Riparian vegetation in the Grand Canyon: Multiple priorities influence management options

Joanna Solins
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Riparian ecosystems support productive and diverse plant communities that provide critical wildlife habitat and can exert important influences on aquatic ecosystems. Riparian vegetation is closely linked to stream flow regimes and the geomorphic features of river channels, and alteration of these characteristics in regulated rivers can have major consequences for the structure and composition of riparian vegetation communities. Construction of the Glen Canyon Dam on the Colorado River in Arizona has vastly changed the downstream ecosystem in the Grand Canyon by altering flow regimes and sediment transport. This paper explores the causes and consequences of changes in riparian vegetation along the Colorado River in the Grand Canyon after the construction of the Glen Canyon Dam, and how current priorities and values for the Grand Canyon and the dam influence vegetation management options.

Riparian vegetation is tied to river flows

Riparian zones can be defined as the areas bordering rivers or streams that are influenced by stream flows, including floods. The life histories of riparian plants are therefore often closely tied to the magnitudes, frequencies, and durations of flows (Hupp and Osterkamp 1996), and hydrology, in interaction with local geology, is generally the most important influence on the structure, dynamics, and composition of riparian zone vegetation (Naiman and Decamps 1997). Stream flows move not only water, but also sediments, and when high flood volumes scour vegetation and channels, they redistribute sediments and create bare substrate for colonization by vegetation. The temporal and spatial heterogeneity of water and substrate availability in riparian zones produces high levels of diversity by creating a variety of conditions that support different plant communities (Tabacchi et al. 1996, Naiman and Decamps 1997, Poff et al. 1997).

Plant species have evolved various morphological adaptations for living in riparian environments, including flexible stems that can bend with flood waters, adventitious roots that allow vegetative reproduction, and the ability to resprout after breakage or burial (Naiman and Decamps 1997). Many riparian plants have also evolved life cycles that utilize or avoid flows of differing magnitudes, making the timing of these flows particularly important (Poff et al. 1997). For instance, trees such as cottonwoods (*Populus* spp.) and willows (*Salix* spp.) disperse their seeds as seasonal floods recede, ensuring moist substrate for germination (Naiman and Decamps 1997, Mahoney and Rood 1998). A number of species also disperse seeds or vegetative fragments to new areas via hydrochory, transport by flowing water (Naiman and Decamps 1997).

Riparian zones play a particularly important role in maintaining biodiversity in arid and semi-arid regions like the Colorado River Basin. The moisture in an otherwise water-limited landscape supports structurally complex vegetation that in turn provides habitat for a large percentage of animals. Although riparian zones in the largely semi-arid American West amount to less than two percent of the total land area, they support more than one third of plant species (Poff et al. 2012), and more than half of all breeding birds (Ralston 2005). Riparian plants also influence aquatic ecosystems by providing organic matter inputs and shade, and by creating channel and floodplain habitat complexity (Naiman and Decamps 1997).

Riparian vegetation of the Grand Canyon

Riparian vegetation in the Grand Canyon is often associated with the debris fans formed at tributary confluences, growing either along the pools that form above the debris fans or on the sandbars in the flow expansions below them; elsewhere, vegetation colonizes channel margin deposits, but the extent of available substrate depends on the width of the canyon floor (Sankey et al. 2015). Vegetation is stratified into zones differentiated by hydrology, as well as by substrate type. Clover and Jotter (1944) described these zones during their 1938 expedition down the Colorado River, providing most of what is known about the pre-dam vegetation in the Grand Canyon (Ralston 2005). Closest to the river channel, where vegetation was frequently disturbed and scoured by floods, Clover and Jotter (1944) noted that moist sandy areas were usually dominated by flood-tolerant, pioneer species like willow (*Salix* spp.) and seepwillow (*Baccharis* spp.), while marsh species such as rushes (*Juncus torreyi*), sedges (*Cyperus erythrorhizos*) and cattails (*Typha latifolia*) occurred rarely, and primarily in tributaries and springs (Clover and Jotter 1944, Turner and Karpiscak 1980, Stevens et al. 1995). Non-native tamarisk (*Tamarix* spp.) shrubs were also already found in this zone, and some other species with wider moisture tolerances, such as rabbitbrush (*Chrysothamnus nauseosus*) and four-wing salt bush (*Atriplex canescens*), also appeared near the shoreline (Clover and Jotter 1944). Drier sandy areas were dominated by four-wing salt bush and arrowweed (*Pluchea sericea*), while talus areas above the flood plain supported rabbitbrush and Mormon tea (*Ephedra torreyana*). The high-elevation benches that would only have been inundated in very large floods were dominated by more mature and stable communities of drought-tolerant mesquite (*Prosopis glandulosa*) and catclaw acacia (*Acacia greggi*), as well as tamarisk (Clover and Jotter 1944, Ralston 2005). The Grand Canyon is unusual for this part of the world in its general paucity of larger riparian trees (Mortenson et al. 2012).

Photographs from before and shortly after the construction of Glen Canyon Dam show sparse riparian vegetation assemblages in the Grand Canyon (Turner and Karpiscak 1980, Sankey et al. 2015). The Colorado River lacks a floodplain through much of the confined, narrow canyon bottom, creating particularly forceful floods that would have scoured vegetation frequently, preventing the establishment of extensive mature plant communities (Clover and Jotter 1944, Turner and Karpiscak 1980, Ralston 2005). These floods also created new sediment deposits, and the renewal of sandbars and channel margin substrates allowed the establishment of native willows and other plants that timed their seed dispersal to correspond with the recession of the high spring floods. Many of these riparian plants can also reproduce vegetatively. Clover and Jottter (1944) noted that willows and tamarisk transported downstream by water would root if they landed in a favorable location, and some native plants like sandbar willows (*Salix exigua*) and arrowweed readily reproduce clonally (Mortenson et al. 2012).

Glen Canyon Dam and riparian vegetation expansion

Since the Glen Canyon Dam was completed in 1963, sediments have been retained behind the dam, and flows through the Grand Canyon have been dramatically altered. The seasonal disturbance of spring floods due to snowmelt has been drastically reduced, and instead vegetation has been subjected to daily flow fluctuations due to hydropeaking (Sankey et al. 2015), the practice of changing river flow volumes in response to hourly changes in electricity demand. Monthly variation in base flows has also been altered, now following electricity and irrigation usage (Turner and Karpiscak 1980). The net effect of the dam has been a general increase in base flows and the elimination of scouring flood flows. These conditions are conducive to the establishment and growth of riparian plants, and have allowed vegetation to rapidly expand into the formerly dynamic and sparsely colonized active channel (Turner and Karpiscak 1980, Sankey et al. 2015). Turner and Karpiscak (1980), who used repeat photography to document vegetation expansion, write: "…in the short period of 13 years the zone of postdam fluvial deposits has been transformed from a barren skirt on both sides of the river to a dynamic double strip of vegetation." The altered hydrology due to the dam also resulted in the formation of numerous new fluvial marsh areas (Stevens et al. 1995).

Much of this new vegetation was scoured away during high flows in the early to mid 1980s. Lake Powell finished filling behind Glen Canyon Dam in 1980, and a period of higher than average precipitation in the next few years led to increased flow releases. In addition to larger peak flows, including a prolonged peak flow in 1983 that reached pre-dam flood levels, base flows were substantially higher in the 1980s than the 1970s. The elevated water tables accompanying these higher flows promoted expansion of woody vegetation in mid-elevation benches, despite the loss of low-elevation vegetation to scour (Ralston 2005). Marshes also re-established quickly after the cessation of high flows: the years between 1986 and 1991 saw a mean increase of 32 wet marshes per year between Lees Ferry and Diamond Creek (Stevens et al. 1995). No subsequent floods have approached the level of the 1983 flood. However, further change to the hydrologic regime occurred after 1992 due to an imposed limitation on hydropeaking. Aerial imagery shows a decrease in unvegetated bare sand area after the reduction of daily flow fluctuations (Sankey et al. 2015). In summary, the current altered hydrologic regime has decreased flood disturbance, increased year-round water availability, and increased habitable space, allowing the expansion of vegetation in both low-elevation bare surfaces and mid-elevation areas. Vegetation on higher benches and terraces, in contrast, is no longer influenced by the river, and responds to changes in precipitation; these areas have seen a reduction in vegetation since the early 1990s (Sankey et al. 2015).

The newly expanded vegetation communities include a mix of native and nonnative species. Native sandbar willow (*Salix exigua*) and nonnative tamarisk initially dominated the vegetation spreading into sandbars, with tamarisk thought to be largely displacing native seepwillow (Turner and Karpiscak 1980). After the large flood of 1983, there was very high tamarisk mortality; however, the new bare substrate also created conditions for widespread tamarisk recruitment, and the current post-dam flow conditions are generally conducive to tamarisk establishment every year (Mortenson et al. 2012). While tamarisk seedlings are generally inferior competitors to native seedlings, tamarisk has a much longer period of seed release, allowing it to take advantage of higher summer flows on regulated rivers (Mortenson et al. 2012). In contrast to the widespread dominance of tamarisk in the upper basin of the Colorado River, though, tamarisk in the Grand Canyon tends to be a co-dominant with native species, although it is ubiquitous across riparian zones (Sankey et al. 2015). Other invasive species of concern include camelthorn (*Alhagi maurorum*), which has taken over many beaches, Ravenna grass (*Saccharum ravennae*), which rapidly colonizes riparian habitats, and Russian olive (*Elaeagnus angustifolia*), another aggressive invader (Grand Canyon National Park 2006). While many native plant species have also expanded their distributions since the dam construction, the Grand Canyon's largest native riparian tree, Goodding's willow (*Salix gooddingii*), has declined significantly due to flow regulation, showing recruitment only after the 1983 flood (Mast and Mast 2010).

Post-dam priorities and values regarding vegetation management

The altered vegetation characteristics of the Grand Canyon have yielded both benefits and drawbacks, which will be discussed in more detail below. However, whether a characteristic is viewed as a benefit or a drawback depends on human values, and various values and priorities for use of the Colorado River and Grand Canyon influence the management options and decisions that affect vegetation in the canyon. The value of Glen Canyon Dam for hydropower and water provision dominates the management priority landscape, and as long as the dam is operational, it limits the options for changing flow and sediment regimes to manage vegetation. However, given this starting point, there is still a range of management decisions, and those made within the Grand Canyon National Park are guided by the park's mission. This mission somewhat problematically contains potentially conflicting goals, though: the national park has mandates to both promote recreational use of the park and ensure its preservation, including the conservation of scenery and wildlife (Mast and Mast 2010). Even these last two seemingly complementary conservation goals may be at odds.

Recreational use of the Grand Canyon's riparian areas is largely due to the whitewater rafting industry, which has boomed after the completion of the Glen Canyon Dam. While some of the growth in this sector was fueled by improved technologies, the relatively stable and predictable post-dam flows allow year-round access and long-term planning conducive to business growth (Mast and Mast 2010). For rafters, riparian vegetation can provide desirable shade in hot weather, but the growth of dense vegetation onto sandbars reduces the number and extent of camping sites—a critical resource for multi-day rafting trips. After the 1983 flood, which temporarily regenerated many sandbars, the combination of vegetation overgrowth and erosion led to the loss of 236 camping sites by 1991—a 48% decrease—with 41% of these losses caused by vegetation overgrowth alone (Kearsley et al. 1994). Vegetation encroachment has continued to decrease campsite area in the Grand Canyon, contributing to an additional 36% loss between 1998 and 2012 (Kaplinski et al. 2014).

The expansion of riparian vegetation in the Grand Canyon has created a conundrum for conservation goals, because wildlife is making use of the newly vegetated habitat. Restoring the Grand Canyon's sparse native riparian vegetation structure and community—arguably part of the national park's mandate—would compromise this habitat and thus contradict the mandate to preserve wildlife. The increased cover of mature woody plants, including tamarisk, has increased habitat for a number of bird species of concern, including the endangered Southwestern willow flycatcher (SWWF) and other neotropical migrant songbirds, as well as bald eagles and peregrine falcons. In fact, SWWF have preferentially nested in dense tamarisk groves, and their nesting sites are all near fluvial marshes (Stevens et al. 2001). The noted increase in marshes and shoreline vegetation in the canyon also helps to support regionally significant populations of summer breeding and winter waterfowl that were not present before the dam (Stevens et al. 1997), although the densification of marsh vegetation may negatively impact the northern leopard frog, which has seen a dramatic population decline in the park (Drost 2005). A highly endangered invertebrate, the Kanab ambersnail, has only two remaining natural populations, and one is located at the Vasey's Paradise spring in Grand Canyon National Park. The increased extent of herbaceous vegetation near this population may benefit the snails, although no population growth has been observed; possible explanations for the lack of population growth include changes in soil moisture and plant community composition, as well as trampling by bighorn sheep that have begun to frequently utilize this perennial vegetation source (Ralston 2005).

Management avenues

One management tactic to preserve native vegetation is to control invasive species that are crowding out native plants. Manual removal of invasive species can be implemented regardless of the flow regime, but it often does not contribute to restoring the physical conditions that favor the growth of native species. In Grand Canyon National Park, there have been a number of campaigns against invasive species in the riparian zone. One effective removal campaign aggressively targeted Ravenna grass starting in the 1990s. Volunteers have removed more than 20,000 plants, and the corridor is monitored every year to ensure that any newly established plants are removed. Prompt removal of the few Russian olives that have been found in the canyon has limited the impact of this species as well (Stevens et al. 2001, Grand Canyon National Park 2006). Other plants have proven much more difficult to control. Camelthorn, which can take over beaches, is considered too widespread for effective eradication efforts on a large scale, and has only been controlled in select locations. Tamarisk control efforts have only targeted side canyons, seeps, and springs where the natural flow regimes are still in place; however, these efforts have been quite successful, achieving a 99 percent reduction in tamarisk cover and an increase in native plants (Grand Canyon National Park 2006). An unplanned additional impact on tamarisk has come from the tamarisk beetle (*Diorhabda* spp.), which was introduced in other parts of the Colorado Basin as a biocontrol agent. The beetle was not intended to make it to the Grand Canyon, but arrived in 2009. There is now worry that beetle-induced tamarisk mortality could proceed too quickly for other species in the ecosystem to fill in, reducing critical habitat for birds such as the SWWF (Minard 2011, Paxton et al. 2011).

Another management tool that has been implemented to address many ecosystem concerns in the Grand Canyon is the use of controlled flood releases from Glen Canyon Dam. The first release in 1996 included the explicit goals of increasing open sandbars for camping and providing water to upper riparian vegetation, while avoiding adverse affects to endangered species (Stevens et al. 2001). Additional floods or planned restoration flows with varying timing and magnitude have occurred in 2000, 2004, 2008, and 2011, but none have approached the magnitude of pre-dam floods (Mortenson et al. 2012). The first test flood succeeded in preventing significant adverse impacts on endangered species, despite removing some habitat, but achievement of the other goals was less clear (Stevens et al. 2001). It appears that high-volume dam releases do temporarily increase sandbars and thus campsite area, but the gains are generally lost in the intervals between high flows (Kaplinski et al. 2014). Floods of this magnitude bury riparian vegetation rather than scouring it, and mature woody species such as tamarisk, sandbar willow, and seepwillow have grown up through the sand deposits with little observed mortality (Stevens et al. 2001). None of these floods have promoted the regeneration of Goodding’s willow (Mast and Mast 2010). On the other hand, Mortenson et al. (2012) found that floods timed outside of tamarisk seed release successfully prevented widespread new tamarisk establishment. Unfortunately, this flood timing could limit seedling recruitment for native species as well. They recommend planned floods be conducted at the beginning of the growing season (March-April) to limit tamarisk germination and increase clonal expansion of native shrubs. Another recent study found that riparian vegetation did not expand in areas that were inundated for at least 5% of the time (18 days/year), which could potentially be a good management tool for keeping vegetation expansion at bay (Sankey et al. 2015).

Conclusions

Flow-regulated rivers present a novel set of ecological characteristics, and we are still learning how to manage these altered ecosystems. There is likely no management panacea for riparian vegetation in the Grand Canyon, as different management priorities are in direct conflict with one another. Even if the extended high flood flows and sediment release required for the maintenance of historical habitat types, germination sites, and camping areas were economically and logistically feasible, this management strategy would result in the loss of important habitat for endangered wildlife, and could promote the establishment of nonnative species like tamarisk. Some factors, like droughts and the arrival of the tamarisk beetle, are out of our control, and will likely have major impacts on riparian vegetation communities. However, by using a combination of invasive species removal techniques and carefully planned controlled high flows, potentially in concert with active restoration of native plant species, we may be able to satisfactorily achieve multiple management objectives.

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