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Tamarisk beetle (*Diorhabda* spp.) in the Colorado River basin: synthesis of an expert panel forum

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Panel forum participants, including panelists, presenters, moderators, and invited audience members.

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Executive Summary

In 2001, the U.S. Department of Agriculture approved the release of a biological control agent, the tamarisk beetle (*Diorhabda* spp.), to naturally control tamarisk populations and provide a less costly, and potentially more effective, means of removal compared with mechanical and chemical methods. The invasive plant tamarisk (*Tamarix* spp.; saltcedar) occupies hundreds of thousands of acres of river floodplains and terraces across the western half of the North American continent. Its abundance varies, but can include dense monocultures, and can alter some physical and ecological processes associated with riparian ecosystems.

The tamarisk beetle now occupies hundreds of miles of rivers throughout the Upper Colorado River Basin (UCRB) and is spreading into the Lower Basin. The efficacy of the beetle is evident, with many areas repeatedly experiencing tamarisk defoliation. While many welcome the beetle as a management tool, others are concerned by the ecosystem implications of widespread defoliation of a dominant woody species. As an example, defoliation may possibly affect the nesting success of the endangered southwestern willow flycatcher (*Empidonax traillii extimus*).

In January 2015, the Tamarisk Coalition convened a panel of experts to discuss and present information on probable ecological trajectories in the face of widespread beetle presence and to consider opportunities for restoration and management of riparian systems in the Colorado River Basin (CRB). An in-depth description of the panel discussion follows.

Panel Findings

In summary, the panel's primary findings/conclusions are:

- Tamarisk beetles are expected to spread throughout the entire CRB, and tamarisk presence, distribution and abundance will likely decline as a result.
- The expected effects of this tamarisk decline on native plant species are dependent upon a number of environmental factors that may be useful in predicting outcomes. Most important is the degree to which the system has changed from historical conditions, including dynamism of the river, soil conditions, and the state of the remnant native plant community.
- Over time, the beetle should reduce wildfire risk and intensity.
- As impacts of the beetle become more evident, decreased bank stability due to loss of tamarisk may lead to increased channel mobility.
- Increased geomorphic dynamism is more likely to occur along systems that retain their natural flow regime. Geomorphic recovery may be rapid where the difference in magnitude between the peak discharge of large floods and small floods is great.
- The impact of the tamarisk beetle on wildlife will depend on the particular response of the site, how successfully desirable native plants establish, and the ability of particular wildlife taxa to utilize alternative riparian habitats that may include a mixed riparian community of natives and remaining tamarisk.
- In the short term, there may be risk to some wildlife taxa that utilize tamarisk-dominated habitats. However, over the long term, some systems should experience benefits to wildlife abundance and diversity, particularly systems where restoration is implemented.
- Tamarisk is not expected to be eradicated by the beetle. Thus, tamarisk will continue to be present in the watersheds where it occurs, although it is anticipated to be at lower levels as a result of the biological control beetle.

Figure 1 – Close-up of an adult tamarisk beetle (*Diorhabda* spp.).

Photo by Ed Kosmicki

- Approved conservation plans for the Lower Colorado River, and elsewhere in Arizona, often assume tamarisk will be a prominent component of future riparian vegetation. This assumption might not be valid in the future due to long-term defoliation impacts.
- Biological control of tamarisk in combination with other weed control and restoration measures can play an important role in making southwestern riparian ecosystems more diverse and functional than when the plant community is dominated by a single species.

The panel concluded that as the tamarisk beetle moves into the Lower Colorado River Basin (LCRB), the selection of management actions to support a transition to a healthy riparian system will depend on the unique suite of characteristics of each sub-basin and the goals of basin managers.

The panel emphasized the importance of basin-specific planning, the necessity of monitoring and inventorying to inform management, and that adaptive management practices will be essential for success relative to varying goals. The panel developed a framework to assist managers in selecting appropriate management strategies and identified future research needed to further inform restoration approaches and management decisions.

Introduction

The tamarisk beetle *(Diorhabda* spp.*)* **(Figure 1)** was released as a biological control agent by the U.S. Department of Agriculture and cooperators to manage tamarisk *(Tamarix* spp.*)*, a non-native plant that is prolific throughout the West and is considered undesirable by many land and water managers. The beetle was extensively researched in a laboratory environment before the first releases in cages in 1999, and then into the wild in 2001, at a dozen sites in seven states (Bean et al. 2013). The first establishment and defoliation was observed at test sites in Nevada, with later effects occurring along the Colorado River in 2004, and at various sites in western Texas from 2004 to 2007. Since then, other populations have established, both with human assistance and through natural dispersal. As a result, the beetles have quickly expanded their range, appearing throughout the Upper Colorado River drainage, as far south as Mojave Lake, Arizona, and across western Texas and New Mexico, covering most of the Pecos River drainage and all but the southern portion of the Middle Rio Grande (Tamarisk Coalition 2014). With documented populations now ranging from Chihuahua, Mexico to California, and into Oregon, Idaho, Wyoming, and Kansas, the tamarisk beetle has quickly become a part of many riparian ecosystems in the West (Bean et al. 2012; Tamarisk Coalition 2014). The efficacy of the beetle, which injures tamarisk through repeated defoliation, is apparent across portions of many western states, where there are large areas of beetle-affected tamarisk (Bean et al. 2007; Pattison et al. 2011; Dudley and Bean 2012; Nagler et al. 2012; Nagler et al. 2014).

There are four different beetle species present in North America and each of these has its own physiological drivers and physical limitations for population and range expansion. (Tracy and Robbins 2009).The northern tamarisk beetle, *Diorhabda carinulata*, is currently present in all UCRB tributaries and the northern portion of the LCRB (to Davis Dam, Arizona) **(Figure 2)**. It may simply be a matter of time before this species establishes farther south, but some argue that it will be a long process dependent upon evolution (Dan Bean 2015, personal communication). A closely related species, the subtropical tamarisk beetle, *D. sublineata*, is now present on the Rio Grande and, due to slightly different ecological tolerances, will likely be able to establish in the lower portions of the LCRB by migrating westward via the Gila River. Establishment in the LCRB is expected to occur rapidly given the rate of expansion from the various release points that have been observed, within perhaps 2-5 years once the beetle becomes established in the system, which will likely be within the next five years (James Tracy 2015, personal communication).

Although many welcome a cost-effective approach to tamarisk management, the ecosystem responses to

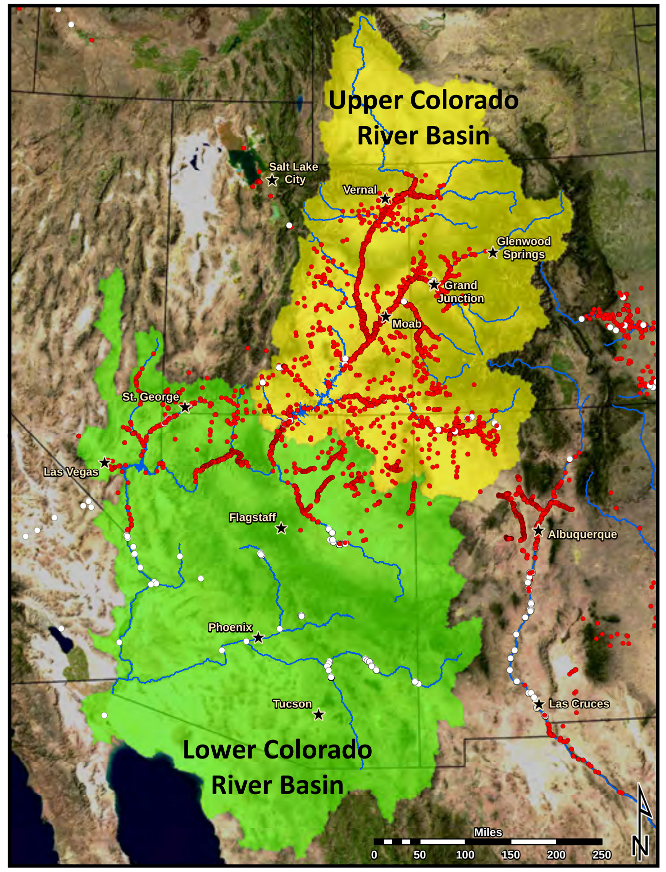

Figure 2 - Map showing the distribution of the tamarisk beetle in the Colorado River Basin. Red dots indicate locations where tamarisk beetles were present at some point during monitoring visits between 2007-2014, whereas white dots indicate locations where beetles were absent in 2014.

Map by the Tamarisk Coalition

widespread defoliation of a dominant woody species **(Figure 3)** are of interest to the resource management and scientific communities. For example, defoliation may already be affecting the nesting success of the southwestern willow flycatcher *(Empidonax traillii extimus)*, an endangered bird that appears to select nesting areas based on vegetation structure and density rather than floristic composition and will use native, mixed, and monotypic tamarisk habitats (USFWS 2002; Paxton et al. 2007; Sogge et al 2010; Dobbs et al. 2012; McLeod and Pelligrini 2013). Defoliation of tamarisk surrounding flycatcher nests results in decreased vegetation cover (Nagler et al. 2014), decreased nest cover (Dobbs et al. 2012; McLeod and Pelligrini 2013), and leads to a possible increase in predation/parasitism (Bateman and Johnson 2015) risk and altered microclimate (Bateman and Johnson 2015; Bateman et al. 2013b), which, when combined with the loss of surface and ground water due to drought, can result in reduced chick survival (McLeod and Pelligrini 2013).

Other potential changes associated with the beetle include: increase in standing-dead biomass, bank destabilization,

Figure 3 - Tamarisk defoliated by tamarisk beetle along the Colorado River near Potash, Utah. Photo was taken approximately one year after beetle establishment in the area.

Photo by the Tamarisk Coalition

restoration challenges concerning soil chemistry and altered hydrology, replacement of tamarisk with other non-native species (Hultine et al. 2010), and temporary increases in wildfire potential (Drus 2013a). As the beetle has expanded its range, multi-disciplinary research and monitoring to document the impacts and interactions of the tamarisk beetle on riparian ecosystems (e.g., Bateman et al. 2010; Bateman and Johnson 2015). However, because the beetle's establishment in riparian ecosystems is a relatively new event, research on the impacts and effects is still emerging. Thus, there is a continual need to synthesize research and observations and develop an understanding of potential ecosystem effects, the scale and time frame of these changes, and what, if any, land management activities should be planned or implemented.

In an effort to provide this type of synthesis, the Tamarisk Coalition (TC), supported by a grant from the Walton Family Foundation (WFF), convened an expert panel on January 13 and 14, 2015, to address questions concerning the uncertainty of tamarisk beetle impacts and management implications.

Purpose of the Expert Panel

A panel of experts from varied disciplines was convened to provide perspective on the possible ecological and geomorphic effects of the establishment of the tamarisk beetle in the CRB, and consider implications for both recovery and restoration of ecosystems basin-wide, including riparian restoration strategies. As previous synthesis efforts have largely addressed the issues concerning tamarisk and water use (Tamarisk Coalition 2009; Shafroth et al. 2010a), the panel did not include this topic in the discussion. The overall goal was to provide expert perspective to inform riparian restoration practices and policy for riparian management in the CRB (e.g., U.S. Bureau of Land Management, U.S. Bureau of Reclamation, Lower Colorado-Multi Species Conservation Program (MSCP), U.S. Fish and Wildlife Service, tribal, state and regional agencies). Information provided by this expert panel may also be useful for other watersheds and states in the West.

The panel **(Figure 4)** included six scientists with expertise in several relevant physical and ecological disciplines (see Appendix A for biographical sketches):

- Dan Bean, Colorado Department of Agriculture Palisade Insectary, Palisade, CO; biological control entomologist
- Anna Sher, University of Denver, Denver, CO; riparian ecologist
- Rebecca Manners, University of Montana, Missoula, MT; fluvial geomorphologist
- Osvel Hinojosa Huerta, Pronatura Noroeste, La Paz, MX; wetland and avian ecologist
- Matt Johnson, Colorado Plateau Research Station/ Northern Arizona University, Flagstaff, AZ; Director/ avian ecologist
- Pat Shafroth, U.S. Geological Survey, Ft. Collins, CO; riparian ecologist

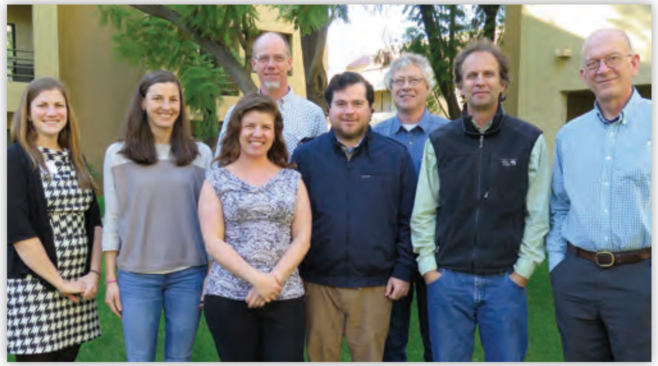

Figure 4 - Tamarisk beetle expert panel participants. Left to right: Stacy Beaugh, Rebecca Manners, Anna Sher, Peter Skidmore, Osvel Hinojosa-Huerta, Tim Carlson, Matt Johnson and Dan Bean. Panelist Pat Shafroth participated remotely.

Photo by the Tamarisk Coalition

The panel was moderated by Tahnee Robertson, Director of Southwest Decision Resources. Representatives from the coordinator, TC, and funder, WFF, also participated in directing questions to the panel:

- Stacy Beaugh, Executive Director, TC
- Tim Carlson, Consultant to WFF
- Peter Skidmore, Program Officer, WFF

Presentations from members of the panel and supplemental experts helped to provide background on existing research on the subject of tamarisk beetle effects:

- *Current and expected tamarisk beetle distribution in the Colorado River Basin*, Ben Bloodworth, Tamarisk Coalition, Grand Junction, CO
- *What are the potential impacts of* Diorhabda *on* Tamarix *in the lower Colorado River Basin?*, Dan Bean
- *Investigating the effects of tamarisk and tamarisk beetle on riparian nesting birds*, Matt Johnson
- *Tamarisk beetle and wildfire interactions in desert riparian systems*, Gail Drus, St. Francis University, Loretto, PA
- *Plant community shifts over time in riparian restoration sites with and without* Tamarix *biological control*, Anna Sher

An invited audience of policy makers and land managers within the LCRB was also included. Invitations were sent to the agency heads of major federal, state, and non-profit organizations, as well as the large water organizations involved in the MSCP Program. Audience members from the following organizations were present during the panel discussion:

- U.S. Bureau of Reclamation
- U.S. Fish and Wildlife Service
- National Audubon Society
- The Nature Conservancy
- Arizona Department of Game and Fish
- Central Arizona Project
- The Metropolitan Water District of Southern California
- The Ruth Powell Hutchins Water Center at Colorado Mesa University

Panel Questions

The following questions were formalized by TC, WFF and the panel members.

1. With the tamarisk beetle as an integral part of the riparian ecosystem, what is the likely trajectory/ecological change in the Colorado River Basin, including the Delta, without management intervention? How might effects vary over different time scales (10/20/50 years)?
   a. Vegetative, geomorphic, etc. transitions if no action is taken?
   b. What is the likely trajectory and dynamic of tamarisk and native plant species?
   c. What are the implications for aquatic and terrestrial animal species including invertebrates?
   d. What are the likely key differences in trajectories between regulated and un-regulated rivers?
2. If ecological recovery is the goal, and the no-intervention trajectory looks favorable and sustainable for it, what management actions could be taken to enhance or accelerate the transition?
   a. What could be done at local, regional, and landscape scales to enhance or accelerate it?
      i. Land management
      ii. Policy and permitting
   b. How do these actions differ for regulated and unregulated systems?
3. If the no-intervention trajectory does not ultimately lead to ecological recovery, and that is the goal, what could be done to actively redirect that transition?
   a. What could be done at local, regional, and landscape scales?
      i. Land management
      ii. Policy and permitting
   b. How do these actions differ for regulated and unregulated systems?
4. On major systems, how do these answers materially impact such programs as the Lower Colorado MSCP? Or the Delta?
   a. Specifically, these original plans were developed under the assumption of large stands of live tamarisk as the status quo. How will changes in this assumption affect participants?
5. What research, not just research outcomes, is needed in the near term to further inform management decisions?

Assumptions and Bounding Statements

Due to the relatively short time period allotted for the panel discussion, as well as the many topics which are peripherally, or even directly, related to the questions listed above, the following assumptions and bounding statements were developed and agreed upon by all panel members to provide some boundaries for the discussion. The wording for each of these was settled upon by the panelists pre-discussion and provided as guidance throughout the dialogue.

1. *Diorhabda* spp. are likely to spread throughout, and colonize, much of the LCRB sometime in the near future, perhaps within 2-5 years, and will likely cause significant defoliation and some mortality of tamarisk in this region.
2. While we acknowledge that potential changes to the water budget associated with effects of the tamarisk beetle are of interest to some resource managers, we are not addressing this topic as part of this particular expert panel.
3. Climate change is occurring in the CRB, and it is likely that effects of the tamarisk beetle on riparian ecosystems will interact with climate change effects (e.g., Sher 2013a). However, there is uncertainty with respect to climate change effects, beetle effects, and their interactions.
4. While land managers will have different objectives/goals with respect to future riparian vegetation, it is assumed that the desired outcome is to move towards a diverse, native plant-dominated assemblage and through that provide for native riparian-dependent species and ecosystem services in order to maximize the long-term diversity of aquatic and terrestrial wildlife species that utilize the riparian corridor. It is likely that this would include a variety of vegetation structural types, stand ages, and riparian vegetation patch turnover.

Panel Findings

For the purpose of making the panel report as robust and comprehensive as possible, the panel findings are augmented with references from past and current research.

Likely trajectories and dynamics of tamarisk and native plant species

The panel concluded that beetles are expected to spread throughout the entire CRB, and tamarisk presence and abundance will likely decline significantly as a result. Monitoring data now show declining tamarisk populations over large landscapes where beetles are currently present (Nagler et al. 2012; Nagler et al. 2014; Hultine et al. 2014). However, there are also locations where beetles have been present for years yet significant tamarisk cover remains, due to the ability of tamarisk to re-foliate even after repeated defoliation (Sher et al. 2014).

Figure 5 - Tamarisk beetle *(Diorhabda* spp.*)* larvae feeding on tamarisk. Groupings of this size are common at sites with large population expansion.

Photo by Greg Joder

Tamarisk beetles are leaf beetles which act by scraping and consuming green tissues, with most damage brought about by the larvae **(Figure 5)**, resulting in desiccated foliage that eventually falls from the tree. This desiccation and subsequent defoliation leads to a decline in green biomass and reduced flowering and seed production (Jamison et al. 2015). Mortality resulting from defoliation is variable, and plants under stress from other factors such as drought, wildfire, or highly saline soils may be more likely to die. The beetle will not completely eradicate tamarisk. Instead there will likely be a new dynamic equilibrium in which beetle populations are proportional to tamarisk biomass, resulting in an ebb and flow of tamarisk populations over time.

The expected effects of tamarisk decline on native and other non-native plant species are dependent on a number of factors. The decline of tamarisk will undoubtedly free up resources for replacement vegetation. Which species become established in the long run, however, will depend on the geomorphic, hydrologic, and climatic processes associated with the site, seed and propagule availability, and the plant traits of species that could colonize or expand (Shafroth et al. 2008). While the initial response within a few years of tamarisk defoliation appears to be that those native species already present become more vigorous (Sher 2013b), it is unclear whether this is a long-term trend. Surveys on sites with 1-15 years since mechanical tamarisk removal show varying responses in native plant cover (Harms and Hiebert 2006). The time frames for long-term effects on vegetative cover are unknown and will be largely dependent upon basin-specific variables including the extent of flow regulation, native plant presence, and flood events.

Where and when the necessary conditions for native/desirable plant establishment exist, tamarisk mortality is expected to facilitate the eventual recruitment and establishment of a healthier mixed riparian community of natives and remaining tamarisk **(Figure 6)**. However, there is concern that other non-native species already present, such as Russian knapweed *(Acroptilon repens)*, Russian olive

Figure 6 - Native willows *(Salix* spp.*)* along the Colorado River growing up through tamarisk that has been repeatedly defoliated but is still alive.

Photo by the Tamarisk Coalition

Figure 7 - Native willow growing vigorously in a tamarisk stand that was burned by wildfire. Tamarisk beetles were present in the system during the fire and suppressed regrowth of the tamarisk. Picture was taken near Dewey Bridge along the Colorado River north of Moab, Utah.

Photo by Dan Bean

(Elaeagnus angustifolia), tree of heaven *(Ailanthus altissima)*, kochia *(Kochia scoparia)*, whitetop *(Lepidium draba* and *L. latifolium)*, arundo *(Arundo donax)*, or native species that may be undesirable to some land managers, such as arrowweed *(Pluchea sericea)* or certain mustards *(Descurainia* spp.*)*, may expand as tamarisk declines.

Tamarisk mortality will facilitate establishment of natives – however, undesirable species such as Russian olive may expand as tamarisk declines.

Over time, the beetle should help to reduce wildfire risk and intensity by altering the relationship between tamarisk and fire, but in the short-term, moderately increased fire risk and intensity may be a consequence of biocontrol defoliation. Initially, herbivory by the beetle can increase the flammability of tamarisk vegetation by desiccating leaves (Drus et al. 2013; Drus 2013b). Repeated herbivory, however, should reduce tamarisk canopy cover and fuel continuity as trees die back (Pattison et al. 2011; Hultine et al. 2013). Fires should then burn with lower intensity and fire movement will be inhibited by sparser vegetation (Drus et al. 2013). Reduced fire intensity may reverse the trend of more fires and allow greater survival of native species following fire, as the mortality of native species has been shown to increase with pre-fire tamarisk abundance and subsequent fire intensity (Drus 2013b; Drus et al. in review). However, the post-fire recovery of native species will depend on the hydrologic regime and other site specific factors (Drus 2013a; Drus et al. in review), and the presence of tamarisk beetles in the system may help by suppressing the vigorous regrowth of tamarisk typically seen after fire (**Figure 7**). The move toward less intense fires should support a transition away from the monoculture-to-monoculture tamarisk "loop" (Brooks et al. 2004), which exists at some sites, enhancing opportunities for natives such as willows and cottonwoods to establish naturally, or with active restoration methods (Drus 2013a; Drus 2013b). Ultimately, the lowest fire risk will be achieved through the reestablishment of less flammable native species.

Likely geomorphic transitions and differences in trajectories between regulated and unregulated rivers

Tamarisk has contributed, along with other drivers including changes to the hydrologic regime and sediment supply, to alterations in river channel form across the Southwestern U.S. (Auerbach et al. 2013). Tamarisk interacts with geomorphic processes in two primary ways. Tamarisk roots increase the cohesion of generally non-cohesive river sediments, stabilizing channel bars and floodplains. During high flows, stems and leaves add hydraulic "roughness" resistance, slowing water velocity and increasing sediment deposition and reducing erosion. As a result, river channels stabilize and narrow, and their cross-sections become more uniform throughout the reach.

Tamarisk alters river channels by stabilizing floodplains, slowing water velocity, and increasing deposition.

Tamarisk has a greater geomorphic effect than some native species such as cottonwood. This is due largely to its multi-stem structure that has a larger impact on the way that water moves through and around objects (Manners et al. 2015). There is no evidence that the root structure of tamarisk adds more cohesion than that of native species (Pollen-Bankhead et al. 2009). Tamarisk does, however, have a suite of physiological and morphological traits that make it more drought tolerant than mesic riparian species (Glenn and Nagler 2005). As a result, it can continue to thrive as floodplains accumulate soil and rise well above the river channel. These stands can retain their high stem density, in contrast to other mature stands of riparian vegetation, such as cottonwood (Lytle and Merritt 2004), thereby supporting and perpetuating narrow, deep channels.

Extensive tamarisk defoliation and mortality should eventually lead to at least a short-term loss of root cohesion and therefore, decreased bank stability, but the degree to which defoliation impacts the root system is still not understood. The impact of defoliated stems on the movement of water and sediment is likely to remain substantial (Griffin et al. 2014). Dead, brittle stems are more likely to be sheared during floods. Along the Rio Puerco in New Mexico, significant flood-induced erosion occurred in a reach where tamarisk and willow died back due to herbicide spraying but not in adjacent reaches where vegetation was not sprayed (Vincent et al. 2009). Eventually, other vegetation will replace *Tamarix* and the ultimate change in bank stability will depend on how the root systems of these species influence bank cohesion.

As impacts from the beetle become significant, systems should see a geomorphic transition that increases dynamic river processes, characterized by the periodic and regular erosion and deposition that is critical for maintaining native riparian systems and the shifting pattern of habitats that promotes associated biodiversity. The timescale and magnitude of the geomorphic response will depend on numerous factors, including the rate at which dead plants deteriorate, the character of the vegetation that replaces tamarisk and the rate at which these plants establish, and the difference between the natural and existing hydrologic regime and sediment supply (Stromberg 2001).

River systems that maintain most of their natural flow regime and sediment supply are the most likely to recover their pre-tamarisk channel form. Where the ratio between large flood and small flood magnitudes is great, channel widening and floodplain stripping are most likely to occur. In these settings, the time frame of recovery may be rapid and depends on the sequence of flood events, the timing of flood events relative to native seed dispersal, and the occurrence of a large flood capable of crossing geomorphic thresholds. Exposure of bare substrate provides opportunities for native species recruitment and establishment (Stromberg 1997). Where the ratio between large flood and small flood magnitudes is not great, channel widening and floodplain stripping may be more restricted and occur more gradually. In both cases, active restoration of native plant species may still be necessary in places where tamarisk has become dominant and native propagules are few.

Floods can provide several functions that promote native plant establishment. In the absence of flooding, more active restoration measures may be necessary.

Systems with highly regulated hydrology and altered sediment supplies may experience some localized channel widening, and enhanced erosion and deposition, but will not return to historic dynamic river conditions. In some settings, there is potential to use controlled flood flow and base flow management to create suitable habitat in support of native plant recruitment and establishment (Taylor et al. 1999; Rood et al. 2003; Shafroth et al. 2010b). In the absence of regular flooding regimes, it may be necessary to initiate more active restoration activities to re-introduce desirable natives into the system (Shafroth et al. 2008).

Implications for animal species

The impact of the tamarisk beetle on wildlife species will depend on the particular response of the site, how successfully native plants establish after tamarisk begins to decline, and the particular wildlife taxa being considered. If there is a generally positive response of native vegetation, there could be a generally positive effect on wildlife. However, if conditions for native plant recruitment are not in place, there may be both short and long-term negative impacts on wildlife. There is currently a high level of uncertainty about expected long-term impacts, however, and the effect will depend on the system and the specific wildlife species involved (Bateman and Johnson 2015). Wildlife responses to tamarisk biocontrol will likely be complex, with some species possibly benefiting from consuming leaf beetles (Dudley and Bean 2012; Bateman and Johnson 2015) or by utilizing hotter, drier microhabitats, while other species may be negatively affected by increased temperatures and reduced foliar cover (Paxton et al. 2011; Dobbs et al. 2012; McLeod and Pellegrini 2013; Mosher and Bateman 2015).

Wildlife responses to tamarisk biocontrol will be complex; some will benefit and others will be negatively affected.

For bird species that nest in tamarisk, defoliation opens up the canopy and can lead to higher rates of predation and brood parasitism (Paxton et al. 2011; Dobbs et al 2012; McLeod and Pellegrini 2013). Defoliation may also occur during nest building, incubation or fledgling (when chicks are leaving the nest), exacerbating the negative effects on these species. However, it should be noted that the timing of defoliation is not consistent across years and may occur early, mid, or late season, or not at all, on a given reach (Jamison et al 2015; Puckett and van Riper 2014). Southwestern willow flycatcher have shown that after one year of tamarisk defoliation they will move to native

Figure 8 - A tamarisk stand along the Virgin River, Nevada before and after defoliation by the tamarisk beetle. Defoliation may occur very quickly, as shown in these photos which were taken just 30 days apart.

Photos by Tom Dudley

vegetation, if it is available nearby and has suitable structure (Dobbs et al. 2012; McLeod and Pellegrini 2013) and, in at least one site, it was observed that because defoliation by the beetle occurred prior to the return of the flycatcher, the birds moved to relict willow patches (Bureau of Reclamation data - Tom Dudley 2015, personal communication). Given that birds nesting in tamarisk likely have a heightened risk of mortality from wildfire (Paxton et al. 1996), such shifts to native vegetation should be encouraged where they are possible (Dudley and Bean 2012). Additionally, studies on the Virgin River in Utah between 2010 and 2014, found that several measures of southwestern willow flycatcher and yellow warbler reproductive success varied between years. Apparent nest success, hatching success, and nest productivity were notably low in 2010 and 2013, yet increased in 2012 and 2014 (Dobbs et al. 2012; McLeod and Pellegrini 2013; Bateman and Johnson 2015). This pattern of annual variation in reproductive success may be due to tamarisk beetles defoliating tamarisk to varying degrees each year, thereby altering the overall condition of riparian habitat from year to year. It will require multiple years of monitoring to understand the habitat changes by the tamarisk beetle that ultimately affect these bird populations.

Defoliation by the beetle also affects habitat through impacts on the microclimate. Data from the Virgin River documented decreases in tamarisk canopy cover **(Figure 8)** as well as an increase in microclimate temperature (+ 3-4° C) and reduction in relative humidity (-50%) associated with the increased solar radiation in defoliated stands (Bateman et al. 2013a; Bateman et al. 2013b; Bateman and Johnson 2015). These changes in solar radiation and microclimate may have significant impacts on wildlife species. Monitoring data have shown a decline in fledging success of southwestern willow flycatcher and yellow warblers in areas affected by tamarisk beetle, much of which can be attributed to changes in the microclimate (Dobbs et al. 2012; Bateman and Johnson 2015). Since biocontrol introduction along the Virgin River in Nevada, there has been an observed steady decline in captures of marked reptiles as well (Bateman et al. 2014). Defoliation has caused changes in microclimate that have made habitats less suitable for some reptile species, due to either an increase in temperatures that exceed the heat tolerance of some species (e.g., common side-blotched lizards, Goller et al. 2014) or a decrease in needed thermal variability (Mosher and Bateman 2015).

> Changes in microclimate due to defoliation have made habitats less suitable for some reptiles.

Overall, birds are likely to be at less risk from tamarisk defoliation than amphibians and reptiles as they have greater mobility and have shown adaptability where suitable alternative vegetation exists (Bateman et al. 2013b; Bateman et al. 2014). Bird and lizard studies are more numerous than studies on other animals, and little is known about tamarisk biocontrol impacts to small mammals, including bats. However, the increased wildfire risk in tamarisk stands will likely have a greater long-term negative effect on all animal species present than tamarisk defoliation.

In the short and long-term, pronounced changes in habitat structure and composition as a result of tamarisk biocontrol are inevitable. Many systems in the Colorado and Rio Grande Basins have broad expanses of monotypic tamarisk stands, while other areas have a mixed tamarisk-native plant composition (Shafroth et al. 2005; van Riper et al. 2008). While biocontrol is not expected to eradicate tamarisk, the introduction of beetles to these systems will reduce plant vigor and increase mortality, ultimately leading to a system where tamarisk persists at lower frequencies. The net change in wildlife productivity in these systems as a result of biocontrol will depend heavily on the plant species that replace tamarisk. Because tamarisk is capable of growing in areas with little water and high salinity, desired native plants may not naturally replace tamarisk habitats that are lost to mortality from beetles (Shafroth et al. 2005). A major concern is that these areas will be colonized by non-native plants (e.g., Russian thistle *[Salsola tragus]* or Russian olive *[Elaeagnus angustifolia]*) that provide poorer quality wildlife habitat than tamarisk, underscoring the need for active native plant restoration in the wake of beetle establishment. Continuing research needs to determine how wildlife diversity and abundance vary in relation to habitat composition prior to beetle establishment and post beetle establishment (Dobbs et al. 2012; Bateman and Johnson 2015; Mosher and Bateman 2015), as well as identify key habitat needs for riparian wildlife species of conservation concern, thereby allowing land managers to devise targeted restoration plans that maximize benefits for these species. Timing of restoration activities is also a key consideration, as restoration sites may require years to mature and should, therefore, be initiated well in advance of expected beetle impacts (Dudley and Bean 2012).

> Targeted restoration plans will be necessary to meet key habitat needs to species of conservation concern.

Suggested management actions to enhance a transition toward a diverse plant assemblage, dominated by native species (see assumption 4)

Following biological control, a number of underlying conditions and processes need to be in place to support the desired transition toward a healthy native plant assemblage. Management actions could include assessing the extent to which these conditions exist, and tailoring actions to fill identified gaps. An assessment of conditions should include hydrologic and geomorphic processes, soil salinity, extent and locations of invasive and native plant communities, and presence and location of threatened and endangered (T&E) species.

The overriding factor for the success of many potential riparian restoration projects in the Southwest is flow regime. In many areas flow regimes have been altered by dams, diversions, and groundwater pumping, often manifesting as decreases in peak flow magnitudes and increases in base flows (Poff et al. 2007). Because the diverse native vegetation and wildlife found in healthy riparian areas rely on water, and often on seasonal availability of that water and associated fluvial processes, the extent to which site hydrology has been altered must be considered as a key factor in a site's ability to be restored or rehabilitated.

For the purposes of informing management and policy, it is useful to consider potential actions and strategies in light of a spectrum of conditions. On one end of the spectrum is an unregulated system with a hydrologic regime that is not highly modified (e.g., the upper Virgin River). As described in Question 1b above, recovery of desirable native plant assemblages is possible on this type of system with limited intervention. On the other end of the spectrum is a highly modified and regulated system (e.g., the Colorado River Delta or lower Colorado River), where it is more challenging to establish the drivers necessary to support a transition to a healthy and diverse native plant community.

Panel members developed a decision tree framework to aid in management decision-making in light of these underlying conditions and drivers (**Figure 9**; see page 12). This tool may be used to determine the likelihood of restoration success on a site, as well as guide the prioritization of work and effective allocation of resources.

Management actions to help support a transition to a healthy native plant assemblage as the tamarisk beetle becomes established may include:

- **Selective clearing:** In areas of extremely dense/extensive tamarisk, selective clearing of tamarisk may be still be necessary to augment beetle impacts (Orr et al. 2014). Some research suggests, however, that active removal of tamarisk (mechanical and chemical) may exacerbate secondary weed colonization (Ostoja et al. 2014) relative to passive tamarisk management (beetle biocontrol), as active methods disturb soils and create ideal conditions for secondary weeds, whereas others have shown that active tamarisk removal methods can decrease secondary weeds such as cheatgrass (Sher et al. 2008).
- **Additional control measures:** In some cases it may be desirable to follow tamarisk removal with additional control measures to address colonization by secondary invasive species.
- **Restoration of native vegetation:** In some cases active revegetation may be required to establish native riparian vegetation in proximity to T&E species for refuge and to serve as sources of native seeds (Bay and Sher 2008).
- **Channel destabilization:** In basins or reaches without significant infrastructure risk, management to promote lateral channel destabilization could be considered to "jump start" restorative processes. Strategies may include disposing of biomass in the channel (Keller et al. 2014) and clearing riverbanks, mid-channel bars, islands, backwaters and side channels of tamarisk.
- **Burns:** In areas where tamarisk is dense/extensive, selective and controlled burns may be used to reduce tamarisk biomass in advance of beetle (Brooks et al. 2008).
- **Beetle "herding":** It may be possible to use beetle attractants (pheromones) and repellents to "herd" the beetle toward or away from particular areas. Tamarisk beetle attractants are available, but research to develop a "natural" repellent has not yet been initiated.

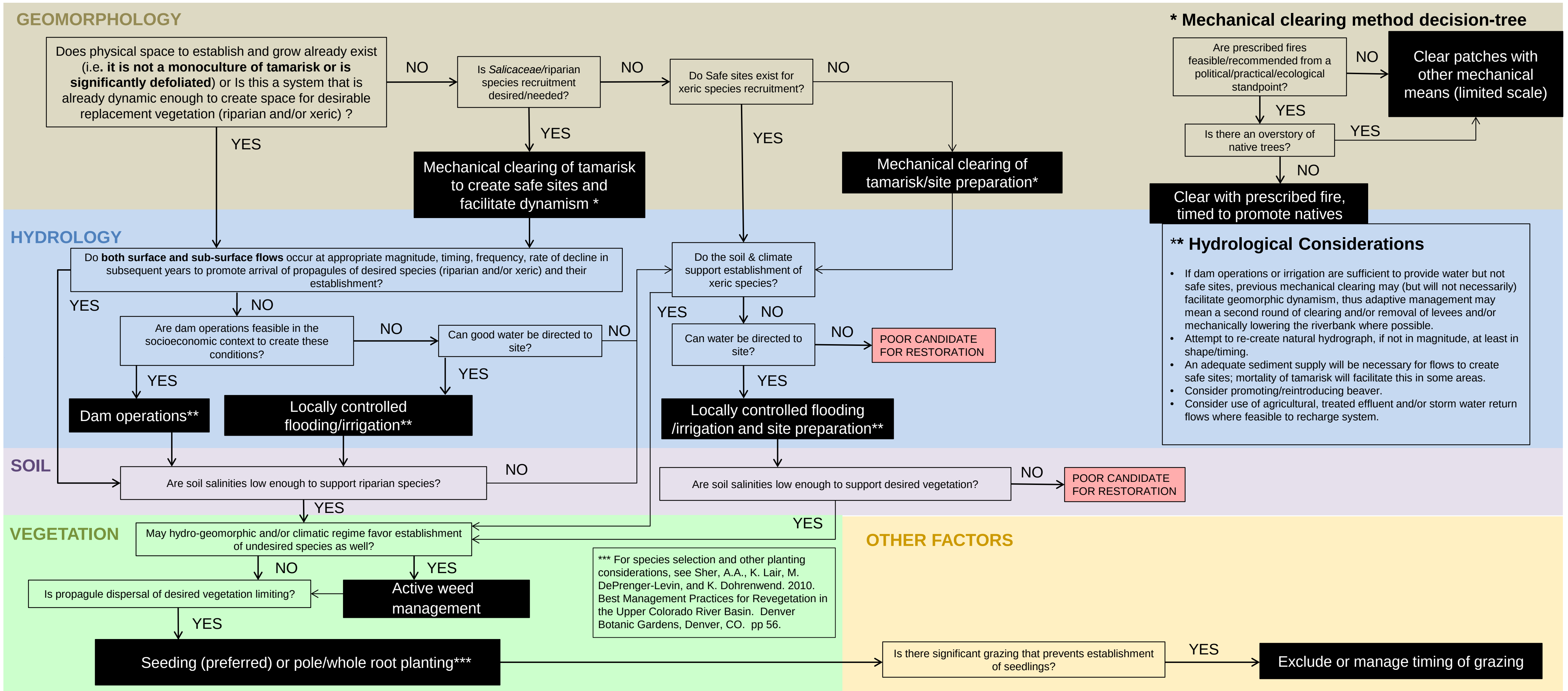

Figure 9 – Decision tree to guide restoration of a self-sustaining community of plant species that will support desirable wildlife in areas now dominated by tamarisk in the context of the biological control beetle. It assumes that this is the overarching goal (step 1) and should be used to assist in steps 2–4 in Shafroth et al (2008); questions can be answered for a reach/river/watershed of interest. For this approach to be self-sustaining, monitoring and adaptive management must be done, i.e. we may need to go through the process of the diagram more than once. This graph is adapted from one created by Gonzalez and Sher, personal communication.

Overarching management implications include the importance of planning to identify early-on those sites where intervention will be most needed as the beetle becomes established. The decision-tree provided in this document can be used to aid in planning efforts. Monitoring and inventorying are key to not only assess baseline conditions ahead of beetle encroachment, but as an ongoing tool to track the effect of the beetle as it moves into the lower basin, and the efficacy of any management actions. Adaptive management practices should be used to help guide activities that enhance success and the provided tools can assist in developing new strategies as site conditions change.

Impact of tamarisk decline on programs such as the Lower Colorado MSCP

Many programs, plans and decisions made over the last decade have been based on the assumption that tamarisk will remain in systems over large areas and will continue to provide some level of wildlife habitat. Movement of tamarisk beetle into these systems, however, will likely challenge this fundamental assumption.

At a strategic level this may impact the scale of projects that are considered viable. Until now, mitigation measures have primarily been smaller-scale, due to funding and capacity limitations of addressing tamarisk removal on a large scale. With the beetle entering the system however, it may now be possible to re-conceptualize the scale at which mitigation can be addressed. In addition, a possible opportunity could exist in some cases to re-allocate funds previously designated for tamarisk control, instead using them for other aspects of restoration.

For specific programs, the implications of the tamarisk beetle will vary. For example, the beetle had not been released when the MSCP planning documents were finalized in 2004. Approximately 5,000 acres of the 126,000-acre project area (103,000 acres of which were identified as tamarisk monoculture) were planned for native riparian restoration/creation (LCRMSCP 2004). However, considering that the beetle will eventually occupy these tamarisk stands and impacts could be significant to both vegetation assemblages and wildlife habitat, it may be both opportunistic and necessary to restore more acreage. Newly developed Habitat Conservation Plans (HCPs) also need to assess how the beetle will affect management strategies by addressing potential changes to existing tamarisk densities. With respect to the Colorado River Delta, there is uncertainty about when the beetle will enter the system, but preparing for the eventuality by refining restoration plans now is important.

> Where beetles are successful, long-term funds previously designated for tamarisk control could possibly be re-allocated for other restoration actions.

Additional research needs

The panel identified a number of priority areas for additional research. A selection of these is presented here. A full list of suggested research topics is included in Appendix B.

- **Beetle genetics:** There is a need for more research into the genetic make-up of the subtropical beetles likely to move into the LCRB. Also, research into behaviorally active compounds that may be used to manipulate beetle populations is needed.
- **Beetle effects on tamarisk:** What are the long term impacts of the beetle on tamarisk and other ecosystem components? Is it possible to model the interaction between the beetle population and the tamarisk population?
- **Replacement vegetation:** What are the effects on native species if tamarisk is removed from the system? What is the threat of undesirable native or non-native vegetation invading after tamarisk decline?
- **Geomorphological and hydrological effects:** What are the effects (above and below ground) of living and dead tamarisk? What are channel impacts of changes in tamarisk stands such as defoliation by the tamarisk beetle and re-vegetation by other species?
- **Flow allocations:** How can we best optimize flow allocations to emulate natural hydrologic processes and promote native recruitment?
- **Wildlife impacts:** There is a need for modeling the impact on species of concern in areas where replacement riparian vegetation is unlikely to establish. What are the defoliation effects on migration habits? How will defoliation by beetles change microclimate? What spatial configurations of tamarisk relative to native species will provide the best alternative habitat for bird, reptiles and amphibians, and small mammal species?
- **Fire regimes:** What risk does vegetation structure pose and what is the likely resultant fire behavior? How long after initial defoliation does full leaf drop occur? Development of a fire behavior model that incorporates an estimate of predicted native mortality.
- **Long Term Bird Monitoring:** Along the Virgin River in Utah, southwestern willow flycatcher and yellow warblers experienced annual variation in reproductive success between 2009-2014 during post-beetle biocontrol (Dobbs et al. 2012; Bateman and Johnson 2015). This annual

variation in reproductive success may be due to tamarisk leaf beetles defoliating tamarisk to various degrees each year, and thereby altering the overall condition of riparian habitat in the St. George study area over the course of this study. Longer-term studies will be necessary to understand the habitat changes ultimately affecting flycatcher populations.

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Appendix A: Panelist Bios

Dan Bean, PhD

Education

- PhD, Entomology, Zoology minor, University of Wisconsin, Madison
- MS, Entomology, University of Wisconsin, Madison
- BA, Biology, University of California, Santa Cruz

Current Positions

- 2005-present: State Biological Control Specialist, Director, Palisade Insectary, Biological Pest Control Program, Colorado Department of Agriculture,
- Affiliate Faculty, Department of Bioagricultural Sciences and Pest Management, Colorado State University, Ft. Collins

Research Expertise

Dan Bean, PhD, is an entomologist who has studied insect development, insect photoperio*dism, and insect/plant interactions in agricultural pests* for over thirty years. He currently works on the biological control of weeds and insect pests for the Colorado Department of Agriculture and is an expert on bio-control of tamarisk using tamarisk beetles in the genus *Diorhabda*. Dr. Bean identified the importance of diapause seasonal timing in determining the range of *D. carinulata* and has also published on the genetics and evolution of *Diorhabda*. In addition, Dr. Bean studies biocontrol of two other relevant invasive species: Russian knapweed and Russian olive.

Anna Sher, PhD

Education

- PhD, Biology, University of New Mexico

Current Position

- Tenured associate professor, University of Denver

Research Expertise

Anna Sher, PhD, is the author of more than 30 scientific publications on plants and plant management, including four books. Her most recent book is an edited volume on the genus *Tamarix* in its invasive range, published by Oxford University Press in 2013. She is one of the foremost experts on the ecology of this species, particularly in the context of riparian restoration. Dr. Sher earned her in PhD studying tamarisk and plant competition, and went on to study the topic in Israel on a Fulbright fellowship. She then completed a post doc on invasive riparian plants at University of California, Davis before accepting a joint position as the Director of Research at Denver Botanic Gardens and a tenure-track professorship at the University of Denver. Her research program is currently focused on understanding plant community response to *Tamarix* removal.

Rebecca Manners, PhD

Education

- PhD, Department of Watershed Sciences, Utah State University

Current Position

- Postdoctoral researcher, Geosciences Department at the University of Montana

Research Expertise

Rebecca Manners, PhD, recently received a National Science Foundation - Science, Engineering, and Education for Sustainability (SEES) fellowship to build a hydrologically driven model of riparian ecosystem dynamics for the Colorado River basin. She has more than 10 years of experience as a fluvial geomorphologist. Her research focuses on the interactions and feedbacks that exist among hydrology, riparian vegetation, and fluvial processes. She works at multiple scales, from the individual plant to the reach scale, to understand how plants and their morphological characteristics alter the size and shape of river channels. For her doctoral research, Rebecca reconstructed the geomorphic and vegetation history of the Yampa River in Dinosaur National Monument to identify the relative importance of hydrologic changes and vegetation community changes as a result of the invasion of tamarisk, in narrowing and simplifying the channel. She continues to investigate the geomorphic effectiveness of tamarisk relative to other native riparian species and think about the geomorphic influence of different species under varying flow regimes and sediment supplies.

Osvel Hinojosa-Huerta, PhD

Education

- PhD, Wildlife and Fisheries Science, University of Arizona
- MS, Wildlife Ecology, University of Arizona
- BS, in Biochemical Engineering and Marine Sciences, Monterrey Institute of Technology, Campus Guaymas

Current Position

- Director of the Water and Wetlands Program, Pronatura Noroeste

Research Expertise

Osvel Hinojosa, PhD, has been working in multiple conservation and research projects in northwestern Mexico since 1997, in particular in riparian and wetland areas of the Sonoran Desert. Some of his recent activities include the evaluation and recovery of endangered species, the implementation of community-based restoration projects and the creation of partnerships with governments and communities for the conservation of nature. He has been leading the efforts to restore the Colorado River delta during the past 17 years, including the implementation of strategies to restore river flows and activities to recover native riparian vegetation. He is an Emerging Explorer of the National Geographic Society, and has served in the Board of Western Field Ornithologists, the Executive Board of the Waterbird Conservation Council of the Americas, the Technical Committee of the Colorado River Delta Water Trust, and the Technical Committee of the Sonoran Joint Venture.

Matthew Johnson, MS

Education

- MS, Biology emphasis: Avian Ecology, Northern Arizona University.

Current Position

- 1992-present: Director, Colorado Plateau Research Station at Northern Arizona University, Flagstaff, AZ

Research Expertise

Matthew Johnson, MS, has 23 years of experience studying avian populations and behavior. He has conducted numerous research projects throughout the western United States, Central America, and Africa. His primary research interests include avian ecology, avian inventory, population monitoring, and population studies of at-risk species (Mexican spotted owl, southwestern willow flycatcher, western yellow-billed cuckoo, common black-hawk and gray hawk). The majority of his work has concentrated on studies of riparian bird populations and communities in relation to habitat along the lower Colorado River, Colorado River in the Grand Canyon, San Pedro, Virgin, Gila and Verde Rivers. He has also conducted research on broad-scale inventory and monitoring programs for birds in all National Parks throughout the Colorado Plateau. Most recently, Matthew has been studying the tamarisk beetle and the effects this biocontrol agent may have on avian populations within the Virgin, Colorado and Rio Grande River Watersheds.

Pat Shafroth, PhD

Education

- PhD, Plant Biology, Arizona State University
- MS, Forest Ecology, Colorado State University
- BA, Environmental Studies and Geography, University of California, Santa Barbara

Current Position

- 1991-present: Research Ecologist, U.S. Geological Survey, Ft. Collins Science Center

Research Expertise

Since 1991, Pat Shafroth, PhD, has conducted research on riparian ecosystems primarily in arid and semi-arid regions of the western U.S. He and his colleagues have focused their work on understanding relationships between surface and ground-water hydrology, fluvial processes, and the dynamics of riparian vegetation. In addition to conducting research on the basic ecological requirements of native and non-native riparian plants, Shafroth and his colleagues have frequently contributed their expertise in applied contexts, such as restoration of riparian areas and the management of non-native species. Dr. Shafroth's related research is currently focused on: 1) vegetation and geomorphic responses to experimental flow releases downstream of dams on the Bill Williams River, Arizona; the Colorado River in Grand Canyon; and the Colorado River delta in Mexico and the U.S.; 2) vegetation and geomorphic responses to dam removal, including monitoring on the Elwha River, Washington, where two large dams were removed in recent years; and contributions to a group of synthesis papers being developed on dam removal; 3) dynamics of non-native riparian plants along western rivers, including patterns of riparian vegetation recovery associated with biological control of *Tamarix* on the Virgin and Colorado rivers, and an associated greenhouse experiment examining responses of native and non-native plants to post-biocontrol soils, litter, and nutrient treatments; 4) vegetation and hydrologic responses to climate change, including effects of climate change on snowmelt flood timing and riparian tree seed dispersal phenology in the Platte River basin; and the effects of climate change on stream intermittency and associated riparian vegetation response in the upper Colorado River basin; 5) various other studies of interactions and feedbacks between fluvial processes and riparian vegetation. Shafroth is the senior or co-author of approximately 50 peer-reviewed articles and chapters related to western riparian plant ecology; collectively, the Riparian Ecology group at USGS has contributed over 150 peer-reviewed publications to this field.

Additional Presenter Bios

Gail Drus, PhD

Education

- PhD, Department of Ecology, Evolution, and Marine Biology, University of California, Santa Barbara

Current Position

- Assistant Professor of Biology and Environmental Studies, Saint Francis University, Loretto, PA

Research Expertise

Gail's research focuses on effects of species invasions on plant community structure and function. She specializes in invasive plant biology, plant community and population ecology, fire ecology, and desert riparian ecology. She has experience developing burn plans, characterizing fire severity and post-fire recovery and utilizing plant physiology to characterize fire damage and to predict plant survival. She has ongoing research collaborations in the fields of plant invasion and riparian ecology. She has a background in ornithology, herpetology, and in the collection of biological specimens related to these disciplines.

Gail has studied *Tamarix* invasion and fire issues since 2006 and has published in the International Journal of Wildfire, the Journal of Biological Control, was a contributing author to the book "*Tamarix*: a case study of ecological change in the American West," has coauthored several government reports related to *Tamarix* invasion, and has several publications in prep. She has also shared her research through numerous invited presentations, posters, and professional meetings such as the Ecological Society of America, Tamarisk and Russian Olive Research Conferences, and Weeds Management Associations. The outcomes of her research have contributed to general ecological knowledge concerning the impacts and management of invasive plant species. She continues studying *Tamarix* and other invasive riparian plants at Saint Francis University.

Ben Bloodworth, MS

Education

- MS, Environmental Science, Alaska Pacific University
- BS, Biology: wetland ecology emphasis, Furman University

Current Position

- 2013-present: Program Coordinator, Tamarisk Coalition, Grand Junction, CO

Professional Background

In his professional career Ben Bloodworth, MS, has worked for the states of Alaska, Mississippi, and Utah. In Mississippi, he worked for two years in wetland mitigation and restoration, aiding in the development of functional assessment models for wetlands, which included working with the U.S. Army Corps of Engineers to create a Hydrogeomorphic (HGM) assessment for tidal marsh wetlands, as well as developing a predictive GIS for wetlands in southern Mississippi, based on HGM classification. In this role, he also assisted in the preparation of wetland restoration plans and the establishment of mitigation banks, including developing criteria for bottomland hardwood restoration. Ben then worked for eight years with the Division of Forestry, Fire, & State Lands in Utah. He spent this time in a diversified role working in wetland ecology, state sovereign lands, invasive species management, community wildfire planning, fuels reduction, and GIS, including serving as the Plans Section Chief on a local Type III Incident Management Team. Ben started with the Tamarisk Coalition two years ago and is the Program Coordinator for the Tamarisk Beetle Education program, actively working with more than 50 partners in eleven states and Mexico to track beetle populations across the western half of the country. He is also the lead for the organization's GIS program and associated online spatial resources.

Appendix B: Suggested Research Questions and Priorities

Beetle genetics

- What is the genetic makeup of beetles moving in the LCRB? How much interbreeding is there and which traits will be carried into the LCRB?
- Can behaviorally active compounds be used to manipulate *Diorhabda* populations?
- Predation of beetles by ants. Can predictions be made about the likelihood of beetle establishment based on ant populations? (Herrera 2003)

Beetle effects on tamarisk

- What long term impact will *Diorhabda* have on tamarisk and other ecosystem components?
- What impact will *Coniatus* have on tamarisk in the basin?
- Is it possible to model the balance between the beetle population and the tamarisk population?
- Why was there significant tamarisk flowering on the Dolores last season (year)?

Replacement vegetation

- Which spatial configurations of tamarisk, relative to native species, will work best to provide bird species alternative habitat into which they will move quickly?
- What is the threat of Russian olive filling the void?
- What is the site potential for vegetation to replace tamarisk?
- What are the likely effects on native species if tamarisk is removed from the system, and what is the replacement value?
- What is the rate at which native vegetation recovers after beetle-related defoliation in areas of mixed vegetation vs. a monotypic stand of tamarisk, and as a function of site potential?

Geomorphological and hydrological

- What are effects (above and below ground) of living and dead tamarisk?
- Better understanding of surface-ground water dynamics.
- Better understanding of ground water dynamics in relation to defoliation
- Stabilizing effects of tamarisk
  - o How stabilizing are the roots? How long are they still stabilizing following mortality? When do we start to see channels beginning to mobilize?
  - o What is the stabilizing (or de-stabilizing) nature of active removal vs. beetle defoliation?
  - o What are the impacts on the channel as a result of changes in tamarisk stands? Does removal result in increased channel mobility? How do these characteristics change over time and under differing hydrologic conditions?
  - o Can removal alone help remobilize a channel without floods?

Flow allocations

- More learning on how to optimize flow allocations.

Wildlife

- Identify which conditions will promote replacement vegetation specifically to support wildlife that are negatively affected by beetle defoliation.
- Model the impact on those wildlife species of concern in areas where replacement riparian vegetation is unlikely to establish.
- How are the conditions within beetle impacted sites going to change microclimate? Some work has been done on temperature and relative humidity. What other variables should be investigated (e.g., flow, changes in patch size)?
- Utilize baseline information on bird populations in mixed stands and tamarisk dominated systems to try and understand the shift that might/may occur under defoliated conditions
  - o There are enough data in some systems to do this (e.g., Salt, Tonto creek, lower Colorado, Verde, Virgin). This is being looked at using satellite imagery.
  - o There is limited information on nesting. The data are primarily on presence/absence.
- What are defoliation effects on migration habits?
- What is the tipping point at which a site is too dry to support the wildlife even if the trees are there?
- What is the percent of native-tamarisk mix needed to maintain desired wildlife species?

Economic impacts

- Could the loss of the major flowering component in a river system potentially impact crops that require pollinators?

Fire

- Continue fire survey in areas where beetles have invaded and fires have burned. Evaluate how long after beetles come in until full leaf drop occurs?
- Wildfire risk assessment model. What risk does the vegetation structure pose and what is the likely fire behavior that will come out of it?

Other

- Climate change. What are the effects of changes in timing of moisture arrival (e.g., in Arizona winters are dryer now)?
- Determine and document adequate site preparation for tamarisk beetle establishment in terms of physiological parameters or potential beetle predators (e.g., ants) on the desired site.

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