Trout Management in the Colorado River below Glen Canyon Dam

By David M. Epstein

ABSTRACT

Introduced trout have become increasingly important to the Colorado River below Glen Canyon Dam, Arizona. The presence of a multi-million dollar rainbow trout (*Oncorhynchus mykiss*) fishery in the Lee's Ferry tailwater influences much of dam management activity. Since the closure of Glen Canyon Dam, different flow regimes have altered the composition of the trout population. Current flows are designed to enhance the fishery to best suit the desires of anglers. Trout are found in decreasing numbers all the way down to Lake Mead, but little is known about the ecology of trout outside of the tailwater. The implementation of other management tactics such as the "trout removal program" centered at the mouth of the Little Colorado River, aims to reduce trout densities in critical habitat areas for Humpback Chub (*Gila cypha*). Contradicting management actions make it difficult to understand fisheries management objectives. With one of its many goals to harm exotic fish populations, the 1996 flood release failed to decrease trout numbers. Since 2003, the winter flow hydrograph out of Glen Canyon Dam has been altered completely with hopes of creating a healthier tailwater trout population composed of bigger fish. These fluctuating winter flows have proven somewhat successful in decreasing recruitment but the desired changes in the fishery have not been conclusive. Management in the interest of trout may detract from efforts to conserve and restore populations of native fishes. Future management goals will determine the fate of Colorado River trout.

INTRODUCTION

Rainbow trout (RBT) (*Oncorhynchus mykiss*) and brown trout (BNT) (*Salmo trutta*) are two of the many exotic fish species found in the Colorado River below Glen Canyon Dam (GCD). Although trout were introduced to the system in the early 1920s, their habitat was limited to clearwater tributaries until the closure of GCD in 1963. While pre-dam river temperatures were as high as 29.5°C in the summer, cold, clear hypolimnetic releases from Lake Powell average 8-10°C year-round and permit the success of trout in the mainstem Colorado River. The proliferation of trout has encouraged the presence of wintering bald eagles in the Grand Canyon since the early 1980s. Due to the physiological incapability of BNT to inhabit colder waters and their use of tributaries for spawning, they are rare in the RBT dominated Lee's Ferry tailwater. The RBT in the tailwater have become a self-sustaining population that is found not to migrate or mix with downstream populations (Schmidt et al. 1998; Valdez and Ryel 1995). The majority of BNT are found downstream, along with RBT, where water temperatures are slightly warmer and clear water tributaries adjoin for spawning habitat.

The fish of the Colorado River are arguably one of the most valuable riverine resources below GCD. While there are many different river resources to manage for: power, rafting, vegetation, cultural resources, gravel bars, biology is on the front burner and, according to J.E. Slaughter of the Arizona Game and Fish Department, "the fish have the loudest voice (personal communication 2005)." Of these fishes, RBT is the most economically important to the system and the humpback chub (HBC) (*Gila cypha*), protected under the Endangered Species Act (ESA), is the most politically important. River managers aim to manage the Lee's Ferry tailwater for the health of a RBT fishery while reducing trout density in areas that are critical habitat for HBC and other threatened native species. While the Arizona Game and Fish Department (AZGFD) historically relied on stocking of hatchery fish to maintain the tailwater fishery, currently the main management tool at their disposal is GCD. In conjunction with mechanical trout removal efforts to decrease abundance of trout near the Little Colorado River (LCR), different flow regimes out of GCD are used to affect trout populations throughout the river (Figure 1). With the goals of river managers in mind, I will investigate different management actions affecting trout and review their effectiveness. Also, I will look the effects of management actions on the Green River, Utah to provide insight into the potential future management of the Colorado River. Analyzing these topics will allow me to then recommend management actions.

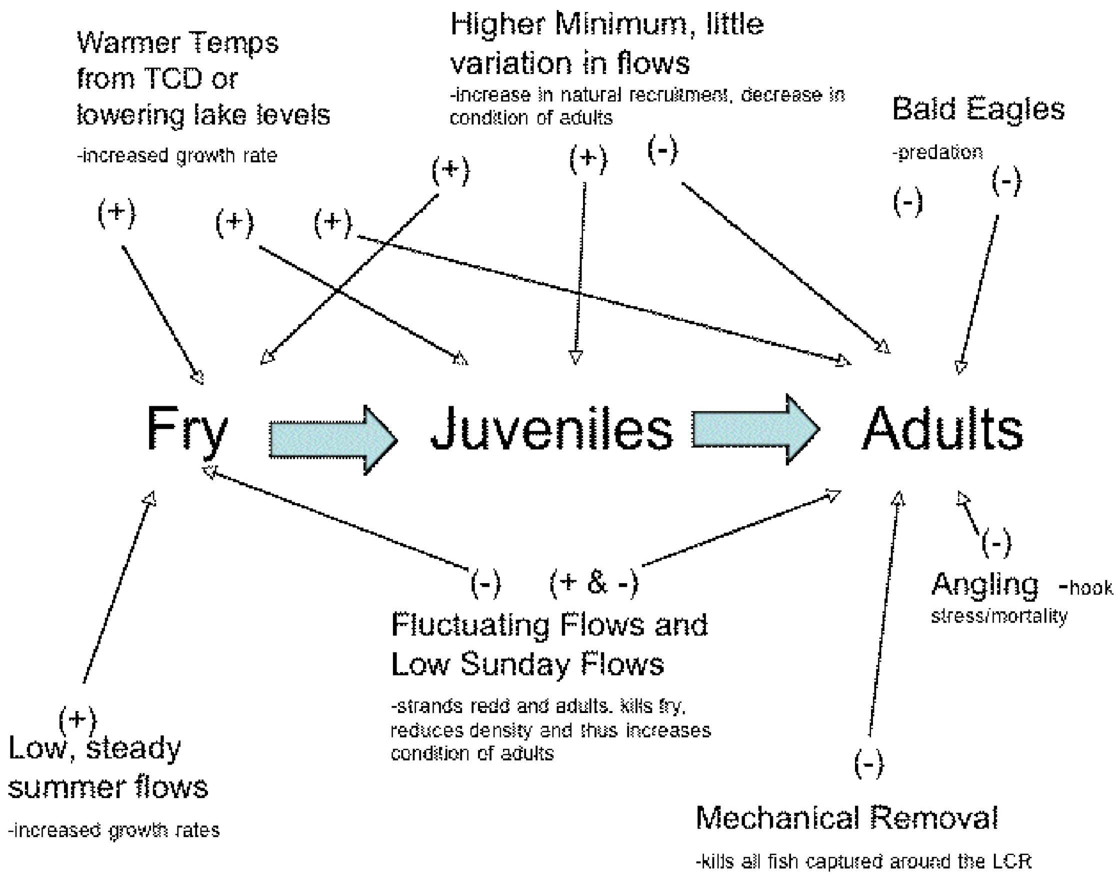

Figure 1. Interactions of different life stages of trout with other natural and human-created components of the Colorado River below GCD.

HISTORY OF FLOW MANAGEMENT

Since the closure of GCD, the Lee's Ferry tailwater has been managed to best serve trout anglers. After early establishment of resident populations of multiple trout species, hatchery fish were continually stocked into the river every year until 1997. BNT stocking averaged 50,000 fish per year and was terminated in 1987 while RBT stocking averaged 70,000 fish per year and was continued until 1997. Prior to 1976, hatchery trout were stocked as "catchables," (ca. 305 mm TL) but in 1976 the management strategy shifted to stocking fingerings as a supplement to natural reproduction (McKinney et al. 1996). Following introductions of benthic algae (*Cladophora glomerata*) and macroinvertebrates (e.g., *Gammarus lacustris*, chironomids, gastropods) into the tailwater during 1966-1969, the fishery achieved a "trophy" status by about 1977

(McKinney et al. 2001). The hatchery stockings helped maintain a put-and-take fishery through the early 1970s, but with shifting values and a growing fly-fishing constituency, the tailwater has slowly become mainly a catch-and-release fishery. However, heavy annual stocking continued into the late 1990s to support high angler catch rates.

Major GCD management actions in the past 25 years have drastically affected trout populations in the Colorado River. It is important to note, however, that prior to 1991 the different flow regimes were not released specifically to affect the trout population. Quality of the Lee's Ferry RBT recreational fishery declined (reduced angler catch rates and mean sizes of fish creeled) between 1980 and 1991 during periods of very low minimum and widely fluctuating releases from GCD (McKinney et al. 1996). Daily water releases commonly moved from less than 5,000 cfs to over 20,000 cfs (with high ramping rates) from 1988-1991 and minimum daily flows approached 3,000 cfs. Prior to 1987, stocked fish comprised an estimated 72.5% of angler harvest due to heavy stocking and low natural reproduction (McKinney 1996). Higher minimum, higher mean, and more stable flow releases from GCD after 1991 provided conditions that supported greater relative abundance of RBT (McKinney et al. 2001). Following flow regime changes imposed in mid-1991, minimum releases were 5,000 cfs and mean daily fluctuations in flows declined more than 50% (McKinney et al. 2001). These higher, more stable flows led to increased abundance and survival of trout and also increased angler catch rates. The increase can be attributed to an increased food base along with an increase in recruitment of naturally-spawned trout to the river. By 1992 or 1993 the fishery was self-sustaining and no longer dependent on stocking.

In the late 1990s management strategies shifted to focus on natural reproduction in the tailwater and trout-related effects on HBC populations. With the shift in flow regime, estimated numbers of RBT more than doubled between 1991 and 1997 (McKinney et al. 1999). This increase in trout density, however, was correlated with a decline in the condition of trout (McKinney et al. 2001). Both the growing concern for the health of the dwindling HBC populations (Valdez and Ryel 1995) and concern from the trout fishing community for the poor condition of RBT in the tailwater, led to further manipulation of the flow regime. In January 2003, daily winter fluctuations in flows were implemented with the intention of decreasing tailwater trout spawning success. Along with a non-native fish removal program centered around the mouth of the LCR, the "trout management" flows are in their third year of implementation. There is consensus among river managers that the tailwater fishery is an extremely valuable resource that must be managed to serve river anglers. Even though it is highly suspected that trout are in part responsible for the decline in HBC numbers, river management aims to improve the tailwater trout fishery where 90% of trout production occurs, while reducing trout populations below Lee's Ferry. This dual management strategy is in the experimental stage and future management decisions may be based on its results.

TROUT LIFE HISTORY

Salmonids (salmon and trout) were historically the dominant fishes of cold-water streams and lakes of North America and Eurasia (Moyle and Cech 2004). Due to their value to anglers as a food source and a sport fish in addition to their ease of propagation, they are currently found in cold freshwater systems across the globe. They have proven to be extremely adaptable and are able to thrive in most systems that provide cold, clear water; exactly what the Colorado River historically did not provide. After more than 80 years in the Colorado River, trout have made the river and its tributaries their home.

Lee's Ferry tailwater RBT spend their whole lives within the 15-mile stretch of river. The convergence with the sediment-laden Paria River at Lee's Ferry provides somewhat of a physical barrier to trout movement. While trout are commonly found far below the Paria River (Valdez 2005), trout born in the tailwater have little reason to move downstream where water quality and food supply both decline. The RBT life history can be divided into five parts: the egg, fry, juvenile, adult and spawning stages (Figure 2).

Figure 2. Basic representations of RBT life history stages (Fulton 2004).

It is important to note that the length of each stage is highly variable, controlled by both abiotic and biotic factors and may be specific to a given stream (Fulton 2004). In the winter, the majority of mature tailwater fish move into shallower, low flow areas near the banks to dig their redds. Angradi et al. (1992) mapped the elevation of RBT redds and found that the peak of spawning occurred between late March and early May with 29%, 59%, and 83% of the redds located above the 11, 8, and 5 kcfs[1] (11,000, 8,000 and 5,000 cfs flow levels) respectively (Korman et al. 2004). Although there are no tributaries within the tailwater reach, it has been documented that both RBT and BNT will use tributaries below Lee's Ferry for spawning (Slaughter 2005).

After a spawning pair of trout has selected a spawning site, they construct their redd. Fertilized eggs are deposited into the gravel and after a few months of incubation, pending cold, well-oxygenated flows, the embryos develop into alevins and after 2-3 months emerge as fry in the spring. These fry cling to the shallow near shore habitats, where water velocity is minimal, to forage and develop. Trout fry typically utilize fallen debris such as tree trunks for habitat, providing protection from the current and predators, but GCD prevents the transport of such debris downstream. As they become fingerlings, growing trout begin feeding on larger macro-invertebrates and may enter the mainstream current. Trout reach reproductive maturity at varying size and age class. Estimated trout growth in the tailwater was 140-191 mm per year for small trout (<305 mm TL) and 10-76 mm per year for large fish (>305 mm TL) (McKinney et al. 1999). When mature and ready to spawn, trout exhibit spawning colors and develop mature gonads. A 500 g female that has lived in a stream for four years typically produces fewer than 1,000 eggs (Moyle and Cech 2004). She will clear off an area of gravel, dig out an area with her tail and release the eggs into the gravel bed. As the eggs are deposited a male releases milt to fertilize the eggs before she covers them with gravel for protection.

1996 EXPERIMENTAL FLOOD

[1] The value kcfs (cfs x 1,000) corresponds to the height of the river at that flow level, indicating where trout dig their redds.

With hopes of rebuilding sandbars above non-flood river levels, depositing nutrients, restoring backwater channels and providing some of the dynamics of a natural system (Patten et al. 2001), a controlled flood release was conducted out of GCD in 1996. A secondary consideration for incorporating spring flood flows into dam operations was that the flood events would reduce alien fish populations (including trout). As an adaptive management strategy, the potential effects of the flood release were largely unknown. It was speculated that the flood would negatively affect the aquatic food base of the river, mainly in the tailwater and at the confluence with the LCR (Patten et al. 2001). Therefore there was potential for indirectly affecting fish populations by displacing their food source. It was thought that the flood would not harm the native fishes because they evolved with such events commonly occurring on the river; however, the effects of the flood on young and non-native fishes were not entirely known.

Post-flood research indicated that the 45,000 cfs (1274 cms) flood flow seemed to have a positive effect on RBT populations. Tailwater trout fed more on the first night of the flood than during pre-flood low flows (McKinney and Persons 1999), likely due to increased drift. Catch rates of RBT increased during the steady 8,000 cfs flows immediately after the flood (Hoffnagle et al. 1999) and in locations where they were rare prior to the experiment (Figure 3). Increases in catch rates were likely due to downstream displacement of fish and concentration of fish in protected habitats such as backwater areas and tributary mouths that might not normally be inhabited by trout. Catch rates of trout <15 cm TL decreased in the Lee's Ferry reach, because the flood carried pushed many of the fish from the Lee's Ferry tailwater downstream. This is easily understood for young fish that would not be able to fight the current or quickly find protection. An indirect benefit on trout and other fish populations may be the re-working of gravel beds and debris fan, as steady flows have potential to armor gravel and make it unusable for fish spawning or for invertebrates as habitat. Overall, the flood flow event was ineffective in harming trout populations. Any changes that mimic the natural system, such as flood events, are only benefiting trout because the system as a whole becomes healthier (Schneidervin 2005). As a fast-water adapted fish, trout are able to handle high discharge and may adjust their behavior to deal with high flow events.

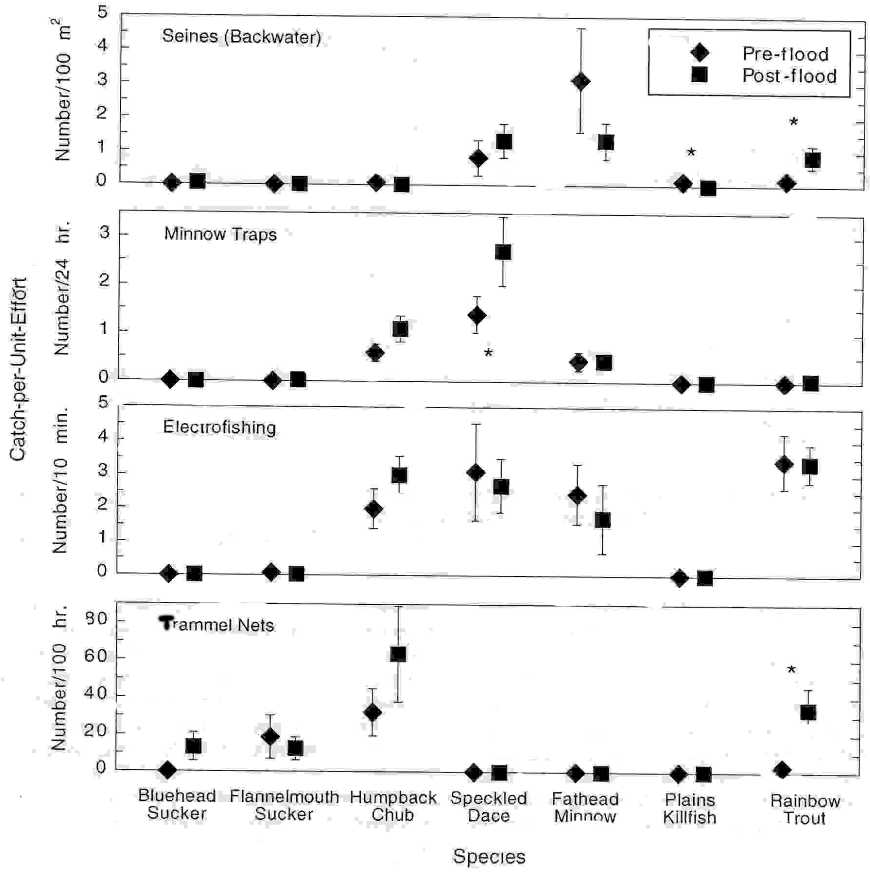

Figure 3. Mean (± SD) catch per unit effort (CPUE) of seven Colorado River fishes in seines, minnow traps, electrofishing and trammel nets during pre and post-flood steady 8,000 cfs flows in 1996 (Hoffnagle et al. 1999).

TROUT MECHANICAL REMOVAL EFFORTS

Experiments done by AZGFD in which tagged hatchery fish were released into the Lee's Ferry tailwater[2] concluded that there is little movement of tailwater trout downstream or into areas inhabited by HBC (Valdez and Ryel 1995). In 1992 and 1993 AZGFD released 78,000 and 73,000 RBT, respectively, with coded wire tags between GCD and Lee's Ferry. Of thousands of fish captured below Lee's Ferry between 1992 and 1993, only three contained coded wire tags and were caught at RM 3.2, RM 3.2 and RM 2.9 (Valdez and Ryel 1995). This shows that RBT in the tailwater section are not

[2] River miles used to describe locations along the Colorado River below Glen Canyon Dam begin with Lee's Ferry (RM 0). The 15-mile stretch between Glen Canyon Dam and Lee's Ferry is known as the tailwater section.

likely to migrate downstream and therefore the tailwater fishery is managed independently of the rest of the river.

The first significant population of HBC found below GCD is at RM 30 and the second at RM 61, where the LCR meets the mainstem Colorado River. Therefore, the large physical separation of the tailwater trout population from HBC populations (>45 miles), combined with evidence of minimal downstream migration of tailwater trout, provides sufficient information for river managers to manage in the interest of the tailwater fishery, even as HBC populations dwindle. Diet analysis of RBT and BNT by the Grand Canyon Monitoring and Research Center (GCMRC) concluded BNT to be the greatest predators of HBC below the LCR, but only by fish over 250 mm TL. RBT samples showed fish as a minimal component of their diet, but RBT are highest in abundance, so the cumulative effect of trout predation could be significant (Yard et al. 2003). The stomach contents of RBT were found to be dominated by detrital CPOM and FPOM and aquatic invertebrates with larger fish below the LCR acting as piscivores. BNT stomach contents were dominated mainly by aquatic invertebrates, with larger fish below the LCR consuming fish as much as 36% of their diet (Yard et al. 2003). However, BNT are opportunists and do not likely prey specifically on HBC but rather on whatever young fish are present. HBC probably make up only 1% of the BNT diet (Slaughter 2005).

Although the actual causal mechanism responsible for the recruitment decline in HBC remains uncertain, monitoring data have suggested that an increase in trout abundance system-wide, especially in the Colorado River near the confluence of the LCR is correlated with a recent decline in HBC abundance (Coggins et al. 2003). While correlation is unable to prove causation, the lack of a fishery for trout in the area around the LCR provides no incentive to encourage trout success, resulting in the trout removal program. In a ten-mile reach centered around the mouth of the LCR (RM 56.2-65.7), the non-native fish mechanical removal program is presently in its third year of operation. The LCR provides spawning habitat for HBC, and during spring runoff many young HBC are displaced downstream into the Colorado River where they are vulnerable to predation by trout. Fish remaining in the LCR potentially have much higher survival and contribute more to annual recruitment than do displaced individuals (Yard and Coggins

2003). The generally observed pattern is that juvenile HBC are typically found in high abundance downstream of the LCR following an elevated LCR flow, but their abundance declines quickly in the weeks and months following the elevated flow event (Yard and Coggins 2003). The program aims to remove 90% of the trout population in the ten-mile reach through electrofishing and euthanasia of caught fish. Fish are captured using electrofishing methods, euthanized and removed from the river for use as fertilizer. Population decline of trout could potentially increase survival of young HBC in the mainstem river.

In the initial efforts of mechanical removal, the program was found to have much greater success than expected (Slaughter 2005). With the third season of a four-year plan already underway, the program has proven that large numbers of trout can be removed from the system and a 60% population depletion level can be sustained. As high as 90% depletion has been achieved in a single trip, but immigration into the reach may replenish population numbers. Also, the program is not able to deplete the trout population or community, but only a percentage of the "catchable" portion of the population (Slaughter 2005). By experimentally thinning out trout populations in the area around the center of this localized HBC population, data from long-term monitoring is expected to provide better information regarding trout-chub interactions. Long-term HBC monitoring data has begun to show a slight increase in HBC numbers, (Slaughter 2005) which seems to be correlated with the reduction in trout around the LCR. However, this correlation can in no way prove causation as many factors influence the HBC population and trout density is the only variable being controlled for.

While the Colorado River below GCD has been altered drastically from its natural state, the under-researched tributaries appear to be significantly less disturbed, and continue to support their historic biological communities and ecological processes (Henery, this volume 2005). Although little research has been done on the tributaries, it is well known that certain streams such as Bright Angel Creek (BAC) provide important spawning habitat for trout as well as native species. It is thought that BAC is one of the centers of the BNT population. Therefore it would make sense to target BAC for the removal of BNT. In November 2003 a weir was installed and operated in BAC until January 2004 (Leibfried et al. 2003). Fish coming up the creek were examined, measured and released (BNT were killed). While the efforts were successful in capturing the majority of the trout coming up BAC to spawn, the program was discontinued after only one year. However, it seems like it should be explored as a future option for the reduction in trout population.

WINTER FLUCTUATING FLOWS

High reproductive success of tailwater trout in recent years has led to density dependent interactions and thus, poorer condition of fish. Flow modifications out of GCD have been aimed at disadvantaging trout recruitment in the Lee's Ferry tailwater to reduce density of fish. Presently in the third season of implementation, daily fluctuations of water releases from 5,000 to 20,000 cfs have taken place from January to March, along with steady low flows (5,000 cfs) every Sunday. The higher flows start daily in the morning to provide the hydroelectric power source to meet the day's energy demand; even though the needs of the hydroelectric power company are said to be secondary to the fish (Slaughter 2005). The winter fluctuating flows are meant to modify wildly fluctuating flows prior to 1991 that discouraged natural reproduction, but also decreased productivity of the tailwater. Present flows do not fluctuate to the extent of the pre-1991 flows nor are the ramping rates as high; therefore trout recruitment should be reduced with minimal impacts to the aquatic food base. By reducing the density of fish, the tailwater would improve as a fishery through increased growth rates and eventually length and weight of RBT.

Trout spawning in the tailwater is thought to occur almost every month of the year; however, the majority of spawning takes place from December to April (Davis 2003). The initial timing of the fluctuating flows was based around the peak of trout spawning. When spawning, trout move to shallower, lower flow areas to construct their redds. Flows must remain at a suitable level to inundate the gravel while the fish build redds, lay eggs, and until the eggs to hatch. Fluctuating flows were meant to disrupt this process. High flows during the day were intended to lure trout into shallow water to spawn (Korman et al. 2003) and then reduced flows at night would dewater redds resulting in desiccation and overheating of embryos (Davis 2003). However, salmonid eggs can tolerate prolonged periods of dewatering (Korman et al. 2003). Even if water levels drop below the location of redds, as long as embryos remain cold and moist, they may remain healthy. Between January and March streamside temperatures in the Grand Canyon are not likely to be warm enough to overheat embryos. The high fluctuations were also thought to reduce the survival of Young-of-Year (YoY) that had already emerged from redds. Higher flows would make trout fry more vulnerable to predation and the rapid lowering of flows would easily leave them stranded. A secondary effect of the fluctuating flows would be the stranding of adult fish in shallow, low flow areas.

As an adaptive management strategy, the winter fluctuating flows were implemented as an experiment whose effects were studied to determine effectiveness. Korman et al. (2003) examined trout redd locations and embryo survival in the tailwater reach. The observations were used to assess the success of the fluctuating flow regime in discouraging recruitment. They found that 50-60% of redd excavation occurred after March 31 and therefore fluctuating flows were released too early. Montgomery and Tinning (1993) determined 10 hours to be the maximum amount of time embryos could be exposed above the water level before mortality occurred. The 2003 study found that redds above 12 kcfs were exposed for 11.5 hours (daily) and the embryos were therefore already dead by April 1. It was determined that 25% of redd excavation occurred above the 12 kcfs mark. Eggs deposited above 8 kcfs had a greater chance of survival as these redds were exposed for only 9 hours. However, repeated daily dewatering of these redds combined with extended exposure during Sunday low flows probably killed many embryos. The total egg loss due to fluctuating flows ranged from 25-40% of all redds constructed prior to April 1. Korman et al (2003) recommended that the flows occur later in the season (February through May) to coincide with the majority of spawning activity. Also, by releasing the flows later in the season, newly emerged young could be targeted by the fluctuating flows. Literature and experimental studies done by Montgomery and Tinning (1993) in the Lee's Ferry reach demonstrate that post-hatch stages of rainbow trout are the most sensitive to fluctuating flows (Korman et al. 2003).

The suggestions of Korman et al. (2003) are specific to the Lee's Ferry reach and similar research is much more difficult to execute in Grand Canyon. It was speculated by Korman et al. (2003) that some of the spawning in the Canyon occurs in deep water where redds would be unaffected by fluctuating flows. Shallow low flow areas are less common in the canyon and therefore trout are thought to use tributaries for spawning as well. Also, impacts of fluctuating flows on trout fry are less severe in steep areas of shoreline irregularity where habitat security is greatest and food availability is maximized with proximity to mainstem flow. Young fish are able to utilize interstitial spaces between rocks and boulders as current breaks while remaining close to mainstem flow that brings food and drift downstream. Valdez and Ryel (1995) have shown that steep angle shoreline debris fans and talus slopes, which are commonly found in Grand Canyon, are the best quality shoreline habitats for young trout (Figure 4). Effects of the flow fluctuations are dampened with greater distance downstream of GCD as flows do not reach the extremes of the fluctuations released from the dam. Therefore, impacts on trout downstream of Lee's Ferry from fluctuating flows will likely be minimal and winter fluctuating flows are mainly aimed to affect the tailwater stretch.

Fluctuating flows have potential to further impact recruitment by causing mortality of adult spawners. During the first three months in the first year of the "trout management" fluctuating flows, EcoPlan Associates, Inc. surveyed areas in the Lee's Ferry tailwater left dry by the 5,000 cfs flows for stranded trout. They found that 503 adult RBT became stranded in shallow, low flow areas sampled and further estimated that a total of 1,742 fish were stranded during the three month flow regime (Davis 2003). About 7% of stranded fish were dead or dying while the vast majority (93%) would have lived. The observed stranding in this study differed drastically from the Angradi et al. (1992) study during fluctuating flows (1,500-30,000 cfs monthly) of 1990. The 503 adult fish found stranded in 2003 was minute in comparison with the 1,924 adult fish stranded during the 18 month Angradi study. Further, 50% of the stranded fish in 1990 were dead or dying compared with only 7% in 2003. The difference in quantity of fish stranded can be attributed to the discrepancy in length of the study and fluctuating flow regimes. The 1990 study lasted 18 months while the EcoPlan study only lasted 3 months in 2003. However, the drastic difference in mortality of stranded fish could be attributed to ramping rates. In 1990 over 70 % of the time down ramp rates exceeded 4,000 cfs/hour and over 25 % of the time they exceeded 6,000 cfs/hour (Davis 2003). Much more gradual down ramping rates as seen in 2003 (2,500 cfs/hour) may be key to the lower stranding mortality rates. Further, much of the mortality in 1990 occurred in summer months where temperatures in stranded pools reached lethal levels. While fluctuating flows have potential to be detrimental in all circumstances, it appears to be largely fluctuating flows with high ramping rates the have the greatest effect.

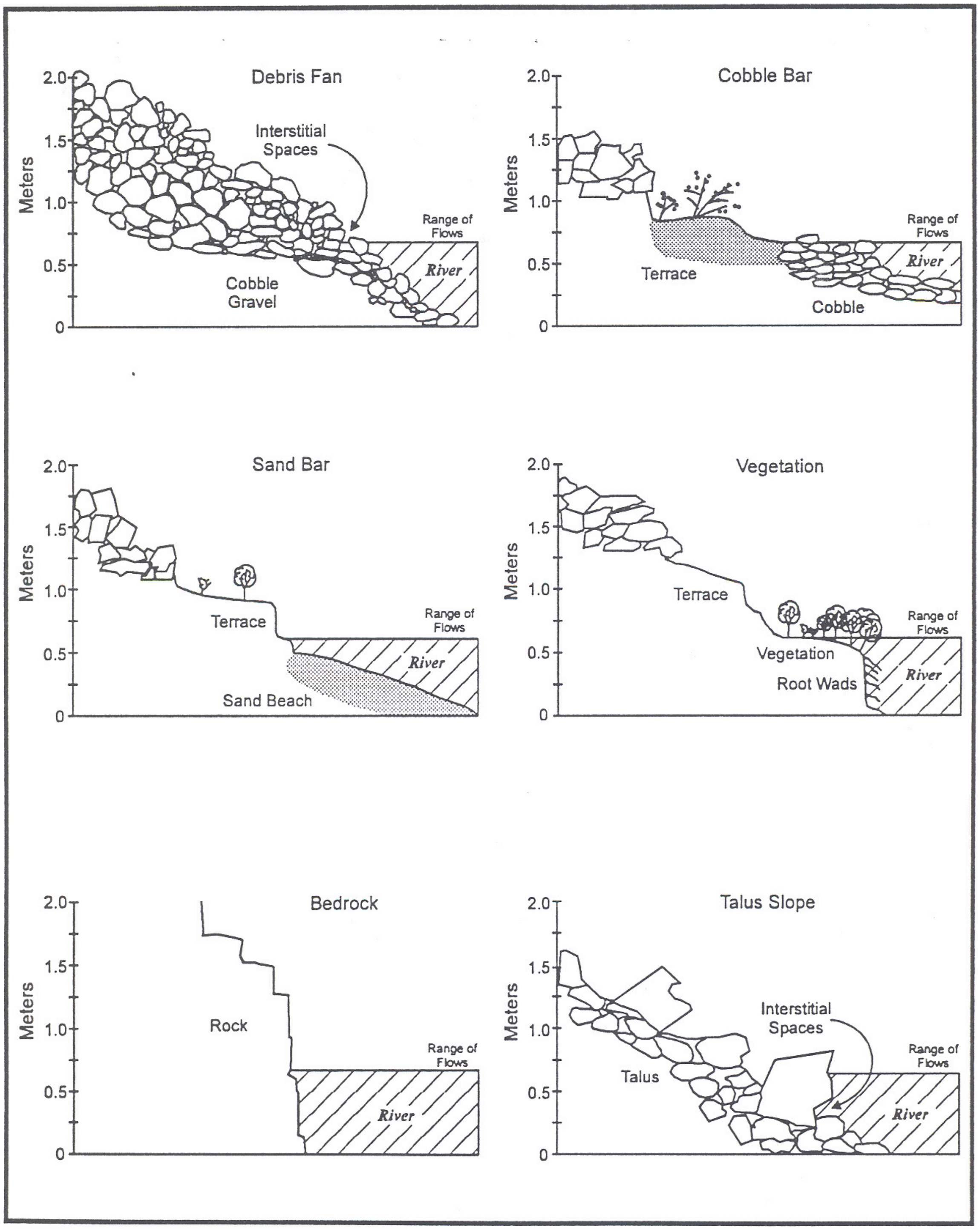

Figure 4. Cross section of different shoreline types in Grand Canyon (Valdez and Ryel 1995).

DISCUSSION

Attitudes and goals in trout management have shifted dramatically since the closure of GCD in 1963. Although the intention to manage trout populations to best serve river anglers has remained consistent, the way the AZGFD has gone about doing this has varied through the years. Since their arrival in the Colorado River, trout have never been managed as an alien pest species, but rather as a species of utmost importance. Native sport fish species had already largely been displaced from the river (Campos 2005, this volume) when GCD was erected and trout were readily available in hatcheries. Therefore with little concern for ecological consequences, heavy and regular stocking of trout began and was centered in the clear Lee's Ferry Tailwater. Early attitudes were concerned with providing anglers with the greatest catch rates possible and the river was managed as a put and take fishery for anglers to keep large numbers of fish. Prior to 1990, flows out of GCD were released independently of the interest of trout or other aquatic biota and the hatchery-stocking program was the factor that controlled trout population numbers.

Research and feedback from anglers indicated that river flows in the late 1980s were having a drastic effect on the tailwater trout population. Once anglers became dissatisfied with the fishing, more attention was paid to the tailwater and focus broadened to explore the different variables affecting the trout population. It was realized that natural reproduction of fish in the tailwater was important and that hatchery stocking and fluctuating flows could be negative factors. Therefore the focus of management shifted in the 1990s to where the stocking program was phased out, and flows were managed to encourage the health of the tailwater RBT population. As concern grew for the HBC, management of the tailwater was not affected at all. It was realized that tailwater fish do not migrate downstream (Valdez and Ryel 1995) and that there is no fishery for trout below Lee's Ferry; therefore trout could be removed from the downstream reaches. While AZGFD is still interested in high catch rates for tailwater anglers, health and size of fish is of more importance to them. Fluctuating winter flows aim to generate a non-density dependent trout population dominated by large, mature fish.

With so many different components of the river to manage for, it is easily understood that management actions are not taken without extensive planning. The

Adaptive Management Working Group (with a distinct Technical Working Group) convenes as a Federal Advisory Committee for management of Glen Canyon Dam and the Colorado River. Utilizing the principles of adaptive management, this committee works to recommend river management policies to the Secretary of the Interior that will best serve the needs of different interests, while protecting downstream river resources. With so many powerful interests involved in the process, somehow it seems strange that major management actions are taken solely in the interest of two fish, one native, one alien. Between the ESA and the economically important tailwater fishery, the fish pull a lot of weight and many of the dam management decisions appeared to be made with the fish in mind. As AZGFD Fisheries Biologist Joe Slaughter said, "Management recommendations are based on chub and RBT…[we] have to look for options that are good for both." The angler constituency of the tailwater has become an extremely powerful player and the AZGFD manages the fishery in response to desires of the anglers. It appears to be an example of the phenomenon of "agency capture" similar to the relationship between the timber industry and the National Forest Service or ranching and the Bureau of Land Management. With many other river components to manage for, a drastic flow modification seems to be an extreme measure only to benefit the tailwater fishery, which only makes up about 5% of the river below GCD. With a component of the river management goals being the restoration of the system, three months of such an unnatural and disruptive flow regime must have its consequences on fish (see Campos and Wilson, this volume, 2005) plant communities (see King and Infalt, this volume, 2005), mammals, reptiles, amphibians (see Dettman, this volume, 2005) and birds (see Schell, this volume, 2005).

The AZGFD does not have a very tight grasp on the health of the tailwater trout fishery. While they presently hope to achieve catch rates of 0.5-1 fish/hour for anglers (2-2.5 fish/minute electrofishing), they are not concerned with accurately quantifying population growth or recruitment suppression (Slaughter 2005). Reproduction in the tailwater reach in the late 90's was extremely high and consequently, the condition of fish suffered. It is clear that the management goal is to improve the condition of fish by decreasing density of fish, however, without clear quantification of the effects of other variables besides flows, there is potential for undesired outcomes to the trout population.

There is no clear understanding how many fish die due to angler related stress or exactly how the population is manipulated by fluctuating flows. However, it is felt that the trout are thriving to such an extent that angler related mortality (normally ~15%) has no effect on the population (Slaughter 2005). It seems that in addition to a 30-40% reduction in spawning success from trout management flows, the angler stress mortality could become significant. While depletion of trout numbers may mean greater average size of fish, total density of fish could decrease to undesirably low numbers. If this happened, the AZGFD would be quick to stock the tailwater with hatchery fish again if it were what anglers wanted (Slaughter 2005). A stocking of tens of thousands of hatchery fish would completely nullify the results of three years of the fluctuating flows and compromise the integrity of a naturally reproducing trout population. It is understood that the fluctuating flows could be having affects on other components of the river system such as sediment exportation (Booth 2005, this volume) that may be detrimental to fish and therefore the flows should only be implemented if their effects on the tailwater fishery are largely beneficial. So far it is not conclusive that the winter flows are creating their desired effect.

PERSPECTIVE

While it is the cold, clear water releases by Glen Canyon Dam out of Lake Powell that allow the trout populations in the Colorado River to exist, the temperature of the water is (on average) 10°C too cold for optimal growth of trout. Releases out of GCD are generally 8°C while ideal RBT temperatures range from 15-22°C. BNT require slightly warmer water (18-24°C) and are therefore much less abundant in the Lee's Ferry tailwater. The Colorado River below GCD on average warms about 1°C per 12-15 river miles in the summer (Valdez 2005); therefore the river may warm 5°C by the time it reaches the LCR. For this reason BNT populations are understandably centered downstream where the water is warmer.

One proposed modification to GCD to improve conditions for RBT in the tailwater and to disadvantage trout downstream, is to release warmer water from GCD by drawing from the epilimnion of Lake Powell. Presently the Bureau of Reclamation is doing an Environmental Assessment for the installation of a Temperature Control Device (TCD) on GCD. The project would include the modification of two of GCD's eight penstocks to draw releases from higher up in the water column of Lake Powell. With a maximum release temperature of 15°C, the warmer flows would presumably enhance the RBT fishery immediately below the dam. Computer modeling studies indicate that additional nutrients, detritus, and algae will be released to the river during multi-level intake structure (MLIS) operations, potentially increasing the productivity in the Lees Ferry Reach (Vermeyen 1999). Further downstream, as the water warms, increased water temperatures would discourage trout success. Warmer temperatures created by the TCD are closer to the ideal natural water conditions for species of native fish such as HBC and therefore might encourage their population growth. This modification proposal is still in a preliminary state.

Similar dam intake modifications have already been implemented on other river systems. The Green River is one of the few river systems in the world that is comparable to the Colorado River in physical characteristics and in native fish fauna. Flaming Gorge Dam (FGD) on the Green River was built at the same time as GCD and both dams were operated similarly until the modification of FGD in 1978. A TCD installed in FGD, along with a more natural flow regime[3], gradually changed the composition of the fishery. Water temperatures released from FGD moved from 4°C year-round to 14°C from May to October. With releases closer to the optimal growth temperatures for trout, growth rates went from .25 in/month to as high as 1.25 in/month (Schneidervin 2005). Also, the higher temperatures allowed BNT to move upstream and compete with RBT that previously dominated the fishery. Presently, BNT are a self-sustaining population that is dominating the fishery while RBT must be stocked annually to supplement for the lack of natural recruitment. In the spring, young BNT that are spawned in the fall may out-compete young RBT that are spawned in the winter. Further, shoreline and backwater habitats, which are ideal for trout rearing, are limited in the Green River and smaller RBT would be easily displaced from these areas. This poses a potential concern for the Lee's Ferry tailwater because it is highly valued as a RBT fishery. However, the angling constituency on the Green River has embraced the change in the fishery. Anglers enjoy

[3] Since 1996 spring flood flows have been released from FGD along with low flows in the late summer (Vinson 2005).

the unique experience of catching BNT that are generally more difficult to catch than RBT (Schneidervin 2005). The TCD on the Green River has created a larger usable river area for native fishes, however, warm water exotic fishes are able to colonize these areas and compete with the native species. With over 25 years of data from the Green River already recorded, Colorado River managers should study the Green River system and assess their goals before manipulating GCD.

Trout are so widespread and well established in the Colorado River that it would be nearly impossible to eradicate them. However, management strategies could move away from encouraging their success in the tailwater. Anglers have proven to be extremely important to the system and presently anglers come to the Grand Canyon only to fish for trout. It is not clear whether this is because native sport fish are rare or have been extirpated from the system or because anglers only want to catch trout. The re-introduction of Colorado River pikeminnow and management for other native species could be done in conjunction with promotion of a native sport fishery (Wilson, this volume 2005). This would allow river managers to manage more directly in the interests of native fishes while serving river anglers.

CONCLUSION

In their 1998 paper Scmidt et al. described the situation on the Colorado River below Glen Canyon dam an ‘intractable dilemma;’ “when you are trying to manage a resource, there are many interests at the table, but there is no single management strategy that serves all interests equally.” This indeed is the case, however, it would seem easier to find one management strategy that could at least serve the interests of all the fish. Current management actions seem contradictory in their attempt to protect threatened native species while promoting a non-native fishery. Trout have become overly important to the Colorado River so drastic management decisions are made in their interest while the interests of native fish and other river components are often secondary. Clearly the complete removal of non-native fishes is not practical, but the selective removal of non-natives from certain river stretches apparently is. It has become clear that maintaining the tailwater rainbow trout fishery is of great importance for river management and while the mechanical removal program is expensive, it seems to be effective in reducing trout numbers around the LCR.

Mainly it is the mechanical removal program that allows river managers to continue to manage flows for RBT success. However, the mechanical removal efforts should be extended to the mainstem LCR, where spawning trout can be targeted. Trout management flows have had some success, but it is not clear that the level of success achieved is worth the stress daily fluctuations from 5,000-20,000 cfs puts on the rest of the system. The question is whether a few years of trout management flows along with mechanical removal will do enough to trout populations so river managers can allow the system to move towards a new equilibrium. With continued experimentation in flood pulses and flow regimes along with the potential modification of the dam, equilibrium may be impossible for the Colorado River. The installation of a TCD could potentially create an equilibrium favoring both the tailwater trout and HBC and other natives. However, the Green River must be studied carefully along with dropping lake levels before action is taken to modify the dam.

Most importantly, management goals must be clearly defined. If in fact trout fishery health is most important, then continued "trout management" flows may make sense along with the installation of a TCD. However, it is not entirely clear that the highly disruptive winter flows are creating the desired effect. If we realize that trout fisheries exist all over the world and that the fish fauna of the Colorado River is unique, managers may cease to act in the interest of trout. If adaptive management continues to move towards restoration of the river back to its natural state, we may see the disappearance of the tailwater fishery and the removal of one of the West's largest dams.

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