Riparian Restoration

Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction and Revegetation

Revised July 2008

Prepared by
Tamarisk Coalition

Funding provided by Colorado Water Conservation Board

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Management of non-native phreatophytes consists of five basic components – 1) planning informed by accurate inventory and mapping efforts, 2) control work, 3) biomass reduction, 4) revegetation, and 5) long-term monitoring and maintenance. Without considering all five components it is unlikely that tamarisk control projects will result in long-term success. The following discussion addresses options for the control, biomass reduction, and revegetation management components. All currently available technologies have been evaluated; however, not all are applicable for a given river location. For example, biomass reduction and revegetation are not always necessary steps in the restoration process. In many situations biomass levels may be very low and natural revegetation can occur.

The intent of invasive species management is to ensure that selected approaches are effective and efficient, and that decisions are well documented. Successful management will also remain open to new or altered approaches based on the latest information, technology, or experiences; i.e., adaptive management.

Tamarisk is the focus of this document's control component because it is the principle non-native phreatophyte in western watersheds. In general, the following discussion applies to Russian olive and other invasive trees but may differ slightly for each (e.g., herbicide used). Cost information, presented in this section, is based on the extensive experience of the Tamarisk Coalition and of the numerous Western tamarisk control efforts. The definitions used within this project for the three relevant restoration components are:

1. <u>Control</u> refers to the removal of invasive species such as tamarisk, Russian olive, and others using hand, herbicide, mechanical, or biological methods.
2. <u>Biomass reduction</u> is the removal of dead biomass through mechanical methods, natural decomposition, or controlled fire.
3. <u>Revegetation</u> refers to the reestablishment of native grasses, shrubs, forbs, wetland species, and trees on disturbed areas through seeding, planting, or enabling natural regeneration to occur.

Tamarisk and Russian Olive Control

Tamarisk can be controlled using single or successional weed management techniques, including chemical, mechanical, and biological techniques. All of the following tamarisk control techniques are viable options, but each must be selected based on local conditions; i.e., "Integrated Pest Management." Integrated Pest Management or IPM is also known as the "toolbox" from which land managers select control techniques for invasive species management. The IPM process is illustrated in Attachment A and considers community values, prevention, cultural management, land stewardship, mechanical or physical removal, biological control, herbicide treatments, and revegetation techniques. A description of each major control technology is presented below describing costs, effectiveness, impacts, and applicability. Note that there are many hybrids of these technologies and actual costs and applicability may vary for each site. Wherever an herbicide is identified as a control option component it is the most widely used product and the product's label application rate should be followed. It is critically important for the reader to understand that **COSTS** developed throughout this document **represent planning level values that must be adjusted for local conditions**; e.g., revegetation costs for similar infestation levels can be dramatically different because of water availability, soil conditions, replacement vegetation, etc. It is equally important to review the full cost of any approach as described in the later sections of this paper.

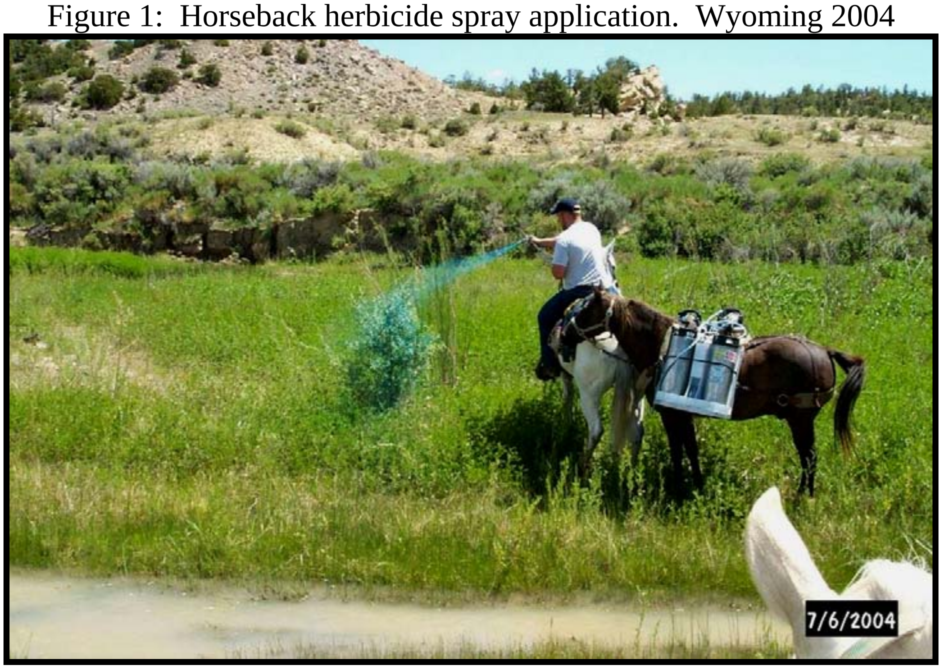
Hand Herbicide Application

There are two types of hand herbicide applications, foliar and basal bark. Foliar sprays are applied directly to vegetation foliage. Basal bark treatment controls seedlings or smaller plants with smooth (basal) bark and a stem that is less than one inch in diameter by spraying herbicide on the bottom 12-18 inches of the stem.

Effectiveness: Foliar and basal bark sprays are approximately 85 percent effective and require some level of maintenance to address resprouts. As density increases and access becomes more difficult, this method becomes more expensive and less effective due to limited abilities to spray herbicide onto all exposed basal bark or leaf surfaces. Both foliar and basal bark sprays are effective regardless of the time of year unless the temperature exceeds 85^{o} F, at which point the triclopyr herbicide used for basal bark application volatizes and can be potentially harmful to workers and surrounding vegetation. If temperatures are anticipated to be above 85^{o} F other herbicides are required. Freezing conditions may also limit its use.

Costs: A general rule of thumb is \$2 to \$5 per plant depending on size; thus, costs are low for very light infestations but quickly escalate in denser stands with larger trees (Tamarisk Coalition 2003).

Figure 1: Horseback herbicide spray application. Wyoming 2004



Pros of Hand Herbicide Application:

1. Inexpensive and effective for light infestations.
2. For inaccessible and remote areas, hand application using backpack, horses, or off-road vehicles is effective.
3. Generally, there is no need to remove dead biomass or to actively revegetation in the light infestations where this approach is typically used.

Cons of Hand Herbicide Application:

1. Not feasible for large infestations.
2. Not possible above 85^{o} F or in freezing temperatures for triclopyr herbicide
3. May require leaving tamarisk standing in an area for a period of years.

Applicability: When density of infestations are light, the use of a foliar or basal bark spray can be effective using backpack sprayers, horseback sprayers (see Figure 1), or vehicle mounted equipment. Thus, hand herbicide application is appropriate for controlling light tamarisk infestations, especially in areas that are difficult to access such as canyons, washes, irrigation ditches, and steep embankments. This approach is especially appropriate for controlling resprouts and other noxious weed control efforts.

<u>Hand Cutting with Herbicide application</u>

This method is referred to as the "cut-stump" approach in which the tree is cut or scored with chainsaws, handsaws, or axes. Within approximately 15 minutes, a solution of triclopyr systemic herbicide (Garlon 4 ® mixed in vegetable crop oil) must be applied to the cut stump. Cut materials are chipped, piled and burned, or piled for wildlife habitat depending on site specific circumstances. This method of tamarisk removal (see Figures 2 and 4) is probably the most widely used method. This approach requires trained sawyers and/or herbicide applicators.

Figure 2: Chainsaw removal of tamarisk in Colorado with proper safety equipment.

Effectiveness: The cut-stump approach successfully controls tamarisk with a regrowth rate of approximately 15 percent. This regrowth will require a second herbicide treatment. Herbicide sprays are effective regardless of the time of year unless the temperature exceeds 85^o F, at which point the triclopyr herbicide volatizes and can be potentially harmful to workers and surrounding vegetation. If temperatures are anticipated to be above 85^o F other herbicides are required. Freezing conditions may also limit its use.

Costs: Hand work is very expensive, ranging from $1,500 per acre in lightly infested areas to $5,000 per acre in heavily infested areas for initial removal (Tamarisk Coalition 2003). To ensure effective control, resprouts must be treated with foliar and/or basal bark herbicide applications.

Figure 3: Hand Control Cost Algorithm

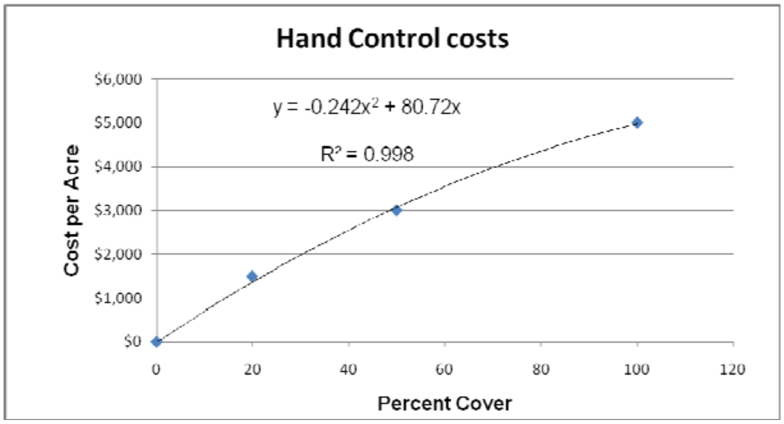


Figure 4: McInnis Canyons Volunteer Project western Colorado using the cut-stump removal technique near Grand Junction, 2007.

Pros of Hand Cutting:

1. Hand cutting effectively removes tamarisk in mixed vegetation without damaging other valuable plants.
2. Hand cutting is appropriate for rough terrain that is not accessible by mechanical equipment.

Cons of Hand Cutting:
1. Cut material must be stacked and burned, chipped, or left in piles for wildlife habitat.
2. Resprouts will require herbicide re-application.

Applicability: Hand clearing tamarisk is appropriate for canyons, washes, irrigation ditches, and along steep river banks which have a high level of access difficulty. For moderate levels of access difficulty, hand removal will be appropriate for some areas of a work site, such as steep slopes. For areas that have a low level of access difficultly, hand control is considered inappropriate because of its high costs.

Hand cutting is considered very appropriate for areas of special concern; areas in close proximity to valuable native vegetation, historic and archeological sites; areas in or around campgrounds; or for projects that involve volunteer support (Figure 4).

<u>Mechanical Removal</u>

Mechanical removal is the use of heavy equipment to physically remove tamarisk. This is accomplished in one of two ways – root crown removal or mechanical cutting with herbicide application to the cut stump. Root crown removal eliminates the need for herbicide.

Root crown removal is the extraction of the root crown by either root plowing and raking or by extraction of the entire plant.

> **Root plowing and raking** Large Caterpillar D-7 or D-8 bulldozers equipped with brush bars are used to remove the above ground vegetation (see Figure 5), root plows to cut the root system below the crown, and root rakes to remove the root crown (Taylor 2003).

Figure 5: Large equipment (Caterpillar D-8) incorporating a deep root rake,
Bosque del Apache National Wildlife Refuge, NM. 2007

This approach is extremely disruptive to the soil, destroys any native plants present, and can support weed viability. It removes vegetation in a manner similar to intense agricultural production preparation. For land managers with access to water rights, and who intend to use agricultural reseeding practices, this approach can work well (e.g. the Bosque del Apache National Wildlife Refuge, NM). This approach is not appropriate for areas with a lack of water rights and a significant presence of native plant species.

Extraction – Extraction is another root crown removal technique which uses a large excavator (such as a CAT 320 or larger) to pluck individual trees from the ground (see Figure 6). This approach has been used in mixed stands of tamarisk, Russian olive, Siberian elm, and native cottonwood throughout New Mexico. This mechanical process completely removes target trees and their root balls from the soil, along with a significant amount of their lateral roots. This approach provides an advantage for projects working to clear ditches and step river banks where other mechanical equipment cannot gain access. It also removes only the target species and does not require herbicide. The rate of removal with an experienced operator is 3 to 8 acres per day. The removed trees are stacked for future mulching, burning, or are left in place (Boss 2006). This approach can result in a significant level of soil disturbance and may require substantial revegetation efforts.
Note: For Russian olive infestations, extraction should only be used for saplings with a trunk diameter less than 3 inches since larger trees can leave behind root fragments that may resprout.

Figure 6: Extraction of tamarisk near Socorro, New Mexico

Mechanical cutting with herbicide application is the mechanical removal of above ground biomass accompanied by herbicide treatment of the cut-stump with triclopyr. This approach is accomplished with either equipment that cuts and mulches the trees or grabs and cuts the trees for removal.

- **Mulching equipment –** Recent work in several parts of Colorado and Utah (see Figure 7) shows that tamarisk can be effectively controlled with specialized equipment to mulch the trees and an herbicide application to the cut stumps. The trees are typically mulched in a six-foot wide path at a rate of 0.25 to 1.5 acres per hour depending on density, terrain, and equipment. The cutting head is either a rotary drum with knife blades or carbide teeth, or a flaying blade that resembles a lawnmower configuration. This latter approach, designed for forest thinning, is somewhat dangerous because the equipment will throw large chunks of wood up to 100 feet; thus, preventing timely herbicide application to the cut stumps. The flaying blades also shred the tree's stump, requiring a large amount of herbicide to achieve effective control. The rotary drum cutting head does not have this safety problem and leaves a relatively cleanly cut stump. The carrier equipment can run on track or rubber tire systems and typically range from 100 to 225 horsepower. 500 horsepower equipment is occasionally suitable for large diameter trees (greater than 12 inches).

Figure 7: 100 HP mulching equipment using a rotary drum cutting head, Grand Junction, CO.

The mulched materials produced can reduce soil disturbance, and provide a good seed bed for native plant recruitment while discouraging establishment of noxious weeds. Tracked mulching equipment causes less soil disturbance because of a lighter footprint than those with wheels. Areas suitable for this approach are wide and somewhat level floodplains or terraces. The distinct advantage of mechanical mulching is that it accomplishes tamarisk control and biomass reduction in one process. Foliar or basal bark herbicide applications will be needed for resprouts.

- **Grab & cut-stump –** Equipment developed for the forest products industry combines a grabbing or holding device that attaches to a tree while a shear or circular saw blade cuts the tree near ground level (see Figure 8). Herbicide is then applied to the cut stump. This equipment is commonly called a “feller buncher” and is produced by several manufactures as a tracked or rubber tired vehicle and can be equipped with a self-leveling capability to work in rough terrain. Recent work in Nebraska has shown this equipment’s usefulness in clearing ditches and step stream banks where other mechanical equipment could not gain access (Beyer, 2007). As with extraction equipment, valuable native vegetation can be avoided. Removed trees are stacked for future mulching, burning, or are left in place. Unlike the extraction technology, this approach can be used to remove Russian olive.

Figure 8: Grab & cut-stump equipment being used on 9-Mile Creek, Nebraska, 2004.

Effectiveness: The efficiency of these mechanical tamarisk removal methods is approximately 85 percent. The use of this equipment is principally limited to areas with good to moderate access. Its use would not be suitable for long, steep embankments, canyons, or other remote locations. Those mechanical techniques requiring herbicide applications are effective regardless of the time of year unless the temperature exceeds 85° F, at which point the triclopyr herbicide volatizes and can be potentially harmful to workers and surrounding vegetation. If temperatures are anticipated to be above 85° F other herbicides are required. Freezing conditions may also limit its use.

Costs: Root crown removal using root plow and root rakes costs approximately $800 to $1,000 per acre (Figure 9). Costs for the extraction technique using an excavator range from $150 to $600 per acre (Figure 10). Costs of mulching and applying herbicide to tamarisk (Figure 11) will range from $350 to $1,050 for high capacity equipment (0.5 to 1.5 acres/hr.), and $400 to $1,200 for medium capacity equipment (0.25 to 0.75 acres/hr.). Grab & cut-stump removal ranges from $250 to $800 for cutting, herbicide application, and stacking of materials for later disposal (Figure 12).

Figure 9: Root Plow/Root Rake Cost Algorithm

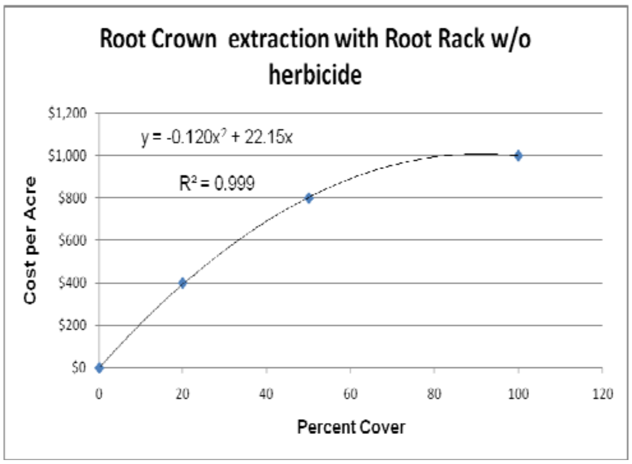


Figure 10: Mechanical Extraction Cost Algorithm

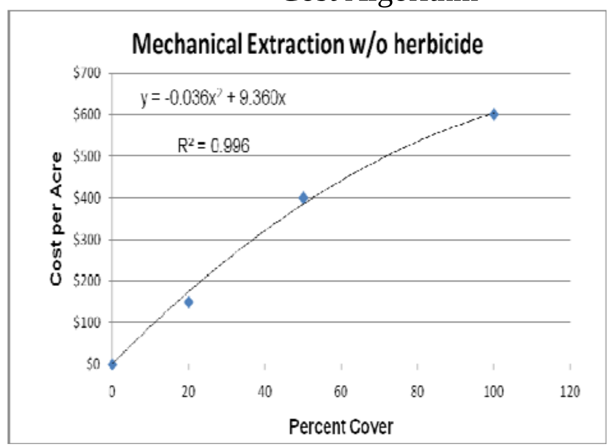


Figure 11: Mechanical Mulching Cost Algorithm

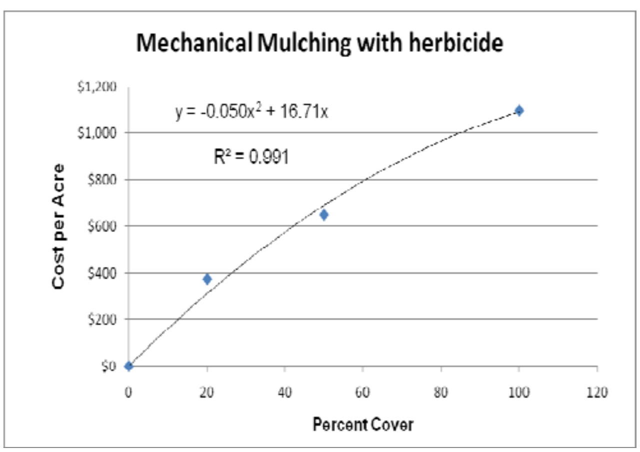
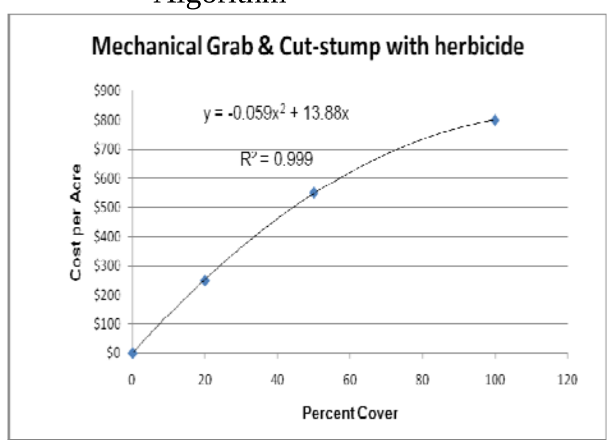


Figure 12 : Grab & Cut-stump Cost Algorithm



Pros of Mechanical Removal Techniques:

1. Extraction and grab & cut-stump equipment can very effectively remove tamarisk in a mixed vegetation stand without killing other valuable plants. Mulching equipment is a little less forgiving, but still effective in mixed stands of natives.

2. Extraction and grab & cut-stump equipment can be used in more difficult terrain and for clearing ditches and river banks. Grab & cut-stump works best on trees greater than 4-inches in diameter.
3. Mulched materials provide a suitable seedbed for revegetation. Care must be taken to prevent re-incorporating viable stems into moist soil, thus avoiding new plant growth. Fall, winter, and early spring are the best times of year for mechanical mulching.
4. Removing root crowns with root rakes greatly disturbs the soil but can benefit revegetation efforts if irrigation water is available.

Cons of Mechanical Removal Techniques:
1. Mulching and root plowing requires relatively level and accessible terrain.
2. Root crown removal using an excavator or root rake creates significant soil disturbance which can promote noxious weed growth and could destabilize embankments.
3. Herbicide re-application will be necessary to control resprouts following initial removal for all of these methods and will increase costs by approximately 20 percent.

Applicability: Root crown extraction works especially well in areas with steep embankments that other mechanical equipment cannot access. It should not be used for Russian olive control. Grab & cut-stump is also best used on steep embankments and is effective for Russian olive. Mulching equipment can be used wherever access is available. Root crown removal using a root rake is inappropriate in areas with limited water rights and significant numbers of native species that would be destroyed.

<u>Aerial Herbicide Application</u>

Aerial herbicide application (see Figure 13) now uses precision agricultural spraying techniques controlled by GPS coordinates and specific flight plans to ensure that herbicide is only delivered to desired locations. Additionally, nozzle design improvements minimize herbicide drift. Herbicide can be delivered by helicopter or fixed wing aircraft. The herbicide typically used is imazapyr (Arsenal ® or Habitat ®) which has been approved for use near water in some southwestern states.

Figure 13: Aerial herbicide application technique being demonstrated with dyed water at 2003 Tamarisk Symposium, Grand Junction, Colorado

Effectiveness: Recent foliar herbicide helicopter applications in New Mexico and Texas have demonstrated a tamarisk kill rate in a range of 85 to 95 percent. Many river corridors have large expanses of tamarisk monocultures and over the past several years large control efforts have taken place. To effectively kill tamarisk, treated trees must be left undisturbed for a minimum of two years for the herbicide to work properly. The rate of application is several hundred acres per day (Hart 2003, Lee 2003).

Costs: Contracted aerial spray application costs have increased in the past five years due to fuel costs for aircraft to a range of $250 to $300 per acre. Due to the high costs associated with helicopter use and mobilization, the minimum control acreage needed to realize these cost rates is approximately 1,000 acres (Lee 2003). Costs per acre increase for smaller acreages. Aerial spray costs do not include the removal of skeleton trees by either fire or mechanical methods, or the revegetation of the areas. This can add significant costs depending on the situation.

Pros of Aerial Herbicide Application:

1. The use of computer aided precision herbicide application allows the helicopter pilot to spray only tamarisk stands and to avoid previously identified native plants. In monotypic stands of tamarisk, such as those found in many parts of the Southwest, this may be an appropriate approach. For areas with a significant mix of native vegetation, this approach is not recommended.

Cons of Aerial Herbicide Application:

1. Aerial herbicide spray is extremely effective in killing tamarisk as well as Russian olive; however, it will also kill most other vegetation, including valuable natives. Some species, such as baccharis and Mesquite, appear to be unharmed; and saltgrass may recover within one year (Tanzy 2004).
3. Some spot herbicide re-application will be necessary.
4. If large, contiguous areas of tamarisk are killed using aerial herbicide application, there may be impacts to wildlife habitat. This is an important consideration when selecting this approach.

Applicability: This approach is recommended for areas with broad monotypic infestations with very limited native vegetation present.

<u>Biological Control</u>

Biological control is the use of specific organisms to control an undesirable organism. For tamarisk, two bio-control agents have been identified – goats (see Figure 14) and a tamarisk leaf beetle (see Figure 15). Both work to control tamarisk by repeatedly defoliating the plant over three to four years.

Goats will feed on tamarisk shrubs if fencing limits other food sources. Typically, a guard dog, herding dog, and goat herder are required. Several private goat herds are available throughout the West but there is limited cost and success information. It is too early to provide good information on the effectiveness, applicability, and pros and cons of using goats as a viable means of controlling tamarisk. A large project is currently underway on the Rio Grande in New Mexico to provide this information.

Figure 14: Goats eating tamarisk leaves and small branches

The tamarisk leaf beetle was found during investigations for an insect tamarisk biological control in the 1980s by the U.S. Department of Agriculture (USDA) under the direction of Dr. C. Jack DeLoach. *Diorhabda elongata*, a beetle from Fukang, in Xianjiang Province of NW China, was then tested extensively in quarantine to ensure safety with respect to non-target impacts. Later, different ecotypes of this beetle species were identified in Chilik, Kazakhstan and Posidi, Crete. In 1995, release permits for this beetle were about to be granted when the USFWS listed the southwestern subspecies of the willow flycatcher (*Empidonax traillii extimus*) as a federal endangered species. This bird was found to nest in tamarisk in New Mexico, Arizona, and southern parts of California, Nevada, Utah, and Colorado. Permission for widespread insect bio-control releases was withheld pending further investigations of potential effects on the flycatcher. However, a number of research sites isolated from the southwestern willow flycatcher nesting areas were allowed and research began at these sites in 1996.

Research was conducted at these sites to determine the insect's life cycle, reproductive and dispersal rates; its impacts on tamarisk and surrounding vegetation; and impacts on wildlife (DeLoach et al.2002, Eberts et al. 2001, Lewis et al, 2003). Both the adults and the larvae of the tamarisk beetle feed on foliage, damaging it directly through predation or indirectly by drying out foliage beyond the feeding point. One of the most important findings was that the Fukang and Chilik beetle ecotypes cannot survive south of approximately the 36^0 N parallel (the southern boundary of Utah and Colorado). Summer day lengths south of this latitude are shorter and prompt adult insects to enter winter hibernation too early in the summer months to survive until the following spring. Currently, the Posidi ecotype is being tested for use in this southern range.

Figure 15: Bio-control (*Diorhabda elongata* adult beetle, actual size ~ 3/16 inch) defoliating tamarisk at Pueblo, Colorado during the summer of 2003. No other plants were damaged.

On December 18, 2003, the USDA Animal and Plant Health Inspection Service (APHIS) published its Environmental Assessment (http://www.aphis.usda.gov/ppd/es/ppqdocs.html) outlining its intention for open releases of the tamarisk leaf beetle in 14 western states north of New Mexico and Arizona in 2004. The final approval for these releases was granted in August 2005. Since the 2004 release, the beetles have extensively defoliated hundreds of acres of tamarisk at the Colorado, Nevada, and Wyoming research sites.

Figure 16: Colorado River at Potash mine boat launch area near Moab, Utah showing defoliated tamarisk, August 15, 2006

Controlled test sites in Delta, Utah found that three to five years of sequential defoliation were required to achieve tamarisk mortality of 70 percent; however, it is unknown how many seasons of defoliation will be required to kill tamarisk a given location (Bean, 2007). Three to five years of consistent defoliation appears to be likely.

The most promising characteristic of the tamarisk beetle is that it inflicts no damage to native plant populations (see Figure 17). Preliminary evidence of effectiveness shows great potential. If biological control continues to progress, it could become one of the main mechanisms for tamarisk control and maintenance. If this is the case, the advantages over other approaches will be significant; i.e., limited use of herbicides and a cost effective, long-term solution. Another observation is that native plant species seem to be flourishing as tamarisk are stressed by the beetle, possibly due to increased light penetration to the understory and/or reduced competition for water and nutrients. It should be noted that Russian olive will not be controlled by this biological control agent.

Figure 17: Defoliated tamarisk and undamaged native vegetation along the Colorado River west of Moab, Utah; August 15, 2006.

Effectiveness: At the Nevada, Utah, and Colorado research sites, tamarisk plants died after three to five successive years of defoliation by *Diorhabda elongata*. It is not absolutely certain whether the insects, once established in a given area, will be more effective at killing large numbers of tamarisk or at acting as a control mechanism to prevent further spread. However, all indications show that they will perform both tasks to some degree. Studies continue at various universities and the USDA to determine the effectiveness of this insect in greater detail.

Combining the beetle with other Integrated Pest Management methods will probably be necessary to achieve the best tamarisk control.

Costs: Goat biocontrol in western Kansas, supported by the Natural Resources Conservation Service in the Arkansas River watershed, cost about $0.50 per head per day over a three year period. Based on this work in a moderately infested area, overall costs were approximately $1,100 per acre (Flowers 2005).

Based on preliminary estimates, the use of *Diorhabda elongata* as a control technique could reduce the expenses of any herbicide and/or mechanical approach to a fraction of its original costs (less than $10/acre). If *Diorhabda elongata* are used in a maintenance role following other methods of tamarisk removal, the costs would not be reduced. An additional $20/acre per year is included to this initial cost estimate to provide a five year monitoring program. Monitoring will be instrumental in determining the rate of beetle spread, rate of defoliation, rate of tamarisk mortality, native plant recruitment, other weed infestations to be addressed, biomass accumulation, and biomass removal approaches. Once the trees are killed, skeleton trees will require removal in moderately to heavily infested areas and revegetation must take place. These costs must also be considered. Removal of dead trees can be accomplished using fire or mechanical mulching equipment.

Pros of Biological Control:

1. Biological control can reduce costs and herbicide use.
2. *Diorhabda elongata* research has been more extensive than any other bio-control agent previously investigated. All indications show that there is no threat to other plant species.

Cons of Biological Control:

1. However, risk is inherent when a new species is introduced. This risk, although minimal, must be considered against the potential benefits.
2. A significant short-term impact of bio-control is the tamarisk vegetation browning that residents may consider unsightly. In response to this reaction education is important for gaining public support.
3. The use of goats as a bio-control agent is expensive, especially as a maintenance technique. Ongoing research in New Mexico should provide important effectiveness information in the near future.
4. Removal of dead trees and revegetation may be required.

Applicability: The use of the bio-control agent *Diorhabda elongata* is applicable to all levels of infestation, is not constrained by access conditions, and can be used in both riparian and floodplain terrace zones.

Dead Tamarisk and Russian olive Biomass Reduction

Removing tamarisk tree skeletons may be important after mechanical root crown removal, biological control, or foliar herbicide control if densities are moderate to heavy. Biomass reduction under these conditions assists planned revegetation efforts, restores aesthetic values, and reduces the wildfire potential of decomposing litter in moderately to highly infested areas. Standing dead biomass in lightly infested areas does not significantly impede natural or planned revegetation, affect aesthetics, or support high wildfire potential. Therefore, such stands could be allowed to naturally decompose. The removal of live tamarisk biomass in sensitive areas is also important due to high wildfire potential.

Dead trees can be removed by mechanical mulching equipment or fire (see Figures 18 - 20).

Figure 18: Large mobile chipper at work on 9-Mile Creek, Nebraska, 2004.

Mechanical mulching control, by its nature manages woody plant material by transforming it into mulch. However, if a large amount of biomass is mechanically mulched and piled, the thickness of the layer produced may actually impede or prevent revegetation. Conversely, properly mulched areas can support native plant growth while limiting weeds.

Figure 19: Fire break in Scott M. Matheson Wetlands Preserve, Moab, Utah using mechanical removal and cut stump approach, June 2004. See Figure 7 for equipment used.

Figure 20: Controlled fire used for dead tamarisk at the Bosque del Apache NWR, NM 2004

Reducing biomass with fire requires adequate fire breaks in sensitive riparian areas to safely burn invasive plants. In addition, air quality may be a concern for large-scale burns as carbon sequestered in the tamarisk will be released instantly. In contrast, mulched or standing dead plants release carbon at a rate that is partially offset by the carbon sequestering growth of other plants. Fire is an option that must be carefully coordinated with local land managers and county air quality personnel. As shown in Figure 20, fire breaks and professional fire fighting personnel are essential because of the intensity of tamarisk fires.

Costs: Biomass removal costs could range from $50 to $150 per acre for controlled burns and from $400 to $800 per acre for mechanical mulching or for mobile chipping units, depending on the density of infestation (Figure 21). If root balls also need to be mulched from either the root plowing or extraction processes, these costs increase by approximately 50 percent (Figure 22). For moderate infestations, fire would probably not be used unless the dead materials are stacked in areas that would not impact native plants. For lightly infested areas, it may not be necessary to remove dead tamarisk trees. In these areas, existing native vegetation is likely to reoccupy the area and should not be hindered by limited numbers of skeleton trees.

Figure 21: Biomass Reduction – Above Ground materials Cost Algorithm

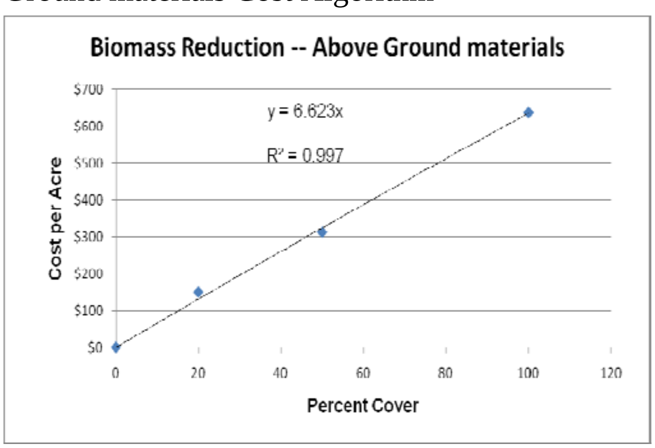
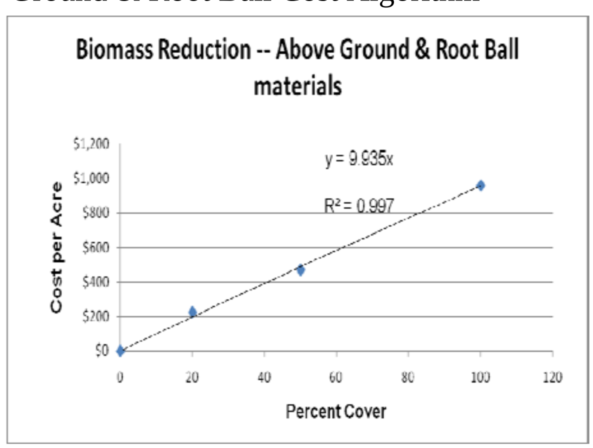


Figure 22: Biomass Reduction – Above Ground & Root Ball Cost Algorithm



Revegetation

One of the most positive aspects of tamarisk and Russian olive control discovered during site surveys is the abundance of native plants present in the understory. River systems in the West typically support an intermixed community of native species that may include:

- Wetland species such as hard-stem bulrush (*Schoenoplectus acutus*), alkali bulrush (*Scirpus maritimus*), three-square bulrush (*Scirpus americanus*), swordleaf rush (*Juncus ensifolius*), baltic rush (*Juncus balticus*), creeping spikerush (*Eleocharis fallax*), beaked sedge (*Carex rostrata*), Nebraska sedge (*Carex nebrascensis*), inland saltgrass (*Distichlis spicata*), alkali sacaton (*Sporobolus airoides*), and scratchgrass (*Muhlenbergia asperifolia*).

- Riparian species such as sanbar or coyote willow (*Salix exigual*), whiplash willow (*Salix lucida*), Fremont cottonwood (*Populus fremontii*), three-leaf sumac or skunkbush (*Rhus trilobata*), inland saltgrass (*Distichlis spicata*), hard-stem bulrush (*Schoenoplectus acutus*), alkali bulrush (*Scirpus maritimus*), three-square bulrush (*Scirpus americanus*), swordleaf rush (*Juncus ensifolius*), baltic rush (*Juncus balticus*), creeping spikerush (*Eleocharis fallax*), alkali sacaton (*Sporobolus airoides*), beaked sedge (*Carex rostrata*), Nebraska sedge (*Carex nebrascensis*), New Mexico privet (*Forestiera neomexicana*), false willow (*Baccharis* spp.), basin wildrye (*Leymus cinereus*), Canada wildrye (*Elymus* canadensis), thichspike wheatgrass (*Elymus lanceolatus*), Lewis flax (*Linum lewisii*), scratchgrass (*Muhlenbergia asperifolia*), silver buffaloberry (*Shepherdia argentea*), Wood's rose (*Rosa woodsii*), and Golden currant (*Ribes aureum*).

- Upland species such as black greasewood (*Sarcobatus vermiculatus*), basin big sagebrush (*Artemisia tridentata* Nutt. spp. *Tridentata*), screwbean mesquite (*Prosopis pubescens*), galleta (*Pleuraphis*), western wheatgrass (*Pascopyrum smithii*), snakeweed (*Gutierrezia* Lag.), scarlet globemallow (*Sphaeralcea coccinea*), bottlebrush squirreltail (*Elymus elymoides*), blue grama (*Bouteloua gracilis*), red threeawn (*Aristida*), needle and thread (*Hesperostipa comata*), shadscale (*Atriplex confertifolia*), fourwing saltbush (*Atriplex canescens*), douglas rabbitbrush (*Chrysothamnus viscidiflorus*), rubber rabbitbrush (*Ericameria nauseosa*), indian ricegrass (*Achnatherum hymenoides*), sand dropseed (*Sporobolus cryptandrus*), as well as numerous forbs.

Depending on individual site characteristics, the abundance of these species may provide natural recruitment or may require more active revegetation (e.g., pole plantings or seeding) following tamarisk or Russian olive control activities. The native plants listed above are good candidates for active revegetation. Site specific characteristics will be identified during the design phase to determine which plants should be used in a given location.

Other invasive herbaceous plants that may be encountered during tamarisk control projects and that should be addressed include the following: Russian olive (*Elaeagnus angustifolia*), Canada thistle (*Cirsium arvense*), cheatgrass (*Bromus tectorum*), diffuse knapweed (*Centaurea diffusa*), hoary cress or whitetop (*Cardaria draba*), kochia (*Kochia scoparia*), leafy spurge (*Euphorbia esula.*), perennial pepperweed (*Lepidium latifolium*), purple loosestrife (*Lythrum salicaria*), and

Russian knapweed (*Acroptilon repens*) (CHIP 2007). It is important to remember that removing other weed species may be the most important revegetation treatment performed. Annual weeds, while a concern, generally do not preclude native plant establishment.

Revegetation considerations constrain removal options. To minimize costs and water resources associated with revegetation, removal should account for the ecological potential of each site. When there are many natives interspersed within tamarisk and Russian olive stands invasive removal must be executed in a manner that protects native seed sources for natural revegetation. Manual control, root extraction, grab & cut-stump, and mechanical mulching are methods capable of sparing interspersed natives, even 1-inch caliper saplings.

The least intensive/disruptive removal and revegetation treatments are preferred when possible. This means avoiding the extensive costs associated with irrigated projects – and relying on the natural regenerative capabilities of most areas. Revegetation may not be necessary where native trees, shrubs, grasses and forbs are present within 25 to 50 feet of removal centers, or on historical sand bars or islands that were frequently inundated in both riparian and floodplain terrace settings (Hart 2003). Where precipitation values are higher such as occurs in the Plains states and a native seed bank exists very little revegetation efforts may be required. For broader areas, active revegetation may be required. Currently, monitoring activities on the Rio Grande and Pecos River in New Mexico are attempting to determine what circumstances require active revegetation.

In broad areas of infestation it is important to pace removal efforts to allow, and encourage, natural native plant regeneration. In such large, dense stands of tamarisk it may be advisable to create vegetative islands and paths within the tamarisk to help speed native regeneration process and to provide fire breaks (Figure 19).

Figure 23: Revegetation at the Matheson Wetlands Preserve in Moab, Utah 2006

In some higher value areas, such as wildlife habitats or high profile/high human use areas, pole plantings, shrub and tubing plantings, and seedings may be desirable to aid in the regeneration process (Figure 23). However, when these kinds of revegetation projects are appropriate, land managers should understand that they can be very expensive (often exceeding $10,000 per acre) and require long-term maintenance commitments.

Successful revegetation is a complex undertaking. As a result, implementing revegetation projects following the removal of invasive species is an inherently site-specific task; however, there are numerous resources available that can aid the planning process. NRCS's Los Lunas Plant Material Center in New Mexico recently compiled an excellent reference guide for riparian restoration/revegetation (USDA 2007). Also, the University of Denver is currently preparing a "Best Management Practices" handbook for revegetation available in 2008. Other resources include:

- **Society for Ecological Restoration**
  Summary: This site provides a reading list for ecological restoration practices, links for many example projects and other resources and support. www.ser.org/reading_resources.asp

- **Riparian Restoration in the Southwest – Species Selection, Propagation, Planting Methods, and Case Studies**
  Summary: This document identifies the natural processes and managed activities that cause the degradation of riparian lands and provides general guidelines to restore the natural system. It describes methods of selecting appropriate revegetation species, processes for producing riparian plants, details planting techniques, and provides case studies of past projects. www.nm.nrcs.usda.gov/programs/pmc/symposium/nmpmcsy03852.pdf

- **Stream Corridor Restoration: Principles, Processes, and Practices**
  Summary: This large and detailed document has a three-tiered design. The first section provides background information describing the basics of stream corridor systems. The second section describes the steps to produce an effective restoration plan. The final section provides guidelines to implement restoration projects.
  www.nrcs.usda.gov/technical/stream_restoration/

- **Guidelines for Planning Riparian Restoration in the Southwest**
  Summary: This restoration guide is intended to address considerations for developing riparian restoration projects and to provide a number of responses or solutions to potential problems. www.nm.nrcs.usda.gov/news/publications/riparian.pdf

- **Guidelines for Planting Longstem Transplants for Riparian Restoration in the Southwest: Deep Planting**
  Summary: This site describes a good technique for revegetating a riparian site that lacks overbank flooding and has a deep water table.
  www.nm.nrcs.usda.gov/news/publications/deep-planting.pdf

- **The Pole Cutting Solution**
  Summary: Guidelines for planting dormant pole cuttings in riparian areas of the Southwest. Planting dormant pole cuttings has proven to be a successful technique for establishing many riparian trees and shrub species. www.nm.nrcs.usda.gov/news/publications/polecutting.pdf

- **Plant Technology Fact Sheet: Tall-Pots**
  Summary: This fact sheet describes the use of tall-pots to establish plants in areas lacking sufficient soil moisture or irrigation availability to revegetate using more traditional means.

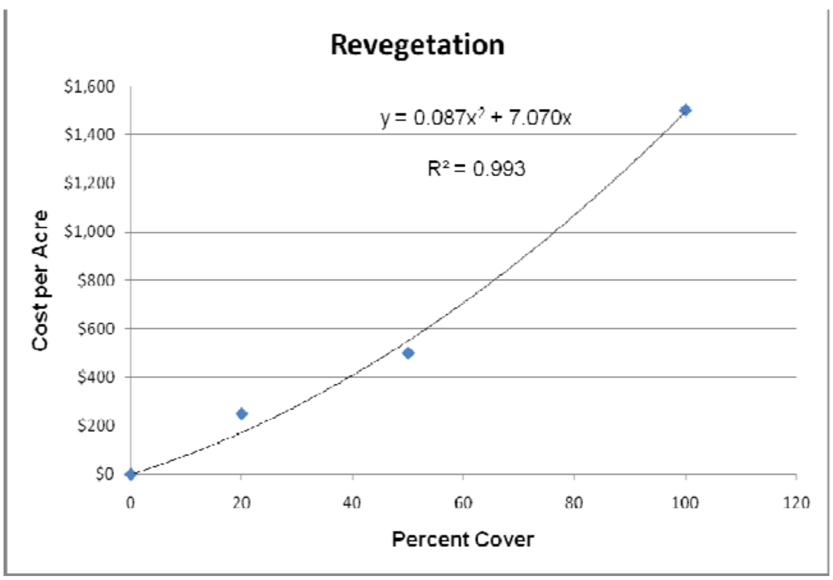
A discussion of the structure, usefulness, benefits, and limitations of the tall-pot revegetation method is included. www.nm.nrcs.usda.gov/programs/pmc/factsheets/tall-pot.pdf

Costs: Generally, the range of costs for revegetation reflects the ability to water an area either naturally or through irrigation practices. Irrigation is only appropriate in areas where water rights and topography would allow its use and where precipitation alone is insufficient. Where water is available through precipitation or is easily accessible by irrigation, revegetation costs are lower. Higher costs reflect the need for extensive irrigation where feasible and appropriate. Revegetation costs include labor, seed, plant materials, wildlife control, fertilizer, equipment rental, weed control, and water.

Revegetation costs have a direct relationship to density and width of infestation. For narrow widths less than 50 feet, natural revegetation may occur but some minor to moderate costs related to soil disturbance and weed control may be required. Costs will shift upward for broader widths (greater than 50 feet) because less native plant seed will be available for reintroduction. The general ranges of costs are: $0 costs where revegetation will be entirely natural, $50 to $250 for minor reseeding, $250 to $500 for moderate revegetation efforts, and $500 to $1,500 for major revegetation activities (Lair 2005, Taylor 1999, Tamarisk Coalition 2003). If soil conditions are poor (e.g., high salinity) cost can be significantly higher.

Successful revegetation requires a level of post-planting commitment to ensure plants are well established and capable of persisting in the future. This includes monitoring plant survival, replacing failed plants, and weed control. These elements typically occur over a three year period following initial control and revegetation activities. Costs for this post-planting component of restoration are a function of infestation levels and control technologies. Light infestations are calculated at 20% of the control and revegetation combined costs. For moderate infestations the post-planting costs are estimated at 25%, while heavy infestations are estimated at 30%.

Figure 24: Revegetation Cost Algorithm



The cost algorithm presented in Figure 24 represents an average cost for riparian revegetation in the 17 western and plains states and is extremely sensitive to availability of water, width of infestation, soil characteristics, native plant seed bank, depth to ground water, etc. For these reasons <u>costs could vary by an order of magnitude up or down</u> from those presented in this figure.

Combined Costs of Technologies for Control, Biomass Reduction, and Revegetation

Table 1 provides a list of technologies, based on the discussions above, and the situations in which they are appropriate. The table displays cost algorithm equations for each control technology and the associated restoration technologies that, together, comprise a complete restoration effort; i.e., resprout treatment, biomass reduction, revegetation, monitoring plant survival, plant replacement, and weed control. The cost equations have been updated to reflect costs in the year 2008 and are presented as cost versus density curves in Figures 25 to 31. ***Although these cost equations are appropriate for planning purposes, it is important to identify site specific conditions and restoration approaches for each project area to develop refined cost estimates.***

Planning, design, monitoring and maintenance costs during the initial 10 years of the restoration effort are not typically considered in developing cost estimates for tamarisk control. However, these components are critical to understand and should be included in the budgeting processes. These elements are a function of the degree of infestation. Light infestations are calculated at 20% of the control, biomass reduction, and revegetation combined costs. Moderate infestation costs are estimated at 25% of these same cost components, while heavy infestations have an estimated cost of 30%.

A generalized time distribution of costs would place control and biomass reduction costs in Year-1, and follow-up controls for resprouts in Year-2 and Year-3. Revegetation will begin shortly after control and biomass reduction is completed in Year-1and continue through Year-2. Monitoring plant survival, plant replacement, and weed control will be on-going in Years 3, 4, and 5. For biological control the time extends 3 additional years. During the remaining years of a 10 year restoration effort, efforts are mostly devoted to monitoring and maintenance. Each site should be assessed to determine time requirements for complete restoration efforts.

Definitions of acronyms used in the table are:

[1] Accessibility definitions:

Highly difficult to access (A^H) – Those areas that can only be accessed by foot, horse, or boat; such as, steep embankments, canyons, and roadless areas.

Moderately difficult to access (A^M) – Those areas that have a mix of level terrain where heavy equipment could be used and steep embankments that would require hand labor or specialized equipment to control tamarisk. A good example is a typical river channel where the side slope adjacent to the river is too steep for equipment use, and the broad, adjoining flood plain that has good access potential.

Low difficulty of access (A^L) – Those areas that are relatively level, near an existing road, and where heavy equipment can be used throughout.

[2] **Density definitions:** Tamarisk density is defined as its canopy cover

Light density (D^L) = 20 percent canopy cover and less

Moderate density (D^M) = 50 percent canopy cover but greater than 20 percent

Heavy density (D^H) = greater than 50 percent canopy cover.

[3] **Biomass Reduction assumptions:** When needed, mulching equipment will be used to reduce biomass three-fourths of the time. The remaining quarter of biomass reduction will be accomplished by controlled burns.

Table 1: Cost Equations for Tamarisk and Russian olive Control Technologies and associated Biomass Reduction and Revegetation

Control Approach	Applicability of Control Approach: Access[1]	Applicability of Control Approach: Density[2]	Biomass Reduction Approach [3]	Revegetation Approach	COMBINED Cost (y) Equations based on Density (x) as Percent Cover (Year 2007 $)
Hand cut-stump with herbicide Figure 25	A^M, A^H	D^L	Not required	Minimal – natural revegetation anticipated	$y = -0.068x^2+100.9x$ Tamarisk and/or Russian olive
		D^M, D^H	Mulching as primary with fire as secondary	Revegetation required because of soil disturbance	
Mechanical extraction w/o herbicide Figure 26	A^L, A^M	D^L	Not required	Some minor reseeding required because of soil disturbance	$y = 0.125x^2+26.10x$ Tamarisk only NOT appropriate for Russian olive
		D^M, D^H	Mulching as primary with fire as secondary	Revegetation required because of soil disturbance	
Mechanical root plowing & raking Figure 27	A^M, A^H	D^M, D^H	Fire	Major revegetation required because of soil disturbance is extreme.	$y = -0.001x^2+35.18x$ Tamarisk and/or Russian olive
Mechanical mulching with herbicide Figure 28	A^L, A^M	D^L	Not required	Some minor reseeding required because of soil disturbance	$y = 0.074x^2+28.13x$ Tamarisk and/or Russian olive
		D^M, D^H	Mulching as primary with fire as secondary	Revegetation required because of soil disturbance	
Mechanical grab & cut-stump with herbicide Figure 29	A^L, A^M	D^L	Not required	Some minor reseeding required because of soil disturbance	$y = 0.086x^2+29.34x$ Tamarisk and/or Russian olive
		D^M, D^H	Mulching as primary with fire secondary	Revegetation required because of soil disturbance	
Aerial herbicide application Figure 30	A^L, A^M, A^H	D^H	Mulching as primary with fire secondary	Significant revegetation required. Limited native plant availability under conditions associated with aerial herbicide application	$y = 0.102x^2+21.43x$ Tamarisk and/or Russian olive
Biological control with *Diorhabda elongata* Figure 31	A^L, A^M, A^H	D^L	Not required	Minimal – natural revegetation anticipated	$y = 0.146x^2+13.54x +110$ Available only for Tamarisk
		D^M, D^H	Mulching as primary with fire as secondary	Revegetation required because of soil disturbance	

Figure 25: COMBINED Cost equation for Hand Control with herbicide
($y = -0.068x^2+100.9x$)

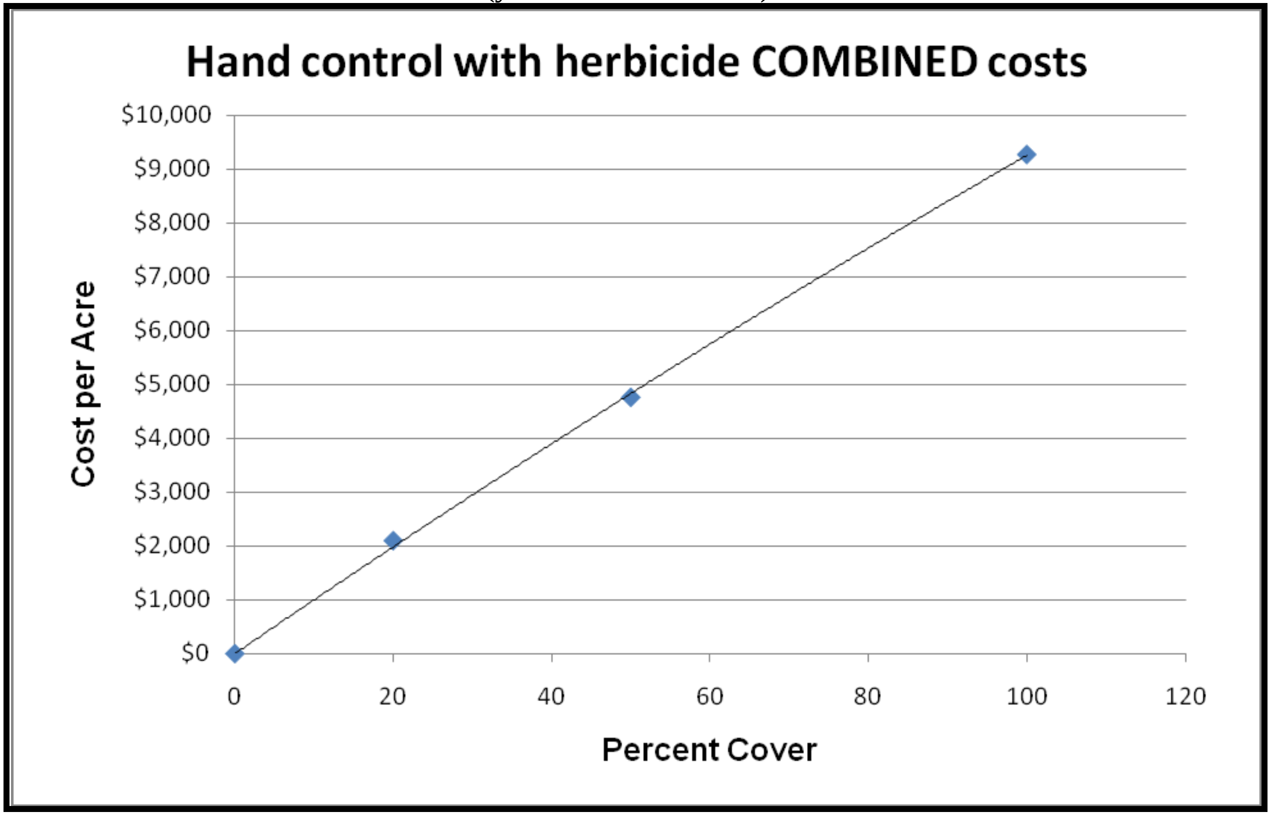


Figure 26: COMBINED Cost equation for Mechanical Extraction without herbicide
($y = 0.125x^2+26.10x$)

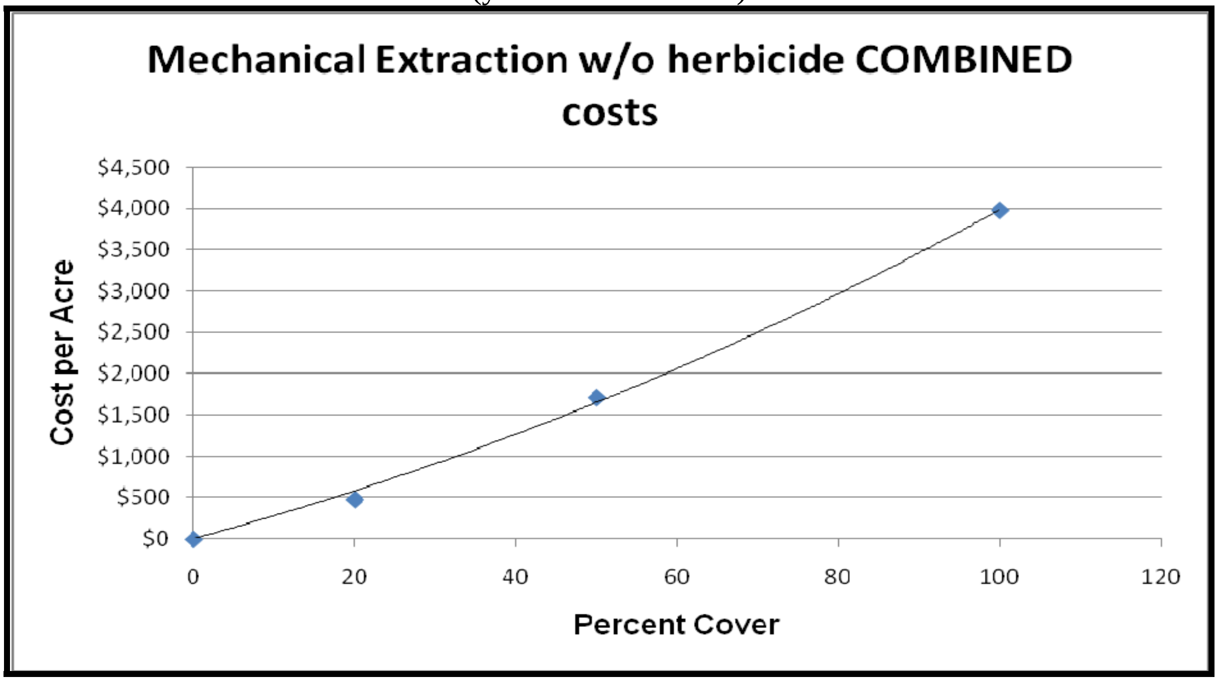


Figure 27: COMBINED Cost equation for Mechanical Root Plow & Rack Rake w/o herbicide
($y = -0.001x^2+35.18x$)

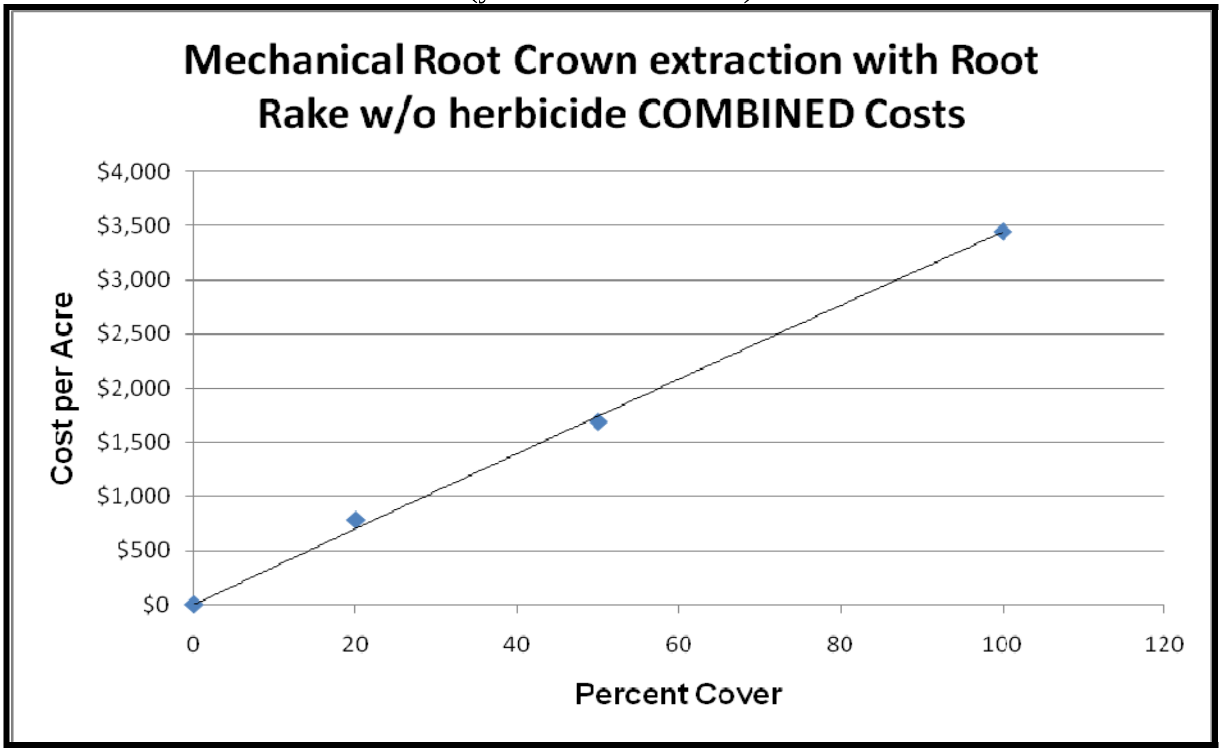


Figure 28: COMBINED Cost equation for Mechanical Mulching with herbicide
($y = 0.074x^2+28.13x$)

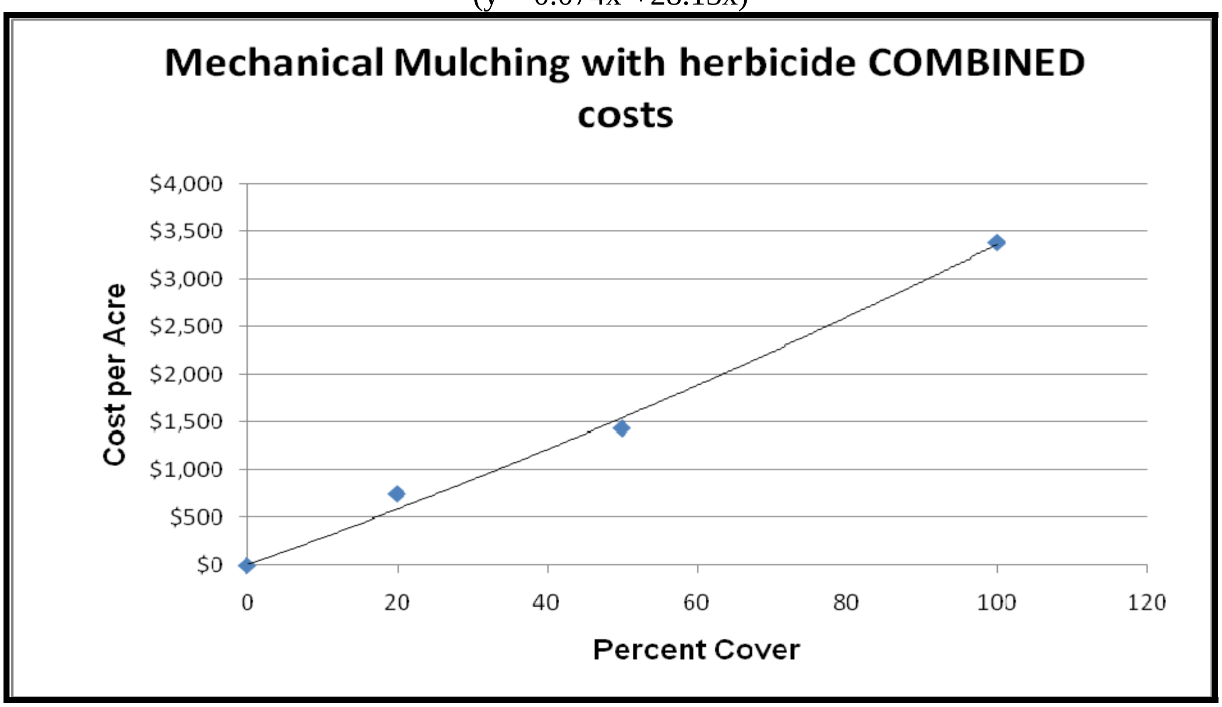


Figure 29: COMBINED Cost equation for Mechanical Grab & Cut-stump with herbicide ($y = 0.086x^2+29.34x$)

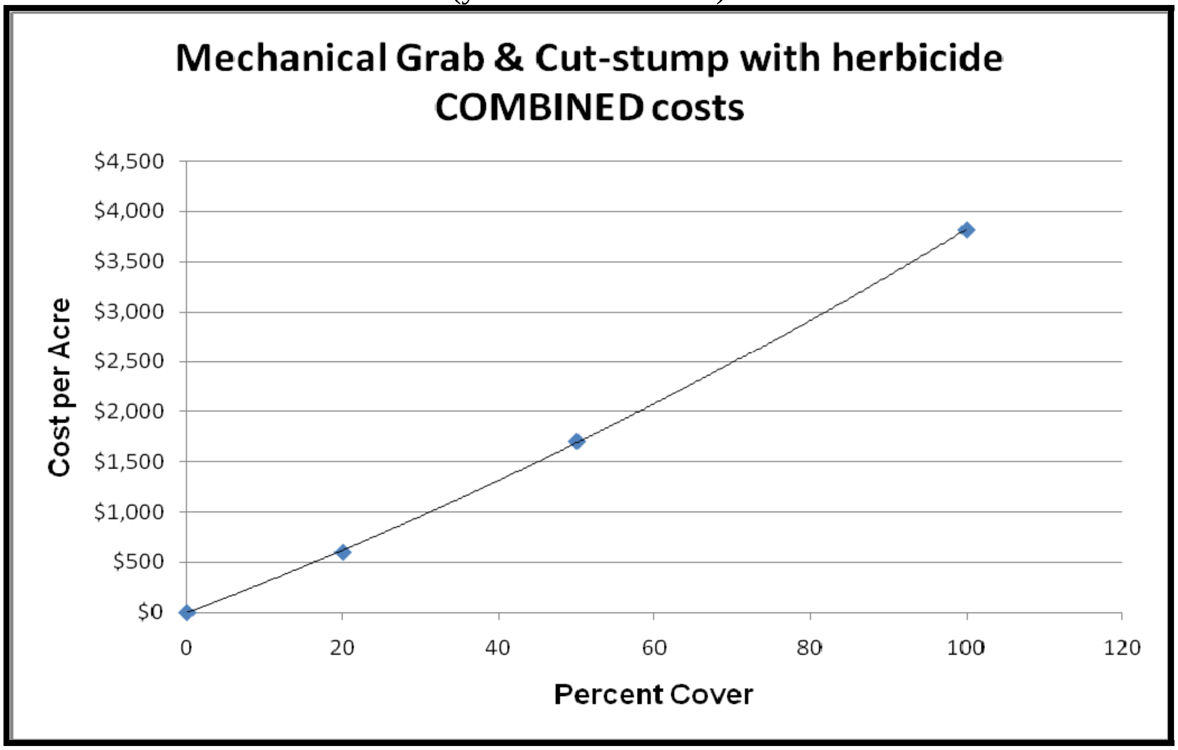


Figure 30: COMBINED Cost equation for Control by Aerial Herbicide Application ($y = 0.102x^2+21.43x$)

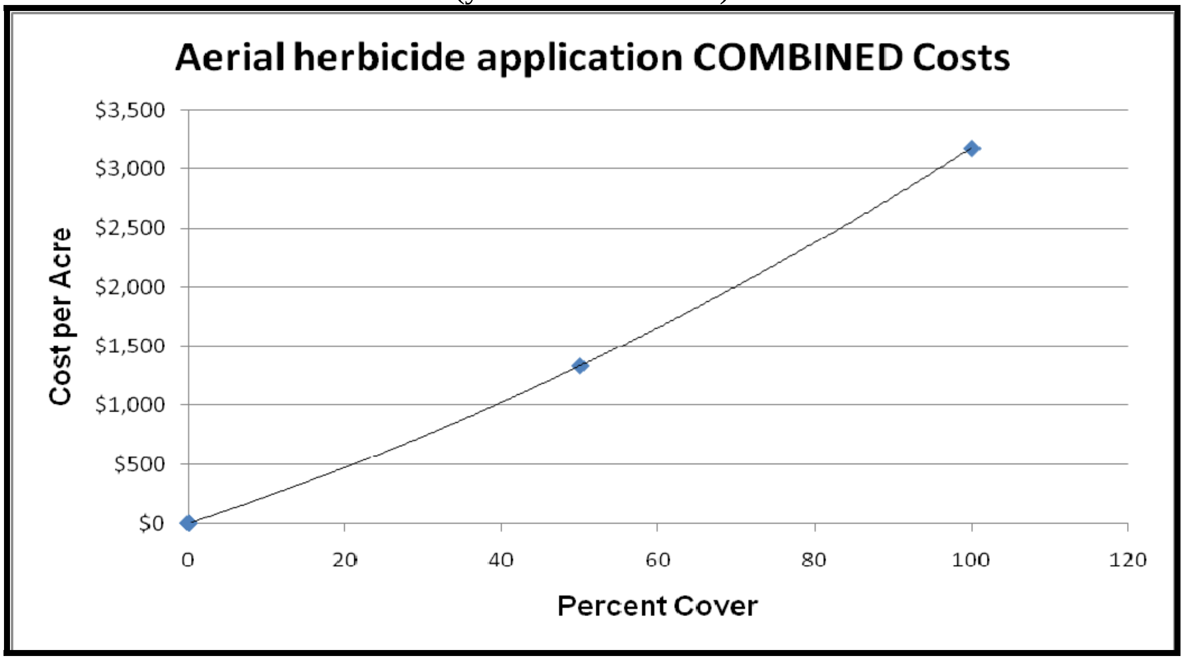
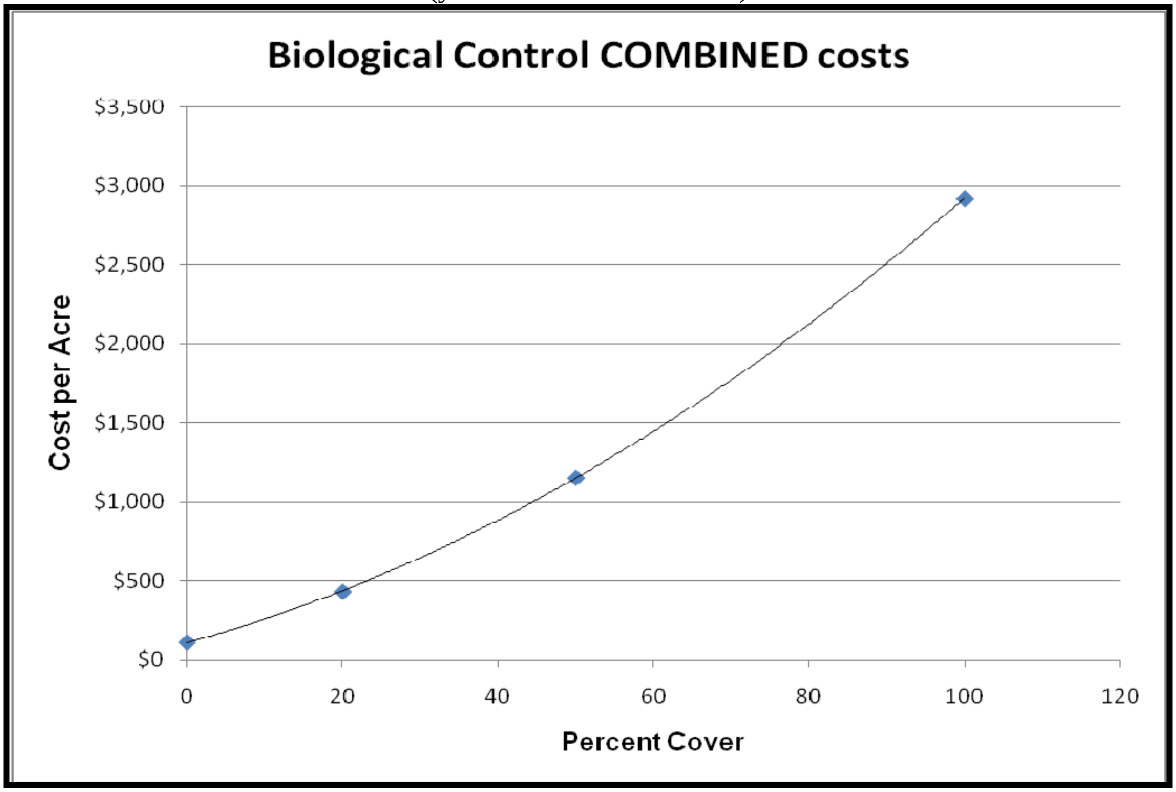


Figure 31: COMBINED Cost equation for Biolgical Control
($y = 0.146x^2+13.54x +110$)



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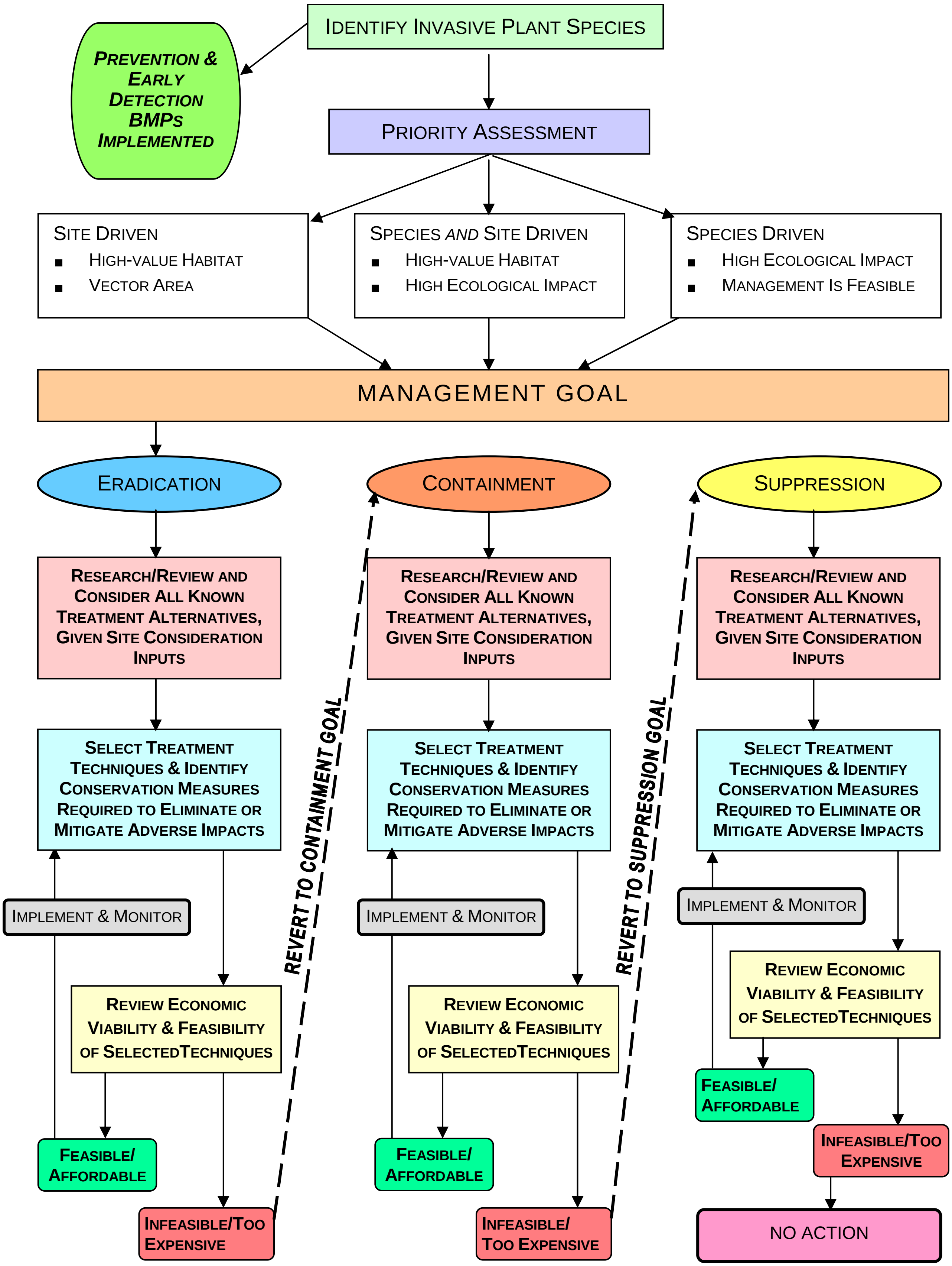
Attachment A
Integrated Pest Management Decision Matrix



Users Guide to
Integrated Pest Management Decision Matrix

Some sections adapted from Morse et al. (2004) and City of Boulder (2003).

IDENTIFY INVASIVE PLANT SPECIES

Invasive Species Identification Screening Questions

The following three screening questions are used to separate those species that are relatively innocuous from those that are invasive or have a high potential to become invasive and should be considered before investing substantial effort in assessing a species:

1. Is this species currently established outside cultivation as a non-native *(i.e.*, as a direct or indirect result of human activity) somewhere within the region of interest?
   - **Yes.** Proceed to screening question 2 below.
   - **No.** STOP. The Invasive Species Priority Assessment is not applicable to this species.

   Note: If this question is not readily answered, assessment of the species may either be deferred, or provisionally begun while further information on the species' status in the region is sought.

2. Is this species known or suspected to be present in conservation areas or other native species habitats somewhere within the region of interest?
   - **Yes.** Proceed to screening question 3 below.
   - **No.** STOP. This species is an insignificant threat to natural biodiversity in the region of interest.

3. Is this species known to meet criteria for invasive as defined by NPS as "an aggressive exotic plant that is known to displace native plant species in otherwise intact native vegetation communities"?
   - **Yes.** Proceed to the priority assessment and begin implementation of prevention and early detection Best Management Practices for all species identified as invasive.
   - **No.** STOP. This species is not considered invasive as defined by NPS or it needs more supporting data of its invasive nature.

PRIORITY ASSESSMENT

Taking Management Action – Priority or Not?

Because it is infeasible to control every invasive plant that occurs in a park or monument, it makes sense to focus management efforts on those species that have or *could* have the greatest impact to monument resources and to the highest value at-risk habitats.

Invasive plants are run through a ranking process that helps managers sort and prioritize invasive species and affected habitats based on several aspects of the species' relative invasiveness, relative importance, or quality of affected habitat:

1. Ecological Impact (risk to regional biodiversity, adverse impacts to soil resources, capacity to alter forage availability, etc.)
2. Current Distribution and Abundance
3. Trend in Distribution and Abundance
4. Control Feasibility / Management Difficulty

Based on consideration of all these factors, a person with good taxonomic skills and knowledge of local or regional ecology can use a ranking process to set priorities for resource allocation.

Initiating on-the-ground management action will then be determined by evaluating inventory data in combination with local priorities that can be site (location) and/or species driven. If the site and/or species of focus is identified as a priority for the monument, management action is deemed necessary. The decision process that follows will consider the potential actions to be taken to address a particular species on a particular site for a particular time period. The proposed project and site will be reviewed by the monument's NEPA interdisciplinary team staff annually to determine if the project 1) falls under the parameters of the monument-wide IPM plan and EA and 2) if sensitive natural or cultural resources or the human environment could be adversely impacted as a result of management (or continuing management).

MANAGEMENT GOAL

Determining Management Goals
Once a particular species and/or site is chosen and management action is deemed necessary, a desired outcome, or management goal, must be established. Goals for treatment of a species on a particular site will be determined by circumstances and practical realities reflected in the IPM Decision Matrix, illustrated in Figure 2 in the main document. Alternatives include:

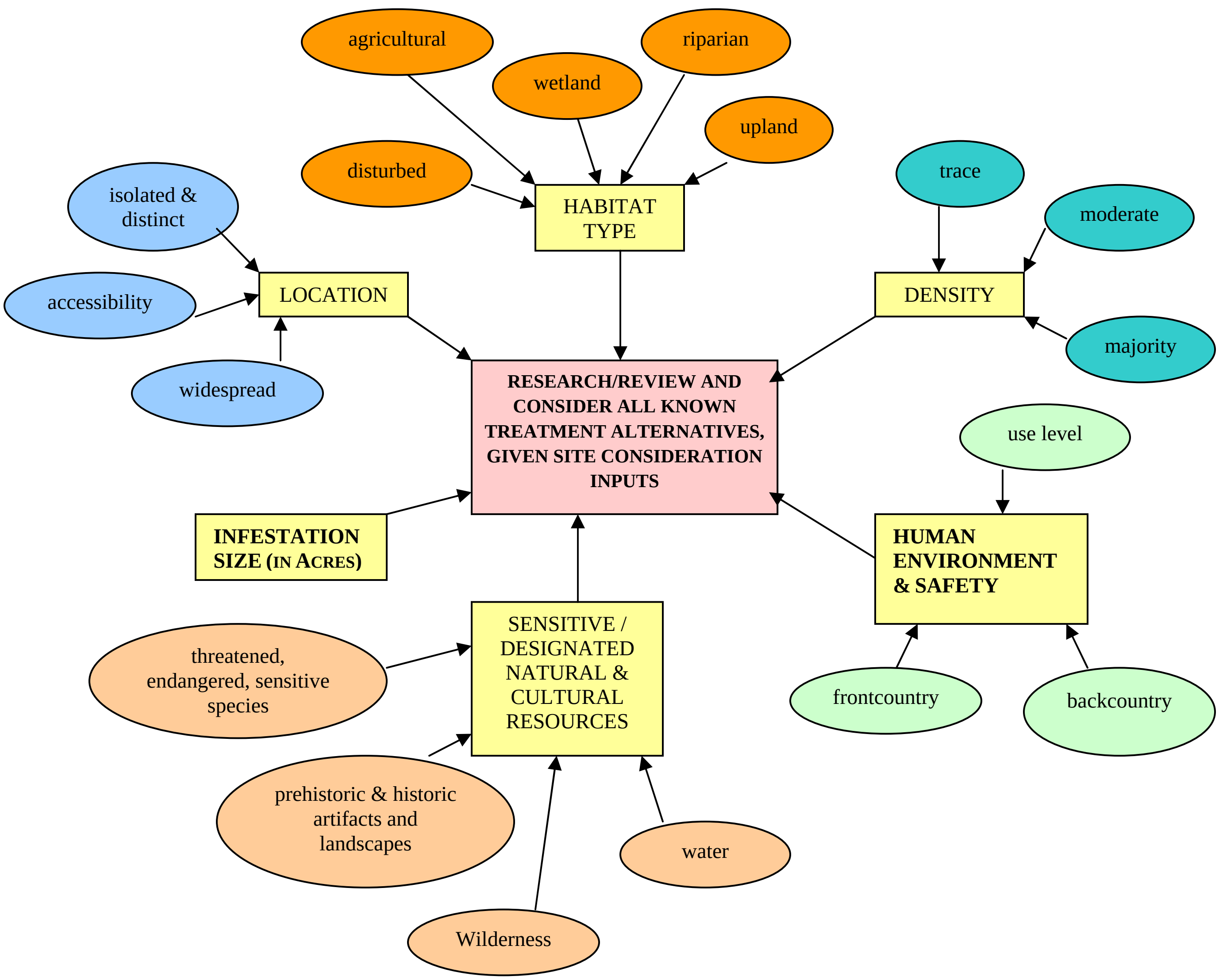
1. **Eradication**: reducing the reproductive success of a noxious weed species or specified noxious weed population in largely uninfested regions to zero and eliminating the species or population within a specified period of time. Once all specified weed populations are eliminated or prevented from reproducing, intensive efforts continue until the existing seed bank is exhausted; may be legally mandated or desirable for a new invader or new site.
2. **Containment:** maintaining an intensively managed buffer zone that separates infested regions, where suppression activities prevail, from largely uninfested regions where eradication activities prevail.
3. **Suppression:** reducing the vigor of noxious weed populations within an infested region, decreasing the propensity of noxious weed species to spread to surrounding lands, and mitigating the negative effects of noxious weed populations on infested lands. This strategy inflicts some damage on the pest with the goal of lessening the rate of spread, but does not usually mean reducing the current infestation. As better techniques are made available or environmental circumstances render a species more susceptible to containment or eradication strategies, areas identified for suppression may be upgraded to containment or eradication status.

In order to appropriately establish a management goal, invasive species problems should always be run through the decision process beginning with the highest goal of eradication. Whether or not the decision-maker(s) reverts to containment or suppression goals depends on local information known about the species itself and the site it occupies. For example, one may assume that a widespread species (such as tamarisk) would automatically be given a management goal of suppression. From a monument-wide perspective, this may be the appropriate management goal. However, if the problem site in the monument is a high-value habitat and tamarisk is present only in small and isolated infestations, then a more appropriate goal may be containment or even eradication *at the particular site*, depending on other site considerations.

RESEARCH/REVIEW AND CONSIDER ALL KNOWN TREATMENT ALTERNATIVES, GIVEN SITE CONSIDERATION INPUTS

On-the-ground Management: Review of Available Techniques

Tool and treatment technique(s) selection will depend on many different variables, called site considerations. These considerations include biotic and abiotic resources and factors that, if not considered properly, are likely to adversely affect the success of the treatment and restoration strategy. In the interest of space, this step is not fully diagramed in the matrix but is detailed on the following page. Please note that the site considerations below represent only a sample of all possible variables.



SELECT TREATMENT TECHNIQUES & IDENTIFY CONSERVATION MEASURES REQUIRED TO ELIMINATE OR MITIGATE ADVERSE IMPACTS

Treatment Selection and On-the-ground Implementation
Once appropriate treatment techniques and tools are identified, resulting impacts caused by their use also need to be identified. All tools and techniques will have some type of consequence, whether intentional or unintended, benefical or adverse, direct or indirect. At this point in the decision-making process, steps need to be identified to reduce or eliminate any potential adverse impact to the site considerations identified above. These steps can be conservation measures that are practices incorporated into the planning phase of the treatment to *prevent* potential adverse impacts (e.g.weed control treatments will occur pre-emergence or post-seed set for the threatened orchid, *Spiranthes diluvialis*) or they can be mitigation measures that fix or correct an impact after action has occurred (e.g. native trees will be planted after tamarisk is removed in riparian areas).

REVIEW ECONOMIC VIABILITY & FEASIBILITY OF SELECTED TECHNIQUES

FEASIBLE/ AFFORDABLE

If the selected treatment techniques and conservation / mitigation measures are affordable, effective, and practical then the treatment plan is approved for implementation.

IMPLEMENT & MONITOR

At a minimum, implementation of any treatment plan will include informal documentation (monitoring) of its effectiveness. More formal monitoring will occur in cases where specific biological or ecological thresholds are identified prior to treatment implementation.

REVIEW ECONOMIC VIABILITY & FEASIBILITY OF SELECTED TECHNIQUES

INFEASIBLE/TOO EXPENSIVE

If the treatment or conservation / mitigation measures selected are NOT affordable, effective, and practical then the treatment plan cannot be approved as it stands and the decision-maker(s) needs to revert to lesser goals of containment or suppression, as indicated in Figure 2.

NO ACTION

There may be cases when all known treatments and conservation / mitigation practices are still not affordable, effective, or practical and a determination of "No Action" must be made. This is not necessarily a decision to not address the problem at all (a "live with it" decision), rather, it is an acknowledgement that the problem may need to be monitored further and re-evaluated at a later date when more data or new control technologies/strategies become available or if changes in environmental circumstances render the problem more easily addressed using available techniques and strategies.