Pre- and post-dam shifts in vegetation throughout the Grand Canyon: What do novel systems mean for management?

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Abstract

Prior to the installation of the Glen Canyon dam, the Grand Canyon experienced relatively frequent, high intensity flooding that acted to scour away vegetation, creating a dynamic plant community along the riparian corridor. Current post-dam flows are heavily regulated, virtually eliminating the canyon's natural disturbance regime. While post-dam high flow experiments have been implemented over the years for a variety of reasons, they have yet to reach the historical severity of pre-dam flood events and are too infrequent to have the same effect on vegetation as the historical flood regime. The lack of regular disturbance has led to the stabilization of substrate along the river banks and, thus, the creation of new habitats. Both native and non-native riparian vegetation have appeared to benefit from this novel system however some could argue that the lack of disturbance has favored invasive, non-native species such as *Tamarix* spp. over native species in the area. Pre- and post-dam vegetation communities throughout the Grand Canyon are discussed here, along with the shifting dynamic between native and non-native species, and how this dynamic, along with a newly introduced biocontrol agent is impacting current and future management of the canyon's vegetation.

Introduction

The installation of the Glen Canyon Dam in northern Arizona tamed the waters of the Colorado River causing dramatic ecological changes, significantly altering the riparian habitats throughout the Grand Canyon (Carothers and Aitchison 1976; Turner and Karpiscak 1980). The constant flow regulation of the Colorado River through the canyon due to the dam has eliminated the relatively frequent, high intensity flooding that historically occurred due to annual snowmelt in the headwaters and occasional summer monsoons (Turner and Karpiscak 1980; Figure 1). Pre-dam flows were inherently variable and seasonal flooding acted to create a highly dynamic system, constantly scouring away vegetation while also reforming the land, thus creating a heterogeneous habitat that supported a variety of plant communities at any given point in time (Clover and Jotter 1944).

Considerable shifts in riparian vegetation associated with the construction of dams have been seen in a number of places (Merritt and Cooper 2000; Tealdi et al. 2011; Reynolds et al. 2014). Vegetation in the Grand Canyon is no exception (Carothers and Aitchison 1976; Turner and Karpiscak 1980). There are various historic accounts describing pre-dam vegetation in the canyon (Powell 1875; Clover and Jotter 1944; Stanton 1965) and most report that vegetation within the reach of annual flooding was scarce due to frequent scouring. Dense, more established vegetation was present prior to the dam existing, but it was limited to areas above the annual flood zone (Clover and Jotter 1944). Since post-dam flows are much more homogeneous than pre-dam flows, vegetation has been able to establish more permanently in areas below the pre-dam high water zone (Figure 2) and climax vegetation is much more abundant (Carothers and Aitchison 1976).

Annual flooding in the Grand Canyon was the system's key disturbance regime and by modifying this regime, the system has been left vulnerable to non-native plant invasions as well as a potential loss in native plant diversity (Hobbs and Huenneke 1992). While the dam may be exacerbating the issue of exotic plant species in the Grand Canyon, many of these species have been a component of the system long before the Glen Canyon Dam was in place (Clover and Jotter 1944). In 1980, the Integrated Pest Management (IPM) program was put in place throughout national parks as a way of identifying potential pests and developing specific management plans for target pests (McCrea and Disalvo 2001). In 2000, the NPS created the Exotic Plant Management (EPM) program to carry out inventory and monitoring on exotic plants as well as prevention, treatment and control of target species. The most prominent species of concern in the canyon, however, has been tamarisk (*Tamarix ramosissim*). There is currently an ongoing Tamarisk Management Program that has been in place since 2000 (Makarick 2011). Tamarisk has been noted in the area as early as the 1930's and has mostly been considered impossible to eradicate (McCrea and Disalvo 2001), leading to management focused on limiting its range rather than total eradication (Makarick 2011). It was not until a little over a decade ago, however, that a new approach to tamarisk removal was introduced, leading to a new era of tamarisk management in the southwest and in the Grand Canyon (DeLoach et al. 2003; Dudley and DeLoach 2004).

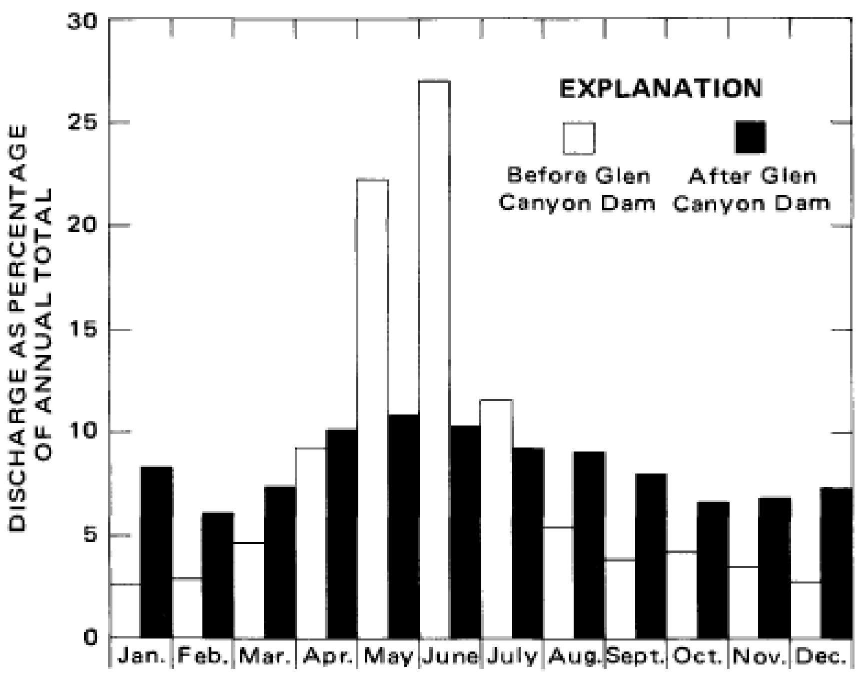

Figure 1: Monthly mean discharge of the Colorado River at Lees Ferry as a percentage of the total annual discharge. Open bars=April 1963 through March 1977; solid bars=calendar year 1901 through calendar year 1962. Turner and Karpiscak 1980.

Pre-Dam Vegetation

In order to effectively discuss post-dam vegetation patterns throughout the Grand Canyon and the associated management, it is important to understand what the vegetation looked like historically. While there are several historic accounts of what the vegetation was like prior to the construction of Glen Canyon Dam (Powell 1875; Clover and Jotter 1944; Stanton 1965), by far the most comprehensive and detailed came from Dr. Elzada Clover and Lois Jotter and their exploration along the Colorado River in 1938. Dr. Clover was a Botany professor at the University of Michigan and Jotter was a graduate student in Botany at the university. From their 1938 expedition down the river and subsequent visits to more accessible areas in the canyon, they produced a thorough description of the vegetation that they encountered called "Floristic Studies in the Canyon of the Colorado and Tributaries" in 1944. The following is a brief description of the five main habitats that Clover and Jotter (1944) described along with the dominating vegetation associated with them.

Habitat 1 – "Moist sand next to the river"
These areas were dominated primarily by *Tamarix* spp. (exotic), *Baccharis* spp., and *Salix* spp. which were present the entire length of the canyon. In some areas lower in the canyon dense stands of willows acted to stabilize the substrate, insuring the persistence of several sandbars even during heavy flooding. These willows were not immune to being ripped out from high floods but, if they were able to establish quickly enough, they were very capable of persisting in great abundance.

Habitat 2 – "Springs and waterfalls"
The moist soil bordering the springs and waterfalls throughout the canyon were abundant with diverse vegetation. While a wide array of different species existed in these areas, the most dominant were *Toxicodendron radicans* (previously *Rhus radicans*), *Cercis occidentalis*, and *Mimulus cardinalis*. Mosses, liverworts and algae were also common plants seen growing in these areas.

Habitat 3 – "Dry sandy shores"
Areas with a buildup of sand that had not been disturbed by frequent flooding were capable of hosting vegetation similar to that found on the talus slopes (described in Habitat 5). Typically, however, plants in this area were described as being "dwarfed or misshapen" due to being buried by sand. Some of the more common species present were *Atriplex* spp., *Phacelia* spp., and *Curcubita* spp., which acted as low growing ground covers.

Habitat 4 – "Rubble and boulder areas"
Boulders were commonly dislodged and relocated during large flood events. Smaller rocks and debris would then build up among the boulders creating a somewhat unique habitat. The boulders acted to trap seeds brought down by the river and then proceed to protect the germinating seeds. While soil was the most limiting factor in these areas, if left undisturbed by flood waters, a small plant community was capable of developing. The initial colonizers of these boulder areas were *Stipa hymenoides* (previously *Oryzopsis hymenoides*), *Chylismia multiiuga* (previously *Oenothera multiiuga*), and an exotic, *Salsola kali*.

Habitat 5 – "Talus slopes"
The instability of the talus slopes along the canyon walls was observed to support a community dominated primarily by pioneer vegetation. The common species in this area varied greatly but

consisted of *Ephedra* spp., *Eriogonum inflatum*, *Atriplex canescens*, and *Stipa hymenoides*. More stable talus slopes were found to be dominated by *Prosopis* spp., *Acacia* spp., and occasionally *Quercus* spp.

The most prominent species were noted for each of the five habitats above, yet it's important to note that all of these habitats hosted a variety of different species compositions and they shifted depending on their location and time since disturbance. It was rare for climax vegetation to exist due to the relatively frequent flooding but not impossible. An alternative to separating the pre-dam vegetation into 5 habitats is to describe it more generally as being composed of three distinct zones (FEIS 1979) much like post-dam vegetation in the following section will be described. The first zone can be described as the area that experienced annual flooding and was thus composed of both ephemeral herbaceous species and mesophytic woody species (e.g. *Salix* spp., *Baccharis* spp.). The second zone, above this ephemeral zone, was considered the high water line zone due to the vegetation being restricted to areas above the reaches of major floods which scoured away vegetation below. Vegetation here was typically denser and composed of multiple woody species that, due to the relative lack of disturbance, were able to successfully establish and grow in this area. The third and final zone described was that of the talus slopes. These areas were much drier and hosted mostly desert and pioneer species rather than riparian species since they were out of the reaches of most floods and were inherently unstable (FEIS 1979).

Post-Dam Vegetation

Post-dam vegetation is typically described in the literature as consisting of 3 main zones: (1) Zone of post-dam fluvial sediments, (2) Zone of pre-dam fluvial sediments, and (3) Zone of pre-dam flood terraces (Figure 2; Dolan et al. 1974; Turner and Karpiscak 1980). These zones contain several plant communities within them and provide a general overview of how the vegetation has shifted due to changes in habitat triggered by an altered disturbance regime. The following is a brief description of these three zones according to Dolan and others (1974) and Turner and Karpiscak (1980).

Zone of post-dam fluvial sediments
These areas are considered to have the most striking differences according to historic photographs. They are characterized by having dense plant growth on either side of the river dominated by *Tamarix* spp. and *Salix exigua*. This denser climax vegetation is novel to the system since pre-dam flooding would have scoured these areas. Also, submerged deposits now host aquatic plants and can be categorized as marsh habitat which was previously non-existent prior to the installation of the dam.

Zone of pre-dam fluvial sediments
No longer under water during annual floods and in some places, as much as 5.5m above the post-dam high water line, this area provides stability for a more permanent plant community but lacks the water for one to flourish. In the 1970's this area was still relatively sparse but it was expected that the community would primarily consist of *Acacia greggii* (catclaw), *Fallugia*

paradoxa (Apache plume), *Prosopis glandulosa* (mesquite) along with a variety of herbaceous species.

Zone of pre-dam flood terraces, eolian deposits and stabilized talus slopes
Pre-dam flood terraces are areas that were historically relatively stable and located above inundation from annual flooding and, in some cases, above the high flood zone. Now, with areas as much as 9m above the present high water line, it's dominated by *Ericameria paniculata*, *Fallugia paradoxa*, *Prosopis glandulosa*, *Acacia greggii,* and *Celtis laevigata* (canyon hackberry). These species are what provide the seed sources for the plants newly occupying the pre-dam fluvial deposits on the zone below. The talus slopes in post-dam accounts are described as being more stable than previously described by Clover and Jotter (1944).

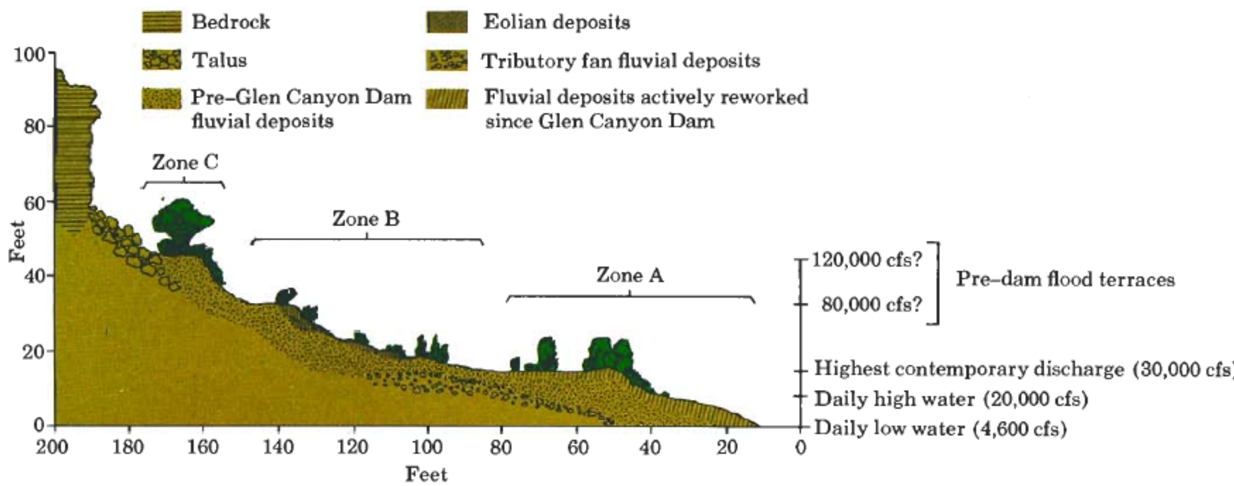

Figure 2: Schematic showing the three main zones of vegetation along the Colorado River. Zone A = post-dam fluvial sediments; Zone B = pre-dam fluvial sediments; Zone C = pre-dam flood terraces. Dolan et al. 1974.

In general, riparian vegetation has become much denser along the Colorado River now that it is no longer removed regularly by annual flooding (Figure 3). In addition to this, new perennial marsh systems have established themselves in certain areas. Tamarisk has flourished the most since the Glen Canyon Dam was installed and is now successfully out-competing the native cottonwoods and willows in newly established areas (Webb et al. 2002).

Vegetation Management

Management programs regarding vegetation along the Colorado River corridor in the Grand Canyon was virtually non-existent until the 21st century. From 1973 to 1976, data on the riparian and aquatic ecosystems were collected with the focus of better understanding the impact of humans on these systems through recreation and the alteration of the flood regime (Johnson 1977). While numerous exotic species were present along the banks of the Colorado River, only a handful were considered invasive, spreading quickly and aggressively (e.g. *Salsola kali* (Russian thistle), *Alhagi camelorum* (camelthorn) and *Eleagnus angustifolium* (Russian olive). By the 70's, tamarisk was already so dominant in the system it was considered completely beyond control and, in some cases, beneficial due to the benefits it was providing to wildlife and visitors through the form of shade and beach stabilization (Dolan et al. 1974; Carothers and Aitchison 1976; Johnson 1977).

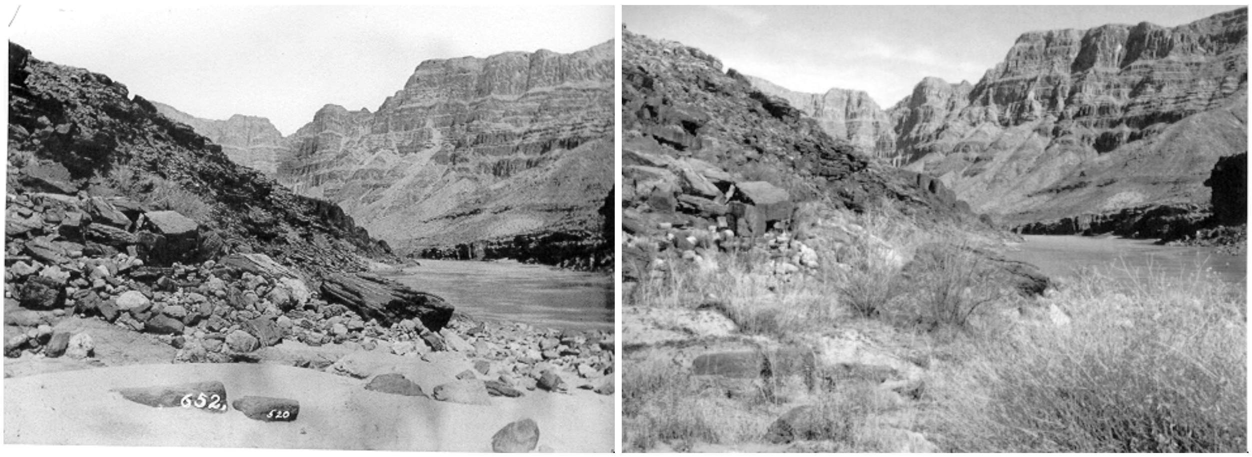

Figure 3: “The New High-Water Zone”- pre- and post-dam images showing the densification of vegetation along the Colorado River. Left: 1889-1990; right: early 1990’s. Webb 1996.

Currently, there are 187 exotic plants species that have been identified within Grand Canyon National Park. Of these, 80 are of special concern because they are capable of either spreading quickly to new areas or actively displacing native plant species (NPCA 2010). Most new invasive species have come in due to road and trail construction and the endless stream of park visitors. These newer species are mainly restricted to highly developed portions of the park and are not currently impacting riparian areas in the canyon. While ongoing management of most exotic species has continued in an attempt to control and potentially eradicate them, the program put in place by the Grand Canyon National Park that has received the most attention is the tamarisk management program which began in 2000 (Makarick 2011). The goal of the program is to remove tamarisk (*Tamarix ramosissima*) from tributaries of the Colorado River in Grand Canyon National Park and has been funded over the years by the Arizona Water Protection Fund, the Colorado River Fund, the Grand Canyon National Park Foundation, the Grand Canyon Wildlands Council, and the National Park Service.

Tamarisk currently occupies 98% of the Colorado River in the Grand Canyon and continues to be the dominant riparian species (Mortenson and Weisberg 2009). Tamarisk can take shrub or tree form and tends to grow in dense stands along riparian areas. It has a deep tap root which makes it a very good competitor for water resources. While removal of tamarisk from the Colorado River tributaries has been relatively successful through the means of mechanical and chemical techniques, without the natural scouring of vegetation that occurred historically, tamarisk will continue to dominate and encroach on native plant habitat. Studies have considered the use of high flow events in order to knock back the tamarisk in the canyon, but due to its prolific seeding abilities, this may cause more harm than good with regard to the spread of the plant (Baldwin 2012; Mortenson and Weisberg 2009).

In 2001, the USDA approved the official release of *Diorhabda elongate,* a beetle from central Asia that lays its eggs on tamarisk foliage and selectively feeds on the plant in the larval and adult stages, effectively defoliating whole plants. The beetle was first released in 1999 into field cages located in 10 sites throughout six western states (DeLoach et al. 2003). The first tamarisk beetle survey along the Colorado River occurred in 2009 and resulted in the discovery that the beetle had reached the river (NPS 2009). The beetles' speedy dispersal has forced management to start preparing for the potentially rapid defoliation of tamarisk plants throughout the Grand Canyon. The effectiveness of the beetle is good for tamarisk management but a potential issue for the wildlife that depends upon it (Hultine et al. 2010). The federally endangered Southwestern Willow flycatcher in particular tends to nest in tamarisk and was the reason this biocontrol program was delayed back in 1994 (DeLoach et al. 2003; Sogge et al. 2004). Efforts are being made to prepare to restore areas previously dominated by tamarisk by planting native tree species in its place in hopes to mitigate the potentially negative impacts caused by the tamarisk dying off too quickly (Makarick 2011).

Summary

After examining the literature that describes pre- and post-dam vegetation along the Colorado River in the Grand Canyon, it is clear that there is a much more widespread understanding of current vegetation conditions than historic conditions. The information that is there, nonetheless, makes it clear that there have been significant shifts in composition, density and distribution of the riparian vegetation. Lack of annual flood extremes has led to the creation of newly stabilized habitat that is capable of hosting dense climax vegetation. While native plants such as *Salix* and *Baccharis* have increased in abundance along the river, tamarisk has arguable benefited the most, currently dominating the banks along the river as part of a novel system that wildlife now depend upon.

Recent changes in the feasibility of tamarisk management and potential eradication has been a source of both hopefulness and apprehension. For decades, tamarisk removal has been dominated by chemical and mechanical removal. These methods are effective on a small scale but lack the ability to fully tackle the vast area infiltrated by tamarisk, leaving land managers with little hope of ever truly getting a hold on the situation. With the introduction of the tamarisk leaf beetle and the subsequent rapid defoliation of large patches of tamarisk, land managers are beginning to shift their focus from answering the question, "How do we minimize the spread of tamarisk?" to "How do we minimize the potential risk that tamarisk defoliation poses to the wildlife populations that rely on it?"

Despite the extensive studies done looking at the effectiveness of the tamarisk leaf beetle on targeting and defoliating tamarisk, future research and monitoring is essential in order to reveal what the ecological impacts on riparian systems will be over the years. Hultine and others (2010) discuss the direct and indirect effects caused by the tamarisk leaf beetle in the west. They then suggest ways land managers can create a successful and effective plan to hopefully better understand, and therefore manage, pre- and post-beetle riparian habitats. Management in the Grand Canyon will benefit the most if efforts are made to identify areas that may require less restoration (i.e. areas that have adequate native plants present already) so that the focus can be on sites that will be the most severely hit by the beetle.

Due to considerable changes in the Colorado River caused by the Glen Canyon Dam and the unlikeliness that natural flows will ever be restored to the canyon, current novel systems will continue to remain. The densification of the riparian vegetation is a trend that would have no doubt been seen even without the presence of tamarisk in the system. Consequently, now that tamarisk may be getting knocked back by the tamarisk leaf beetle, managers need to figure out how to replace it with native vegetation. A land once relatively devoid of vegetation due to scouring annual floods now has a faunal community that relies so heavily on the newly established vegetation that managers need to be strategic in their management as to ensure the integrity of the habitat.

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