Macall Teague

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Term Paper

The Colorado River Delta:
Examining Past and Current Conditions and Exploring Restoration Strategies

Introduction

The Colorado River Delta has been significantly impacted by the altered stream flow of the Colorado River. Historically, the river flowed from its headwaters in the Rocky Mountains of Colorado, through the southwestern United States, into the Gulf of California, supporting rich ecosystems of plants and animals along the way. The Colorado River is a critical source of water throughout the southwestern United States and has been heavily diverted to support agriculture, hydroelectric power, and urban use throughout seven states and parts of Mexico (Luecke et al. 1999, Meko et al. 1995). Today, diversions from the Colorado River supply water to roughly 40 million people, irrigate more than 5.5 million acres of land, and produce more than 4200 megawatts of hydropower (U.S. Department of the Interior 2012, Kendy et al. 2017). As a result, water levels within the river have been greatly reduced, causing the once-lush wetland and riparian habitats of the delta to dry up, resulting in a loss of habitat for many species (Hinojosa-Huerta et al. 2013). This 1,440-mile river and its 244,000 square-mile watershed has more water diverted from it than any other river basin within the United States while also flowing through some of the most arid land in the country (Meko et al. 1995). These diversions, coupled with high evaporative losses, have significantly reduced the quantity and quality of water entering the delta.

The Colorado River Delta was once a large desert estuary covering 780,000 hectares, consisting of vast networks of diverse ecosystems including brackish and freshwater wetlands, riparian corridors, and intertidal zones near the Gulf of California (Glenn et al. 1996). As much as 70% of the Colorado River's silt load was deposited in the delta, creating rich soils and vast, fertile habitats (Luecke et al. 1999). In addition, the interaction between the river and the Gulf of California created miles of tidal estuaries which served as rich breeding grounds for marine animals (Ezcurra et al. 1988). The highly variable precipitation regimes and flood cycles within the Colorado River watershed created dynamic ecosystems populated by a diverse array of resilient plant and animal species (Luecke et al. 1999). MacDougal (1907), an early explorer of the delta, estimated the delta was once home to 200-400 species of plants and documented large quantities of wildlife including migratory birds, beavers, jaguars, and fish. Additionally, the delta is home to endangered species such as the desert pupfish (*Cyprinodon macularis*), totoaba (*Totoaba macdonaldi*) and vaquita, an endemic species of porpoise (*Phocoena sinus*) (Carriquiry and Sánchez, 1999).

The highly variable flows of the Colorado River were dependent on rainfall and snowmelt within the watershed. Prior to the installation of dams, instantaneous flows into the delta could vary from near zero to 6000 m^3 per second, with annual flows averaging 20.7 x 10^9 m^3 per year from 1986-1921 (Glenn et al. 1996). The construction of the Hoover Dam (1931-1936) marked the beginning of profound change for the Colorado River. For six years after the construction of Hoover Dam no water flowed into the delta as water was captured for the filling of Lake Mead (Glenn et al. 1996). This was again repeated after the construction of Glen Canyon Dam where, from 1963 to 1981 as Lake Powell filled, water was prevented from entering the delta (Glenn et al. 1996). These events were causes of major ecological damage as the ecosystem dried and native vegetation began to desiccate (Glenn et al. 1996). Whereas water previously flowed freely and unincumbered into the delta, the Colorado River is now impeded by 10 dams and over 80 major diversions (Luecke et al. 1999). Even after the reservoirs were filled, the once variable flow to the delta became highly regulated and lacked transport of essential sediment and nutrients (Glenn et al. 1996).

Current Conditions of the Delta

The effects of human-use on the Colorado River have affected the delta in many ways, including reducing the flows of freshwater inputs, decreasing biodiversity, and altering sediment transport. Due to the overallocation of Colorado River water, the delta has experienced a nearly 75 percent decrease in annual flows (Luecke et al. 1999). The delta today encompasses roughly 150,000 acres and is situated in a desert region between the Cucapá Mountains to the west and the Sonoran Desert to the east (Zamora-Arroyo et al. 2001). The climate is characterized by having low annual rainfall, mild winters, and hot, dry summers (Hinojosa-Huerta et al. 2013, Nelson et al. 2013). In this arid climate evaporative losses are high, leading to additional water loss from this already water-limited system. Today, the delta is surrounded by nearly 500,000 acres of agricultural fields in the Mexicali and Imperial Valleys which provide critical inputs into the delta via agricultural runoff and wastewater (Stromberg 2001). Collectively, the reduced flows, high evaporative losses, and introduction of agricultural drainage water within the delta have led to increases in soil and water salinity.

The decrease in the quantity and quality of water entering the delta has had significant impacts on native vegetation. These changes have altered the distribution and abundance of native plant species, leading to large scale colonization of invasive species throughout the delta (Glenn et al. 1999). By the 1970s, areas once inundated with water were transformed into dry, barren, ground colonized heavily by invasive species (Glenn et al. 1996, Kendy et al 2017). The remaining wetlands within the delta are both natural and anthropogenic (i.e. human engineered) and are fed predominantly by artesian springs, agricultural drainage water, and tidal flows from the Gulf of California (Glenn et al. 1999). The water that reaches the delta is devoid of nearly all silt and nutrients (Luecke et al. 1999). This reduction in silt deposition is increasing the rate at which the delta is eroding, resulting in greater rates of erosion than accretion, furthering habitat loss (Thompson 1968, Luecke et al. 1999). The losses and fragmentation of wetland and riparian habitats have been profound, with habitats for native species such as cattails (*Typha domengensis)*, common reeds (*Phragmites australis*), cottonwoods (*Populus fremontii*), willows (*Salix gooddingii*), and mesquite (*Prosopis glandulosa and P. pubescens)* being reduced by 95 percent (Luecke et al. 1999).

Collectively, these conditions have led to changes in vegetation composition as competition for limited resources increase amongst native and invasive species. Species more tolerant to salinity and drought conditions, such as salt cedar (*Tamarix ramosissima)* and iodine bush (*Allenrolfea occidentalis*), have become more common while native species that require more water, such as cottonwoods and willows, have declined (Glenn et al. 1996). Today, the once lush riparian corridor within the delta has long reaches of dry, bare channels that are inundated with salt cedar and contain only a few sparse stands of native cottonwood and willow (Glenn et al. 1996, Kendy et al. 2017).

These reductions in habitat and native vegetation have also impacted wildlife that depend on the delta's ecosystems (Hinojosa-Huerta et al. 2013). Bird populations that depend on the delta for nesting, breeding, foraging, and winter stopovers have declined as habitat extent has declined (Hinojosa-Huerta et al. 2013). In addition to negatively affecting wildlife, invasive species can also alter the physical structure of habitats by changing soil composition, vegetation density, and water availability (Zamora et al. 2001, Stromberg 2001, Hinojosa-Huerta et al. 2013). Areas colonized by salt cedar are also more prone to burning, increasing the occurrence of fire events in the delta (Nagler et al. 2005). Salt cedar can spread fire rapidly and resprouts quickly following fires, whereas native species are less fire adapted (Nagler et al. 2005). When fires become more frequent, this can further repress the recruitment of native species, increasing levels of invasive colonization throughout the delta (Nagler et al. 2005). This can increase the degradation or loss of native habitats and impact the distribution and abundance of native species.

Habitat loss and degradation is one of the leading causes of population decline for migratory birds in North America and is the primary threat cited for most of the bird species listed under the Endangered Species Act (Darrah et al. 2017). Riparian areas are of significant importance to migratory birds traveling between their breeding grounds in the northern United States and Canada and their wintering grounds in Central or South America (Darrah et al. 2017). Nearly 200,000 shorebirds and 60,000 ducks and geese use the delta annually (Morrison et al. 1992, Mellink et al. 1997). Additionally, at least 110 species of neotropical migratory land birds visit the delta during their migratory movements (Patten et al. 2001). Changes in riparian habitat due to anthropogenic alterations of hydrologic regimes is a main driver of habitat loss and can strongly affect the composition and phenology of vegetation (Stromberg 2001, Zamora-Arroyo 2001, Darrah et al. 2017). Food availability is a key component of habitat quality because it can dictate which populations of bird species are able to utilize the habitat (Darrah et al. 2017). This is especially true for small migratory birds, many of which rely on the delta and whose ability to carry fuel and store reserves is exceeded by the energy demands of long-distance migration (Darrah et al. 2017). This emphasizes the need for high-quality bird habitat with robust native vegetation populations within the delta that allows for replenishment of fat reserves (Lindström 2003). Native trees provide superior habitat and food sources for birds than the invasive salt cedar and the phenology of native vegetation better aligns with migratory patterns than non-native vegetation (Darrah et al. 2017). This highlights the importance of successful recruitment of cottonwood and willow seedlings, which have been shown to sustain growth into maturity after establishment when salinity and shallow groundwater levels are favorable (Zamora-Arroyo et al. 2001).

Restoration Efforts in the Delta

The main strategies implemented in an effort to restore the delta include planned water releases, habitat restoration, community-based restoration, and sustainable water management. Successful restoration of the Colorado River Delta is dependent on binational collaboration between the United States and Mexico. In order to restore the Colorado River Delta, strategies have been implemented by nongovernmental agencies (NGOs), the U.S. Bureau of Reclamation, and Mexico’s National Water Commission amongst others (Zamora-Arroyo et al. 2005). These strategies include water management practices to increase stream flow and sediment transport, wetland restoration to reduce surface water loss, and habitat restoration to increase the abundance and diversity of native species (Zamora-Arroyo et al. 2005).

In November 2012, Minute 319: Interim International Cooperative Measures in the Colorado River Basin, was signed by the International Boundary and Water Commission (IBWC), comprised of representatives from both the United States and Mexico (IBWC 2012). This five-year agreement allocated a total of 195 million cubic meters (Mm^3) of water to the Colorado River Delta between 2013-2017 through base flow or pulse flow applications (IBWC 2012). The difference between pulse flows and base flows are their volume and duration. Pulse flows are high-volume events where approximately 130 Mm^3 of water is released into the delta over the course of an eight-week period. Base flows are low-volume events where roughly 65 Mm^3 of water are released over the course of several months (IBWC 2012).

Per the Minute 319 agreement, the United States and Mexico agreed to each provide a one-time allocation of 130 Mm^3 to be delivered as a pulse flow and a coalition of NGOs agreed to provide 65 Mm^3 of water to be administered as base flows (Kendy et al. 2017). These water releases have been timed to coincide with the annual spring floods to emulate the natural flooding that once replenished the delta's ecosystems. On March 23, 2014, Morelos Dam was opened and delivered the first pulse flow to the delta (IBWC 2012). In conjunction with this pulse flow, scientists monitored streamflow discharge and its impacts, including groundwater recharge, native vegetation germination and survival, evapotranspiration rates, channel and floodplain disturbance, and the effects on migratory bird populations (Kendy et al. 2017).

Prior to the pulse flow, scientists collected baseline data to help assess changes induced by the application of water (Kendy et al. 2017). In total, 4000 acres were inundated with water from the pulse flow, many of which had been dry since the last El Niño events in 1998 when water was released into the delta by the U.S. Bureau of Reclamation (Pitt et al. 2017). Although many acres were successfully wetted, the spatial extent of the coverage was not consistent across the landscape. For example, hydraulic models predicted that the flow would inundate 1400 acres near the Laguna Grande restoration complex, yet empirical measurements indicated that only 650 acres were successfully wetted, less than hypothesized

(Kendy et al. 2017). This is in part due to variations in hydraulic conductivity across the delta, as well as differences in microtopography and floodplain disturbances (Kendy et al. 2017). It was estimated that 94 percent of the 130 Mm^3 released infiltrated the soil profile and served to recharge both soil water and groundwater. This was evidenced by the nearly nine-meter increase in local groundwater levels that occurred shortly after the pulse flow took place (Pitt et al. 2017).

One method under evaluation was passive restoration, where no treatments aside from added water were implemented. For this method, natural recruitment of native tree species was evaluated. Cottonwood and willow seedlings require saturated, bare soils, and access to a shallow groundwater table for successful germination and recruitment through the growing season (Glenn et al. 1996, Kendy et al. 2017). Results indicated that the pulse flow did not contain sufficient velocity to scour stands of existing invasive vegetation, resulting in cottonwood-willow germination occurring in fragmented areas with bare soils that had undergone pre-pulse disturbances, such as fire (Kendy et al. 2017). Overall, natural recruitment of cottonwood and willows was low and only occurred at five out of 19 experimental transects (Kendy et al. 2017). Additionally, many areas that did have successful germination did not have sufficient access to shallow groundwater, leading to eventual desiccation (Shafroth et al. 2017). Conversely, salt cedar had successful germination and recruitment at 16 out of 19 experimental transects indicating that pulse flows in the absence of active land management could further increase the presence of this invasive species (Shafroth et al. 2017).

Shafroth et al. (2017) suggest that in addition to pulse flows, active land management must also be done in order to increase areas with bare ground and create favorable conditions for germination. Their study showed that in the absence of active land management, the pulse flow was only minorly successful at promoting the recruitment of new riparian seedlings. The primary reasons driving low levels of native species recruitment were attributed to little or no viable seed present in the seedbank for some species, insufficient soil moisture, insufficient groundwater levels throughout the growing season, and increased competition from established vegetation (Shafroth et al. 2017). Restoration of native vegetation was most successful in sites of active management and restoration. Previously, when water was delivered to the delta during high-flow years, little to no warning was given prior to the release, making active management difficult and unfeasible (Pitt et al. 2017). One of the benefits of the pulse flow is that it allows for advanced planning and site preparation prior to the release of water. The results from Shafroth et al. (2017) indicate that restoration of native vegetation was most successful in sites where non-native vegetation was mechanically cleared and where channels were graded and reconnected to the main river channel. Implications from this study show that future management decisions would benefit from leveraging quantitative modeling approaches which link seedling recruitment success with local hydrology in a spatially explicit way (Shafroth et al. 2017). Additionally, local communities have also been involved in restoration efforts through the establishment of community-led conservation programs (Zamora-Arroyo et al. 2001). NGOs have cultivated community support for these programs, and have provided opportunities for local residents to aid in the restoration of degraded habitats, extend outreach to promote sustainable use of natural resources, and provide further economic restoration-oriented opportunities for local residents, including work at native nurseries (Zamora-Arroyo et al. 2001).

Discussion and Conclusion

The Colorado River Delta has undergone major transformational changes due to upstream diversions of the Colorado River. This once vast desert estuary has been reduced in extent, species richness, and habitat quality. Many species, including migratory birds (some of which are listed as threatened or endangered), rely on the delta for breeding grounds, winter stopovers, and forage sites. The binational agreement between the United States and Mexico led to the Minute 319 agreement, allocating roughly 325 Mm^3 of water to the delta between 2012-2017. These flows proved in March 2014 proved to be hugely beneficial, both in terms of ecological restoration and also in terms of opportunity for scientific research.

The results from experiments conducted after the 2014 pulse flow demonstrate that deliveries of water will have more significant impact when coupled with active management actions to improve restoration outcomes (Schlatter et al. 2017). In order to ensure successful germination of riparian tree species, areas should be cleared of all salt cedar stands, soils should be graded and cleared of any existing salt crust, and availability of viable seed should be ensured (Schlatter et al. 2017, Shafroth et al. 2017). Additionally, identifying conservation priorities will help to inform and guide restoration efforts throughout the delta (Zamora-Arroyo et al. 2001). Setting these site-specific conservation priorities includes identification of key species, biological processes, and habitats to be restored as well as setting restoration benchmarks and goals (Zamora-Arroyo et al. 2001). Key recommendations for future restoration efforts on the Colorado River Delta include: dedication of annual water in the forms of pulse flows and base flows, removal of invasive salt cedar stands prior to the application of water, development of a native seedbank and nursery, further study sediment transport in order to maximize ecological benefit of dedicated flows, incentivize neighboring land owners to improve riparian habitat on their land adjacent to the river, and encourage local community engagement in restoration efforts through seed collection, invasive species removal, and restoration of native riparian forests (Zamora-Arroyo et al. 2001, Pitt et al. 2017, Schafroth et al. 2017).

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