CHAPTER 12: TAMARISK ECOLOGY IN THE GRAND CANYON—INVASION, CONTROL, AND FUTURE MANAGEMENT

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INTRODUCTION

An essential counterpart to the preceding discussion of native riparian plants (see M. Kelso in this volume) is an examination of invasive plants, and the interaction between hydrologic flow regime and invasive populations. Grand Canyon riparian areas are now home to numerous invasive plant species, many of which are characterized by prolific seed output, rapid germination and growth, robust vegetative spread, and/or seed dispersal over long distances (Makarick 2008). Invasive inner-canyon species that have garnered the most attention from Grand Canyon managers and visitors include Russian olive (Elaeagnus angustifolia), camelthorn (Alhagi maurorum), Ravenna grass (Saccharum ravennae), cheatgrass (Bromus tectorum), sowthistles (Sonchus spp.), whitetop (Cardaria draba), and several knapweed species (Centaurea spp. and Acroptilon repens). Perhaps the most notorious riparian invasive in the Grand Canyon and other areas throughout the western United States is known as tamarisk or saltcedar, which is a hybridization of Tamarix species native to Eurasia (Gaskin & Schaal 2002). While tamarisk has been associated with negative impacts on native species and ecosystems, in many areas it is now incorporated into the riparian habitat. Riparian areas make up less than 2% of the land in the U.S. Southwest, but over 65% of wildlife in the region depend on this habitat (Makarick et al 2002). Management of these crucial areas requires a deep understanding of key actors such as tamarisk; many factors play into the interesting and complex question of how to treat this well-established invader.

HISTORY OF TAMARISK IN THE GRAND CANYON

As is the case with many currently invasive plant species, tamarisk was first introduced and spread in the U.S. deliberately by private and public land managers (Wyman 2007). Brought in as early as 1805, tamarisk was planted widely as an ornamental, a wind break, and for bank stabilization purposes (see Figure 1) (Zouhar 2003, Stevens 2009). Essentially naturalized by the 1870s, saltcedar was planted through the 1930s and now occupies between 1 and 1.6 million acres from northern Mexico to Montana, and from Kansas to central California (Shafroth et al 2005). Efforts to control this wildly successful exotic species began in the 1960s and continue today.

Tamarisk arrived in the Grand Canyon between 1922 and 1938, where it occupied high terraces and tributaries in the years before the 1963 completion of the Glen Canyon Dam (Stevens 2009). The dam drastically decreased downstream sediment loads, greatly reducing material for new terraces and sand bars (see papers by N.

Figure 1. Tamarisk growing along the Colorado River in the Grand Canyon (NPS.gov/grca)
Burley, E. Bartolomeo, and S. Gibson in this volume). At the same time, the reduction in peak flood magnitude and increase in base flow associated with hydropower operations resulted in a more stable riparian zone, with more consistent moisture throughout the year (Stevens et al 1995, Ralston 2010). The riparian plant community expanded under the new hydrologic regime, with increases in cover and density of native species such as sandbar willow and cattails, and a dramatic expansion of tamarisk in the Grand Canyon (see Figure 2) (Turner & Karpiscak 1980, Stevens 2002). Perhaps due to priority effects, superior competitive ability in post-dam conditions, or both, tamarisk has become a riparian dominant and in some areas has been able to establish a vigorous monoculture (Stevens 2002, Makarick et al 2002, Zouhar 2003).

Figure 2. Photographs taken in 1889/1890 (left) and replicated in the late 1900s (right) show the expansion of Grand Canyon riparian vegetation over the century (Webb 1996).

WHY IS TAMARISK SO SUCCESSFUL IN POST-DAM CONDITIONS?

While tamarisk was present in the Grand Canyon prior to the completion of the Glen Canyon Dam, there is a general consensus that this species expanded rapidly just after the hydrologic regime change (Turner & Karpiscak 1980, Stevens 2002, Makarick et al 2002). Factors in the success of tamarisk relative to many native species in the more stable post-dam riparian areas can be associated with two general advantages: the ability to spread quickly and the capacity to grow in conditions unfamiliar to many natives.

Rapid Spread

Stevens (2002) states that a mature tamarisk plant can produce $2.5\times10^8$ seeds each year; while other sources do not all report such high numbers, the production of hundreds of thousands of seeds by a single plant may be common (Makarick 2011). Zouhar (2003) presents a comprehensive review of tamarisk regeneration and spread mechanisms. Tamarisk plants can flower in their first year, and reproduce sexually through much of the growing season, which contributes to prolific seed production. Seeds are very small and are readily dispersed by wind and water, which enhances spread especially in riparian areas such as the inner Grand Canyon. With no dormancy requirements, tamarisk seeds can germinate within 24 hours in favorable conditions, with a germination rate between approximately 20% and 50% depending on the time of year. Tamarisk can also produce new plants vegetatively from stem fragments, which may be transported by water as well. The production of numerous propagules capable of traveling long distances likely contributed to tamarisk arriving first in many newly stabilized riparian areas. In this case, inhibitory priority effects (Young et al 2001) associated with reduction of space or nutrients for later-arriving species may have promoted development of tamarisk monoculture.
Advantage Relative to Natives in Altered Hydrologic Conditions

Tamarisk is often found in areas common to Fremont cottonwood (*Populus fremontii*), sandbar willow (*Salix exigua*), and Goodding’s willow (*Salix gooddingii*). Altered stream flows across the U.S. Southwest have been associated with a relative increase in tamarisk over these native species (Stromberg et al 2007, Merritt & Poff 2010). This comparative effect may be due at least as much to the generally poor performance of native plants under altered hydrology as to tamarisk doing particularly well under these conditions (Merritt & Poff 2010). For example, native species such as cottonwood are adapted to release seeds in synchrony with natural flow regimes, taking advantage of the natural scouring floods that open and moisten new sites for germination (see M. Kelso in this volume). With altered flow, germination sites are often not available and cottonwood populations decline (Merritt & Poff 2010). Unlike many natives, tamarisk produces seeds throughout the summer, and germination is favored by the unnatural consistent base flow imposed by dam operations (Zouhar 2003, Stromberg et al 2007). Sources such as Zouhar (2003) state that tamarisk out-performs many native riparian plants in "harsh" environmental extremes, such as drought and high salinity. While altered flow regimes have increased base flows in the Grand Canyon, such that low-lying areas are in fact more consistently wet throughout the year, tamarisk may be able to persist in the slightly higher, drier areas and thereby produce more seeds that swamp out nearby native species. Tamarisk is more drought tolerant than many natives because it is a facultative phreatophyte once established (meaning that it can use surface water from unsaturated soil as well as ground water); it also has a deep and extensive root system (DiTomaso 1998, Zouhar 2003). Salinity in Grand Canyon soils has increased with the altered hydrology (see A. Oliver in this volume), which would favor tamarisk over most native plants that do not tolerate salinity. Both of these harsh conditions are exacerbated by tamarisk itself, as discussed in the following section.

Tamarisk Impacts on Native Species and Ecosystem Function

One reason that the tamarisk invasion has received so much attention is its demonstrated direct negative impacts on native species and ecosystems. Once established, tamarisk may form dense monoculture stands through vegetative reproduction that exclude other plant species (Makarick et al 2002). The high capacity to stabilize sediments—associated with its deep roots—for which tamarisk was originally planted by land managers combines with the lack of scouring floods in the altered hydrologic regime to maintain these stands for decades, which would not have been possible under natural hydrologic conditions (see Figure 3) (Lovich & Hoddle 2011). Not only are native plants unable to germinate in tamarisk stands, but the associated sediment impoundment (Zouhar 2003) may reduce materials that would otherwise create new open sand bars for native germination. Tamarisk has a higher evapotranspiration rate than many native plants under dry or saline conditions, which decreases water availability and exacerbates these conditions under which tamarisk outperforms native species (see Figure 3) (Nagler et al 2003).
According to some sources, tamarisk also increases soil salinity via salt deposition excreted from the leaves, though the lack of flooding associated with altered hydrology likely plays a larger role in salt accumulation in the soil (Zouhar 2003). High salinity prevents the germination of many native plants, while tamarisk germination is not negatively affected (Zouhar 2003). Tamarisk also increases fire frequency and sprouts rapidly after fire, unlike most native riparian plants (Lovich & Hoddle 2011). In some sites it is only those native plants that are also halophytic and fire-tolerant, such as arrowweed (*Pluchea sericea*), that codominate with tamarisk; in many cases these plants are ultimately outcompeted (Zouhar 2003).

In addition to impacting native plants, tamarisk has also been associated with negative effects on wildlife and ecosystem species diversity. Some studies suggest that tamarisk offers little value to most native reptiles, amphibians, mammals, and birds (Lovich & de Govenain 1998). In addition to decreasing water available to other plants, tamarisk may compromise water sources for bighorn sheep, deer, salamanders, toads, and other wildlife (Stephenson & Calcareone 1999, Makarick 2002). Some comparisons of tamarisk-dominated areas with those occupied with mature native cottonwood and willow have found lower abundance and diversity of various vertebrates and macroinvertebrates in invaded habitat (Zouhar 2003, Bailey et al 2001). Counterexamples have also been found, as discussed in Section VI of this chapter. However, the negative impacts on ecosystems—both real and perceived—and negative consequences for rafters and other human visitors have driven efforts to reduce or eradicate tamarisk using various control methods (Makarick et al 2002).

**TAMARISK CONTROL METHODS**

In Grand Canyon National Park, managers are pursuing chemical and mechanical control of tamarisk in tributaries and side canyons, developed areas, and springs that are located above the pre-dam water level of the river (Makarick 2011). Given the association between altered hydrology and tamarisk spread, another approach is to determine whether the High Flow Experiments (discussed by N. Burley in this volume) that may provide some benefits of the
former natural flow regime might also help to control tamarisk (Ralston 2010). In addition, the tamarisk leaf beetle is a biocontrol that was approved for release in 2001; while not released in Grand Canyon NP, it was found there in 2009 (Oltrogge & Makarick 2009). As with many invasive species, the most effective control is gained through monitoring, prevention, early detection, and local eradication (Zouhar 2003). The efficacy, advantages, and disadvantages of control methods associated with Grand Canyon NP are discussed below.

**Chemical and Mechanical Control**

Tamarisk may be difficult to kill using only chemical or mechanical treatments alone, but combined approaches may be more effective (Zouhar 2003). Mechanical control can be appropriate in early or small invasions where plants are easier to uproot (Lovich 2000). Zouhar (2003) discusses root plowing and cutting as initial effective approaches to heavy invasions, and herbicides such as imazapyr, triclopyr, and glyphosate to enhance mortality. One of the most common and effective treatments is to remove the aboveground portion of the plant and apply herbicide to the remaining cut stump (Lovich 2000). Tamarisk readily resprouts if treated with fire alone, but summer fire treatment may be used in combination with chemical and mechanical methods to enhance tamarisk mortality (Zouhar 2003). The broad scale tamarisk removal project Grand Canyon National Park involves hand crews using combination chemical-mechanical treatments best suited to each target site (Makarick 2011). By 2011, approximately 275,000 tamarisk plants had been removed from over 6,000 acres in the park, with only 12 percent of treated trees requiring additional control; the project is now in a cyclic maintenance phase (Makarick 2011).

**Effects of HFEs on Tamarisk**

Ralston (2010) discusses riparian vegetation changes in response to the HFEs, and the March 2008 HFE in particular. The 1996 and 2008 experimental flows primarily buried vegetation rather than scouring it, so these would not have played an important role in removing well-established tamarisk stands. Even scouring floods do not necessarily favor natives, however—following the uncontrolled scouring floods in the mid-1980s, tamarisk seedlings dominated newly exposed sediment deposits. By comparison to these uncontrolled floods and a Low Summer Steady Flow experiment in 2000, the March 2008 HFE resulted in relatively lower subsequent tamarisk seedling establishment. This suggests that, even if the HFEs cannot remove most established tamarisk, at least these flows will not contribute significantly to its spread if they are timed before the April-September tamarisk seed production. A March flow can provide a chance for native plants to establish in open areas, potentially reducing site availability for tamarisk seedlings.

**Tamarisk Leaf Beetle Biocontrol**

In some cases, introducing herbivores from an invasive plant’s native range can help to control the plant populations; the tamarisk leaf beetle (*Diorhabda* spp.) has been investigated as a biocontrol for tamarisk (Zouhar 2003). After study to determine the predicted range limits and targets of this species, tamarisk beetles were released in some western areas in 2001 (Oltrogge & Makarick 2009). Apprehension about releasing these beetles relates to the potential for damage to non-target plants, losing the ecological or economic benefits of tamarisk, leaving open niches for other invasive plants, and the fact that native vegetation may not be able to recover or survive in areas where tamarisk is removed (Zouhar 2003). The beetle was not to be released within 200 miles of habitat for the southwestern willow flycatcher, an endangered bird that now nests in tamarisk; it was not released in Grand Canyon National Park (Oltrogge &
Makarick 2009). The tamarisk beetle was found in the park and other unanticipated locations in 2009, however, and the USDA halted beetle release at that time in response to a lawsuit to protect willow flycatcher habitat (Sands 2009, Makarick 2011). Beetle populations are currently widespread in the Colorado Plateau (see Figure 4), and obvious signs of defoliation are visible in the Grand Canyon (Makarick 2011). Studies have not yet shown that the beetle contributes to tamarisk mortality, but episodic defoliation does reduce tamarisk water use, which is a desired outcome of tamarisk control (Hultine et al 2010a).

![Distribution of Tamarisk Leaf Beetle](http://www.fronterasdesk.org/news/2011/sep/05/tamarisk-river-environment-non-native-plants)

**Figure 4.** Distribution of the tamarisk leaf beetle in the Colorado Plateau as of 2010, including locations in Grand Canyon National Park.

**IMPACTS OF TAMARISK REMOVAL ON NATIVE ECOSYSTEMS**

Tamarisk may not be ideal habitat for wildlife, but especially in heavily invaded areas it may be in use as the best habitat available (Zouhar 2003). In the Grand Canyon, many bird species do nest in tamarisk, including mourning dove, Southwestern willow flycatcher, Bell’s vireo, yellow warbler, and blue grosbeak (Makarick et al 2002). Some insect species use tamarisk, and these provide food for foraging bats; peregrine falcons may in turn prey on bats or birds foraging around tamarisk patches (Makarick et al 2002). Anderson (1998) suggests that at higher elevations, the diversity of communities associated with tamarisk stands is not necessarily lower than diversity in native vegetation.

The relative use of tamarisk can vary dramatically by geographic location and species. If this invasive plant has occupied an area for a substantial length of time there may be other species reliant on its presence. The southwestern willow flycatcher is one example: some studies on this endangered bird have found no negative effects from breeding in tamarisk (Sogge et al 2008), and the bird’s reliance on this habitat in some areas has led to a halt in tamarisk biocontrol (as discussed above). Another example is described by Converse et al (1998), which found that densities of subadult humpback chub—an endangered fish—were almost twice as high near vegetated shorelines (occupied largely by tamarisk) as the chub densities associated with natural talus and debris fan shorelines. In this case, the chub may be making use of increased cover and shade associated with these novel riparian shorelines to avoid predation from non-native fish. In both of these examples, and in other cases of wildlife utilizing tamarisk, the question is whether tamarisk control and removal can be followed by replacement with native species that will provide at least the same habitat value. Stromberg (1998) compared 30 traits between locations occupied by tamarisk and by Fremont cottonwood in riparian areas, and found that the functional role of these two species was equivalent for
about half of the traits that indicate riparian ecosystem function. Can the system that emerges after tamarisk control permanently exceed this level of function?

**REMOVAL VERSUS RECONCILIATION**

While negative effects have been associated with the presence of invasive tamarisk, there may also be negative consequences to its removal in riparian areas in the Grand Canyon and throughout the west. Management of this species requires a site-specific evaluation of these factors, incorporating a consideration of the economic cost of removal and the likelihood of its efficacy as well (Shafroth et al 2005). In the Grand Canyon, tamarisk occupies a novel niche space that was not present before the completion of the Glen Canyon dam. Native plants are not necessarily well-suited to this entire niche even in the "best case" scenario of complete tamarisk eradication. Tamarisk removal without native colonization can leave open space to facilitate the spread of many other opportunistic invasive plants, and result in net habitat degradation (Sogge et al 2008, Hultine et al 2010b).

Ecologists have suggested that incorporating some level of native vegetation into tamarisk-dominated areas may bring the habitat benefits of natives without the higher cost and risk associated with full-scale tamarisk removal efforts (van Riper III et al 2008). Here the question is whether this mixed community can be self-sustaining under altered hydrologic conditions, even with the potential aid of experimental flows, or if a tamarisk monoculture would soon return. Examples of successful establishment of native communities in formerly tamarisk-dominated areas are few and far between, even with more comprehensive removal methods; long-term persistence of these communities is still more elusive (Zouhar 2003). In the Grand Canyon, where there is little flexibility to reincorporate a significant degree of natural flow characteristics into the regime, replacing tamarisk with a sustainable native plant community seems unlikely if not impossible in many areas. Grand Canyon National Park has pursued a program of tamarisk control in areas that are newly invaded or where removal potentially has a high value for wildlife or humans, which is a well-reasoned approach to this high-profile invasion. The composition and value of what ultimately persists in these treatment areas, however, remains to be seen.

**SOURCES CITED**


