ECOLOGY AND MANAGEMENT OF *ARUNDO DONAX*, AND APPROACHES TO RIPARIAN HABITAT RESTORATION IN SOUTHERN CALIFORNIA

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Abstract

By far the greatest threat to the dwindling riparian resources of coastal southern California is the alien grass species known as *Arundo donax*. Over the last 25 years the riparian forests of coastal southern California have become infested with *A. donax* which has spread by flood-fragmentation and dispersal of vegetative propagules. *Arundo donax* dramatically alters the ecological/successional processes in riparian systems and ultimately moves most riparian habitats towards pure stands of this alien grass. By current estimates there are tens of thousands of acres of *A. donax* along the major coastal drainage systems of southern California, including the Santa Ana, Santa Margarita, Ventura, Santa Clara, San Diego, and San Luis Rey rivers. The removal of *A. donax* from these systems provides numerous downstream benefits in terms of native species habitat, wildfire protection, water quantity and water quality.

Introduction

Arundo L. is a genus of tall perennial reed-like grasses (Poaceae) with six species native to warmer parts of the Old World. *Arundo donax* L. (giant reed, bamboo reed, giant reed grass, arundo grass, donax cane, giant cane, river cane, bamboo cane, canne de Provence), is the largest member of the genus and is among the largest of the grasses, growing to a height of 8 m (Fig. 1). This species is believed to be native to freshwaters of eastern Asia (Polunin and Huxley 1987), but has been cultivated throughout Asia, southern Europe, north Africa, and the Middle East for thousands of years and has been planted widely in North and South America and Australia in the past century (Perdue 1958; Zohary 1962). It was intentionally introduced to California from the Mediterranean in the 1820's in Los Angeles area as an erosion-control agent in drainage canals, and was also used as thatching for roofs of sheds, barns, and other buildings (Hoshovsky 1987). Subsequent plantings have been made for the production of reeds for a variety of musical instruments including bassoons and bagpipes. Today it is an invasive pest throughout the warmer coastal freshwaters of the United States, from Maryland to northern California.

Arundo donax is a hydrophyte, growing along lakes, streams, drains and other wet sites. It uses prodigious amounts of water, as much as 2,000 L/meter of standing *A. donax*, to supply its incredible rate of growth (Perdue 1958; Iverson 1994). Under optimal conditions it can grow more than 5 cm per day (Perdue 1958). *Arundo donax*

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stands are among the most biologically productive of all communities. Under ideal growth conditions they can produce more than 20 tons per hectare above-ground dry mass (Perdue 1958).

Perhaps as much as 90% of the historic riparian habitat in the southern part of California has been lost to agriculture, urban development, flood control, and other human-caused impacts (Jones and Stokes 1987; Katibah 1984). The greatest threat to the remaining riparian corridors today is the invasion of exotic plant species, primarily *Arundo donax*. This alien grass readily invades riparian channels, especially in disturbed areas, is very competitive, difficult to control, and to the best of our knowledge does not provide either food or nesting habitat for native animals. *Arundo* competes with native species such as *Salix* (willows), *Baccharis salicifolia* (mulefat), and *Populus* (cottonwoods) which provide nesting habitat for the federally endangered bird, the least Bell's vireo (*Vireo bellii pusillus*), the federally threatened bird, the willow flycatcher (*Empidonax traillii eximus*) and other native species (Hendricks and Rieger 1989; Franzreb 1989; Zembal 1986, 1990).

Ecological value of native riparian systems

Like most riparian systems, the cottonwood/willow riparian forest is a dynamic community, dependent upon periodic flooding to cycle the community to earlier successional stages (Warner and Hendrix 1985). Periodic floods of large magnitude and migration of the river channel are essential to depositing fresh alluvium where seeds and vegetative propagules of *Baccharis*, *Salix*, and *Populus* can germinate and take root (Gregory et al. 1991; Richter and Richter 1992). Adequate moisture and an absence of subsequent heavy flooding is critical to the survival of the young trees through their first year. As these seedlings mature they increase channel roughness and alter flow during small flood events, increasing sediment deposition (Kondolf 1988; Richter and Richter 1992; Stromberg *et al.* 1993). Sediment deposition builds river terraces and, as they elevate, other plant species colonize resulting in further diversification in the floodplain community (Richter and Richter 1992).

When *Populus/Salix* riparian scrub, which may include such species as *Baccharis salicifolia*, *Vitis californica*, *Rubus ursinus*, and *Urtica dioica* ssp. *holosericea*, reaches four or five years of age, it begins to exhibit the structural diversity required for breeding by the bird, the least Bell's vireo (Franzreb 1989; Hendricks and Rieger 1989). Least Bell's vireo, along with the riparian birds, southwestern willow flycatcher, yellow-breasted chat (*Icteria virens*), yellow warbler (*Denroica petechia*), and many other species may continue to use this diverse community for another ten to twenty years. Gradually the canopy of the maturing *Salix* and *Populus* begins to shade out the diverse understory of vascular plants required by these birds. Older riparian gallery forests will continue to be used by western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), Cooper's hawk (*Accipiter cooperii*), warbling vireo (*Vireo gilvus*) and other species (Zembal 1990; Zembal *et al.* 1985), but as the stand ages the diversity of the flora and fauna within the forest declines. Annual flooding, channel migration, and occasional large flood events maintain this cycle of succession and therefore maintains a mosaic of diverse natural communities (Gregory *et al.* 1991).

Arundo donax as a competitor

Within its introduced range, *A. donax* is an aggressive competitor. *Arundo donax* flowers in late summer with a large, plume-like panicle. Fortunately for California land managers, the seeds produced by *A. donax* in this country are seldom, if ever, fertile. It is not known if this is because of clonal isolation or because of the physiological effects of climate as has been observed in the related *Phragmites communis* (common reed) (Haslam 1958; Rudescu *et al.* 1965). *Arundo donax* is well adapted to the high disturbance dynamics of riparian systems as it spreads vegetatively. Flood events break up clumps of *A. donax* and spread the pieces downstream. Fragmented stem nodes and rhizomes can take root and establish as new plant clones. Thus invasion, spread, and therefore management, of *A. donax* is essentially an intra-basin and downstream phenomenon.

Once established *A. donax* tends to form large, continuous, clonal root masses, sometimes covering several acres, usually at the expense of native riparian vegetation which cannot compete. Root masses, which can become more than a meter thick, stabilize stream banks and terraces (Zohary and Willis 1992), altering flow regimes. *Arundo donax* is also highly flammable throughout most of the year, and the plant appears highly adapted to extreme fire events (Scott 1994). While fire is a natural and beneficial process in many natural communities in southern California it is a largely un-natural and pervasive threat to riparian areas. Natural wild fires usually occur during rare lightening storm events in late fall, winter, and early spring. Under these conditions the moist green vegetation of riparian areas would normally act as a fire break. Human-caused wild fires, in contrast, often occur during the driest months of the year (July through October). Drier conditions in riparian zones at this time of year make them more vulnerable to fire damage. Because *A. donax* is extremely flammable, once established within a riparian area it redirects the history of a site by increasing the probability of the occurrence of wildfire, and increasing the intensity of wildfire once it does occur. If *A. donax* becomes abundant it can effectively change riparian forests from a flood-defined to a fire-defined natural community, as has occurred on the Santa Ana River in Riverside County, California. *Arundo donax* rhizomes respond quickly after fire, sending up new shoots and quickly outgrowing any native species which might have otherwise taken root in a burned site. Fire events thus tend to help push riparian stands in the direction of pure *A. donax*. This results in river corridors dominated by stands of giant reed with little biological diversity.

Arundo donax as habitat

All evidence indicates that *A. donax* provides neither food nor habitat for native species of wildlife. *Arundo donax* stems and leaves contain a wide array of noxious chemicals, including silica (Jackson and Nunez 1964), tri-terpines and sterols (Chandhuri and Ghosal 1970), cardiac glycosides, curare-mimicking indoles (Ghosal *et al.* 1972), hydroxamic acid (Zuñiga *et al.* 1983), and numerous other alkaloids which probably protect it from most native insects and other grazers (Miles *et al.* 1993; Zuñiga *et al.* 1983). Areas taken over by *A. donax* are therefore largely depauperate of wildlife. This also means that native flora and fauna do not offer any

Fig. 1. Arundo donax. Plant × 1/3; spikelet and floret × 3 (from Hitchcock and Chase 1950).

significant control mechanisms for *A. donax*. It is uncertain what the natural controlling mechanisms for this species are in the Old World, although infestations of corn borers (Eizaguirre *et al.* 1990), spider mites (El-Enany 1985) and aphids (Mescheloff and Rosen 1990) have been reported in the Mediterranean. In the United States a number of diseases have been reported on giant reed, including root rot, lesions, crown rust, and stem speckle (USDA 1960), but none seems to have seriously hindered the advance of this weed.

Recent studies by the Santa Ana Watershed Project Authority (Chadwick and Associates 1992) suggest that *A. donax* also lacks the canopy structure necessary to provide significant shading of bank-edge river habitats, resulting in warmer water than would be found with a native gallery forest of *Populus* or *Salix*. As a result, riverine areas dominated by *A. donax* tend to have warmer water temperatures, which results in lower oxygen concentrations and lower diversity of aquatic animals, including fishes (Dunne and Leopold 1978). In the Santa Ana River system this lack of streambank structure and shading has been implicated in the decline of native stream fishes including *Gila orcuttii* (arroyo chub), *Gasterosteus aculatus* (three-spined stickleback), *Rhinichthys osculus* (speckled dace), and *Catostomus santaanae* (Santa Ana sucker). This lack of stream-side canopy structure may also result in increased pH in the shallower sections of the river due to high algal photosynthetic activity. In turn, high pH facilitates the conversion of total ammonia to the toxic un-ionized ammonia form which further degrades water quality for aquatic species and for downstream users (Chadwick and Associates 1992).

Control methods

A suite of methods is needed to control *A. donax* depending upon the presence or absence of native plants, the size of the stand, the amount of biomass which must be dealt with, the terrain, and the season.

The key to effective treatment of established *A. donax* is killing of the root mass. This requires treatment of the plant with systemic herbicide at appropriate times of the year to ensure translocation to the roots. Only one herbicide is currently labeled for wetlands use by the EPA; Rodeo®, a tradename formulation of glyphosate, produced by Monsanto Corporation. Glyphosate is a broad-spectrum herbicide which can be used on *A. donax*, *Tamarix ramosissima* (salt cedar), and most other monocots and dicots. It has proven very effective against *A. donax* (Finn and Minnesang 1990; Jackson 1994; USDA Forest Service 1993). Other herbicides might also be used as labels and conditions allow. Monocot-specific chemicals, such as Fusilade-DX® (fluazapop-butyl) and Post® (Sethoxidan), might be particularly useful for treating *A. donax* in stands with a substantial component of native dicots; however, neither is currently labeled for wetlands use.

The most effective treatment on *A. donax* is the foliar application of a two-to-five percent (2–5%) solution of Rodeo applied post-flowering and pre-dormancy at a rate of 0.5 to 1 l/hectare. During this period of time, usually mid-August to early November, the plants are actively translocating nutrients to the rootmass in preparation for winter dormancy which results in effective translocation of herbicide to the roots. Recent preliminary comparison trials on the Santa Margarita River (Omori 1996) indicate that foliar application during the appropriate season results in almost 100%

control, compared with only 5–50% control using cut-stem treatment. Two to three weeks after foliar treatment the leaves and stalks brown and soften creating an additional advantage in dealing with the biomass: cut green stems might take root if left on damp soil and are very difficult to cut and chip. Treated stems have little or no potential for rooting and are brittle. They may be left intact on the ground or chipped *in situ* for mulch.

Cut-stem treatment requires more time and man-power than foliar spraying and requires careful timing. Cut stems must be treated with concentrated herbicide within one to two minutes in order to ensure tissue uptake (Monsanto 1989). This treatment is also most effective post-flowering. The chief advantage of the cut-stem treatment is that it requires less herbicide that can be more-or-less surgically applied to the stem. Because of its reduced efficacy, and due to the labor required, it is rarely cheaper than foliar spraying except on very small, isolated patches or individual plants.

A popular approach to dealing with *A. donax* has been to cut the stalks and remove the biomass, wait three to six weeks for the plants to grow to about one meter tall, then apply a foliar spray of herbicide solution. The chief advantage of this approach is that less herbicide must be applied to treat the fresh growth compared with tall, established plants, and that coverage is often better because of the shorter and uniform-height plants. However, cutting of the stems may result in the plants returning to growth-phase, drawing nutrients from the rootmass. As a result there is less translocation of herbicide to the roots and less root-kill. Therefore many follow-up treatments must be made which negates any initial savings in herbicide and greatly increases the manpower costs.

Pure stands (>80% canopy cover) of *A. donax* or *T. ramosissima* are most efficiently treated by aerial application of an herbicide concentrate, usually by helicopter. Helicopter application can treat at least 50 hectares per day. Special spray apparatus produces extremely fine droplets (400 microns) of concentrated herbicide which actually reduces herbicide use, minimizes over-spray, and results in greater kill.

In areas where helicopter access is impossible, where *A. donax* makes up the understory, where patches are too small to make aerial application financially efficient, or where weeds are mixed with native plants (<80% cover), herbicides must be applied by hand. Street-vehicles with 400 liter spray tanks are a good alternative where road access is available, but small "quad-runner" vehicles equipped with 60 liter sprayers are the preferred approach where the streambed is not so rocky as to prevent access. Twenty liter backpack sprayers are the final alternative where the vegetation is too dense, or the landscape too rugged for vehicles to be effective.

Methods for vegetation removal include use of prescribed fire, heavy machinery (e.g. bulldozers), handcutting by chainsaw or brushcutter, hydro-axe, chipper, biomass burning or removal by vehicle. Removal of the biomass should only be done where the weed cover is so dense as to prevent recovery by native vegetation after treatment, or where cut vegetation might create a debris-dam hazard during flood events. Prescribed fire, or burning piles of stacked biomass, is the most cost-effective way of removing biomass as long as it does not threaten native vegetation or other resources. Chipping is more costly in terms of equipment and labor, and cut, dried chips pose no threat for regeneration or for forming debris dams. Hauling of biomass by vehicle is extremely expensive and should only be done as a last resort. Most landfills will not accept *A. donax* and those that do will only accept it if cut into short lengths and bagged into plastic trash bags, making the labor costs far too great. The use of heavy machinery such the Hydro-ax® is extremely expensive. The machines are very slow – a Hydro-ax can only cut about 1-5 ha per day.

Riparian restoration and management

One of the prime incentives for riparian habitat restoration has been endangered species recovery, including the federal Endangered Species Act (ESA). The ESA has focused attention on declining species and sought to protect those species in greatest risk by provisions against take (Under the ESA the term "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct). Focus of the legislation has been on individual protected species with little attention given to the dynamics of the natural systems of which these species are a part. There are important historical and legislative reasons for this approach. In the 1970's, when the ESA was drafted, ecologists and wildlife managers were highly focused on single species; system-oriented approaches were not widely applied. In addition, it is far easier to attach legal definition to something tangible, such as an individual animal, than it is to the more vague concept of ecological processes (Gregory *et al.* 1991).

The concept of habitat restoration developed in response to the "take" provisions of the ESA as a means of mitigating site-specific damage. While re-vegetation has been carried out in a wide variety of natural community types, its earliest successes and its greatest application has been in mitigation of losses of riparian forests. In southern California, riparian re-vegetation has been pursued as an ever-evolving artform in response to the perceived need for replacement of habitat for the federally and state endangered least Bell's vireo (*Vireo bellii pusillus*) and a suit of other endangered or candidate species including the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), and the willow flycatcher (*Empidonax traillii*) (Anderson and Miller 1991; Baird and Rieger 1989; Parra-Sjizz 1989; RECON 1988).

It may be argued that the main reason why riparian re-vegetation has received so much attention is because it is so relatively easy to achieve. This ease is a result of the very dynamics of riparian systems – they are high-disturbance systems composed of flood-adapted and resilient species. *Salix, Populus, Baccharis,* and other riparian plant species establish easily by fragmentation in flood events in addition to seeding in flood-washed sediment beds. As a result riparian re-vegetation essentially requires only plant material (cuttings or rooted stock) and water (irrigation). However, such re-vegetation projects can be extremely expensive.

It is also important to recognize that re-vegetation does not necessarily equate with habitat restoration. While the matrix plant species of habitats are relatively easy to establish, the dynamics of native riparian communities are poorly understood. Establishing a *Salix/Populus* stand on a stream-side terrace will probably not provide the community diversity of a natural stand or the dynamic processes required to establish it. While some re-vegetation programs have been successful in terms of establishing a matrix of riparian habitat which is used by some native species, re-vegetating is the not necessarily the best way to create habitat.

The best way to address habitat loss in southern California riparian systems is through a comprehensive program of eradication of *A. donax, T. ramosissima*, and other invasive aliens, and relying on natural physical processes, especially flood dynamics, for the recovery of native natural communities and species. This approach might be just as easily argued for other high disturbance-adapted communities.

This strategy is based upon two of important factors. First, riparian habitats are flood-dynamic communities, dependent upon natural cycles of flood scouring and sediment deposition to create the proper conditions for community establishment (Gregory *et al.* 1991; Richter and Richter 1992; Stromberg *et al.* 1991). The Santa Ana, Santa Margarita, San Luis Rey, and many other southern California streams have all of the factors necessary for the recovery and maintenance of healthy riparian communities and riparian species. These watersheds retain flood regimes sufficient to move and sort sediment and extensive sources of seed and vegetative propagules for *Salix* and other native riparian plants. Second, the only real threats to the integrity of the system are (1) habitat fragmentation by development and (2) introduced exotic species which have altered the successional dynamics and stability of the natural communities. In other words, the native riparian communities of the Santa Ana and other major riparian corridors (and thus riparian-dependent species such as least Bell's vireo) are limited, not by the capacity of the community to regenerate, or the available area of riparian zones, but by the capacity of native species to compete with aggressive invasive exotic species, chiefly *A. donax*.

The majority of the limited resources available for riparian management on these rivers should therefore be directed at managing for the process of riparian systems: removing the key perturbation from the system, thereby allowing natural flood dynamics to operate and the natural communities to recover. Attempts to re-vegetate riparian species in floodplains that retain both native riparian species and flood regimes are redundant, and resources spent to this end are largely wasted. This is not to imply that riparian (and other habitat) re-vegetation efforts should not be applied; however, they should be applied judiciously and only in situations where specific management goals are achieved by carrying out a re-vegetation project (e.g. closing up an important corridor or re-establishing native species in a depauperate watershed). Relying on natural processes for the recovery of the riparian communities has the following major benefits:

a. Cost-effectiveness. Riparian forest restoration is extremely expensive, often on the order of tens of thousands of dollars per hectare. This necessarily limits the size, and therefore the biological value, of any funded restoration project. *Arundo donax* can be removed from most areas of a river for a fraction of the cost of revegetation, opening up areas for natural re-colonization by native riparian species.

b. Biological value. As indicated above, the high cost of re-vegetation limits the size of restoration projects. Additionally, artificially-produced riparian habitat lacks the high stem densities characteristic of naturally regenerating riparian habitat, making the actual biological value of re-vegetated sites questionable. Much higher value may be achieved by removing invasive exotics such as *A. donax* from the system. Areas opened up for recolonization which are subsequently flood-scoured and naturally seeded or "planted" with vegetative propagules spread by the flood are more likely to recover in high stem density habitat.

c. Natural vulnerability. Riparian systems are, by nature, dynamic. The natural flood process that produces the conditions for natural riparian establishment also puts artificially (and naturally) created habitat areas in flood jeopardy. This makes riparian revegetation a high-risk investment of limited resources. Several expensive revegetation projects on the Santa Margarita and Santa Ana Rivers were damaged or lost to flood scouring in January 1993. Some of these areas recovered with high stem-density *Salix* scrub when *A. donax* was controlled. Other sites, without such weed control efforts, succeeded to high density *A. donax* colonies.

Summary

By virtue of its growth characteristics, adaptations to disturbance, especially fire, its lack of natural predators and competitors in North America, and its unsuitability as food or habitat for native wildlife, *Arundo donax* has established itself as one of the primary threats to native riparian habitats in the western United States.

Control and management of *A. donax* within a watershed requires a coordinated, watershed-wide approach. *Arundo donax* should be removed from the watershed beginning in the upper tributaries to prevent reinfestation of treated downstream sites from upstream sources. Removal of *A. donax* requires treatment with systemic herbicides in order to kill the large root mass.

Past practices of riparian restoration have focused on re-vegetation of small sites without consideration of natural riparian processes. Resources should be spent on managing for the natural dynamic processes of these systems on a watershed-wide scale. In coastal southern California the primary perturbation to the natural riparian succession process is invasion by *A. donax*, and its removal from river systems will have a far greater beneficial effect on most riparian species than planting of riparian vegetation.

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