Arundo Eradication Plan: Cuatro Ciénegas, Coahuila, Mexico

Prepared by:
Suzanne McGaugh, Iowa State University, EEOB
Dean Hendrickson, University of Texas-Austin, Texas Memorial Museum
Gary Bell, The Nature Conservancy, New Mexico, Conservation Science
Tom Dudley, University of California Santa Barbara, Marine Science Institute
Kelly Lyons, Trinity University, Department of Biology
Valeria Souza, Instituto de Ecología de la UNAM
Lucas McEachron, Florida State University,

With participation of persons attending the Taller sobre de *Arundo* sponsored by The Nature Conservancy and Pronatura, including representatives from Desuvalle, A.C., Universidad Iberoamericana, Instituto de Ecología de la UNAM (IE/UNAM), CONANP, University of Texas, Iowa State University, Florida State University, the community of Cuatro Ciénegas, PRONATURA-Noreste, and The Nature Conservancy.

Program Information

Recently, a number of wetlands and rivers in Cuatro Ciénegas, Coahuila, Mexico have become infested with an alien weed species known as Giant Reed (*Arundo donax*). Public and private agencies with ownership and/or management responsibilities share a common concern in dealing with the immediate threats of excessive transpiration of water, wild fires, and loss of habitat that are commonly associated with this species.

The focus of this management plan is the eradication and long-term management of Giant Reed in the Cuatro Ciénegas Natural Protected Area. Secondary objectives include revegetation of key areas where aesthetics and/or lack of recovery by native vegetation requires habitat enhancement.

Background

The valley of Cuatro Ciénegas, in Coahuila, México, is ranked among the world's most unique ecosystems. Harboring over 70 endemic species, its endemism is higher than any other place in North America (Stein et al. 2000). Much of the valley's biotic diversity is associated with a diverse complex of hundreds of geothermal springs, lakes and streams that exhibit extreme temperature and water chemistry variation often over very small spatial scales. Many of the species are classified as endangered or threatened by the Mexican government and the Convention on International Trade of Endangered Species (CITES). The extreme fragility of the ecosystem resulted in it being declared a National Protected Area (Secretaria de Desarrollo Social 1994). However, continued threats to biodiversity include water exploitation, exotic species' invasions, industrial development, and rapidly increasing tourism and population growth.

Over the last five decades, the Cuatro Ciénegas valley has attracted many researchers with interest in long term conservation of the area. At the recent Cuatro Ciénegas researcher's meeting, 'Congreso de Investigadores de Cuatro Ciénegas,' direct conservation concerns of valley were addressed, and the growing invasion of *Arundo* *donax*, the Giant Reed, climbed near the top of this list. In addition, in the reexamination of invasive species by Programa de Especies Invasoras de México, organized by Conocimiento y Uso de la Biodiversidad (CONABIO), *A. donax* is now considered as one of the top threats to native ecosystems. This bamboo-like, perennial grass is a notoriously aggressive threat to warm freshwater ecosystems (Polunin and Huxley 1987). Establishing by rhizomes, it spreads clonally and quickly displaces native vegetation (Khudamrongswat et al. 2004). *Arundo donax* is placed among the fastest growing terrestrial plants in the world (nearly 10 cm/ day (Dudley 2000)), and, per unit of biomass, it is reported to use three times more water than native vegetation in a southern Californian riparian system (Else 1996). Complete homogenization of habitats by Giant Reed sets the stage for substantial modification of physical and chemical characteristics of an ecosystem including accelerating fire cycles and enhanced flooding events (i.e. Bell 1997; Dudley 2000). Currently, management authorities in the United States are spending large amounts of money attempting to control invasions in California (Dudley 2000). Establishment of new populations of Giant Reed occurs readily through movement of rhizomes and stems downstream of established populations. Fortunately, no caryopses have been found among Giant Reed populations of the Cuatro Ciénegas valley (Lyons *pers comm*., Eguiarte et al. presentation 2005). As such, spread, and therefore management, of Giant Reed in the Cuatro Ciénegas valley is essentially an intra-basin and downstream phenomenon. In the Cuatro Ciénegas Protected Area, new populations are also established where heavy machinery is used to dredge canals for water management (*pers. obs*. Lyons, Bell, Hendrickson and McGaugh). Therefore, containment of the species in this region will also require education regarding the movement of rhizomes and stem parts on the tires of land-moving machinery.

Concerns over the invasion of Giant Reed led The Nature Conservancy and Pronatura Noreste to sponsor the *Arundo* Control Symposium in Cuatro Ciénegas during June 2005. As indicated in the minutes of that symposium (Appndix 1), representatives from the community of Cuatro Ciénegas, four agencies, and five universities addressed steps needed for eradication. Experts agreed that, currently, the invasion is manageable. Due to the aggressive nature of the plant and the high conservation priority of the region, the consortium determined that immediate action is necessary to minimize the cost and ecosystem impact incurred by any delay in management of Giant Reed.

At the end of the *Arundo* Control Symposium in Cuatro Ciénegas in June 2005, all present agreed to collaborate to achieve the following goals by the dates indicated:

1) **Conduct experiments investigating impact of herbicide on the stromatolites (summer and fall 2005).**
2) **Develop an operating plan of action and costs, detailing application procedures, the spatial sequence of application, mechanisms to reduce re-invasions, and subsequent monitoring (September 2005).**
3) **Enact a public awareness campaign on the negative impacts of the *Arundo* in the town of Cuatro Ciénegas and surrounding ejidos (September 2005).**
4) **Implement local eradication and control measures of Giant Reed in CC Protected Area after safety experiments are completed.**

Progress to date (1 September 2005)

1) **Conduct experiments investigating impact of herbicide on the stromatolites (summer and fall 2005) –** Funds remaining in the Arundo Workshop project were sufficient to fund laboratory experiments that began at UNAM in August of 2005. Field trials are planned for November 2005. (Valeria Souza, pers. comm.).
2) **Develop an operating plan of action and costs, detailing application procedures, the spatial sequence of application, mechanisms to reduce re-invasions, and subsequent monitoring (September 2005) -** This document (finalized on Sept 1, 2005) constitutes the first draft of such a plan. Simultaneous with the release of this document, and complementing it, web pages (see http://www.desertfishes.org/cuatroc/organisms/non-native/arundo/Arundo.html) were published that further explain and justify the urgency of moving forward with an Arundo control project in Cuatro Ciénegas. Also simultaneously, we announced the availability of new email discussion list, CCArundo@lists.cc.utexas.edu. All participants at the summer Arundo workshop have been subscribed to this list, and subscription is open to any interested person (see http://www.desertfishes.org/cuatroc/list.php to subscribe). We hope that this use of this list by all interested persons will facilitate finalization of this plan and implementation of control efforts.
3) **Enact a public awareness campaign on the negative impacts of the *Arundo* in the town of Cuatro Ciénegas and surrounding ejidos (September 2005) -** The web page mentioned in item 2 (above) provides basic information about Arundo and attempts to explain specifically the risk that this plant represents for the future biological integrity and human economy of the Cuatro Ciénegas region. It is made available via the web with the intent of facilitating development of public education projects. An obvious first step would be translation of the web page to Spanish. We welcome volunteers to do that.
4) **Implement local eradication and control measures of Giant Reed in CC Protected Area after safety experiments are completed –** We provide this draft as the first step toward finalizing a plan and implementing eradication and control measures. We feel that it is now important that future progress toward this goal be locally managed and welcome offers from other individuals to take charge of coordinating the rapid review, finalization and implementation of a plan.

Remediation considerations

Considerations for local control and possible eradication of *Arundo* in the CC Protected Area, included manual removal, fire and herbicide application. Members of the Consortium and Preserve staff were universally chemical-adverse, preferring removal of *Arundo* through non-chemical, mechanical methods; however, we ultimately determined that this would not be an effective approach for *Arundo*.

Fig. 1. *Arundo donax* approximately two weeks post burn along the Ocampo Road, in Cuatro Ciénegas, Coahuila, Mexico.

In California, a great effort in time and money has been expended in developing effective procedures for *Arundo* removal. Unfortunately, management techniques such as manual and mechanical removal in addition to fire, implemented in the Santa Ana and Santa Margarita and River basins, have proven ineffective and result in extensive collateral damage to ecosystems (Bell 1993, 1997). Since *Arundo* propagates readily from small fragments of rhizome and stem, manual or mechanical removal often results in dispersal of plant propagules. Root and rhizome masses are easily left behind and accidentally moved to new locations. In addition to these downfalls, manual eradication is expensive. For example, the price for only the above ground biomass cutting (not including removal from the site) has been reported at $5000 USD per acre (Bell 1993). Finally, due to the sensitive nature of the CC Preserve ecosystems we also wish to avoid disturbance of the hardened calcareous soils. Disturbance results in substantial changes to the local hydrology and may create yet more microhabitat for *Arundo* and other non-indigenous invasive species that respond positively to disturbance.

Fire, by itself, likewise is not a solution. While fire effectively removes all above ground biomass, *Arundo* regenerates substantially more quickly after fire (see Fig 1.) and rapidly outgrows native species that may have otherwise taken root in a burned-over site. Fire events, thus, tend to push wetland communities to monocultures of Giant Reed with little or no additional plant species diversity (Bell 1993).

Treatment of *Arundo* with a wetland-approved herbicide containing glyphosate has provided direct, effective control of the plant without high risk of reinfestation or dispersal of biomass, and thus the invasion (Bell 1997). Due to its effectiveness, glyphosate can be applied in fine sprays limiting exposure to other plants and animals. In addition, glyphosate is appropriate for environmentally sensitive areas because its bioavailability is diminished quickly after application, and it has been formulated for use in aquatic environments. Although this method is putatively the most flexible, efficient and has been widely accepted elsewhere, application of herbicide must be approached with caution.

Herbicide trial

Although glyphosate was declared by the United States Environmental Protection Agency (1993) to "not pose unreasonable risks or adverse effects to humans or the environment," prudence when applying herbicides is necessary in this fragile ecosystem for three main reasons. First, Cuatro Ciénegas' ecosystem is adapted to low nutrient levels and excess phosphorus and other resources have been shown to be detrimental to invertebrates. Secondly, due to the low resource content and high salinity, cyanobacteria complexes have precipitated calcium carbonate, forming stromatolites. These complexes provide the basal strata of the food chain in some localities within the basin, but also are extremely rare in their living form (EPA 2001). In areas such as the Shark Bay World Heritage Property in western Australia, the stromatolites take the highest conservation priority (EPA 2001). In addition, cyanobacteria are the basic structure from which chloroplasts (the photosynthesis center of the plant cell) are derived evolutionarily. The possibility that these organisms contain the same molecular pathway, which is attacked by glyphosate, must be addressed and investigated. In the same vein, other photosynthetic organisms such as algae, another source of food for many in this environment, may be affected by glyphosate application. Lastly, we must take into consideration public safety concerns about the use of herbicides.

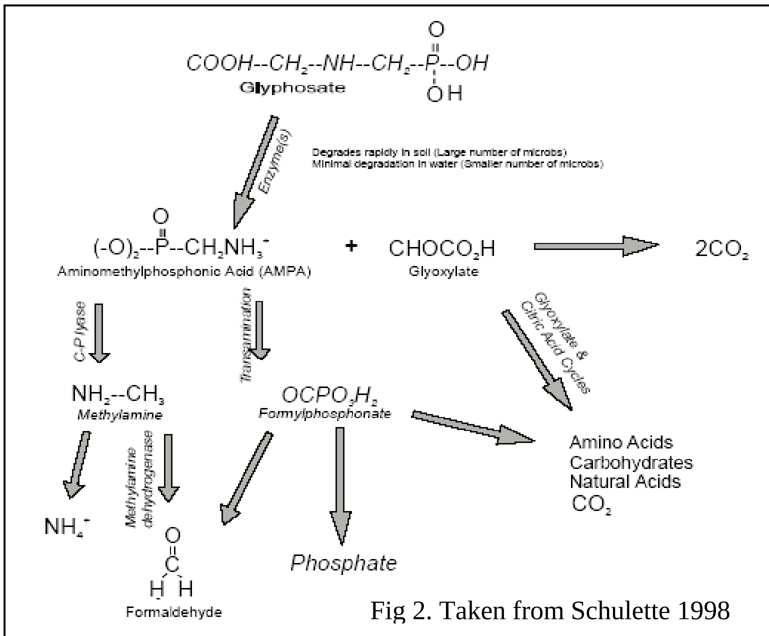

Fig 2. Taken from Schulette 1998

<u>Molecular pathway of the herbicide</u>

Glyphosate, the active ingredient in AquaMaster™, is a non-selective, post-emergence herbicide that is easily transported by the phloem throughout the plant (Franz *et al.*, 1997). Glyphosate is absorbed through the leaf into the plant cells where it is transported to meristematic tissues (Laerke, 1995). Once taken up by the plant, glyphosate inhibits the activity of a chloroplast-localized enzyme, 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), found in the shikimic acid pathway of plants (DellaCioppa *et al.*, 1986). The creation of chorismate is prevented. Subsequently, aromatic amino acids are not produced and protein synthesis is terminated (Franz *et al.*, 1997). Since glyphosate fits into and disables the protein synthesis pathway, it acts more slowly that some typical herbicides and wilting and discoloring of the plant occurs in 4-14 days. This property, however, allows it to be utilized and degraded by microbes and be bound up in soil particles (Franz *et al*. 1997).

Environmental safety

Aerial volatilization is not a fate for glyphosate (Franz *et al*. 1997). Though, aerial drift may cause damage to non-target plants, this problem is minimized when wind velocities are low (Schulette 1998).

In aquatic systems, glyphosate is very soluble (11,600 ppm at 25 OC Kollman and Segawa, 1995) having an octanol-water coefficient (logKow) of -3.3. Glyphosate is stable in water at pH 3, 5, 6, and 9 at 35 °C and it is stable to photodegradation in pH 5, 7 and 9 solutions under natural sunlight (as specified by US EPA's reregistration eligibility decision (RED) 1993). These levels are similar to the pH range of 6.9-7.7 seen in Cuatro Ciénegas (Johannesson 2004). Studies indicate that hydrolytic decomposition is low, and microbial activity and sediment absorption is mainly responsible for degradation seen (Bronstad and Friestad 1985, Kirkwood 1979, Ghassemi *et al*. 1981). Confirming this in forest ecosystems, Schulette (1998) reviewed the decomposition of glyphosate waterways high in suspended sediment. For ponds and streams, first-order half-lives were found to be 1.5-11.2 days and glyphosate was undetectable in 3-14 days, respectively. For all aquatic systems, sediment appears to be the major sink for glyphosate residue.

In soil, glyphosate is resistant to chemical and sunlight degradation, substantially nonleachable, and has a low propensity to runoff (apart from being adsorbed in colloidal matter (Schulette 1998). Half-lives range from 3 to 130 days (U.S. EPA 1990; USDA 1984), with soil field dissipation half-lives averaging 44-60 days (Kollman and Segawa 1995; WSSA 1989). The degree of soil binding depends on availability of unoccupied phosphate binding sites (Sprankle *et al*. 1975). Therefore, soil phosphate level is the main factor determining soil absorption, because of competition with inorganic phosphate (Sprankle *et al*. 1975). Microbes are mainly responsible for decomposition. So, the rate of the degradation is dependent on the composition of the microbial fauna (both aerobic and anaerobic) and the soil factors that affect their activity (Eriksson, 1975). ^{14}C-labeled glyphosate studies indicate that 55% of the herbicide was metabolized and converted to ^{14}CO2 within 4 weeks in sandy, loam soil (USDA, 1984; Rueppel *et al*., 1977). Although, inactivation and decomposition are completed by microbes, Stratton and Stewart (1992) concluded that glyphosate has no significant effect on the numbers or respiration rate of bacteria, fungi or actinomycetes in forest soil and overlying forest litter. Furthermore, nitrogen fixation, nitrification and denitrification activity are not adversely affected by the application of glyphosate (Muller *et al*. 1981). Lastly, glyphosate supports quick regrowth, because it shows no pre-emergent activity even when applied at high rates (Franz *et al*. 1997). For example, less than one percent of the glyphosate in the soil was found to be absorbed via the roots of plants that emerged post-herbicide application (Ghassemi *et al*. 1981).

Public and wildlife safety

Glyphosate is classified under the second to lowest toxicity rating by the U.S. EPA (U.S. EPA 1993), and properties such as high water and low fat solubility indicate its low bioaccumulation potential. In fact, excretion of 97.5% of the administered dose in rats, and additional investigations follow the same trend in other mammals, birds, and fish (Franz *et al*., 1997). Li and Kole (2004) enforced sublethal (nearly lethal) exposure levels on the topmouth gudgeon, *Pseudorasobora parva* and measured gill ATPase and liver esterase activity at 8th, 16th, 24th and 65th days of exposure. Although an inhibiting effect occurred, recovery appeared with time. Similarly, oral dose experiments performed by the U.S. EPA's R.E.D. displayed that glyphosate is nearly non-toxic to upland birds, slightly toxic to waterfowl, slightly to non-toxic to warm and cold water fish. Oral dose LD_{50}/LC_{50} (concentration that produces 50% mortality) is >5000mg/kg for rat, an amount classifying glyphosate as nontoxic (Monsanto 2002). Chronic exposure in mammals results in no cellular changes and no increased cancer risk (U.S. Department of Agriculture 1981, EPA 1988).

Henry et al (1994) rejected that when Rodeo® (exactly the same product as AquaMaster™, but produced by DowAgrosciences) is applied as a tank mixture with X-77 Spreader® and Chem-Trol® (abbreviated RTM) creates an acute danger to native aquatic invertebrates. They argued that acutely toxic RTM concentrations surpassed expected or measured amounts in water from wetlands treated with the RTM. Similarly, when the maximum application rate for AquaMaster™ of 0.9375 gallons/acre is applied to one-foot deep water body, with no interception by foliage, the concentration drops to 1.4mg/l. For *Arundo* in Cuatro Ciénegas, we expect to apply a 1.5% solution or 0.12 pints of AquaMaster™/gallon of diluted solution with at most 40 gallons of diluted solution/ acre 0.6 gallons of AquaMaster™/ acre as recommended by the Specimen Label for AquaMaster™ (Monsanto 2002). LD_{50} or EC_{50} (concentration at which growth or immobilization of 50% of the test organisms is achieved) for AquaMaster™ is >1000mg/l for bluegill sunfish, >100mg/l for rainbow trout and 166mg/l for green algae (Monsanto 2002, U.S. EPA 1993)

<u>Suspected stromatolite safety</u>

Studies have shown interesting effects of glyphosate on cyanobacteria, the main component of stromatolites. For example, Shikha et al. (2004) assayed chlorophyll content and alkaline phosphatase activity in phosphorus starved and phosphorus plentiful photoautotrophic cyanobacteria, *A. doliolum*. Chlorophyll increased when cyanobacteria were exposed to glyphosate and then supplemented with Pi and a declined when they were Pi-starved. Alkaline phosphatase activity enhanced in response to addition of glyphosate (40 ug/ml), but the activity remained unaltered by addition of glyphosate in the Pi-starved treatment. The results suggested that cyanobacteria may be sensitive to glyphosate in the absence of phosphate and that there exists a glyphosate-induced depletion in the phosphate content of the cells, as evident from the stimulated activity of alkaline phosphatase. However, alkaline phosphatase activity in the Pi-starved bacteria may not be impacted by glyphosate, because the cellular phosphate reserve may be unavailable for further reduction.

Toxicity to cyanobacteria and algae depends on the species or strain (World Health Organization 1994). Wängberg & Blanck (1988) exposed 16 species in pure cultures to Roundup® for 14 days. For the most sensitive species growth was inhibited completely with 16 mg Roundup®/liter for *Raphidonema longiseta* (green algae) and *Anabaena* sp. (cyanobacterium) and 131 mg Roundup®/liter for the least sensitive species *(Selenastrum capricornutum*, green algae) (World Health Organization 1994). In

Pseudomonas chlororaphis (heterotrophic bacterium), Roundup® inhibited respiration at concentrations of $\geq$ 2623 mg/liter, but in *Aeromonas hydrophila* (heterotrophic bacterium) respiration was only slightly affected at these concentrations (Chan & Leung, 1986). Exposure duration was six days.

The response variability warrants tests on the individual microfauna in the Cuatro Ciénegas systems. However, it is extremely important to note that the effectiveness of AquaMaster™ is dependent on the herbicide making contact with plant foliage. It does not control submerged vegetation or other organisms. We, therefore, suspect that the chemical will have little impact on stromatolites and other submerged photosynthetic organisms. In addition, applications directly to foliage in the CC Protected Area will consist of a 1.5% glyphosate acid solution (7200mg/liter). Water body concentrations after interception by foliage in the course of normal applications are substantially lower than what is seen in the experiments discussed above (Monheit 2004, Trumbo 2005). Furthermore, studies in which Roundup® was the test herbicide cannot be used as an appropriate measure for the potential impact of AquaMaster™. AquaMaster™ is formulated specifically for aquatic systems and contains no surfactant, chemicals used to make herbicide application more effective and a source of toxicity for many aquatic species (Henry et al. 1994). Wetland-safe surfactants are available and recommended application methos minimize exposure of organisms to both surfactants and Aquamaster (Monheit 2004). Roundup® contains a surfactant, is not approved for wetland use in either the U.S. or México, and will not be used in Cuatro Ciénegas.

Herbicide experimental protocol

Experimental plots will be established by IE/UNAM in different sites in Rio Mesquites, Saca Salada canal, as well as in the agricultural canals. In each site, a control and an experimental "plot" will be established in triplicate. In the experimental plot, AquaMaster™ will be sprayed in a 1.5% solution in conjunction with the surfactant XXX The control plot will be sprayed with the dilution base (water) will be sprayed to the plants

We will measure two response variables to determine the impact of AquaMaster™ on microbial (stromatolite) diversity and nitrogen fixation, a key ecosystem function of stomatolites. Measures will be made at time 0 (t0, before AquaMaster™ application) and time 1 (t1, one week post AquaMaster™ application). At t0 and t1, a water (5 liters), sediment (10 grams) and stromatolite (10 grams) sample will be taken from each control and treated plot for a total of 24 samples (12 plots x 2 collection dates). DNA will be extracted from these samples and analyzed with TRFLP of the 16S ribosomal DNA gene. Also at t0 and t1, *in situ* nitrogen fixation will be assessed. As parallel work, *in vitro* experiments will be performed with different doses of AquaMaster™ on local cyanobacteria that are under axenic culture in the Molecular and Experimental Evolution laboratory at IE/UNAM, Mexico. If at t1, we detect significant effects of AquaMaster™ application on the microbial community, follow-up measures will be conducted six months post AquaMaster™ application (t2) to determine ecosystem recovery.

Based on previous research we expect the impact to the microbial community to be minimal and transient. If, however, we do find significant effects of the herbicide, its use must be considered in light of the eventual impact of *Arundo* on this ecosystem. The extreme water depletion, shading, invariable nutrient flow changes, and fire hazards associated with the inevitable wider establishment of this plant will be unfavorable to the Cuatro Ciénegas ecosystem. And, due to its aggressive nature we anticipate its spread. Protection of the valley from the detrimental impacts of *Arundo* is perceived by this consortium as a critical conservation and public service goal. Should the results of this study demonstrate a negative but transient impact on the CC ecosystem, we must weigh the pros and cons of herbicide use taking into account the likelihood that the impact of *Arundo* may far exceed that of small scale herbicide use that would be required at this time.

Eradication

If the AquaMaster™ is shown not to exert any long-term adverse effects on the ecosystem it will be used to eradicate the remaining stands with the main goals to:

1. Remove and keep riparian areas clear of Giant Reed.
2. Be prepared to take advantage of wildfires that clear stretches of the river of stands of Giant Reed, where herbicide can then be applied to regenerating stalks.

<u>Application</u>

Through the efforts of Californian workers, we have learned that herbicides are most effective when applied in the post-flowering stage, when the plant is sequestering nutrients to the rhizomes (Bell 1997, Monsanto, 2002). Using the plants own translocation system, less herbicide is necessary and the rhizomes are targeted. Therefore, application rates are critical as an overdose may kill the parts of the plant first contacted by the herbicide, and prevent further absorption and translocation (carried along with nutrients to other parts of the plant after absorption).

Needless to say, application procedures outlined by Monsanto for AquaMaster™ will always be followed (see Monsanto Specimen Label for instructions): http://www.cdms.net/ldat/ld4BL000.pdf

Important guidelines for the application of AquaMaster™:

1) There is no restriction on the use of treated water for irrigation or recreational purposes
2) To treat areas upstream or within ½ mile of potable water intake, the water intake must be turned off for at least 48 hours. If the glyphosate level is under 0.7 parts per million (determined by laboratory analysis), the water intake may be turned back on.
3) Workers should wear gloves, long sleeves, pants, shoes, and socks.
4) Always use a heavier dose when the vegetation is dense.
5) For Giant Reed 1.5%- 2% solution should be applied in late summer to early fall with hand held equipment.
6) Heavy rainfall 6 hours after use will reduce efficiency, heavy rainfall 2 hours after application will require reapplication.
7) Extremely cool or cloudy weather following treatment may slow activity of glyphosate and delay development of visual symptoms.
8) The day of application, applications must be made working downstream- upstream to avoid over-concentration in downstream

areas. This is not to say the total eradication process should happen downstream to upstream, only the application per day.

9) For cut-stump application 50%-100% concentration of the chemical must be applied immediately after cutting.
10) Apply with care to avoid nontarget species.
11) AquaMaster™ does not control submerged vegetation.
12) Consult local agencies as permits may be required for application.
13) A surfactant must be used for efficient absorption by the plant.

Where infestations are penetrable, a 1.5% solution will be directly hand applied with brushes, and herbicide guns to the stalks of the *Arundo* when the stands consist of individually accessible plants. Alternatively, backpack sprayers, ladders, and kayaks will be employed to achieve most thorough application in areas of dense invasion with a 2% solution (9600mg/liter of glyphosate acid).

Cut-stem treatment is extremely cost-effective in terms of chemical use, but is labor-intensive and is not proven to prevent number of follow-up treatments (G. Bell *pers comm*.). Aerial application of AquaMaster™ is efficient in effort and monetary expenditures for large infestations (Bell 1997). Aerial application, using AquaMaster™ concentrate, may be considered for a dense infestation outside of the Cuatro Ciénegas Natural Protected Area like Rio de Nadadores at Celemania. Bell (1997) recommends that proper spray equipment and experienced personnel results in better coverage, less over-spray, and less wastage than ground-spraying operations. Aerial application must be made according to the AquaMaster™ supplemental label. In addition, documentation for spraying in California may be useful: http://www.cdms.net/ldat/ld4BL003.pdf .

Man-power for the application will be garnered from SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales), Desuvalle, and parties attending the Desert Fishes Council Meeting: Invasive Species Workshop in November 2005. Among these will include licensed applicators of AquaMaster™. Any volunteers from any agency are welcome to assist.

The first priority is to eradicate the *Arundo* within the valley. After the *Arundo* of the valley has been eliminated the invasion of Rio Nadadores at Celemania will the addressed. However, aerial application will most likely be necessary in this area.

Localities and Herbicide Application Schedule

Khudamrongswat et al. (2004) recommended that since waterways serve as a major dispersal agent, upstream management is required to prevent future spread. Likewise, Bell (1993) emphasizes that removal of the Giant Reed should begin at the 'top' of the river. Preliminary data collected on the invasion in the Cuatro Ciénegas Natural Protected Area include GPS maps and photographs of individual stands throughout the large reaches of the suspected flow paths. Herbicide application will follow an overall scheme of working upstream to downstream including in the main river of the valley, the Rio Mesquites.

Application will begin near the head waters of the Rio Mesquites, Tierra Blanca, and follow it into the Saca Salada canal. This route will be split into two days, each day working downstream to upstream to prevent accumulation of herbicide. On Day 1 eradication of the following invasions will be attempted: stands near Rio Mesquites palapas, small stands within the El Laberinto, small stand near Centro de Informacion, and any stands upstream which have not yet been documented. On Day 2 we will focus on the following stands: Saca Salada exit of valley, Saca Salada, Dos Cuartes, and Don Julio. GPS coordinates for each may be obtained from Lucas McEachron and Dean Hendrickson (lucasmc@holly.colostate.edu and deanhend@mail.utexas.edu, respectively).

On Day 1 and Day 2, simultaneous application will take place at localized stands at Anteojo, along the main road near the turn off point to Las Salinas, the dry canal by the cemetery, and the canal that brings water from El Cañon into the town of Cuatro Ciénegas (application to be supervised by Beningo Vasquez).

For new *Arundo* stand identification within the valley, mapping efforts will be expanded for a more thorough picture of the status of the invasion of the basin. It is urgent to compile all the air photographs that exist of the valley of CC to understand the spatial dynamics of the bodies of water and of the distribution of reeds (*Phragmites* and *Arundo*) and to identify areas that are in need of more photographic data. This will be conducted by Lucas McEachron of Florida State University in collaboration with Ignacio March of the Nature Conservancy. The Comisión Nacional de Áreas Naturales Protegidas (CONANP) has agreed to take air photos in areas that have an acknowledged need for additional attention. Any newly discovered stands will be appended to either Day 1 or Day 2 of eradication in November 2005.

Follow-up

Follow-up treatment must be made to ensure that re-sprout *Arundo* or missed plants do not re-establish on the site. The number of follow-up treatments and their timing is dependant on the timing and success of the initial treatment. Usually at least two, and often as many as five, treatments are necessary to eradicate Giant Reed from a site. WE NEED LONG TERM, DEDICATED VOLUNTEERS IN CUATRO CIÉNEGAS TO HELP HERE.

Monitoring

The sites will be checked at least annually for the first three years after treatment and any re-sprouting *Arundo* or other invasive species will be removed. Monitoring and treatment of the site are always prescribed after significant flood events, which might carry new Giant Reed root material onto the site.

Any areas undergoing disturbance (i.e. canal building, significant road traffic, and water level fluctuations) should be high priority for intense monitoring. Such areas in the basin which require special concern include the Las Salinas area of ephemeral drying, Canal Don Julio, Rio Mesquites, and Saca Salada. WE NEED LONG TERM, DEDICATED VOLUNTEERS IN CUATRO CIÉNEGAS TO HELP HERE.

Revegetation

Re-vegetation does not necessarily equate with habitat restoration (Bell 1997). While riparian species are relatively easy to establish, the dynamics of native riparian communities are poorly understood or appreciated. Some re-vegetation programs have been successful in terms of establishing a matrix of riparian habitat that is used by native species. However, we need to avoid the dogma that re-vegetating is a direct route to habitat creation. In addition, such re-vegetation projects are extremely expensive.

With limited resources available, energy and money will be invested primarily in monitoring areas of removal to prevent reinfestation, and surveying the area for additional invasions. Subsequent evaluations will follow. For example, if in two years after removal invasive plants are moving into recently eradicated areas and native vegetation has still not reestablished, revegetation may be considered.

Front Back Inside

Fig 3. *Arundo* control brochure developed for outreach, needs translation to Spanish

Community outreach

Calegari (1997) noted that most Cuatro Ciénegas residents feel disconnected from research scientists who frequent the town, and the same message was voiced during the first Cuatro Ciénegas Congresso de Investigadores. However, community involvement and education are imperative to conservation efforts (McDonald et al. 2004). Therefore, this effort will include necessary education and serve as an invaluable medium to bridge the gap between the scientists and the local community, bringing them together in an attempt to control this invasive plant that obviously stands to affect all components of the local economy and ecosystem. The experimental procedure to test the safety of the application in the pozas will be performed not only by trained international scientists but also by a team of selected high school students that will participate in the field and in the lab in Mexico City.

Suggestions from the community at the *Arundo* workshop included development and dispersion of a brochure detailing the impacts of *Arundo*, explaining the severity of the threat to the water resources, and emphasizing that the native reed *Phragmites* is still a suitable construction material for fences, roofs, and palapas. This brochure has been developed (Fig 3.).

Expense & Timeline

Date	Action	Responsible Persons	Expense
July 1, 2005	Management plan completed	Suzanne McGaugh	$0.00
July 1, 2005-October 1, 2005	Compiling of aerial photography and targeting areas with infestation or in need or more mapping	Lucas McEachron	$0.00
October 1, 2005	Herbicide Experiments Completed	Valeria Souza and	$1560

	(covered by TNC grant)	Luis Eguiarte	
October 1, 2005-November 1, 2005	Approval of protocol by SEMARNAT/ CONANAP, and acquire any other (if any at all) necessary permission	? This could be you!	
July 1, 2005-November 1, 2005	Investigation of cost, permitting procedures associated with aerial application in Rio Nadadores at Celemania. At a 1.5% solution: 0.12pints of AquaMaster™/gallon of diluted solution with at most 40gallons of diluted solution/ acre 0.6 gallons of AquaMaster™/ acre for ~15 acres		
July 1, 2005-November 1, 2005	Translation and dispersion of brochure to community members (printing cost covered by TNC grant)	? This could be you!	$500
July 1, 2005-November 1, 2005	Acquisition of herbicide from Helena in Salinas, Coahuila	? This could be you!	
November 20, 2005	First Application At a 1.5% solution: 0.12pints of AquaMaster™/gallon of diluted solution with at most 40gallons of diluted solution/ acre 0.6 gallons of AquaMaster™/ acre for 4 acres Possible application of Reio Nadadores at Celemania	Dean Hendrickson, Suzanne McGaugh, SEMARNAT	
January 1, 2006	Written summary of treatment	Dean Hendrickson, Suzanne McGaugh	
September 2006-November 2006	Continued monitoring. Follow-up, summary of treatment.	? This could be you!	
September 2007-November 2007	Continued monitoring. Follow-up, summary of treatment.	? This could be you!	
September 2008-November 2008	Continued monitoring. Follow-up, summary of treatment.	? This could be you!	
Total			$XXXX

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Appendix 1

***Arundo* Control Symposium Notes complied and transcribed by Igancio March**

Taller sobre control de *Arundo donax* en Cuatro Ciénegas, Coahuila, México.

Junio 4, 2005.

Notas tomadas por I.J. March.

Participaron personas de PRONATURA-Noreste, Desuvalle, A.C., Universidad Iberoamericana, Instituto de Ecología de la UNAM, CONANP, Universidades de Texas y Iowa, y personas de la comunidad de Cuatro Ciénegas, y The Nature Conservancy.

Ignacio J. March (The Nature Conservancy, Programa México).

- Presentación del Plan de trabajo sobre especies invasoras en México.

Gary Bell (TNC New Mexico).

- Proyecto en *Arundo* en California
- A veces los impactos de las invasoras no son tan obvios.
- Necesitamos ser asertivos en que batallas contra invasoras debemos pelear.
- En California los ecosistemas con *Arundo* eran muy diferentes que CC.
- En hábitat riparios tuvieron que considerar las diversas condiciones ecológicas y de inundaciones en diversos estados sucesionales. Hicieron modelos conceptuales de la dinámica ecológica de los hábitat riparios.
- Las inundaciones cada 10 o 50 años llevan a los ecosistemas riparios al estadío inicial.
- Usualmente las especies nativas pueden recuperarse. La vegetación riparia tiene una elevada resiliencia.
- *Arundo* viene de la India y entró a Europa y Africa hace quizás 1,000 años, y está ya en la mayor parte del mundo incluyendo Australia, Hawaii, etc y en la mayor parte de su distribución es un problema.
- *Arundo* crece muy rápido y es muy competitivo y agresivo cuando el sistema ripario es joven; no se establece tan fácilmente en estadíos sucesionales más maduros.

- *Arundo* es especialmente exitoso cuando las condiciones de luz, agua, etc son de stress.
- *Arundo* hace que los fuegos tengan una mayor intensidad y eso puede hacer que las demás plantas mueran mientras *Arundo* sobrevive pudiendo ocupar el nicho de la vegetación madura quemada.
- Puede llegar a lo 8 m de altura.
- Tiene muchos impactos altera los hábitat, altera las condiciones de los ríos y de las inundaciones, alteran la temperatura de los hábitat e incluso la química del agua, y también bloque la luz que antes llegaba a los canales y corrientes de agua.
- En cuanto llega el *Arundo*, tarde o temprano se convierte en un rodal puro ("*pure stand*") de *Arundo*.
- La evapo-transpiración de *Arundo* es enorme y por ello provoca importantes pérdidas de agua para los ecosistemas y también para las actividades humanas por lo que además tiene un fuerte impacto económico.
- A veces *Arundo* tapona los drenajes naturales y puede provocar inundaciones que causan grandes pérdidas económicas.
- El *Arundo* le roba el agua a las especies nativas y a los ecosistemas locales, pero también a la gente local que la requiere.
- El *Arundo* ya está creciendo en lugares en donde hay estromatolitos en CC.
- El control se hace mecánico, con fuego, con herbicidas y con control biológico.
- El control mecánico representa diversas dificultades y tiene poca eficiencia ya que se remueve la biomasa pero sin erradicar a la planta. Se dispersa a través de fragmentos que tengan meristemos, por lo que el control mecánico puede incluso ayudar a su dispersión. La disposición de la biomasa es un problema pues es muchísima y es difícil encontrar donde disponerla.
- El fuego tampoco es una opción ya que además de que tiene un impacto sobre plantas no adaptadas, el efecto es contraproducente ya que no mata completamente a las plantas y de hecho las hace menos suceptibles a ser controladas químicamente.
- El control con herbicidas es la opción más efectiva; se usa **Gylphosate** (en un producto llamado Rodeo) diseñado para humedales. Otras fórmulas pueden ser tóxicas para diversos organismos acuáticos. Este químico es insertado en la bioquímica de la planta y así la mata. Los residuos que caigan al agua se desnaturalizan muy rápido antes de que sean incorporados por los organismos acuáticos. Se están desarrollando otros químicos aún más eficientes. Es un aminoácido modificado; puede tener efectos contraproducentes con los ecosistemas acuáticos de CC pues finalmente aporta nutrientes que pueden promover a otras bacterias y micro-organismos.
- Se puede aplicar con una aspersora individual, un pequeño vehículo, o con avionetas o helicópteros.
- Con que una gota caiga en la planta, la mata.
- Se puede cortar la planta y aplicar inmediatamente en el tallo cortado. Sin embargo es más eficiente la aplicación foliar.
- Es muy importante dar seguimiento a las zonas bajo tratamiento.

- El control biológico está aún en fases experimentales y se hace utilizando diversos dípteros y al menos cuatro hongos que son específicos al *Arundo*. Sin embargo tardará años en que se pueda implementar.
- Las lecciones aprendidas son:
  - Hay que mapear la distribución.
  - Hay que comenzar cuanca arriba y entonces desplazarse hacia la cuenca baja.
  - Aplicar después de la floración.
  - Hay que controlar *Tamarix* al mismo tiempo.
  - Hay que buscar alianzas con otros actores que son afectados también por *Arundo*.
  - No hay que subestimar el impacto de *Arundo* sobre los ecosistemas locales.
  - Sin el uso del herbicida no se puede erradicar *Arundo*.
  - Hay que atacar tempranamente, no hay que tardarse.
  - Solo hay que usar herbicidas aprobados para humedales.
  - Si se restaura activamente la vegetación original hay que usar material genético local.

- Ya se ha comenzado a mapear con GPS los lugares en CC con *Arundo* (Lucas).
- Se considera que la invasión de *Arundo* en CC es relativamente joven. Hace 30 años en "El Cariño" había puro *Phragmites* y ahora hay puro *Arundo*. El Cariño está fuera de la ANP.
- El *Arundo* se usa para hacer cortinas, cielos de techo, y otros objetos; cercas para las aves de corral, etc. El carrizo de "El Cariño" es el que la gente de CC prefiere utilizar. También se usa *Phragmites*.
- En el ANP "Maderas del Carmen" están con problemas muy graves con *Arundo* y *Tamarix* y como está en cañones es muy difícil aplicar los herbicidas o lo que sea.
- Hay varios equipo de especialistas trabajando con *Arundo* y son un recurso; como el Team *Arundo* del Norte.
- En lugares donde ocurren heladas no ocurre usualmente el *Arundo*, pero puede infestar en cualquier otro lugar en
- Los lugares con estromatolitos en CC se caracterizan por tener una fuerte escasez de fosfatos. En Churince por los aportes de fosfatos por los excrementos de los visitantes provocó un crecimiento desmedido de dinoflagelados y diatomeas.
- Se harían experimentos de aplicación del herbicida para ver como pudieran afectar a los estromatolitos.
- Hay que prevenir la dispersión de *Arundo* en otros sitios que no lo tienen ahora. No solo hay que invertir en el control.
- *Phragmites* es el carrizo nativo muy similar a *Arundo* cuando este está poco desarrollado.
- Se tiene que diseñar un plan de erradicación muy cuidadoso, definiendo muchos aspectos preventivos, de eficiencia, considerando la restauración, etc.
- Uno de los retos es que se hace con los restos del *Arundo* pues los nutrientes descargados masivamente pueden tener un fuerte impacto sobre los ecosistemas.

Luis Eguiarte (Instituto de Ecología de la UNAM).

- Genética de poblaciones del *Arundo*.
- Ecología evolutiva de las especies invasoras son un reto importante desde el punto de vista teórico. Hay distintas hipótesis.
- Del total de plantas en México (23,000 spp.) solo hay 618 de especies invasoras (es decir el 2.7 %). Esto está muy por debajo de lo que ocurre en otros países (que están por los 10 al 15 % de planatas invasoras).
- En 1820 es cuando llegó *Arundo* a California; quizás en México entró después.
- *Arundo* es C3, crece muy rápido y consume más agua que cualquier otra planta.
- Tiene pocos enemigos naturales pues tiene diversos compuestos secundarios que la protegen.
- Es muy utilizado en México (Muebles, techos, cercas, pirotecnia, ornamental, artesanías, etc). Se cree que se puede usar para producir alcohol.
- No produce semillas fértiles, Se propaga vegetativamente. Puede ser clonal.
- En México es una de las plantas invasoras más agresivas y más distribuída.
- Villaseñor y Espinoza-García publicaron en 2004 un artículo.
- Hizo un análisis preliminar de la distribución de *Arundo* en México con base a los datos de ejemplares colectados y depositados en herbarios.
- En CC desplaza al mesquite (*Propsopis* sp.).
- *Schinus molle* (el pirul) llegó de Perú luego de la conquista. en 1550. Es el árbol dominante en muchas zonas. Varias aves lo dispersan. Luego llegó a España. En México su variación genética es muy baja en contraste con Perú y España.
- *Reseda luteola* fue también introducida de España para producir un colorante amarillo para textiles.
- La estructura genética de las invasoras puede tener patrones muy diferentes, unas muy diversas y otras no.
- Han hecho estudios genéticos sobre el zacate buffel (*Pennisetum ciliare*); hay poca variación genética y esto puede facilitar las estrategias para combatirlo.
- En *Arundo* hay poca variación genética pero tampoco es tan clonal como se esperaría.
- Se quiere conocer sobre la entrada y dispersión en México y comparar la genética de las poblaciones de CC y de Meztitlán.
- *Arundo* vino desde España.
- En CC aparentemente hay uno o dos genotipos en un Primer, en otros hay tres, etc.
- **Conseguir el trabajo: Buhle *et al* (2005). Bang for buck: cost effective ...invasive species.**
- Se plantea que la gente sea la que controle el *Arundo* a través de su utilización.
- Aparentemente a peor calidad de agua el *Arundo* es más abundante.
- En todo el río Bravo, *Arundo* es sumamente abundante.
- No se han visto ejemplares con semillas, sólo con flores.
- *Arundo* tolera mucha sombra; en Meztitlán está creciendo bajo los nogales aunque en bajas densidades.

- Los aspectos genéticos son de la mayor importancia pues puede darse la situación de que se generen mutaciones que los haga resistentes a los herbicidas.
- Se plantea la posibilidad de utilizar ejemplares colectados antiguamente en Cuatro Ciénegas y tratar de conseguir los genotipos para compararlos con los actuales y conocer más sobre la variación genética del *Arundo* a través del tiempo.
- Hay que tener cuidado de que la gente no empiece a usar pesticidas de alto impacto ambiental para erradicar el *Arundo*.
- Rodeo se puede comprar en México y es producido por Monsanto.
- Antes de ningún control, es necesario elaborar un plan que se somete a la SEMARNAT, junto con un manifiesto de impacto ambiental, y antes hay que hacer una prueba experimental.
- A veces hay que remover físicamente los mogotes que forma el *Arundo* para que se pueda regenerar la vegetación nativa.
- Hay que evitar la producción de sedimentos que se puedan lavar a las pozas y además de alterar el balance de nutrientes enturbien el agua y afecten la luz que llega a las bacterias y algas.
- Cada sitio en CC deberá tener una estrategia diferenciada con el uso del herbicida.

Comentarios generales de la mesa.

- En Cuatro Ciénegas los fosfatos son clave ya que es un ecosistema con especies que prosperaron en condiciones de gran escasez de fosfatos. Por ello la alteración de los niveles de fosfatos puede dañar a muchas de las especies y las condiciones ecológicas.

- Han utilizado ya en CC herbicidas para erradicar otras plantas que les afectaban de distintas maneras, pero se ignoran los efectos e impactos que haya podido tener sobre el ecosistema y la biodiversidad.

- Se considera que es esencial actuar pronto y con eficiencia y antes de que el problema con *Arundo* cause mayores impactos y sea más difícil de erradicar.

- Es muy importante poner un plazo de tiempo concreto para hacer el experimento lo antes posible y en su caso diseñar el plan de erradicación.

- La CONANP tiene entre sus políticas la erradicación de especies invasoras que afectan a la biodiversidad que se pretende proteger en las áreas protegidas.

- Hay poca organización en lo que se refiere en los esfuerzos de erradicación de *Tamarix*, y se reconoce que este grupo tiene un avance importante de organización.

- La estrategia de erradicación debe ser ordenada pero eficiente y rápida, y debe incluir el entendimiento, interés y participación de la comunidad local. Se requerirá informar de manera muy efectiva y clara a la comunidad de CC. Se deberá explicar muy claramente que el herbicida que puede utilizarse para erradicar a *Arundo* no afecta en lo absoluto a la gente o a los animales domésticos.

- No va a ser fácil lograr el entendimiento de la gente sobre la urgencia de erradicar al *Arundo*. La gente tendrá que adaptarse a utilizar el carrizo nativo (*Phragmites*) como alternativo, que es más delgado que el *Arundo*.

- El recurso agua, el más preciado y necesario para todos, esta siendo robado por el *Arundo*. El agua es más importante que los carrizos.

- Revisándose fotos antiguas, se ve que *Phragmites* se ha incrementado mucho por los cambios en los mantos freáticos y la desecación causada por las actividades humanas.

- En Río de nadadores (Celemania) 50 KM al E de CC, se piensa que el *Arundo* es responsable de la extinción de una especie de pez colectada por R.R. Miller en 1961.

- Se considera que quizás la dispersión de *Phragmites* puede ser una "invasión primaria" que tolera poca disposición de fosfatos pero luego que cambian las condiciones y los niveles de fósforo entonces llega *Arundo* como invasor secundario.

- Es urgente compilar todas las fotografías aéreas que existan del valle de CC para poder entender la dinámica espacial de los cuerpos de agua y de la distribución de carrizos (*Phragmites* y *Arundo*).

- La CONANP puede poner la cámara para tomar las fotos aéreas pero alguien tiene que pagar el costo del vuelo en avioneta.

- Se plantea elaborar una propuesta de la estrategia de erradicación de *Arundo* que defina todas las actividades que se requieren efectuar, incluyendo:

    - Campaña de concienciación pública ("Public awareness campaign") sobre los impactos negativos del *Arundo* y la alternativa del *Phragmites*.
    - Los experimentos de impacto del herbicida sobre los estromatolitos en Saca Salada (Que está fuera del área protegida).
    - Todo lo relacionado con los permisos y aspectos legales.
    - Un plan operativo de acción y costos, detallando todos los procedimientos, la secuencia espacial de aplicación, etc.
    - Costos del total de volúmen de herbicida que se requerirá para erradicar a *Arundo* del Area Protegida.
    - Los mecanismos y medidas para disminuir las probabilidades de re-invasiones.
    - Un plan de seguimiento o monitoreo.

- En Noviembre habrá una importante reunión en CC sobre los peces del desierto y este evento y tal vez se puede aprovechar para contar con la consulta a expertos de la estrategia.

- Para el 1º. de Julio 2005 se plantea tener el borrador del plan.

- Los experimentos tardarían dos meses y se requerirán $ 2,000 USD.

- Es importante que esta estrategia se vea bajo una alianza (*partnership*) entre muchas instituciones académicas, del gobierno y civiles, y esto la hace más atractiva para buscarle financiamiento.

- Es básico comunicarle a la gente que no se puede usar cualquier veneno para acabar con *Arundo*, se requiere utilizar uno que tenga el mínimo impacto al ecosistema y que prácticamente solo afecte a esta planta. También debe saber la gente que el fuego no termina con el *Arundo* y que por lo contrario lo favorece para dominar los paisajes.