory. In North America there is no significant grazing by animals or damage by indigenous insect. Insects for classical biological control are being introduced USDA-ARS. The first of four insects was released in Texas 2009. There is no evidence that biocontrol agents will impact spread.
	Reproductive potential/spread (non-human)	3 / 5	Arundo is spread by moving water during flood events.
	Potential spread by humans	4 / 5	Arundo is not a popular ornamental in the nursery trade. Arundo is being evaluated as a possible biofuel. It is not a contaminant in agricultural commodities or other products.
Impact	Economic	3 / 10	Establishment could result in financial losses due to limitations on recreational activities, may increase property maintenance costs and increase costs for control on public lands.
	Environmental	6 / 6	Environmental impacts would likely occur in priority habitats and result in loss of plant, animal and insect species richness. Competition for water and increased stream temperatures may result from invasion.
	Health	0 / 6	No impact.
Control	Probability of dectection	3 / 10	Plant are large and showy. Access to habitat for control may be limited or difficult.
	Control efficacy	2 / 6	Glyphosate applications have proven to be effective.
	Total	**41/90**	

Risk Category: 55-90 = A 24-60 = B < 24 = unlisted.
Vers. 3.6 12/2/2010 (Modified by ODA from the USDA-APHIS Risk Assessment for the introduction of new plant species)

Appendix B: Control Area Order

603-052-1206
Definitions

As used in OAR 603-052-1206 to 603-052-1211 unless the context requires otherwise:
(1) “Giant reed” or “giant cane grass” means the plant species *Arundo donax* L. For purposes of this rule the term “giant reed” or “giant cane grass” applies to whole plants, plant parts, rhizomes, harvested plant parts, and seeds. For purposes of this rule, “giant reed” or “giant cane grass” does not include variegated varieties of giant reed as defined in subsection (4) of this section.
(2) “Feral giant reed” means whole plants of the plant species *Arundo donax* growing outside of permitted production areas or as otherwise inconsistent with this rule.
(3) “Riparian area” means a zone of transition from an aquatic ecosystem to a terrestrial ecosystem, dependent upon surface or subsurface water, that reveals through the zone’s existing or potential soil-vegetation complex the influence of such surface or subsurface water.
(4) “Special Flood Hazard Area” means an area inundated during the 1% annual flood (also known as 100-year flood or a base flood) as determined from the January 2011 version of the Flood Insurance Rate Maps of the Federal Emergency Management Agency (FEMA) available through the Department of Land Conservation and Development at: <http://oregonriskmap.com/index.php?option=com_content&view=category&id=11&Itemid=12>.
(5) “Variegated varieties of giant reed” means horticultural varieties of *Arundo donax* with striped or spotted leaves. Variegated varieties may include but are not limited to varieties marketed as “Peppermint Stick,” “Variegata,” and “Golden Chain,” or other ornamental varieties that can be visually distinguished from “giant reed” or “giant cane grass.”
(6) “Wetland” means areas that are naturally inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.
Stat. Auth.: ORS 570.405
Stats. Implemented: ORS 570.405
Hist.: DOA 29-2012, f. & cert. ef. 12-12-12

603-052-1209
Purpose

Giant reed, *Arundo donax*, is a promising bio-energy crop because of its high biomass yield. It is also grown as an ornamental and as a source of reeds for woodwind instruments. Giant reed is highly invasive in riparian areas in some regions of the United States such as California, Texas, and Florida. It is the intent and purpose of OAR 603-052-1206 to 603-052-1211 to balance goals to develop new agricultural crops and support renewable energy development from agricultural feedstocks while protecting natural resources and preventing the establishment of giant reed in riparian areas where it could cause major negative impacts to the natural resources of the State of Oregon.
Stat. Auth.: ORS 570.405
Stats. Implemented: ORS 570.405
Hist.: DOA 29-2012, f. & cert. ef. 12-12-12

603-052-1211
Control Area

(1) As authorized by ORS 570.405, a statewide control area is established to reduce the risk of uncontrolled spread of giant reed into the environment in order to protect the horticultural, agricultural or forest industries of the state.
(2) Extent of Control Area: All of the State of Oregon.
(3) Commodities Covered: All life stages of giant reed, Arundo donax.
(4) Prohibited Acts:
(a) Giant reed is prohibited from being imported, planted, propagated, or grown except as allowed in this rule in sections (5) through (7) below.
(b) Giant reed shall not 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.
(5) Permit Requirements:
(a) Except as specified in OAR 603-053-1211(7)(b), giant reed shall not be planted or grown in Oregon without a permit from the Oregon Department of Agriculture (ODA).
(b) Applications for permit must be in writing to ODA and include specific locations, detailed maps of the field locations, and any water bodies in the vicinity of all proposed field locations. Applications for a permit to produce giant reed must be sent to: Plant Program Area Director, Oregon Department of Agriculture, 635 Capitol St. NE, Salem, OR 97304 or emailed to: <dhilburn@oda.state.or.us>.
(c) ODA will review the application upon its receipt and share the application information with noxious weed control officials in the county(ies) where production of giant reed is grown or proposed to be grown.
(d) ODA may deny an application or may issue a permit with any conditions as may be necessary to prevent the uncontrolled spread of giant reed or as necessary to protect the horticultural, agricultural or forest industries of the state. Conditions that ODA may require include, but are not limited to, conditions requiring notification to ODA of the dates when

giant reed fields are planted and are taken out of production, annual updates on field locations, or any other precautions related to site-specific risk factors presented by a proposed growing location.
(e) Permit holders will be assessed an annual fee of $2.00 per acre payable to ODA before planting and every twelve months thereafter, to cover the cost of monitoring fields where giant reed is produced and the cost of surveys for feral giant reed in the environment. Monitoring and surveys are necessary to ensure that giant reed has not escaped outside of contracted production areas and is necessary for enforcing the terms of the control area established in this rule.
(f) Any equipment used in giant reed production fields must be cleaned free of soil and plant debris prior to leaving production fields.
(g) Planting stock collected from the wild outside of Oregon must be washed free of soil and must be accompanied by a phytosanitary certificate indicating that the stock has been inspected and found free of soil and harmful pests, diseases, and weeds.
(h) In vitro and container-grown giant reed planting stock imported for biofuel production must meet plant health requirements for nursery stock entering Oregon from the state of origin.
(i) In-state producers of biofuel planting stock are subject to the same requirements as biofuel producers if plants are field grown. In vitro and containerized production of biofuel planting stock in Oregon does not require a bond or a permit, but containerized giant reed planting stock shall not 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.
(j) Green giant reed must not be transported outside the fields where it is grown unless it is in a covered container or the load is tarped. Harvested giant reed that is conditioned (crushing, chipping, chopping, or shredding) and dried in the field need not be transported in closed containers and such loads need not be tarped (e.g. bales of giant reed).
(6) Bond; Conditions for Ceasing Production of Giant Reed:
(a) Contractors (or growers if there is no contractor) for the production of giant reed for other than ornamental or woodwind reed purposes (see (7) below) must supply a bond or another form of acceptable collateral furnished by a surety company authorized to do business in Oregon in favor of the State of Oregon through its Department of Agriculture. The amount of the bond/collateral will be $100/acre up to a maximum of $1,000,000. The permit will not be issued until the Department has received the bond/collateral. The purpose of the bond is to cover any and all costs associated with the detection and eradication of giant reed inside or outside of production fields if the Department determines feral giant reed must be eradicated in order to protect the agricultural, horticultural or forest resources of the State. The bond/collateral must be in place for the duration of permitted production and remain effective for 3 years after production ceases.
(b) The holder of a permit for the production of giant reed that ceases production of giant reed must completely eradicate giant reed in a manner that prevents former giant reed production fields from becoming a source of propagules that could lead to accidental spread of giant reed in the wild.
(c) Any holder of a permit issued by ODA must monitor any and all areas upon which giant reed was produced under permit for at least three years after production ceases to ensure that all giant reed plants are killed and any source of propagules are eradicated. ODA may require additional monitoring time as it determines is necessary to assure complete eradication of giant reed from areas under contract for production.
(d) Any and all costs associated with eradication of giant reed in production fields and adjacent property owned or controlled by the producer after production has ceased is the responsibility of the permit holder.
(e) Oregon State University Research and Extension Centers are exempt from sections (5)(a) and (6)(a) of this rule for the purpose of allowing research related to giant reed production and control.
(7) Conditions for Ornamental and Woodwind Reed Plantings: Giant reed has been used as an ornamental plant in Oregon for many years. It is also grown as a source for woodwind reeds. Ornamental or woodwind reed plantings could result in feral populations. In order to lower the risk of ornamental or woodwind reed plants becoming feral, giant reed is being phased out of the nursery trade. Variegated varieties such as “Peppermint Stick,” “Variegata,” and “Golden Chain,” may continue to be grown and sold in Oregon unless ODA and State Weed Board list giant reed as a noxious weed.
(a) After December 31, 2013, only variegated varieties of giant reed may be sold in Oregon for ornamental or woodwind reed purposes.
(b) A permit is not required for ornamental or woodwind reed plantings of variegated varieties of giant reed totaling less than 1/4 acre.
(c) Ornamental and woodwind reed plantings of giant reed existing before these rules were adopted will not be considered feral unless they are in Special Flood Hazard Areas or the ODA determines such populations are becoming invasive. Any plantings of giant reed or variegated varieties of giant reed over 1/4 acres are subject to the permitting requirements in OAR 603-052-1211(5).
(d) If the ODA and the State Weed Board determine giant reed is a noxious weed, all ornamental uses of giant reed shall terminate and all production will require a permit.
(8) Eradication and Control of Giant Reed:
(a) Except as stated in (7) above, ODA considers giant reed plants detected outside of contracted production fields as feral plants, which shall be eradicated or controlled.
(b) Any person owning or occupying property upon which feral giant reed is detected must contact the ODA within 48 hours of detection.
(c) Upon detection of feral giant reed, ODA may develop a survey, eradication, and monitoring plan to control or eradicate detected feral giant reed. Consistent with its authorities, ODA may develop and conduct appropriate measures to control

or eradicate feral giant reed, may enter into a contract for the purpose of controlling or eradicating feral giant reed, or take any measures necessary to control or eradicate feral giant reed consistent with law.
(d) Control or eradication of feral giant reed may be implemented at no cost to a person owning or controlling land within this state upon which feral giant reed is detected. However, ODA may request any person owning or controlling land within this state to control, prevent the spread of, or eradicate feral giant reed, subject to supervision of such activities by ODA.
(e) If ODA is unable to control or eradicate feral giant reed on private property, then consistent with the provision of ORS 570.405(2), any person owning or controlling land within this state must take measures to eliminate or prevent the possibility of spread of feral giant reed to other lands and ownerships. Control measures for feral giant reed must be implemented in a timely manner as determined by ODA. Treatments must provide sufficient levels of control to make progress toward the goal of eradication.
(9) Review:
(a) ODA will conduct a thorough review of these rules after PGE’s test burn (now scheduled for 2014) and before large acreages of giant reed are planted. The best available science, experience with test plots, survey results, and plans for expansion of giant reed production will be taken into consideration when determining whether these rules should be amended.
(b) Before December 31, 2022, the Department will conduct a thorough review of the effectiveness and necessity for this rule. If by that date giant reed has not been declared a noxious weed by ODA and the State Weed Board, the bond/collateral requirement (6)(a) sunsets unless specifically extended via amendment to this rule.
Stat. Auth.: ORS 570.405
Stats. Implemented: ORS 570.405
Hist.: DOA 29-2012, f. & cert. ef. 12-12-12; DOA 3-2014, f. & cert. ef. 2-20-14

Appendix C. Comparison of treatment methods for Arundo (from: Team Arundo Del Norte 2007)

General Comments:

- All project areas could need FWS consultation: Section 7 or 10.
- All methods require at last 5 years follow-up for resprouts.

METHOD[1]	**BEST USE**	**TIMING**	**TOOLS/ EQUIPMENT**	**POSSIBLE PERMITS**[2]	**REVEGETATION**	**Typical division of labor cost over 10 years**	**ADVANTAGES**	**DISADVANTAGES**
SPRAY ONLY Spray leaves and stems with systemic herbicide.	For small and large infestations where full-height applications are feasible. Use on pure stands of *Arundo*.	When plant is green. Best in late summer/early fall when plant energy is transferred to roots.	Herbicide, back-pack sprayer, power sprayer, or aerial (plane, helicopter).	County Ag Commission permit for pesticide application by non-landowner.	Can be initiated four months after treatment. Stands that are left standing can have plants planted into them. Mowed stands can also have plants planted after mowing.	Yr1: 84% Yr2: 7% Yr3: 3% Yr4: Yr5: 2% Yr:6 Yr:7 2% Yr:8 Yr:9 Yr:10 2%	Low soil disturbance. Requires less labor than other methods.	Risk from drift to non-target plants. Licensed applicator needed if non-landowner applies herbicide. Aerial (aircraft) applications are non-target and work poorly. Require use of low concentration per label.

METHOD[1]	BEST USE	TIMING	TOOLS/ EQUIPMENT	POSSIBLE PERMITS[2]	REVEGETATION	Typical division of labor cost over 10 years	ADVANTAGES	DISADVANTAGES
BEND AND SPRAY Bend over canes to concentrate surface area of clump or lay flat on ground. Spray. Leave on ground to compost, or mow and mulch standing canes later.	Mixed and pure stands. Small or large infestations. Bending generally only done around or near desirable vegetation. Where none occurs, can use Spray Only method.	Spray in late summer/early fall when plant energy is transferred to roots. Cut or mulch dead canes approx. three months after treatment.	Flail or fixed tooth mower to mow/mulch *Arundo*. Not required for all stands.	County Ag Commission permit for pesticide application by non-landowner. Permit(s) to work in channel with backhoe if biomass reduction occurs.	Can be initiated four months after treatment. Stands that are left standing can have plants planted into them. Mowed stands can also have plants planted after mowing.	Yr1: 84% Yr2: 7% Yr3: 3% Yr4: Yr5: 2% Yr:6 Yr:7 2% Yr:8 Yr:9 Yr:10 2%	Very effective. Less risk of drift. Uses less herbicide than Spray-Only method. Biomass can be left on site. Potential reduction in labor costs to remove biomass. Low soil disturbance.	Increased labor costs to bend canes. Licensed applicator needed Standing dead *Arundo* could pose fire risk. If using flail/fixed tooth mower, heavy equipment operator needed. Access and slope must be suitable to use mower.
CUT, RESPROUT, AND SPRAY Cut and remove canes; allowing roots to resprout, then following up with foliar spray	Historically used with pure stands, large infestations.	Cut in spring to summer. Spray regrowth in late summer/early fall when plant energy is transferred to roots. (This rarely occurs--in practice multiple retreatments occur throughout	Loppers or power brush cutter (steel-blade weed whacker), herbicide, sprayer.	County Ag Commission permit for pesticide application by non-landowner. Permit(s) to work in channel if biomass reduction occurs. Definite DFG 1600 permits.	Must wait until re-sprouting is low enough to allow planting- typically two years.	Yr1: 46% Yr2: 20% Yr3: 10% Yr4: 10% Yr5: 5% Yr:6 5% Yr:7 2% Yr:8 Yr:9 Yr:10 2%	Low soil disturbance. Potentially less risk of non-target herbicide drift than when spraying full-grown canes. Can use volunteers for cutting cane.	Risk from drift to non-target plants. Licensed applicator needed. Multiple repeat treatments required. Cane can reach original height before retreatment, thus negating advantages. Shorter canes translocate less herbicide, resulting in poorer results.

METHOD[1]	BEST USE	TIMING	TOOLS/ EQUIPMENT	POSSIBLE PERMITS[2]	REVEGETATION	Typical division of labor cost over 10 years	ADVANTAGES	DISADVANTAGES
		the year.)						
CUT STUMP Cut stalks to within 2" of ground, then immediately apply undiluted glyphosate to stump.	Small stands, mixed vegetation, close proximity to water, and for follow-up treatments.	Anytime during growing season. Best in late summer/early fall when plant energy is transferred to roots.	Chainsaw, loppers, herbicide.		Must wait until re-sprouting is low enough to allow planting- typically one or two years. Usually fairly high ruderal weed cover due to lack of Arundo mulch layer.	Yr1: 63% Yr2: 18% Yr3: 5% Yr4: 5% Yr5: 5% Yr:6 Yr:7 2% Yr:8 Yr:9 Yr:10 2%	Low soil disturbance. Low risk of non-target herbicide drift. Can use volunteers for cutting cane and removing. Volunteers can work near applicator.	Requires handling high-concentration herbicide. Risk of spillage. Impractical for large infestations.
INJECTION[3] Concerntrated herbicides injected into stalks at 90º angle.	In very sensitive, high visibility work areas. Also when selective (internal) placement of herbicide is desired.	Best suited in late summer or fall, or when plants actively growing up through a killing frost.	JK injection gun www.Jkinjectiontools.com	County Ag Commission permit for pesticide application by non-landowner.	Ability to plant back or revegetate area immediately. Depending on site, circumstances may warrant waiting 6-9 months to see if retreatment needed.	Yr 1: 25% Yr 2: 70% (dead stem removal) Yr 3: 5%	May not need to retreat, especially if inject all stems in each clump. Useful in areas with sensitive species since low risk of herbicide drift.	Labor-intensive. Impractical for large infestations.

[1] Up to 5 years follow-up monitoring for resprouts.
[2] Significant vegetation removal may require a CDFG Stream Alteration Agreement.

[3] Injection rate for *A. donax* has not yet been labeled. Check with local herbicide representative for updated information.

This information is intended as guidelines for selecting a method(s) of *Arundo* eradication, and is not an endorsement of any particular herbicide.

Sources: Arundo: A Landowner Handbook: Arundo Eradication and Coordination Program and SMSLRWMA.org web site.