Green River Riparian Vegetation below Flaming Gorge Dam: Is there Evidence of Recovery from Serial Discontinuity?

by Heather L. Bowen

ABSTRACT

Riparian vegetation has changed considerably on the Green River between Flaming Gorge Dam and Split Mountain since the closure of the dam. The Serial Discontinuity Concept predicts that river ecosystems recover from regulation impacts with increased distance downstream from the dam (Stanford and Ward 2001). Impacts of the Flaming Gorge Dam on the Green River have resulted in a decline in native Fremont cottonwood (*Populus fremontii*) abundance along alluvial and canyon reaches attributed to modified flow regimes, decrease in suitable sediment, change in suitable soil moisture, increased intra- and inter-specific competition, and increased herbivory. Reduced flood magnitude, number and timing, and increased base flows have resulted in a floodplain morphology that is not conducive to native plant species recruitment. In conjunction with the altered flow regime, an increase in non-native plant species abundance, especially tamarisk (*Tamarix* spp.), has caused channel narrowing throughout the Green River. The Yampa River is the largest tributary providing a natural flow regime in this stretch of the Green River. The Yampa offers sediment and moisture that promotes seed rain and recruitment and reduces island stabilization and channel adjustment. The smaller tributaries may also contribute a small, but less significant source of sediment and flow to the Green River. The stretch of the Green from the dam to the confluence of the Yampa appears to be sediment starved. Though the Yampa confluence does not correct this deficit, it drastically lessens it bringing the sediment budget to a quasi-equilibrium. As a result, experimental studies of the Green River suggest that impacts of the Yampa tributary do influence the recovery of Serial Discontinuity on the Green River.

INTRODUCTION

Riparian zones are transitional areas regularly influenced by freshwater that extend from the edge of water bodies to the edge of upland communities (Naiman *et al.* 2005). Riparian vegetative zones function as extremely important ecosystems that offer high productivity, habitat and act as buffer zones minimizing downstream flooding effects by slowing water and trapping sediment. This paper will discuss the numerous abiotic and biotic impacts of flow regime on the riparia of a regulated section of the Green River from Flaming Gorge Dam to Split Mountain. Impacted components of Green River fluvial processes include sediment transport, soil moisture, competition, and herbivory. This paper will also discuss the relationship between these impacts and the Serial Discontinuity Concept which suggests a positive correlation between an increased distance downstream of the dam and ecosystem recovery (Stanford and Ward 2001).

Background

Construction of Flaming Gorge Dam on the Green River in 1963 resulted in modification of flood frequency, duration, intensity (Uowolo 2005) and timing that directly impacted the establishment of many riparian plant species. Prior to construction of the dam, flow patterns of the Yampa and Green rivers were very similar (Andersen 2005). The high plant species variation resulting from these historic flow regimes is now seen only on the unregulated Yampa River. The effects of hydrologic changes as a result of Flaming Gorge Dam are evident when comparing species diversity and distribution on the Green River to the Yampa River. The Yampa River hydrograph (Fig.4) illustrates a natural flow regime and possible influences on vegetative seed rain, floodplain recharge, and channel adjustments.

The dynamic processes of sediment erosion and deposition result in cleared regions of fresh substrate for colonization of riparian plants. Patterns of erosion and deposition are a product of the geomorphology of the river and vary drastically between canyons and alluvial valleys on the Green River. Since the construction of Flaming Gorge Dam, average sediment supply has been reduced by 57% (Grams and Schmidt 2002), and has shifted from predominantly upstream sources of suspended loads to predominantly

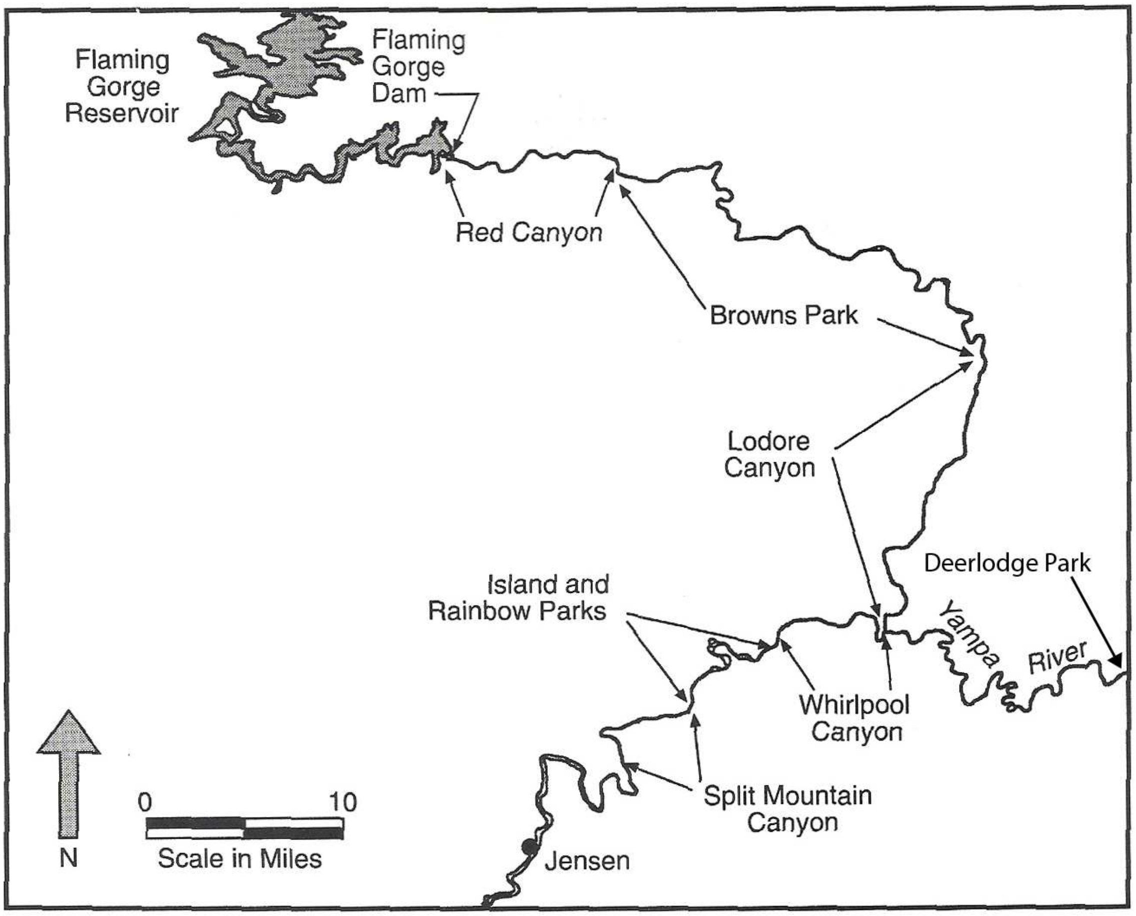

Figure 1. Map of the Green River between Flaming Gorge Dam and Split Mountain Canyon. Including Deerlodge Park on the Yampa River. (Modified from LaGory K.E. and Van Lonkhuyzen 1995)

bank erosion and tributary derived input. River regulation alters the floodplain environment by decreasing recruitment and elevation of native plant species, and increasing invasibility by non-native plants (Uowolo 2005, Decamps *et al.* 1995) primarily because of the difference in life history of native and non-native plants. In addition, the change in erosion and sedimentation has led to channel narrowing as well as a shift toward a marshland community accustomed to prolonged inundation.

The native riparian vegetation of the Green River is extremely sensitive to soil moisture and possesses specific moisture requirements for reproduction and growth. River regulation reduced the scouring peak flows many native riparian plant species of the Green River are adapted to. In addition, regulation has raised base flow levels which increased inundation time.

Native species are adapted to flow regimes that raise the water table and enhance soil moisture (Andersen 2005) but do not maintain a high base flow and allow water levels to recede. Regulated flow regimes do not follow this natural trend of soil moisture and instead may cause physiological stress to native plants by increasing anoxic groundwater conditions. As a result, regulated flows on Green River increase the invasion of non-native plants that are more tolerant of physiological stresses than the native plant species.

Intra-specific competition in cottonwood seedlings for soil moisture also limits their ability to recruit, as does inter-specific competition with non-native plant species. Inter-specific competition is more prominent on regulated rivers where the flow regime is more stressful to native species than non-native species as a result of their individual life histories.

a) b) c) d)

Figure 2. a) Tamarisk (*Tamarix ramosissima)* bordering the Green River and trapping sediment (www.rogerzellmer.com/photo). b) Tamarisk in bloom. Seeds ready to be dispersed in late July through September (http://www.azdot.gov/Highways/NResources/images/Weed_DesertTamarisk_Bloom.jpg). c) Fremont Cottonwood (*Populus fremontii)* native to the Green River (www.treeutah.org/eco_trees.html) d) Cottonwood seeds (http://165.234.175.12/photos/Angiosperms/cottonwood%20cotton.jpg).

RIPARIAN VEGETATION LIFE HISTORIES

Native Plants

Many plants native to the Green River are finding life under water-regulated conditions more difficult than their non-native counterparts. Fremont cottonwood (*Populus fremontii)* (Fig.2c), Box elder (*Acer negundo)* and Coyote willow (*Salix exigua)* are a few native perennials that rely solely on groundwater throughout their entire growing season (Naiman *et al.* 2005).

However, some native seedlings, such as cottonwood, die if subjected to the prolonged inundation (Cooper *et al.* 1999) resulting from regulated flow.

Cottonwood seed rain (Fig.3) begins in mid-June on the Green River at Island Park (Fig.1) and begins in early June at Deerlodge Park just after the Yampa River reaches peak flow stage (Cooper *et al.* 1999). Historically, seed rain coincided with the declining limb of the spring hydrograph on the Green River and the Yampa. As a result of regulation, cottonwood seed rain does not accurately coincide with the declining hydrograph at Browns Park and therefore does not have access to suitable seed beds. Seed rain does coincide with the unregulated hydrograph at Deerlodge Park and the hydrograph at Island Park below the confluence of the Yampa (Cooper *et al.* 1999). Cottonwood seed rain will typically last for the duration of 4-5 weeks on the Green and Yampa Rivers (Cooper *et al*. 1999). Cottonwood seeds (Fig.2d) may not be fully viable when released and may die within 2-3 days if suitable habitat is not found (Taylor 2000).

Non-Native Plants

Tamarisk was introduced to the region of the Green River sometime in the 1930s (Cooper *et al.* 2003) prior to dam construction. The first episode of channel narrowing on the Green River coincided with the introduction of tamarisk (Grams and Schmidt 2005) because tamarisk is more tolerant of harsh environmental extremes than many native species. Tamarisk is a shrub-like tree (Fig.2a) with deciduous foliage and deep, expansive roots that are capable of extracting water from unsaturated soils (Zouhar 2003). This type of groundwater use makes tamarisk a facultative phreatophyte (Zouhar 2003). Even in drought-like conditions, such as those created by dam regulation, tamarisk can exert effective control of stomatal water loss and thus increase their survival (Zouhar 2003). Some researchers have thought that *Tamarix* litter accumulation and salt exudation may increase soil salinity, but that is not found to be impacting cottonwood recruitment in areas of Browns Park (Merritt and Cooper, 2000).

Mature tamarisk are capable of producing several hundred thousand seeds (Fig.2b) in a single growing season which can germinate in less than 24 hours after settling (Zouhar 2003). Research by Cooper and others (1999) found that tamarisk seed rain (Fig. 3) began after, and often corresponded with, the period of maximum cottonwood seed dispersal through out all study sites. Tamarisk seed rain continued until mid-September, extending far beyond the end of cottonwood seed rain in early August (Cooper *et al.* 1999). Tamarisk seeds may remain viable for a minimum of 24 days during harsh conditions (Zouhar 2003).

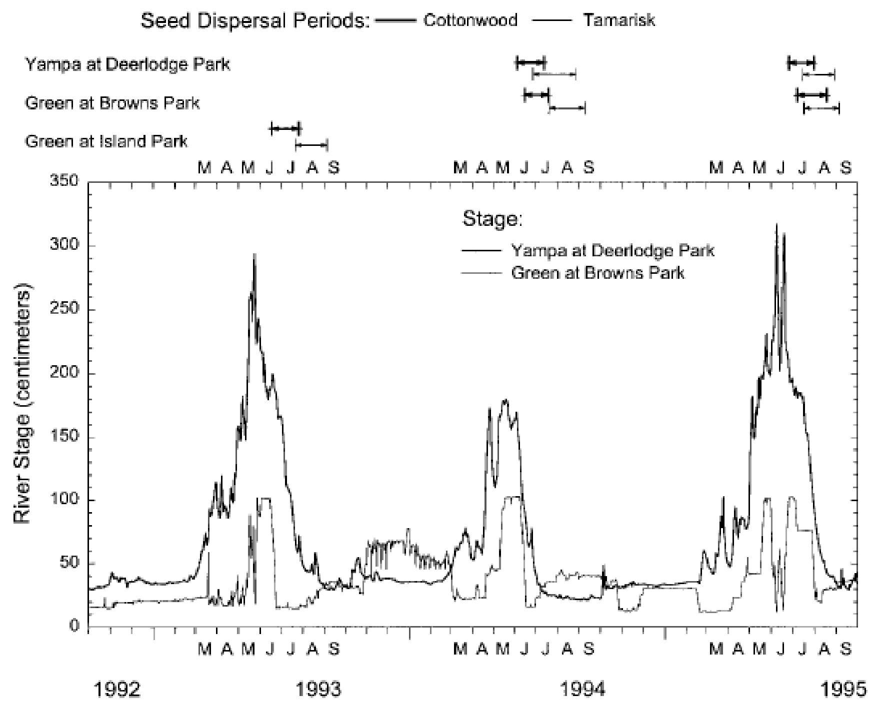

Figure 3. Daily mean stage from Oct. 1993 to Oct. 1995 for the Yampa River in Deer Lodge Park and for the Green River in Browns Park. Period of seed rain shown as horizontal arrows. (Cooper *et al. 1999)*

IMPACTS OF HYDROLOGY

The hydrologic regime of a river is the primary control on the river's riparian vegetation. The spatial and temporal variations of water flow are important to both surface flow and ground water flow due to their impacts on moisture regimes, supply of organic matter and nutrients, sediment dispersion, and terrestrial animals (Naiman *et al*. 2005). Hydrology on the Green River is non-uniform because of the regions unique geology and geomorphology. The river flows through wide meandering sections of low gradient alluvial valleys and quickly alternates to bedrock-confined canyons (Fig.1) where water reaches a greater height (Merritt and Cooper 2000). River regulation by dams typically reduces both annual maximum or peak flow and raises annual low or base flow, reducing the range of water levels available to banks (Cooper *et al*. 1999). Mean annual flow on the Green River has changed only slightly as a result of the dam. However, seasonal variation and mean annual instantaneous peak flow have been reduced considerably, while mean annual base flow has increased (Fig.4) (Merritt and Cooper 2000).

Due to the variation in seed rain between native and non-native plants, the timing and quantity of water at high flows is crucial for recruitment of native plants (Fig.3). Dam regulations have altered not only the amount of water flooding the Green River, but also the timing at which the flooding occurs. Under dam regulations water height during inundation is considerably lower and flood timing ends earlier. Cottonwood and tamarisk seeds are scattered throughout the range of floodplain surfaces and elevations that are left moist as the flow pulse recedes. During years of successful cottonwood germination in Browns Park, seedlings were primarily found on islands and cut-banks as these were the only area with moist surface soils (Cooper *et al*. 1999) and fresh sediment deposits. In years when peak flows lasted through the months of cottonwood seed rain (Fig.3), seeds were unable to recruit because of prolonged island inundation. This in turn fueled recruitment of tamarisk which germinated later and were able to settle during the declining hydrograph (Cooper *et al*. 1999). This pattern was not seen at Deerlodge Park on the Yampa or below the Yampa confluence probably because of the natural flow variation provided by the Yampa River (Fig.4) (Cooper *et al*. 1999). Modifications in hydrologic processes could potentially affect every stage of recruitment from quantity and quality of seed rain to the growth and survivorship of seedlings (Cooper *et al.* 1999).

Terrace formation

As a result of regulated flow, the pre-dam floodplain is no longer participating in active recruitment and because of bank erosion is now a defined terrace (Grams and Schmidt 2005). The formation of new floodplain elevations are the result of lower flows and recruitment of non-native species such as tamarisk. The lowest elevation floodplain referred to as the *post-dam floodplain* by Grams and Schmidt (2005) is covered with annual vegetation and active sediment (Fig.5). This bench becomes inundated yearly with Flaming Gorge Dam's peak discharge of 130 m^3/s. The *intermediate bench* is higher in elevation and becomes inundated between the volumes 130 m^3/s and 340 m^3/s. Since 1963 this was only seen in four years (Grams and Schmidt 2005). The *post-dam*

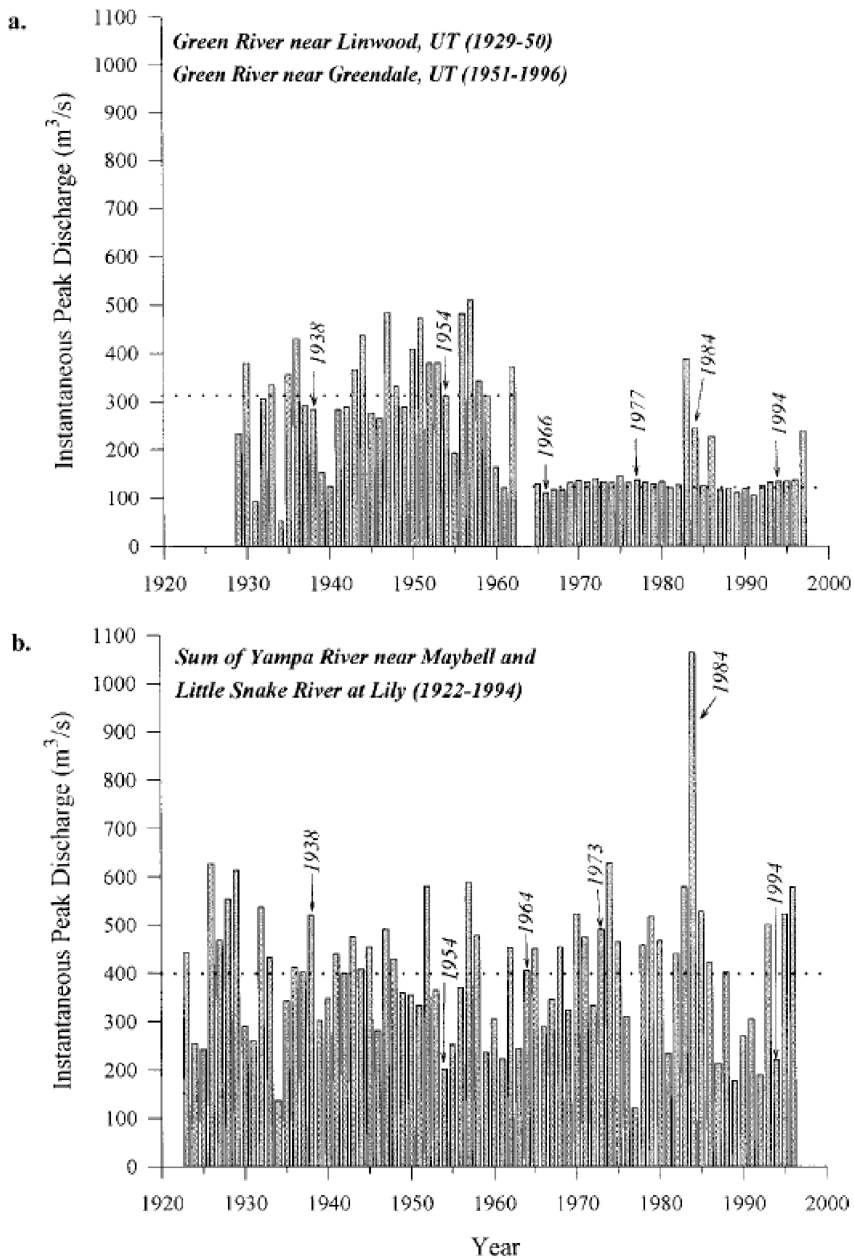

Figure 4. Instantaneous peak discharge for the a) Green River in Browns Park and the b) Yampa River at Deerlodge Park

floodplain and the *intermediate bench* are both primarily inhabited by perennial woody vegetation. Tamarisk, willow and to some extent cottonwood are found on these floodplains because of the available soil moisture and sediment deposits. The high-elevation, *cottonwood-boxelder terrace* (Fig.5) has not been inundated since the construction of Flaming Gorge Dam. Inundation of this terrace requires flows greater than 340 m³/s (Grams and Schmidt 2005). This terrace is mostly occupied by mature cottonwood in the meandering reaches and box elder in the canyon regions (Grams and Schmidt 2005).

Diversity of riparian vegetation is also greatly correlated to the hydrology of the river and resulting land formations. A large percentage of riparian species found bordering the Green River are also found along the Yampa. However, less than half of the species along the Yampa can be found on the Green (Uowolo *et al*, 2005). On the Green, cottonwood populations are consistently seen at higher elevations. However, on the Yampa River, Merritt and Cooper (2000) found cottonwoods present at all elevations. Uowolo and others (2005) concluded that hydrologic regulation accounted for the major differences in diversity between regulated and unregulated rivers such as the Green and Yampa Rivers.

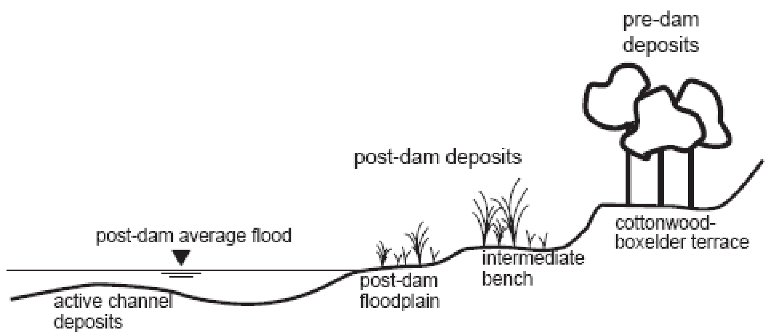

Figure 5. Sketch of mapped geomorphic levels and the stage of post-dam average flood (Grams and Schmidt 2005).

Sediment

Riparian vegetation relies on sediment erosion and deposition during periods of high flows to destroy and create suitable seedbeds (Cooper *et al.* 1999; Campbell and Green 1968; Hupp and Osterkamp 1996; Scott *et al.* 1996). Prior to dam construction, both the Yampa and Green rivers peak flows were able to carry large amounts of suspended sediments and bed load sediment (Cooper *et al.* 1999). Since the construction of Flaming Gorge dam, upstream sediments are now trapped behind the dam, resulting in a significant decrease in sediment load (Cooper *et al.* 1999) available to downstream reaches. Existing sediment contributions on the post-dam Green River below Flaming Gorge Dam are derived from the river bed, banks, debris-fans, and tributaries (Grams and Schmidt 2005).

In addition to magnitude and frequency of flooding, the geomorphology of parks and canyon regions affect sediment transport and storage (Elliot and Anders 2004).The reduced flood magnitudes have allowed for stabilization of active channels by riparian vegetation in the *post-dam floodplain* and the *intermediate bench* (Grams and Schmidt 2005). Flow regulation has also resulted in a reduced number of scouring flows that remove new vegetation and mobilize sediment. Large flows such as those seen in 1984 (Fig.4) scoured bars and deposited sediment that later facilitated cottonwood recruitment (Cooper *et al.* 2003).

Canyon regions such as Red Canyon and Lodore Canyon (Fig.1) are regions dominated by debris-fans. These sediment deposits contribute to the aggradation of the *post-dam floodplain* (Grams and Schmidt 2005) in alluvial reaches. Below Red Canyon, small tributaries such as Red Creek and Vermillion Creek contribute fine sediment to Browns Park during periods of snow melt and summer rainstorms (Merritt and Cooper 2000). These restricted meandering areas, such as Browns Park, undergo channel narrowing primarily by mid-channel islands and side channel sediment accumulation (Grams and Schmidt 2005). The reduced peak flows result in the stabilization of these sediment accumulations by vegetation colonization (Fig.6). Dominant plant species associated with these islands include common spikerush (*Eleocharis palustris),* knotted rush *(Juncus nodosus),* common threesquare *(Schoenoplectus pungens),*and narrowleaf willow *(Salix exigua)* (Cooper *et al.* 2003). Reduced magnitude and frequency of discharge have caused the deposit of fine sediment in eddies behind islands in Browns Park, enlarging them in the downstream direction. As channel narrowing continues (Fig.6) in these low gradient regions, the resulting erosion of the *cottonwood-box elder terrace* increases (Grams and Schmidt 2005).

Prior to dam closure, channel width, and island and point bar formation were similar in Browns Park and Deerlodge Park (Merritt and Cooper 2000). Today, as a result of flow regulation, riparian vegetation driven channel narrowing (Fig.6) has been described in nearly all reaches downstream of Flaming Gorge Dam (Grams and Schmidt 2005). Two large known events of channel narrowing directly relate to the non-native vegetation. In the 1930s during a natural period of low flows, tamarisk introduction is thought to have been the first cause of channel narrowing. Following dam construction in 1963, there was a period of a few years when little to no discharge was released as the reservoir was being filled. During this time previously active islands and point bars in Browns Park were colonized (Merritt and Cooper 2000) by tamarisk and other non-native species (Grams and Schmidt 2005) leading to a reduction in average channel width (Fig.6). As a result, channel width throughout the Green River has reduced and the reach is considered to be actively changing from meandering to braided (Merritt and Cooper 2000; Schumm 1977; Friedman *et al.* 1998).

The active channel area of the Yampa in Deerlodge Park appears much the same today as it did in photographs taken in 1938, thought the channel has migrated laterally with vertical cutbanks on the outside of bends and floodplain deposition on the inside (Merritt and Cooper 2000). Riparian vegetation species that established in these formerly active channel regions primarily include cottonwood and willow (Merritt and Cooper 2000). Sediment contribution to riparian zones on the Yampa is attributed primarily to bank erosion by overbank flooding, and headwater and tributary sediment loads (Arp and Cooper 2004). Unlike the post-dam Green River, sedimentation and erosion on the Yampa are nearly balanced on an annual time scale (Arp and Cooper 2004).

The Yampa River is an important contributor to the sediment budget and riparian vegetation of the Green River below their confluence. Historically, it is thought that the Yampa contributed about the same amount of sediment and flow as the Green River above their confluence (Grams and Schmidt 2005). Construction of Flaming Gorge Dam caused a severe sediment deficit on the Green River that is lessened below the confluence by the contribution of the Yampa (Grams and Schmidt 2005).

Sediment deposition and erosion is also important to the flux of mineral and organic matter (Arp and Cooper 2004). Riparian vegetation may function to maintain water quality by retaining nutrients and other compounds with sediment storage (Arp and Cooper 2004). In riparian areas nitrogen and organic matter is imported by trapping sediments, and surface runoff from surrounding areas (Adair *et al.* 2004; Walker 1989; Brunet *et al.* 1994; Vought *et al.* 1994; Pinay *et al.* 1995; Tremolieres 1998).

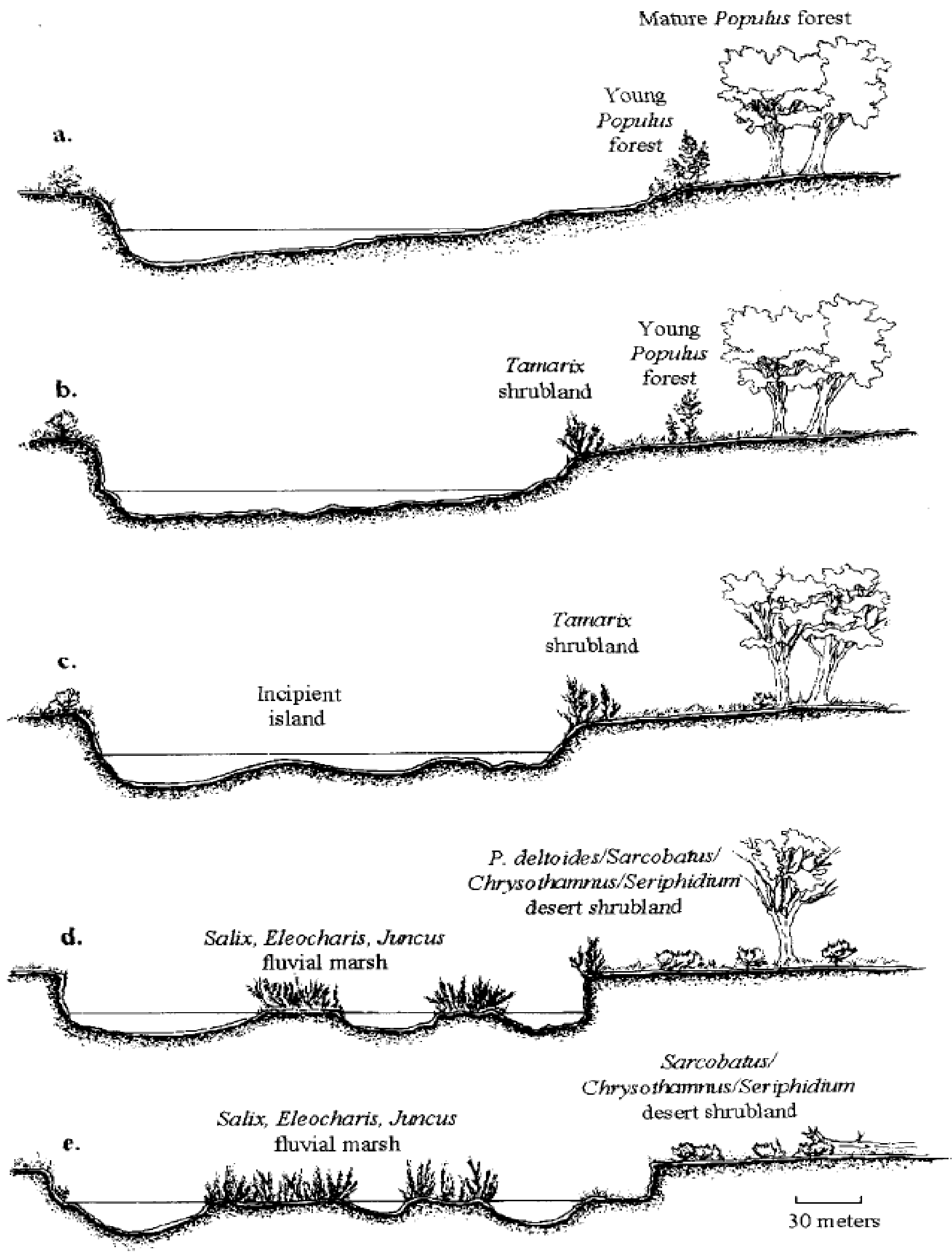

Figure 6. Model of channel adjustment resulting from flow regulations on the Green River in Browns Park. (a) shows the pre-dam meandering channel. (b) shows channel narrowing and the beginning of terrace formation, including non-native species, as a result of dam closure. (c) and (d) show continued channel narrowing including island and bar stabilization by marsh riparian vegetation (Merritt and Cooper 2000).

Soil Moisture

Soil moisture is vital for recruitment of cottonwood and other native plants because of their dependence on groundwater for most of the year. Cooper and others (1999) found that the rate of decline of the groundwater table in areas that support cottonwood seedlings was identical to the rate of river stage decline. As a result of the dam, soil moisture will either reduce quickly or remain inundated for extended periods (Fig.3). In Browns Park, successful germination of cottonwood seedlings was restricted to islands and steep cutbanks, but Copper and others (1999) found no cottonwood seedling survivors in these regions the next year. In 1994 Merritt and Cooper (2000) found that inundation of islands and mid-channel deposits in Browns Park lasted three times longer than inundation in Deerlodge Park. Prolonged inundation, as a result of increased base flows during the growing season, is thought to have caused high seedling mortality in Browns Park (Cooper *et al.* 1999), possibly because seedlings find prolonged submersion in anoxic groundwater too stressful (Andersen 2005). In support of this theory, Merritt and Cooper (2000) found that maximum water table depth was never greater than 0.5m in Browns Park but water table depth exceeded 1.5m in Deerlodge Park during late summer. Mortality at Deerlodge Park and Island Park was not the result of prolonged inundation (Cooper *et al.* 1999), since the groundwater table recharged by Yampa River floods was able to significantly reduce over time. In these regions, seedling mortality was primarily caused by desiccation or substrate erosion during high flows in the following growing season (Cooper *et al.* 1999). Today the actively accreting bars and backwaters that support cottonwood recruitment and survival in Deerlodge Park and Island Park, are all together absent in Browns Park (Cooper *et al.* 1999) as a result of regulated flows.

Andersen (2005) found that the reduction in soil moisture on the Green River above the Yampa confluence caused structural adjustment of mature cottonwood. Historical cottonwood forests are thought to have supported greater leaf area and higher tree density. This trend is seen on the Yampa River, but is unlike cottonwoods found on the Green River today (Andersen 2005). Existing cottonwoods on the regulated Green River have adapted to drought conditions by implementing massive dieback of leaves, branches and roots in the upper soil profile (Andersen 2005). These drastic adaptations to reduced water availability are not, however, sufficient to sustain cottonwood establishment (Andersen 2005) when competing with physiological adaptations such as those of non-native tamarisk.

Competition

River regulation further complicates native riparian plant lifestyles by increasing abundance of highly competitive species such as tamarisk (Cooper *et al.* 1999). Nevertheless, both intra- and inter-specific competition may be effecting recruitment of cottonwood seedlings. Cooper and others (1999) found that all seedlings germinating beneath older cottonwood cohorts on bars and in backwaters suffered nearly 100% mortality, resulting from lower gravimetric water content beneath previously established cottonwoods.

The difference between seed dispersal timing of native and non-native plants, as well as their different physiological water efficiency (Cooper *et al*. 1999) are important inter-specific competitive effects that may be inhibiting native riparian vegetation recruitment. An overlap in tamarisk and cottonwood seed dispersal along the Green River, results in mixed-species seedling populations (Cooper *et al.* 1999). Early summer peak flows increase cottonwood recruitment, whereas mid to late summer flows promote tamarisk recruitment (Cooper *et al.* 1999). In mixed populations, tamarisk fares better than cottonwood because of its comparatively superior survivorship when water is limited (Cooper *et al*. 1999; Busch and Smith 1995). As a facultative phreatophyte, tamarisk is able to out-compete native obligate phreatophytes, such as cottonwood, (Zouhar 2003) for available soil moisture. In low water years when there is little groundwater for cottonwood recruitment and in high water years when bars remain inundated for extended periods of time, tamarisk is able to establish while cottonwood is not.

Herbivory

Many organisms use riparian areas as habitat. The species assemblage on the Green and Yampa Rivers using the riparian vegetation range from large mammals such as moose and elk, to medium sized mammals such as beaver and rabbit, to small mammals such as mice and rats, and even non-mammal species such as beetles, geese and carp (Andersen and Cooper 2000). Some of these herbivores, such as elk, moose, beaver and rabbits, are known for their consumption of cottonwood and willow (Andersen and Cooper 2000). Andersen and Cooper (2000) found a reduction in sapling survivorship by small mammals at Island Park, but found small mammals had no detrimental affect at Deerlodge Park. Impacts of both medium and large mammals were found at both Island Park and Deerlodge Park.

Mammals were found to have a larger detrimental effect on sapling survivorship at the regulated Browns Park and Island Park than at the unregulated Deerlodge Park, possibly because effects of mammals at Deerlodge Park were masked by the reduction in sapling height by beetles (Andersen 2005). Andersen (2005) found a negative impact of leaf beetle herbivory on cottonwoods at Deerlodge Park and postulated a correlation to large flood events. For an overwhelming population of leaf beetle to occur, there must also be a large number of cottonwood germinants which only appear after a large flood.

Flooding of various degrees temporarily removes non-climbing mammals, such as voles, from a sapling site. As a direct result of reduced magnitudes of flooding on the Green River, a high abundance of voles and rabbits at Island Park were found to reduce cottonwood survivorship by clipping saplings (Andersen and Cooper 2000). A small amount of increased flow may be enough to remove these small mammals from a site, however, increasing floodwaters may promote visitation by aquatic herbivores (Andersen and Cooper 2000).

Beaver herbivory, present at all alluvial sites on the Green and the Yampa, is clearly tied to flow regime since the river level determines the level of access to saplings (Andersen 2005; Breck *et al.* 2003). Browns Park is more susceptible to sapling cutting by beaver than Island Park and Deerlodge Park (Andersen 2005) because of the intense flow regulation seen in this region by Flaming Gorge dam. The reduced magnitude of flooding results in a reduction of distance between saplings and the river margin (Andersen 2005) making saplings at Browns Park available at lower elevations than at Island Park and Deerlodge Park. However, Andersen and Cooper (2000) found that plants cut by beaver remained alive. In addition they found evidence suggesting Fremont cottonwood in particular appeared to be resilient to stem damage.

MANAGEMENT FOR RIPARIAN VEGETATION

Prior to the construction of Flaming Gorge Dam, tamarisk invasions were already impacting the Green River. Effects of non-native riparian vegetation are reduced on the Yampa River primarily because of the unregulated flow regime present there. There is evidence suggesting that dense tamarisk patches prevent the recruitment of cottonwood by depleting soil moisture (Cooper *et al.* 1999) and can change channel and floodplain sediment storage (Cooper *et al.* 2003).

Flows needed to recruit seedlings are different from those needed to sustain sapling and adult trees (Stromberg and Pattern 1991; Andersen 2005) and different than those needed to minimize herbivory. Management flow regimes should maximize resources for both seedlings and saplings and minimize potential for herbivory. Management flow regime designs for the Green River should include inter-annual variability for desired biodiversity and reduced herbivore interactions (Andersen 2005), and also recharge floodplain moisture and sediment by way of long floods or rapid succession of flooding. Such hydrographs may maintain the active channel and therefore increase recruitment by native plant species and reduce establishment of non-native species. Increased magnitude of flooding during appropriate times will also increase the event of scouring, sediment deposition and soil moisture that would be suitable for cottonwood establishment. Sustainable cottonwood recruitment would then depend upon subsequent high flows in following years to provide adequate soil moisture (Cooper *et al.* 1999).

Management flows proposed by the Bureau of Reclamation Final Environmental Impact Statement in 2000 do not adequately attend to the restoration of the Green River riparian vegetation above the confluence of the Yampa River. The Bureau of Reclamation's flow recommendations for Reach 1 above the Yampa confluence, suggest maximum spring flows during a wet year of 244 m^3/s (USBR 2006). This magnitude is not large enough to inundate higher elevations such as the *cottonwood-boxelder terrace,* and has merely a 10% chance of occurring. Flood duration specified in Reach 1 is dependent on the amount of water being received by Reach 2 below the confluence (USBR 2006). The resulting duration may not be adequate for the formation of suitable cottonwood seedbeds and groundwater recharge. In Reach 2 below the Yampa confluence, the Bureau of Reclamation suggests flow duration of a minimum of four weeks (USBR 2006), but does not specify a maximum duration. This may result in prolonged inundation through the period of cottonwood seed rain, causing reduced cottonwood recruitment and increased tamarisk germination. Inter-annual variation is also very important, as is a reduction in base flow levels. Current recommendations attempt to incorporate both, but again fail to adequately address the reach above the confluence of the Yampa. The managed flow recommendations, though they may possibly benefit the native riparian vegetation, may not reduce existing non-native vegetation abundance. Therefore a plan to excavate existing tamarisk should also be considered.

CONCLUSIONS

Riparian communities on the Green River in Utah have greatly changed since the closure of Flaming Gorge Dam in 1963 as a direct result of the regulated flow regime. The divergence of the Green River away from its natural hydrograph has strongly effected sedimentation, soil moisture, competition and herbivory along its reaches and ultimately results in less riparian diversity. The consequent sediment stabilization has lead to an overall change of the river from meandering to braided, and an increased rate of invasive plant species and decreased recruitment by native species. Regulated flow has caused marsh-dominated islands and shrub dominated floodplain terraces (Merritt and Cooper 2000). As a result of absent inundation, pre-dam floodplains are acting as sources of sediment to the suspended sediment load that is ultimately being deposited mid-channel.

The Yampa River offers a large amount of sediment and flow variation that have helped to reset the system below the confluence. Compared to historical sediment budgets, the Yampa River today is the primary contributor of natural flows to the Green River offering cottonwood recruits available sediment and nutrients. Cottonwood seed rain below the confluence of the unregulated Yampa closely follows the declining hydrograph, increasing cottonwood recruitment and precluding tamarisk establishment. However, release from the power plant still maintains a relatively higher base flow below the confluence, often prolonging inundation of some islands and therefore promoting the presence of non-native plant species and marsh vegetation in these regions. Effects of Flaming Gorge Dam on native riparian vegetation are lessened below the confluence of the Yampa River suggesting some recovery of the Green River from Serial Discontinuity.

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