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Changing Perceptions of Change: The Role of Scientists in *Tamarix* and River Management

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Abstract

Initially introduced to western United States to provide ecosystem services such as erosion control, *Tamarix* by the mid-1900s had became vilified as a profligate waster of water. This large shrub continues, today, to be indicted for various presumed environmental and economic costs, and millions of dollars are expended on its eradication. In this review, we examine the role of scientists in driving changes in perceptions of *Tamarix* from valuable import to vilified invader and (in some instances) back to a productive member of riparian plant communities. Scientists over the years have sustained a negative perception of *Tamarix* by, among other things, (1) citing outmoded sources; (2) inferring causation from correlative studies; (3) applying conclusions beyond the scope (domain) of the studies; and (4) emphasizing findings that present the species as an extreme or unnatural agent of change. Recent research is challenging the prevailing dogma regarding *Tamarix*'s role in ecosystem function and habitat degradation and many scientists now recommend management shifts from "pest plant" eradication to systemic, process-based restoration. However, prejudice against this and other non-native species persists. To further close the gap between science and management, it is important for scientists to strive to (1) cite sources appropriately; (2) avoid reflexive antiexotic bias; (3) avoid war-based and pestilence-based terminology; (4) heed the levels of certainty and the environmental domain of studies; (5) maintain up-to-date information on educational Web sites; and (6) prior to undertaking restoration or management actions, conduct a thorough and critical review of the literature.

Key words: anti-exotic bias, invasive species, riparian restoration, scientific rigor.

Introduction

Vegetation changes (i.e., plant invasions; Davis et al. 2005) are triggering ecosystem management actions worldwide. Ideally, management actions are driven by societal preferences as informed by scientific knowledge (Christensen et al. 1996; Lackey 2004). In actuality, though, policy and management often rest on emotional reactions to perceptions as much as on the analysis of facts (Ingram 1973). Our attachment to "biogeographical distributions is fundamentally emotional" (Trudgill 2008:102), and emotions can run high regarding introduced and invasive species (Brown & Sax 2004). For example, we have heard academicians at scientific conferences refer to Saltcedar (*Tamarix*, or Tamarisk) as "evil," which is a bit startling to say the least. In the course of our riparian research, each of us has altered our views regarding introduced biota. As reformed xenophobes, we are concerned that a reflexively antiexotic viewpoint can provoke needlessly negative attitudes among resource managers and young scientists, reducing scientific rigor and credibility.

Tamarix, purportedly "the second-worst invasive plant species in the United States" (Schaal et al. 2003:197), is the touchstone for our examination of the role of science in invasive species management. Deliberately introduced to United States, *Tamarix* species and hybrids are now common along many rivers of western United States and northern Mexico (Friedman et al. 2005). *Tamarix* has been indicted for various presumed environmental and economic costs (Zavaleta 2000), and millions of dollars are expended on *Tamarix* eradication (Shafroth & Briggs 2008). The Salt Cedar and Russian Olive Control Demonstration Act, a federal law enacted in 2006, calls for $80 million to be spent on projects including plant removal, and individual states have dedicated additional money to *Tamarix* control. *Diorhabda elongata*, a beetle imported from Asia, has been widely released on western rivers as a *Tamarix* biocontrol agent (Dudley & DeLoach 2004; Dennison et al. in press).

The western riparian landscape certainly has been greatly transformed, with *Tamarix* as a key element in this process. But it appears to us, through years of following, researching, and helping shape the *Tamarix* story, that an unduly, negative perception of the species has been created and sustained by scientific authors; in effect, scientists have contributed to a rationalized scapegoating of *Tamarix* as an agent of change because of its ability to thrive in

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anthropogenic habitats. As research accumulates, however, scientists are increasingly convinced that *Tamarix* is (at least) as much a "passenger" of change as a "driver" and has positive ecological values of its own; many, thus, are recommending management shifts from "pest plant" eradication to systemic, process-based restoration. Yet, several high-profile governmental, industry, and conservation groups continue to use the widely available body of misinformation regarding *Tamarix* in preparing legislation, executive orders, management policies and plans, and promotional and educational materials. Some scientists, too, redisseminate outdated, inaccurate information in journal articles, further contributing to the disconnect between science and management.

In the following sections, we explore scientists' roles in driving changes in perceptions of *Tamarix* from valuable import to vilified invader and (in some instances) back to a productive member of riparian plant communities. We delve into the literature on several specific issues to examine how the process of information generation and reporting has framed the *Tamarix* story. We hope that our efforts will reduce the lag time between information generation and information use (Messmer et al. 2001) and bring management of *Tamarix* and other similar species in line with the current state of ecological knowledge.

Geomorphic Functions and Values

During the late 1800s and early 1900s, resource managers in western United States were concerned about wind-borne soil erosion from agricultural lands (Quinn 1982). When the era of large-scale dam construction began in the arid West (Graf 1999), sedimentation of reservoirs also became a management concern. All available plant species—whether local or from afar—were considered for their functional value in addressing resource management challenges (Pauly 2007). *Tamarix* species had been on the American scene for some time (Peck 1818) and were soon widely planted as windbreaks, soil stabilizers, and for other purposes (Thornber 1916; Bennett 1938; Horton 1964; Robinson 1965). Scientists contributed by describing environmental tolerance limits and evaluating the success of planting efforts. For example, Carleton (1914:693) found *Tamarix* "by far the most drought resistant and otherwise hardy of all the trees and shrubs …."

Because of the many introductions, coupled with affinity to local ecosystems, *Tamarix* soon naturalized. Scientists weighed in on the merits of the functional changes following from planting or self-seeding (Bryan & Hosea 1934; Hoover 1937). For example, the water capacity of Lake McMillan on the Pecos River (New Mexico) had diminished by a quarter because of high rates of sediment inflow from the uplands (Taylor 1930). *Tamarix* colonized the inlet delta and by 1930 covered at least 6,000 acres. Of this change, Taylor (1930:54) wrote, "Silt problems at McMillan Reservoir, which were at one time of a very serious nature, have been materially lessened by the accidental propagation of this foreign … shrub."

Water Wars

The primary factor that changed perceptions of *Tamarix* from positive to negative during the mid-1900s was competition for water in the arid southwest. As a case in point, the plans of the Phelps Dodge mining company to expand its Morenci, Arizona, copper mine (a water-intensive industry) in the 1930s were stymied by unavailability of additional stream water (Gatewood et al. 1950; Cleland 1952; Jackson 1991). Research ensued, with hydrologists studying water use by *Tamarix* and other phreatophytes. The research continued into the 1960s, motivated by desires to determine how much water could be salvaged for human use (Graf 1992).

Early studies reported very high rates of evapotranspiration (ET). However, as scientists later learned, the techniques used tended to overestimate water use (Shafroth et al. 2005). The early, often indirect, estimates of *Tamarix* water use ranged as high as 3–4 m/yr, although values as low as 0.8 m/yr were also reported (reviewed in Di Tomaso 1998; Glenn & Nagler 2005; Shafroth et al. 2005). These findings left the impression that very large quantities of water could be made available by clearing phreatophytes. Robinson (1952:59), for example, extrapolated from "all available data" that 15 million acres of phreatophytes were wasting up to 25 million acre-feet of water annually in 17 states.

Tamarix was singled out, with Hughes (1968) citing a 1950 study showing it to have higher water use than other plants including Cottonwood (*Populus*). Horton (1977:124), in an early symposium on riparian habitat, noted "These stands [*of Tamarix*] attracted little attention until it was realized they were using large amounts of water." Harris (1966:420) reported "their nuisance value is increased by the fact that tamarisk transpires large quantities of precious water." Some of the assessments were pejorative: not only did they use much water but Saltcedar were deemed hazardous, useless, and alien (Bowser 1957).

Into later decades, the high-end estimates continued to be frequently expressed and dire consequences were alluded to (Hoddenbach 1987). Di Tomaso (1998:332) stated that "One large tree can absorb 760 L of water a day" and went on to say that *Tamarix* in the southwest uses "almost twice as much water per year as the major cities of southern California." Zavaleta (2000:463) drew on a paper by Johns (1990) that reviewed articles published from the 1930s to 1980s to conclude that "under no condition has tamarisk been found to transpire less than native vegetation" but neglected to include his caveat (Johns 1990:28) that water requirement for *Populus*, *Salix*, and other species is "difficult to quantify with confidence." Students of ecological restoration learned from Holl and Cairns (2002:421) that *Tamarix* "is lowering the water table and altering flood regimes along many streams in the southwestern United States (Glausiusz 1996)." Glausiusz (1996:30) is an article in a popular science magazine that asserts without any scientific citation: "With their voracious appetite for water, [tamarisks] have sucked streams and oases dry." In another popular magazine, people read that "Each year, tamarisks in the United States suck up three times more water than is used by all the households in the city of Los Angeles" (Millar 2004:32).

Beginning in the 1980s, improved methods for measuring stand-level rates of ET became available and new studies revised our understanding of riparian water-use rates (Goodrich et al. 2000). Moisture flux tower and sap flow measurements of *Tamarix* and other riparian species were scaled to whole river reaches using tower-calibrated remote sensing. These studies, on a variety of rivers, showed stand-level estimates of *Tamarix* ET to range narrowly from 0.75–1.45 m/yr, with a mean value of about 1 m/yr (Devitt et al. 1998; Cleverly et al. 2002, 2006; Westenburg et al. 2006; Owens & Moore 2007; Nagler et al. 2008*a*, 2008*b*; Dennison et al. 2008). Another study demonstrated that river-scale ET levels remain fairly constant across rivers despite differences in *Tamarisk* prevalence (Nagler et al. 2005*b*).

It seems logical to suppose that removal of *Tamarix* (or any plant that uses groundwater) should result in lower riparian water use and therefore higher flows in a river system, but empirical studies suggest otherwise. For example, a large-scale, chemical eradication program initiated on the Pecos River in Texas in 1999 resulted in extensive mortality of *Tamarix*, but no documented increase in river flow as of 2003 (Hart et al. 2005). Various processes preclude the potential water salvages. Vegetation removal may raise the water table, but consequently produce more bare-soil evaporation (Hu et al. 2006). Furthermore, it is impractical to maintain bare floodplains and rivers banks. Cleverly et al. (2006) reported a one-time annual savings of water when *Tamarix* and Russian olive (*Elaeagnus angustifolia*) were removed from beneath Plains cottonwood (*Populus deltoides*) but projected the ET reduction to be short-lived because of rapid understory regrowth.

Hopes that significant quantities of water can be salvaged for human use remain a prime motivation for *Tamarix* eradication schemes (Zavaleta 2000; Shafroth & Briggs 2008), despite recent reviews and reports indicating that such actions offer no panacea for western water shortages and despite studies concluding that ET rates show relatively small variability between *Tamarix* and other woody phreatophytes (Graf 1992; Shafroth et al. 2005; Owens & Moore 2007; Nagler et al. 2008*b*). The studies suggesting that such a possibility were methodologically unreliable and are now out of date.

The Correlation/Causation Conundrum

Soil Salinity

Soil salination is another ecosystem function widely ascribed to *Tamarix*. Walker and Smith (1997:84), for example, stated that "Salinization of flood-plain habitats may be the most important single way that the invasion of salt-cedar fundamentally alters ecosystems." The evidence that they cited was a study by Busch and Smith (1995), who demonstrated that *Tamarix* was the predominant species along a river with saline soils and groundwater, but a minor presence relative to *Populus* and Willow (*Salix*) along a nearby, less saline river. Busch and Smith (1995) did not resolve the conundrum of whether saline soils "cause" Saltcedar abundance or whether Saltcedar abundance "causes" high soil salinity. Walker and Smith (1997) assumed the latter to be correct, despite Busch and Smith's (1995:368) own conclusion that "Distinct adaptations for dealing with salinity and water stress … are apparently responsible for the shifts in riparian community structure which accompany ecosystem change."

Others concluded that the high salinity in some *Tamarix* habitats derived from cultural practices (e.g., river regulation, irrigation inflows) or geologic factors (e.g., ancient salt deposits). *Tamarix* is known to have high salinity tolerance (Shafroth et al. 1995; Vandersande et al. 2001), and Carman and Brotherson (1982) attributed high salinity in *Tamarix* soils versus *Elaeagnus* soils to interspecific differences in tolerance ranges. Anderson (1996:9), similar to Brotherson and Field (1987), concluded that riparian vegetation along some southwestern rivers is changing in composition partly owing to the "slow but inexorable increase in soil salinity" resulting from anthropogenic actions.

Recent studies, although still limited in number, indicate that *Tamarix* does not uniformly salinize habitats. On the free-flowing San Pedro River in Arizona, with little salt to concentrate and a high frequency of floods, soil salinity levels are low in all vegetation types including *Tamarix* (Stromberg 1998*b*; Bagstad et al. 2006). Ladenburger et al. (2006) also reported low salinities under *Tamarix* and *Populus* trees in regularly flooded drainages of Montana (with values slightly higher under *Tamarix*), in contrast to the much higher salinities on high topographic surfaces of regulated drainages vegetated by halophytic shrubs including *Tamarix*. They conclude "Clearly, *Tamarix,* especially large plants, impact soil conditions directly beneath their canopies in a manner comparable to native shrubs in arid upland sites" (p. 122). Unaccountably, in their abstract they emphasize *Tamarix*'s ability to salinize soils, providing contrasts only with bare soil patches and not with other plant species, perhaps perpetuating the archaic stereotype expressed on a Nature Conservancy Web site (http://tncweeds.ucdavis.edu/worst/tamarix.html#map; accessed 8 May 2008): "Tamarisk is often called saltcedar because it oozes salt from its leaves. This salt accumulates in the soil and makes it very difficult for other plants to grow nearby. Saltcedar also sucks large amounts of water from the ground, transforming valuable desert streams and ponds into salty dry basins."

Species Replacement

Another complexity is the "chicken and egg" question. Which came first: establishment of *Tamarix*, followed by decline of other plant species, or the decline of other plant species, followed by establishment of *Tamarix*? The chronology of shifts in species dominance can be difficult to determine, as can the mechanisms, but an understanding of the causes of change is critical for making informed management choices (Gurevitch & Padilla 2004).

The notion that *Tamarix* is a primary cause of the decline of other plant species is prominent in policy representations. According to a National Park Service "Least Wanted" species Web site, "Saltcedar disrupts the structure and stability of native plant communities and degrades native wildlife habitat by outcompeting and replacing native plant species" (http://www.nps.gov/plants/ALIEN/fact/tama1.htm; accessed 8 May 2008). Review articles provide more complexity. Di Tomaso (1998:327, 329), for example, notes that *Tamarix* establishes on bare soil, often facilitated by human-caused alterations to river flows; he also goes on to say that *Tamarix* then *replaces* other woody species such as *Salix, Populus*, and *Prosopis* (mesquite) and that its "infestations *lead to* dramatic reductions in native woody and herbaceous plant composition and abundance" (italics ours). However, none of his supporting articles (Engel-Wilson & Ohmart 1978; Weeks et al. 1987; Crins 1989; Frasier & Johnsen 1991; Hughes 1993; Lovich et al. 1994) are mechanistic studies of vegetation change.

An alternative interpretation, espoused by many (Harris 1966; Haase 1972; Horton 1977; Engel-Wilson & Ohmart 1978; Everitt 1980; Anderson 1996; Smith et al. 1998), is that *Tamarix* is not so much "crowding out the natives" as (1) establishing in areas newly available for colonization (such as alluvium exposed by dam and reservoir construction); (2) replacing those that had been cleared (for fuel or lumber, agricultural development, or phreatophyte control); and/or (3) replacing those that failed to thrive under the new environmental conditions of altered flood and fire regimes, lowered water tables, increased soil salinities, and increased herbivory by ungulates. Of its spread along the Rio Grande, for example, Everitt wrote "There is no evidence that *[Tamarix]* actively displaced native species …" (1998:658).

The many autecological studies of *Tamarix* and co-occurring species inform our understanding of the causes of vegetation change. Ware and Penfound (1949:483) observed that *Tamarix*'s reproductive phenology differed from that of *Populus* (with the latter more closely linked with winter/spring flood recession), and Merkel and Hopkins (1957) described the great rooting depth of *Tamarix.* Ecophysiologists clarified *Tamarix*'s status as a facultative phreatophyte capable of persisting in dry habitats (Busch et al. 1992; Horton et al 2001; Glenn & Nagler 2005). Population biologists demonstrated that, contrary to common presumptions, *Populus* seedlings outcompete those of *Tamarix* (Sher et al. 2000; Sher & Marshall 2003). Field studies in one ecoregion showed that where winter floods were unchecked by dams, water tables high, and salt loads low, *Populus* or *Salix* predominated over *Tamarix* (Stromberg et al. 2007*b*). Another study examining the processes of vegetation change, however, found that *Tamarix* became prevalent on a western river prior to hydrologic alterations from upstream damming (Birken & Cooper 2006).

Future studies may reveal the full array of mechanisms that drive vegetation shifts toward *Tamarix*. On many rivers, though, *Tamarix* is better adapted to prevailing conditions than the old natives. A revised hydrology where spring floods were impounded and summer flows subsidized by irrigation delivery reduced *Populus* and *Salix* populations but accommodated *Tamarix*, as did one in which water diversions or groundwater pumping created drier conditions (Stromberg et al. 2007*a*). Livestock grazing has facilitated shifts from more palatable species to *Tamarix* (Hughes 1993; Stromberg 1997). Once established, feedbacks may perpetuate its presence (Suding et al. 2004); however, ongoing environmental fluctuations, in some settings, cause forest dominance to shift through time between *Tamarix* and *Populus–Salix* (Stromberg 1998*a*; Nagler et al. 2005*a*).

Introduced Plants and Endangered Birds

In the arid southwest, riparian zones provide critical habitat for migratory and resident bird species. Riparian forests, particularly those composed of *Populus and Salix*, are renowned for their high avian density and diversity (Hunter et al. 1987). In sharp contrast, Shafroth and Briggs (2008:95) observed that it is commonly assumed that "*Tamarix* does not provide useful habitat for birds" and the corollary that "complete removal of *Tamarix* from an area is advisable if the goal is to restore bird habitat." However, a recent review (Sogge et al. 2008) concluded that many birds—including several rare or endangered species—do breed in *Tamarix* in southwestern United States, with relative use varying geographically.

The case of one endangered species, the southwestern *Empidonax traillii extimus* (Willow flycatcher*)*, provides a window into changing perceptions. At the time of the bird's listing as an endangered species, *Tamarix* was included among the factors contributing to its population decline (USFWS 1995), consistent with growing dismay that human-introduced species constituted a fundamental "threat to biodiversity" (Wilcove et al. 1998:607). Zavaleta (2000:464) noted the "controversy over the importance of tamarisk stands to the endangered Southwest willow flycatcher" but concluded that "available evidence indicates that native riparian vegetation provides superior habitat to the songbird." As evidence, she cited Brown and Trosset (1989), Yong and Finch (1997), and DeLoach (1997), despite the following: Brown and Trosset (1989:260) stated "The tamarisk community created by the operation of Glen Canyon Dam … has enhanced breeding habitat for these 11 species of birds [flycatcher, included]." Yong and Finch (1997) reported that flycatchers have greater fat-replenishment rates in *Salix* stands than in *Populus* stands or agricultural sites, but they do not mention *Tamarix*.

Attitudes about *Tamarix* took a notable turn in response to scientific studies linking its recovery positively to the federally endangered flycatcher. About 25% of the flycatcher nests, throughout its range, were found to occur in *Tamarix*-dominated habitat (Sogge et al. 2003; Durst et al. 2006) with higher percentages in Arizona (Paradzick & Woodward 2003). Studies by Owen et al. (2005:1268) showed "no evidence that flycatchers breeding in saltcedar habitats are suffering negative physiological effects and reinforce the idea that such negative effects should not be assumed *a priori*." The USFWS, concerned over loss of habitat for the flycatcher, denied permission to introduce *Tamarix* biocontrol insects in parts of the bird's range (USDA 2005).

Research is increasing our understanding of the factors that create high-quality bird habitat on southwestern rivers. Habitat complexity and landscape heterogeneity are clearly important: Fleishman et al. (2003) concluded that non-native plant species (notably *Tamarix*) did not negatively affect bird species richness, provided the vegetation was structurally complex. van Riper et al. (2008) found a threshold response, with a sharp increase in bird species when "native species" reached 20–40% cover, reflecting the importance of tall broad leaf trees such as *Populus* to many upper canopy riparian specialists (Hunter et al. 1987, 1988). Proximity of surface water and moist soil also are critical for many riparian birds (Hinojosa-Huerta et al. 2008).

More on Biodiversity: The Importance of Environmental Context

In ecological studies, there is a domain of findings or environmental context in which the results hold true (Pickett et al. 1994). Applying findings out of context—perhaps unwittingly because of a scarcity of applicable studies—has shaped perceptions of *Tamarix*'s influence on plant species diversity and other ecosystem attributes. For example, many reviews state that *Tamarix* stands contain few plant species ("Monotypic stands of *Tamarix* are considered by many to be biological deserts" Brock 1994:33). These initial conclusions were based on a sparse pool of primary studies that were conducted on dammed rivers—Hildebrandt and Ohmart (1982) on the Pecos and Campbell and Dick-Peddie (1964), Engel-Wilson and Ohmart (1978), and Ellis (1995) along the Rio Grande. These studies left unanswered the question of whether diversity in *Tamarix* stands is also low in other riverine management contexts.

Plant species diversity often is low on flow-regulated rivers (Uowolo et al. 2005) for many reasons. For example, flood suppression can reduce spatiotemporal heterogeneity and reduce the ability of colonizing species to coexist with competitors. In contrast, along one free-flowing desert river, where episodic floods still create a heterogeneous floodplain mosaic, plant species richness was similarly high in stands of *Tamarix* and other woody vegetation types (Stromberg 1998*b*; Bagstad et al. 2006).

Gurevitch and Padilla (2004:470) surmised that "… if invasives are not a primary cause of extinction or major contributors to declines of species … but are instead merely correlated with other problems, the resources and efforts devoted to removing exotics might be better focused on more effective means to preserve threatened species." There remains uncertainty as to whether expansion of introduced species causes, or results from, altered ecosystem processes (MacDougall & Turkington 2005). Assuming the latter to be largely true in the *Tamarix* case, Stromberg and Chew (2002) advocated a shift in emphasis from eradicating neophytes to restoring the conditions that allow the historically abundant plant species to once again thrive. Similarly, Lesica and Miles (2001:240) noted "Minimizing the spread of tamarisk in riparian areas in Montana can best be accomplished by managing for cottonwood."

From Targeted Eradication to Systemic Restoration

"Phreatophyte control" was a prevailing riparian management theme in the American southwest during the mid-twentieth century. With the intent of increasing water supplies for a growing human population, *Tamarix*, *Populus*, *Prosopis*, and other species (native and non-native alike) were cleared from several western rivers (Graf 1992). However, some scientists were explicitly circumspect. Hughes (1968:52) noted that "phreatophytes are not always bad—most have some beneficial value," going on to discuss the value of *Tamarix* stands to beekeepers and honey producers, and cautioning that the "public may have to decide whether they want water or wildlife."

By the 1970s, increasing numbers of southwesterners began to call for riparian ecosystem protection, paralleling a nation-wide shift from resource extraction toward resource preservation (Johnson & Haight 1984; Graf 1992). Meanwhile, a subtle nativism crept into the discussion. Campbell (1970:50) wrote "Decisions to *indiscriminately* eradicate all phreatophytes on floodplains are now being challenged by some wildlife managers and conservation groups." Today, efforts to clear species such as *Populus* are much less common but efforts to eradicate *Tamarix* persist.

The goals of would-be *Tamarix* eradicators vary: water salvage, increased biodiversity, native species reestablishment, or simply "defense" of nature. The large, federally funded efforts to suppress *Tamarix* in western riparian ecosystems involve burning, herbicide application, mechanical removal, and biological control (Shafroth & Briggs 2008). "Lay" environmentalists adopted the professionals' disdain for *Tamarix* and impassioned rhetoric begat volunteer "tammywhacking" (handcutting stems followed by herbicide application). One environmental studies professor mused about keeping volunteers satisfied with the "negative moment" of "wreaking havoc on flourishing vegetation" and proposed that tammywhackers were "liberating nature" already "distorted by the impact of human interference" (Rodman 1990:65–66). Although many of the eradication efforts focus on rivers with extensive stands of *Tamarix*, organized removal events also occur at nature preserves where *Tamarix* is a minor component of a diverse plant community.

River restoration often is undermonitored and underreported, precluding timely feedback for adaptive management (Bernhardt et al. 2005). There has been, however, a recent spate of studies assessing *Tamarix*-related restoration efforts. One concluded that "Land managers should be prepared for persistent depauperate plant communities following tamarisk removal if additional restoration measures are not instigated" (Harms & Hiebert 2006:461). Greater restoration success has been achieved where additional efforts, such as releasing overbank flows or extensively replanting, have been undertaken (Taylor et al. 2006; Bay & Sher 2008). However, rereconfiguring streamflow regimes (e.g., Rood et al. 2005) or land-use practices are difficult on large, multiple-use rivers. Few managers are technically able (or administratively empowered) to instigate or fund measures over large spatial scales to restore the processes that increase riverine landscape heterogeneity or shift vegetation toward less stress-tolerant taxa. In such cases, Sogge et al. (2008) concluded that maintaining *Tamarix* is a logical approach to riparian bird conservation. To guide managers through the maze of river restoration options, authors (Taylor & McDaniel 2004; Shafroth et al. 2008) have developed guidelines that include explicit and realistic goal setting.

Conclusions

Perceptions regarding "alien-invasive" plant species are changing. Under scrutiny, some negative allegations fail to hold true (Davis 2003), and eradication efforts are being questioned because of potential collateral harm to endangered species (Zavaleta et al. 2001). For some introduced plant species, scientists have observed that untested hypotheses form the basis for eradication efforts (Hager & McCoy 1998). In the *Tamarix* case, new information arising from the many studies published in recent decades is challenging the prevailing dogma regarding its role in ecosystem function and habitat degradation. In response, there have been shifts in management from single-species eradication to holistic ecosystem restoration (Shafroth et al. 2008).

Although there are calls to reframe the issue in scientifically neutral terms (Larson 2005), to reduce the use of hyperbole (Larson 2007), and to be more objective (Brown & Sax 2004), to a large degree, prejudice against non-natives persists (Brown & Sax 2005). To achieve a greater degree of objectivity, and bring management practices in line with current knowledge (for *Tamarix* and other plants classified as "alien invasives"), many actions are needed. First, scientists need to cite sources appropriately. Inappropriate citation is all too common in the scientific world (Simkin & Roychowdhury 2003) and the *Tamarix* case is no exception. Some sources cited are outmoded, particularly with respect to ET rates; others are anecdotal, irrelevant, or off-topic. Generation by generation, citation by inappropriate citation, a mythology has been created about *Tamarix*.

Second, generators and users of information need to review sources critically. Conclusions may be based on spurious "facts" derived from anecdotal evidence, or causation may have been inappropriately inferred from correlation. Results may apply only in certain contexts. In the *Tamarix* case, for example, some functional changes to ecosystem properties may occur only on dammed and flow-regulated rivers. Further, findings may change with the passage of time, as long-term resident species respond and adapt to the neophyte.

Third, it is important for scientists to strive to recognize and avoid reflexive antiexotic bias on their own part and assess whether bias exists on the part of the authors they consult. This will involve examining scientific articles to see whether negative findings are emphasized (e.g., those presenting the species as an extreme or unnatural agent of change) or, perhaps, deemphasized. Further, avoiding war-based and pestilence-based terminology (e.g., invasion, infestation, weed, aggressive) will foster a greater degree of scientific objectivity. As Everitt (1980:80) remarked, "use of the terms 'aggressive colonizer' and 'invader' in describing saltcedar implies at least a subconscious belief that the species is somehow capable of actively destroying preexisting communities and occupying their territory."

Finally, rigorous multiregion, multiriver, and multitaxa studies are needed to provide a more thorough and contextualized understanding of the causes of vegetation change and of the ensuing changes in ecosystem functions. Such ecosystem-based studies will inform restoration efforts, as will thorough review of successes and failures of prior restoration approaches including *Tamarix* clearing, tree planting, and streamflow naturalization. There is much literature, for example, indicating to us that the purported economic value of *Tamarix* removal (including substantial water salvage or salinity reduction) is illusory. In many cases, as well, it is clear that removal of *Tamarix* may have unintended negative consequences for some of the very biota one is intending to help.

Implications for Practice

Before undertaking restoration or management actions in response to vegetation shifts toward introduced species (such as *Tamarix* along rivers of western United States), make sure to:

- read review articles critically and skeptically to make sure that information on the species is factually correct and that references have been accurately and appropriately cited
- heed the environmental domain of the findings of primary studies and do not apply results out of context

- pay attention to levels of certainty reported in primary studies and to the nature of the experimental evidence underpinning the reported conclusions

When writing papers on this topic:

- read primary sources before you cite them
- avoid reflexive antiexotic bias

When posting or distributing educational information on introduced plant species:

- maintain up-to-date information
- present the information in neutral terms

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