Ecology and Management of Native Fishes in the Green River

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ABSTRACT

Native fish populations in the Green River have adapted to the naturally variable environmental conditions of their basin for millions of years. Over the last century, anthropogenic changes in this system have resulted in decreased native fish distributions and abundances. Declines in native fish populations are mostly attributed to two sources. The first is the operation of Flaming Gorge Dam, including the reduction of temperature and seasonal variation in flow, which results in decreased spawning success, poor growth, and habitat that was unfit for the rearing of young. Second, the introduction of non-native fishes negatively impacts natives through competition, predation on young, and the introduction of associated parasites and diseases. The recovery management plan is extensive and includes modifications to the operating procedure of Flaming Gorge Dam to allow flow and temperatures to better mimic natural conditions, non-native species management, stocking of hatchery-reared endangered fishes, research and monitoring, and public outreach. As these imperiled fishes possess life histories that are intimately tied to all facets of the natural system, this type of integrative plan is necessary for success. Its effective planning and implementation, however, can be time-intensive, a luxury that the fishes do not have.

INTRODUCTION

The Colorado River basin, which harbors the Green River, has been described as "an aquatic island in a terrestrial sea" (Molles 1980), as it has had no major connections to neighboring river basins for millions of years (Carlson and Muth 1989). This geographic isolation resulted in a suite of unique native fishes. These species became highly specialized to survive in the variable environmental conditions of the basin, commonly possessing life history traits such as high fecundity, rapid early growth, and longevity.

Today, the Green River, from Flaming Gorge Dam to its confluence with the Colorado River, is home to 12 species of native fish (Table 1) (Muth et al. 2000). Their tightly bound relationship with the natural system has left these fishes particularly vulnerable to human-induced environmental changes (Valdez and Muth 2005). As a result, the river's degraded water

Table 1. Native fishes found in the Green River between Flaming Gorge Dam and the Confluence with the Colorado River (from Muth et al. 2000)

Family and Common Name	Scientific Name	Present Distribution in the Green River System and Comments[a]
Cyprinidae		
Humpback chub	*Gila cypha*	Federally listed as endangered. Population concentrations are located in the Green River in Desolation and Gray Canyons and the Yampa River in Yampa Canyon. The fish is incidental in the Green River in Whirlpool and Split Mountain Canyons; in the Yampa River in Cross Mountain Canyon; and in the lower Little Snake River. Highly adapted to life in canyon environments. Adult habitat includes deep pools and shoreline eddies; young occupy warm, quiet habitats such as backwaters and eddies.
Bonytail	*Gila elegans*	Federally listed as endangered. It is considered extirpated in the Green River system but may persist in extremely low numbers in the main stem. It is considered adapted to main-stem rivers, where it has been observed in pools and eddies.
Roundtail chub	*Gila robusta*	Widespread, found in streams and rivers with warmer water. It is generally rare in the middle and extreme lower Green River; common to abundant elsewhere. Adult habitat includes riffles, runs, pools, eddies, and backwaters with silt-cobble substrate and adjacent to higher-velocity areas. Young occupy low-velocity shoreline habitats.
Colorado pikeminnow	*Ptychocheilus lucius*	Federally listed as endangered. It is widely distributed in warm-water reaches of the Green River and lower sections of larger tributaries. Adult habitat includes deep, low-velocity runs, pools, and eddies or seasonally flooded lowlands. Young occupy low-velocity, shallow, shoreline habitats (e.g., backwaters).
Speckled dace[b]	*Rhinichthys osculus*[b]	Widespread, common to abundant. It occupies permanent or intermittent cool- or warm-water streams and rivers and small to large lakes. In streams and rivers, adults are generally found in shallow runs and riffles with rocky substrates. Young occupy low-velocity shoreline or seasonally flooded habitats.
Catostomidae		
Bluehead sucker	*Catostomus discobolus*	Widespread, common to abundant. It is found in a variety of habitats, ranging from cool, clear streams to warm, turbid rivers. Adults prefer deep riffles or shallow runs over rocky substrates. Young occupy low-velocity shoreline or seasonally flooded habitats.

Family and Common Name	Scientific Name	Principal Distribution in the Green River System and Comments[a]
Catostomidae (Cont.)		
Flannelmouth sucker	*Catostomus latipinnis*	Widespread, common to abundant. It is found in warm-water reaches of larger river channels. Adults typically occupy pools and deeper runs, eddies, and shorelines. Young occupy low-velocity shoreline or seasonally flooded habitats.
Mountain sucker	*Catostomus platyrhynchus*	Incidental to rare in the Green River upstream of the Yampa River confluence and in headwaters of the Yampa and White Rivers; common in tributaries of the Duchesne, Price, and San Rafael Rivers. It prefers cool, clear streams with rocky substrates.
Razorback sucker	*Xyrauchen texanus*	Federally listed as endangered. It is found in warm-water reaches of the Green River and lower portions of major tributaries; it primarily occurs in flat-water sections of the middle Green River between the Duchesne and Yampa Rivers. Adult habitat includes runs, pools, eddies, and seasonally flooded lowlands. Young presumably require nursery habitat with quiet, warm, shallow water such as tributary mouths, backwaters, and especially floodplain wetlands.
Salmonidae		
Cutthroat trout[c]	*Oncorhynchus clarki*[c]	Rare to common in certain upstream river reaches (e.g., Green River downstream of Flaming Gorge Dam; stocked in tailwaters) or impoundments. It prefers cold, clear headwater streams.
Mountain whitefish	*Prosopium williamsoni*	Incidental to rare in the Green River upstream of the Yampa River confluence and in lower sections of the Yampa and White Rivers; common in upper sections of the Yampa, White, and Duchesne Rivers. It prefers streams and rivers with cool, swift water and gravel or rubble substrates.
Cottidae		
Mottled sculpin	*Cottus bairdi*	Rare to common in the Yampa, Duchesne, Price, and San Rafael Rivers and in the Green River near the Yampa River confluence. It prefers cool-water riffles and deep runs with rocky substrates in streams and rivers.

quality, habitat destruction, dam-related flow and temperature modifications, and the introduction of non-native fishes have led to sharp declines in the distributions and abundances of all native fishes in the Green River. One-third of the species are currently afforded federal protection under the Endangered Species Act, while three others are noted as "species of concern" at the state level (Muth 2000, Valdez and Muth 2005).

The imperiled condition of these native fishes has received national attention and led to the establishment of The Upper Colorado River Endangered Fish Recovery Program (UCRRP) in 1988. Comprised of public and private organizations, this working group executes research and management plans, with the ultimate goal of re-establishing healthy, self-sustaining populations of native fishes. The purpose of this paper is to 1) explore the ecologies of these fishes, with special consideration of the big-river species, 2) describe the causes behind population declines, 3) examine the distributions and abundances of native fishes in light of the serial discontinuity concept, and 4) discuss management measures in place to assist in the recovery of native fishes in the Green River.

NATIVE FISH ECOLOGY AND CURRENT STATUS

The following sections group the native Green River fishes by their environmental preferences, describe their general ecologies (i.e. morphologies, habitat associations, diets, and reproductive processes), and note their current status.

Cool-Water Fishes

Species in this group are typically found in upstream reaches. They include the mountain sucker (*Catostomus platyrhynchus*), mottled sculpin (*Cottus bairdi*), mountain whitefish (*Prosopium williamsoni*), and the Colorado cutthroat trout (*Oncorhynchus clarki*) (Muth et al. 2000). Descriptions of the latter two species are covered by Börk (2006, this volume).

Mountain Sucker

Figure 1. Image of a mountain sucker (Colorado State University, 2005).

The mountain sucker (Fig. 1) attains a maximum size of 8in TL. It is characterized as having a sleek body and a subterminal mouth for bottom feeding with a cartilaginous plate used for scraping food from the substrate. These fish exhibit a brownish-green coloration dorsally and white ventrally (Moyle 2000). Mountain suckers prefer cool, clear streams with temperatures ranging from 13 to 23ºC and swift water flow. They are typically found in small groups near transitions between pools and runs that are closely associated with cover. Here, they feed primarily on algae and small benthic invertebrates, but mud and silt, consumed inadvertently, also comprises a large portion of their gut contents (Isaak et al. 2003). Their breeding behavior involves short migrations into small streams from May to late June with water temperatures between 9 and 11ºC. Spawning takes place in riffles and eggs adhere to the gravel substrate (Issak et al. 2003).

Historically, mountain suckers were distributed throughout the upper portion of the Green River. Today, the tailwater temperatures are too cold for this fish, and their downstream distribution is limited to the confluence with the Yampa River (Muth et al. 2000).

Mottled Sculpin

Figure 2. Image of a mottled sculpin (The Native Fish Conservancy, 2005).

Mottled sculpin (Fig. 2) are small, stout fish with a maximum size of 6in TL. They have morphological features that help them to remain on the stream bottom in fast flows, including large fanlike pectoral fins, the lack of an air bladder, and a dorso-ventrally flattened head (Moyle 2000). These fish have large mouths and eyes and an irregular coloration of brown and black (Valdez and Muth 2005). This species is found in cool, clear streams with rocky substrates. They are benthic feeders that nocturnally forage for snails, oligochetes, insect larvae, and amphipods (Sigler and Sigler 1996). Mottled sculpin spawn in riffles from May to June when the water temperature reaches about 12ºC. Clusters of eggs are attached to the undersides of stones. The male guards these eggs and keeps them free of silt until the fry emerge and drift downstream (Valdez and Muth 2005).

Populations of mottled sculpin appear to be healthy in the Green River despite the significant amount of human disturbance in the area. This species can be found between the tailwaters and the confluence with the Yampa River (Muth et al. 2000).

Broad Requirement Fishes

These fishes have fairly flexible environmental requirements, making them the Green River natives with the widest distributions. Members of this group include the roundtail chub (*Gila robusta*), bluehead sucker (*Catostoma discobolus*), and speckled dace (*Rhinchthys osculus*).

Roundtail Chub

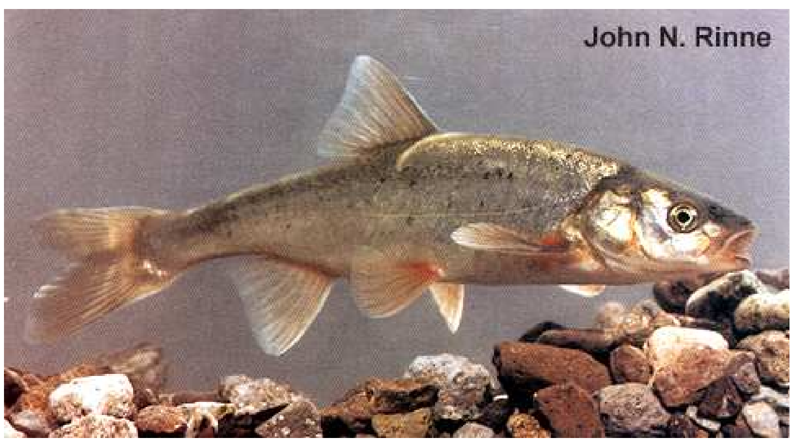

Figure 3. Image of a roundtail chub (The Native Fish Conservancy, 2005).

The roundtail chub (Fig. 3) is characterized as having a cylindrical body that is laterally compressed. These fish have a large, sub-terminal mouth and a caudal fin with slightly rounded edges (Rees at al. 2005a). They are silver-green in coloration and can reach a maximum size of 20in TL (Valdez and Muth 2005). This species is often found in stream reaches with complex pool and riffle habitats. Juveniles and adults are found in deep, low-velocity habitats that are associated with cover such as woody debris (Rees et al. 2005a). They are opportunistic feeders, consuming insects, fish, plant material, and even lizards (Valdez and Muth 2005). Spawning occurs from May to June when temperatures reach 14 to 22ºC and usually coincides with a period just after peak runoff. Although the spawning behavior for this fish has not been observed, it is assumed that they broadcast adhesive eggs over cobble substrate (Rees et al. 2005a).

The roundtail chub was historically common to the Green River. Today, despite its widespread distribution, they are rarely found between the dam and the confluence with the Yampa River (Muth et al. 2000). The roundtail chub is not federally listed as endangered, but has been given a state classification of "species of concern" in Colorado and Utah (Valdez and Muth 2005).

Bluhead Sucker

Figure 4. Image of bluehead suckers (The Native Fish Conservancy, 2005).

This bluehead sucker (Fig. 4) is a medium sized fish, growing to 18in TL. It is distinguished by a broad, bluish head and a subterminal mouth with cartilaginous ridges for scraping (Valdez and Muth 2005). Scales are moderate to small in size, and the body is olive to black on the sides and yellow on the belly (Ptacek et al. 2005). Bluehead suckers can survive in cool clear streams or warm turbid waters, but prefer areas with rocky substrate and temperatures of 20ºC or less. These fish rest in deep pools, eddies and runs (Ptacek et al. 2005, Valdez and Muth 2005) and move to riffles to feed on algae and Chironomidae larvae (Ptacek et al. 2005). Spawning occurs from April to May in smaller tributaries where the ideal temperature is 18.2 to 24.6ºC and water velocity about 1.45ft/s. Eggs are broadcast over cobbles in pools or slow runs.

The population of bluehead suckers in the Green River is in decline. They are abundant at and below Browns Park, but uncommon upstream (Muth et al. 2000). This species is not federally listed as endangered, but has been given a state classification of "species of concern" in Colorado and Utah (Valdez and Muth 2005).

Speckled Dace

Figure 5. Image of a speckled dace (The Native Fish Conservancy, 2005).

The speckled dace (Fig. 5) is the smallest native fish of the Green River, attaining a maximum length of 3in TL. Rounded fins and an elongate body characterize this fish. The mouth is subterminal and may or may not have two small barbels at the corners (Valdez and Muth 2005). This species can tolerate an array of environmental conditions, allowing it to be widespread in the Green River. In addition, it can be found in a variety of habitats. They are benthic feeders and consume insects and plant material (Valdez and Muth 2005). Speckled dace in the Green River main-stem enter tributaries to spawn. Often, this occurs with the two high-water events: spring runoff and late summer rains. This may be limited to tributaries that have a temperature range from 17 to 23ºC (Valdez and Muth 2005).

Speckled dace were common throughout the Green River but are now rarely collected from the dam to the confluence with the Yampa River (Muth et al. 2000).

Warm-Water Fishes

Known as the "big-river fishes," members of this group prefer to inhabit large river bodies that have warm water temperatures. Species include the flannelmouth sucker (*Catostomus latipinnis*), the Colorado pikeminnow (*Ptychocheilus lucius*), the humpback chub (*Gila cypha*), bonytail chub (*Gila elegans*) and razorback sucker (*Xyrauchen texanus*).

These fishes evolved in large river environments over millions of years, resulting in morphologies specifically adapted to steep flow gradients, turbid waters, and large-scale seasonal variations in both temperature and flow (Valdez and Muth 2005). For example, eyes are typically reduced in size due to their lack of importance in a turbid environment. The Colorado pikeminnow, bonytail chub and humpback chub are members of the family Cyprinidae, which have a Weberian apparatus, a bony connection from the air bladder to the inner ear that can amplify audio signals in the turbid system. Adaptations to flowing waters include streamlined bodies, thin caudal peduncles and embedded scales, all of which reduce drag. Several members also have develop a hump before the dorsal fin which is believed to be a response to predation pressures by the piscivorous Colorado pikeminnow by increasing its body height relative to the predator's gape (Portz and Tyus 2004). These species receive a great deal of attention for their unique appearances and also for their rapidly declining numbers.

Flannelmouth Sucker

Figure 6. Image of a flannelmouth sucker (The Native Fish Conservancy, 2005).

The flannelmouth sucker (Fig. 6) is a large species, growing to 26in TL. It is characterized as having a streamlined, tapering body, a thin caudal peduncle, and large fins. Eyes are small in size and scales are small and imbedded. The mouth is subterminally located and lips are well developed. Typical adult coloration is olive to grey dorsally and white ventrally with some yellow and orange between (Rees et al. 2005b). Adults are habitat generalists and can be found in pools, eddies, and runs, preferably with water temperatures around 25ºC. They are rarely found in cool headwater streams. These fishes are omnivorous benthic feeders, eating detritus, seeds, plant material and aquatic invertebrates (Rees et al. 2005b, Valdez and Muth 2005). Spawning migrations to tributaries begin in the early spring and spawning occurs from

May to June. Water temperatures at this time are 16 to 18.5ºC. Eggs are deposited over sand and gravel bars (Rees et al. 2005b, Valdez and Muth 2005).

This species was historically widespread throughout the upper Colorado basin, but has now been reduced to eight populations, one of which is in the Green River. Here, it has been displaced downstream of Flaming Gorge Dam to warmer areas (Vanicek et al. 1970). The flannelmouth sucker is not federally listed as endangered, but has been given a state classification of "species of concern" in Colorado and Utah (Rees et al. 2005b).

Colorado Pikeminnow

Figure 7. Image of a Colorado pikeminnow (The Native Fish Conservancy, 2005).

The Colorado pikeminnow (Fig. 7) is the largest minnow in North America, said to grow to 5.9ft and weigh 80lbs, however the largest confirmed weights are only about 34lbs (Miller 1961). This species has a long cylindrical body with a thick caudal peduncle. The mouth is terminal, with thick lips and toothless jaws. This top predator in the Colorado River basin possesses long, sharp pharyngeal teeth. Adults are silvery green dorsally transitioning to a white ventral color (USFWS 2002).

Habitat use by the Colorado pikeminnow is diverse and varies with reproduction and development. During most of the year, juveniles and adults of this species inhabit deep, low-velocity eddies, pools, and runs. In the spring, flow and temperature changes cue this species to make a long spawning migration into floodplain habitats for feeding and resting. Spawning activity takes place after peak spring run-off from June to August when temperatures are 16ºC or greater. In the Green River basin, spawning sites in the lower Yampa River in Yampa Canyon and in the lower Green River in Gray Canyon have been documented. Eggs are broadcast over cobble where they incubate in interstitial areas. Larvae emerge from the cobbles within two weeks and are swept downstream to backwater nursery areas. They remain in these warm, food-rich habitats for 2-4 years before moving upstream to establish their own home ranges. After spawning, adults return to their home ranges in late summer and early spring, remaining there until the next spawning season. This long round-trip migration may be up to 590mi (Muth et al. 2000, USFWS 2002a).

The diet of Colorado pikeminnow varies with growth and development. Individuals less than 2in TL eat primarily zooplankton and midges. When they reach 2 to 8in TL foraging shifts to invertebrates and fishes. Finally, at sizes greater than 8in TL, they are piscivorous. Large adults occasionally consume birds, mice and rabbits (Muth and Snyder 1995).

This species was once widespread throughout the warm waters of the Green River and its tributaries. Today, there is an estimated 8,000 adults in the Green River subbasin, and they are rarely found above Lodore Canyon. The Colorado pikeminnow was classified as endangered in 1967 under the Endangered Species Preservation Act and protected by Endangered Species Act in 1973 (USFWS 2002a).

Bonytail Chub

Figure 8. Image of a bonytail chub (The Native Fish Conservancy, 2005).

The bonytail chub (Fig. 8) attains a maximum size of 22in TL and has a streamlined body, with embedded scales and a concave skull transitioning into a muscular hump before the dorsal fin. The caudal peduncle is very thin, and fins are large and falcate. Coloration is olive dorsally and creamy white ventrally (Marsh 2004).

The ecology of this species is poorly understood because of taxonomic misclassification between chub species in the area (Valdez and Muth 2005) and because it was extirpated from most of its native range before early in-depth fish surveys were conducted (USFWS 2002b). This species has been observed in pools and eddies. It has been suggested that, like other members of its genus, the bonytail spawn in the spring over rocky substrates. Spawning was last noted in the Green River in Dinosaur National Monument in 1969 from June to July when water temperatures were 18ºC (Vanicek and Kramer 1969). It is believed that flooded habitats are important nursery areas for young. This species feeds at the surface and on drift materials, consuming plant debris and algae, and beetles and grasshoppers (USFWS 2002b, Marsh 2004).

Following construction of Flaming Gorge Dam, this species was extirpated from the area below the dam to the confluence with the Yampa River (USFWS 2002b). This fish was listed as federally endangered under the Endangered Species Act in 1980. Despite this classification, the Green River population probably does not reproduce and this fish is considered to be functionally extinct. There are no abundance estimates for this species due to their low encounter rates (Valdez and Muth 2005).

Humpback Chub

Figure 9. Image of a humpback chub (The Native Fish Conservancy, 2005).

The humpback chub (Fig. 9) reaches 19in TL in size and is characterized by a fusiform body that is laterally compressed with a fleshy predorsal hump. The caudal peduncle is narrow and the fins are large and falcate. Adults are olive-grey dorsally to white ventrally. Scales are imbedded and the head has small eyes and a subterminal mouth (USFWS 2002c).

Humpback chubs are unique among the big-river fishes in that they exhibit very high site fidelity, rarely venturing outside of their home ranges. Their entire life cycles occur in canyon-bound areas that have deep water, fast currents, and rocky substrates (USFWS 2002c). Spawning takes place from spring to summer as flows decline from the spring peak and temperatures are between 16 and 22ºC (Valdez and Muth 2005). Little is known about spawning habitat, but it presumably occurs over mid-channel cobble or gravel bars where small, semi-adhesive eggs become lodged in the substrate interstices (Hamman 1982). The young remain close to the substrate to avoid being washed downstream and develop in near-shore areas with low velocities and structure like debris fans and vegetation. As they grow, humpback chub move to deeper, swifter habitats (Muth et al. 2000, USFWS 2002c).

Diets of the humpback chub are not fully described, but it is clear that they are opportunistic feeders. In the Grand Canyon, they consume aquatic inverts, green algae, terrestrial inverts, and occasionally fish and reptiles (Muth et al 2000, USFWS 2002c).

This species was classified as endangered in 1967 under the Endangered Species Preservation Act and federally protected by the Endangered Species Act in 1973. It is difficult to describe early population abundances and distributions due to taxonomic difficulties and early extirpation. Today, there are five populations of humpback chub in the upper Colorado River basin, including one estimated at 1,500 individuals in the Green River in Desolation and Gray Canyons (Valdez and Muth 2005).

Razorback Sucker

Figure 10. Image of a razorback sucker (U.S. Fish and Wildlife Service, 2005).

The razorback sucker (Fig. 10) is a robust fish with a maximum size of 39in TL. The body is elongate and mildly compressed. The distinguishing feature is a bony, sharp-edged dorsal keel. This hump seems superficially similar to the hump of the big-river chubs, but an examination of the morphology reveals that this species hump is bony, while the chubs' are mostly muscle mass. The mouth is located subterminally. Dorsal coloration is olive to brown, becoming white to yellow ventrally (USFWS 2002d).

Adult home range habitats include deeper runs, eddies, and backwaters. It is believed that this species lives a very sedentary life during the non-spawning season. High flows from spring run-off occurring from mid April to June cue spawning. Adults make small to moderately long migrations to spawning areas and then rest in backwaters near the spawning sites. Spawning occurs over mid-channel cobble bars when the water temperature is 15ºC. Larvae drift downstream to nursery floodplains to mature (Muth et al. 2000, Valdez and Muth 2005).

Razorback sucker larvae have a terminal mouth and consume planktonic cladocerans, rotifers, algae, and midge larvae. As they mature, their mouths move to a ventral location. Little is known about the diets of juveniles, but gut contents from 6 individuals in the Green River were composed of algae and detrital ooze. Adults consume mostly benthic invertebrates, including Ephemeroptera, Trichoptera, and Chironomidae. They also eat algae, and detritus in lesser amounts (Muth et al. 2000, USFWS 2002d)

Historically common in the Green River main-stem and in the lower portions of its tributaries, today, the razorback sucker exists in the middle Green River with a population size estimated to be only 100 individuals. Natural reproduction occurs in the wild, but survival beyond the larval period is extremely low. Therefore, wild stocks are composed primarily of older fishes (Marsh and Minckley 1989). The razorback sucker was listed as federally endangered in 1991 (Valdez and Muth 2005).

Causes of Native Species Decline

Although many anthropogenic factors have hastened the decline of native fishes (i.e. early food fisheries, degraded water quality, etc.), two major threats exist for these species in the Green River. These are 1) environmental changes directly linked to the operation of Flaming Gorge Dam, and 2) the introduction of non-native fishes to the system.

Impacts of Flaming Gorge Dam

Flaming Gorge Dam was completed on the upper end of the Green River in 1962 for the purpose of generating hydroelectric power. A recreational trout fishery was also planned for the reservoir behind the dam. At the time, any non-sportfish species was regarded as a “trash” fish that needed to be removed before it could compete with or prey on trout. The original plan for elimination was to poison the reservoir with rotenone, allowing the substance to detoxify before releasing it beyond the dam and re-stocking the trout. A delay in the dam’s construction, however, meant that the poisoning needed to be carried out before the dam was closed while the water temperature still allowed the toxin to work effectively. Despite efforts to detoxify the rotenone carried downstream, native fishes were killed in Dinosaur National Monument and even as far as Split Mountain Canyon. Over the next few years, some native fishes did begin to recolonize these areas. The impact of this poisoning on native fishes has never been fully assessed, but it is assumed to have been widely detrimental (Carlson and Muth 1989, Holden 1991).

Changes to the natural flow regime have been linked to declines in native fish distribution and abundance. Before the dam, the Green River experienced median peak spring flows of 11,654cfs between April and June, with fairly consistently low base-flows during the remainder of the year. After the dam, this seasonal variation was eliminated as flows became homogenous year-round (Fig. 11), with median spring peak flows of only 2,931cfs and high base-flows. The peak flow has exceeded 7,063cfs only a handful of times since dam completion due to weather related complications. The effects of these regulations diminish downstream (Fig. 11). The natural flow regime is important to the ecology of big-river fishes for a number of reasons. The increased spring flows are important signals for migration and spawning. High flows aid in preparing spawning areas, mobilizing sediments to form cobble bars or to reshape existing ones and cleaning sediment from substrate that could burry eggs and suffocate larvae. Spring transport is also necessary for the creation of and connection to backwater habitat and floodplains used by larvae in the summer (Muth et al. 2000, Birchell and Christopherson 2004). Additionally, low base-flows transport some larvae to downstream rearing habitats. When releases from Flaming Gorge Dam are too great, larvae are swept past these areas into unsuitable portions of the river (Schmidt and Box 2004).

The dam also alters the natural thermal regime of the Green River. Before the dam, temperatures ranged from near freezing in the winter to almost 30ºC in the summer. After the dam, however, there was a large reduction in thermal variation, with temperatures ranging from 4 to 13ºC. The cold summer temperatures decreased the success of egg incubation and larval survival for the big-river fishes, and in 1978, the penstock modifications, originally installed to aid the trout fishery, were used to selectively withdraw warmer water from higher in the reservoir. Because water temperatures increase downstream, this provided better temperatures for natives in Lodore Canyon and below, but the temperatures are still too cold for many natives from the dam to the Yampa River confluence (USFWS 2005b). Additionally, the warmer winter temperatures in the river and daily fluctuations related to power generation cause surface ice to break-up. This is linked to increased movement in endangered fishes that are overwintering, which could in turn increase stress levels and affect their survival (Valdez and Masslich 1989).

Non-Native Fishes

As of 2000, 25 nonnative fish species have been documented in the Green River main-stem downstream of Flaming Gorge Dam. These species are a threat to native fishes because they compete with them for resources, prey on them (especially during early life stages) and introduce diseases and parasites into this system (Muth et al. 2000). This topic is covered in greater detail by Baker (2006, this volume).

Serial Discontinuity Concept

The serial discontinuity concept claims that dams cause extreme perturbations to river ecosystems. It predicts that the intensity of this regulation-based disturbance should decrease with increasing distance from the dam due to the influence of tributary inputs (Stanford and Ward 2001). In the Green River, the impacts of Flaming Gorge Dam are, in fact, decreased as the warm, sediment rich waters of the un-regulated Yampa River enter the system. Additionally, the smaller influences of tributaries, such as the White, Duchesne, Price, and San Rafael Rivers, help to mitigate the effects of the dam further downstream (Muth et al. 2000).

As the Green River returns to a state more similar to its natural conditions, the native fish fauna, unfortunately, does not follow suit. The cold, regulated tailwaters are hospitable to only one non-salmonid native, the mottled sculpin. As would be expected downstream, large amelioration of flow and temperature regimes provided by the Yampa River does increase the diversity of native fishes, but many are found only in small numbers. This trend of increasing diversity does not, however, continue, as the warmer, lower velocity downstream reaches of the Green River are dominated by non-native fishes. These species decrease the fitness of natives largely through predation and competition (Muth et al. 2000). The abundances of native fishes in lower reaches may also be decreased as a result of poor spawning habitat conditions upstream of their homeranges.

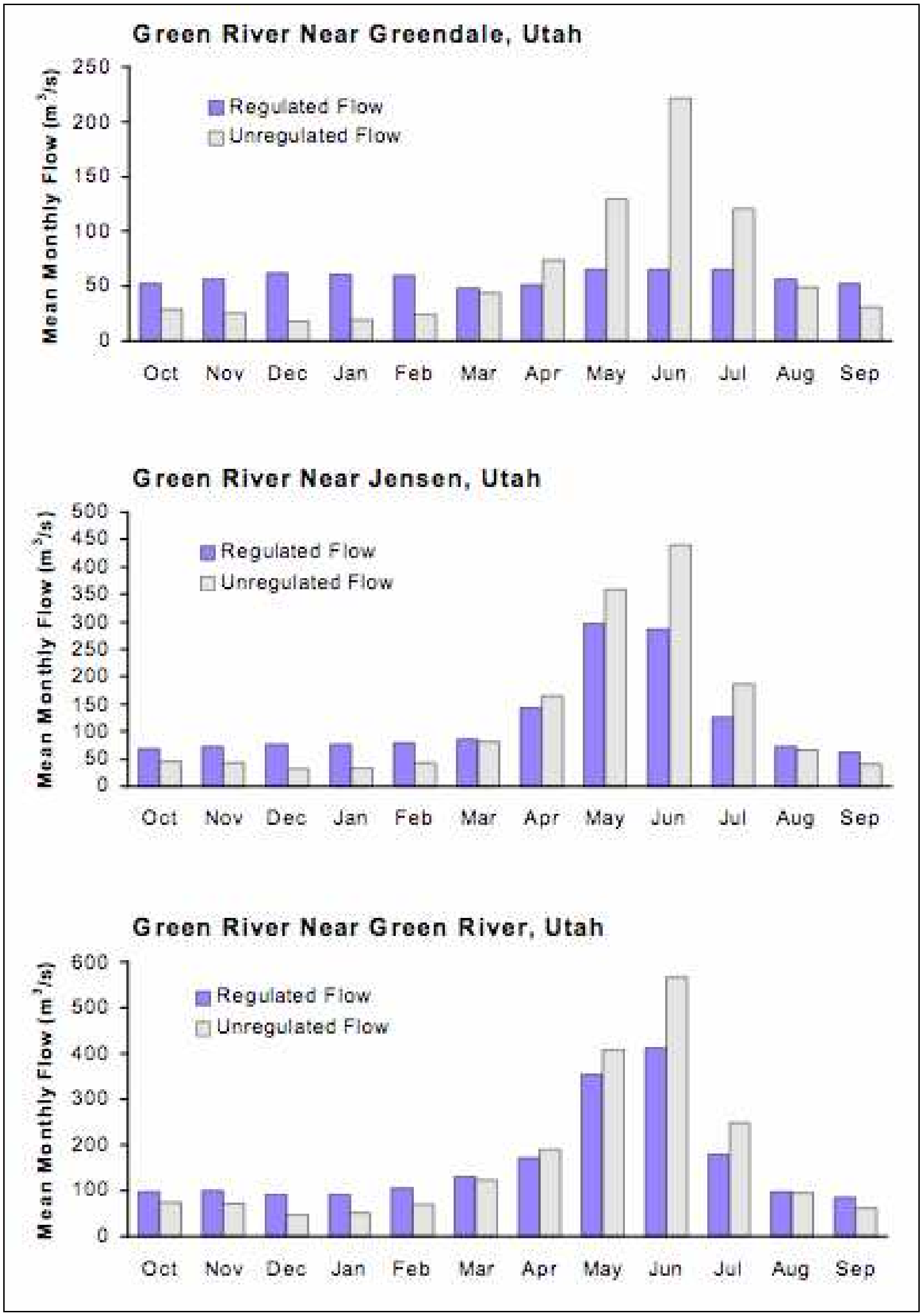

Figure 11. Monthly mean regulated flows in the Green River from 1963-1996. This period is divided into unregulated flow (pre-dam condition) and regulated flow (post-dam condition). Sites are arranged in order of distance from the dam, with Greendale, UT being the closest (From Muth et al. 2000)

Native Fish Management

At the time that Flaming Gorge Dam was under construction, the idea of managing native fishes other than salmon and trout was unheard of in the American West. The botched Green River poisoning, however, was a turning point. The event drew national attention to the declining numbers of native fishes and is believed to be a primary driver in the move towards native fish management (Holden, 1991).

Today, four of the big-river fishes are federally protected under the Endangered Species Act and are in danger of extinction in all or a significant part of their ranges. These listings require the government to work towards the recovery of these species, ultimately assisting in the formation of self-sustaining wild populations (USFWS 2002b). Management activities in the Green River that are working towards recovery are described below.

Modifications to Flaming Gorge Dam Operating Procedures

Until 1978, the dam operated with very few considerations beyond power generation and trout abundance. Water releases were from a single outlet deep in the reservoir and a minimum flow of 812cfs maintained their trout fishery. Then, in 1978, the dam was retrofitted with penstocks, hoping that slightly warmer waters would aid the fishery. Despite the addition of this structure, temperatures maintained through 1985 were still too cold for native fishes. The first large modification of flow coming out of Flaming Gorge Dam occurred between 1985 and 1991 as a result of an environmental impact investigation of the Strawberry Aqueduct and Collection System, located southwest of the dam. In 1980, the USFWS issued a Biological Opinion that determined that aqueduct-related flow reductions to the Green River would harm the continued existence of the endangered humpback chub and Colorado pikeminnow. A decision was made to compensate with extra water released from Flaming Gorge Dam. In addition, the dam operations were to be altered to in an attempt to benefit these fishes. This involved the creation of summer flow regimes that would be evaluated in relation to fish health and survival. These flows were altered slightly over the next few years, via research releases (Muth et al. 2000). A Biological Opinion in 1992 that resulted from these evaluations noted that these flows were also likely to harm native fish populations. New flows and thermal standards were proposed that resembled more historic conditions involving a wide variety of peak and base flows based on that year's hydrologic condition. In addition, daily fluctuations due to the power plant operations would be minimized (Muth et al. 2000, USBR 2006) (see Table 2 for detailed information). These new flow and temperature regimes will be implemented in spring of 2006 and monitored for effectiveness (USBR 2006).

Non-Native Fish Management

The UCRRP adopted a plan to identify management policies that would minimize negative impacts of non-natives to endangered fishes. The plan includes physical non-native removals, removal of bag and possession limits for these species, and ceasing the stocking of non-natives within river reaches designated as critical habitat for endangered fish (Valdez and Muth 20005). This topic is covered in greater detail by Baker (2006, this volume).

Stocking Programs

Tyus (1991) states that the options for recovering a species that has already declined to critically low numbers are limited. For species like the razorback sucker, which have very low larval survival and bonytail chub, which no longer naturally reproduce, stocking programs are part of an effort to prevent extinction. Hatchery facilities are now able to spawn and rear all of the endangered big-river fishes. The UCRRP operate four native fish hatcheries in Utah and Colorado. They are: J.W. Mumma Native Aquatic Species Restoration Facility (bonytail chub and Colorado pikeminnow), Wahweap Fish Hatchery (bonytail chub), Ouray National Fish Hatchery (razorback sucker) and the Grand Valley Endangered Fish Facility (razorback sucker). All operations of culture, propagation, and stocking involve consideration of genetics and population sizes (Czapla 1999).

Native fishes have been raised in hatcheries since the 1980s, but there was little to no coordination between states during stocking. Nesler et al. (2003) provided an integrative stocking plan for the states of Utah and Colorado. The stocking plan focuses mainly on bonytail chub and razorback suckers, with the hope of creating two redundant populations for each species in the Green River. Razorback suckers are being stocked annually with 9,930 fish stocked per population for six years and 5,330 bonytail chub are stocked annually per population for the same time period. Both species are released at 8in TL (approximately 2+ years) to avoid early life stage mortalities. There are no plans to stock humpback chub, as they are believed to be reproducing naturally. It may, however, be considered in the future to expand

Table 2. Recommended flow and temperature plan for the Green River (from USBR, 2006)

		Hydrologic Conditions and 2000 Flow and Temperature Recommendations[1]				
Location	**Flow and Temperature Characteristics**	**Wet[2] (0–10% Exceedance)**	**Moderately Wet[3] (10–30% Exceedance)**	**Average[4] (30–70% Exceedance)**	**Moderately Dry[5] (70–90% Exceedance)**	**Dry[6] (90–100% Exceedance)**
Reach 1 Flaming Gorge Dam to Yampa River	Maximum Spring Peak Flow	8,600 cfs (244 cubic meters per second [m^3/s])	4,600 cfs (130 m^3/s)	4,600 cfs (130 m^3/s)	4,600 cfs (130 m^3/s)	4,600 cfs (130 m^3/s)
	Peak flow duration is dependent upon the amount of unregulated inflows into the Green River and the flows needed to achieve the recommended flows in Reaches 2 and 3.					
	Summer-to-Winter Base Flow	1,800–2,700 cfs (50–60 m^3/s)	1,500–2,600 cfs (42–72 m^3/s)	800–2,200 cfs (23–62 m^3/s)	800–1,300 cfs (23–37 m^3/s)	800–1,000 cfs (23–28 m^3/s)
Above Yampa River Confluence	Water Temperature Target	64 degrees Fahrenheit (°F) (18 degrees Celsius [°C]) for 3-5 weeks from mid-August to March1	64 °F (18 °C) for 3-5 weeks from mid-August to March 1	64 °F (18 °C) for 3-5 weeks from mid-July to March 1	64 °F (18 °C) for 3-5 weeks from June to March 1	64 °F (18 °C) for 3-5 weeks from mid-June to March 1
Reach 2 Yampa River to White River	Maximum Spring Peak Flow	26,400 cfs (748 m^3/s)	20,300 cfs (575 m^3/s)	18,600 cfs[7] (527 m^3/s) 8,300 cfs[8] (235 m^3/s)	8,300 cfs (235 m^3/s)	8,300 cfs (235 m^3/s)
	Peak Flow Duration	Flows greater than 22,700 cfs (643 m^3/s) should be maintained for 2 weeks or more, and flows18,600 cfs (527 m^3/s) for 4 weeks or more.	Flows greater than 18,600 cfs (527 m^3/s) should be maintained for 2 weeks or more.	Flows greater than 18,600 cfs (527 m^3/s) should be maintained for 2 weeks in at least 1 of 4 average years.	Flows greater than 8,300 cfs (235 m^3/s) should be maintained for at least 1 week.	Flows greater than 8,300 cfs (235 m^3/s) should be maintained for 2 days or more except in extremely dry years (98% exceedance)
	Summer-to-Winter Base Flow	2,800–3,000 cfs (79–85 m^3/s)	2,400–2,800 cfs (69–79 m^3/s)	1,500–2,400 cfs (43–67 m^3/s)	1,100–1,500 cfs (31–43 m^3/s)	900–1,100 cfs (26–31 m^3/s)
Below Yampa River Confluence	Water Temperature Target	Green River should be no more than 9 °F (5 °C) colder than Yampa River during summer base flow period.	Green River should be no more than 9 °F (5 °C) colder than Yampa River during summer base flow period.	Green River should be no more than 9 °F (5 °C) colder than Yampa River during summer base flow period.	Green River should be no more than 9 °F (5 °C) colder than Yampa River during summer base flow period.	Green River should be no more than 9 °F (5 °C) colder than Yampa River during summer base flow period.
Reach 3 White River to Colorado River	Maximum Spring Peak Flow	39,000 cfs (1,104 m^3/s)	24,000 cfs (680 m^3/s)	22,000 cfs[9] (623 m^3/s)	8,300 cfs (235 m^3/s)	8,300 cfs (235 m^3/s)
	Peak Flow Duration	Flows greater than 24,000 cfs (680 m^3/s) should be maintained for 2 weeks or more, and flows 22,000 cfs (623 m^3/s) for 4 weeks or more.	Flows greater than 22,000 cfs (623 m^3/s) should be maintained for 2 weeks or more.	Flows greater than 22,000 cfs (623 m^3/s) should be maintained for 2 weeks in at least 1 of 4 average years.	Flows greater than 8,300 cfs (235 m^3/s) should be maintained for at least 1 week.	Flows greater than 8,300 cfs (235 m^3/s) should be maintained for 2 days or more except in extremely dry years (98% exceedance)
	Summer-to-Winter Base Flow	3,200–4,700 cfs (92–133 m^3/s)	2,700–4,700 cfs (76–133 m^3/s)	1,800–4,200 cfs (52–119 m^3/s)	1,500–3,400 cfs (42–95 m^3/s)	1,300-2,600 cfs (32–72 m^3/s)

[1] Recommended flows as measured at the United States Geological Survey gauge located near Greendale, Utah, for Reach 1; Jensen, Utah, for Reach 2; and Green River, Utah, for Reach 3.

[2] **Wet** (0% exceedance): A year in which the forecasted runoff volume is larger than almost all of the historic runoff volumes. This hydrologic condition has a 10% probability of occurrence.

[3] **Moderately Wet** (10–30% exceedance): A year in which the forecasted runoff volume is larger than most of the historic runoff volumes. This hydrologic condition has a 20% probability of occurrence.

[4] **Average** (30–70% exceedance): A year in which the forecasted runoff volume is comparable to the long-term historical average runoff volumes.

[5] **Moderately Dry** (70–90% exceedance): A year in which the forecasted runoff volume is less than almost all of the historic runoff volumes. This hydrologic condition has a 20% probability of occurrence.

[6] **Dry** (90–100% exceedance): A year in which the forecasted runoff volume is less than almost all of the historic runoff volumes. This hydrologic condition has a 10% probability of occurrence.

[7] Recommended flows 18,600 cfs (527 m^3/s) in 1 of 2 average years.

[8] Recommended flows 8,300 cfs (235 m^3/s) in other average years.

[9] Recommended flows 22,000 cfs (623 m^3/s) in 1 of 2 average years.

populations into the Lodore, Whirlpool, and Split Mountain complex. Stocking for recovery has not been a priority for Colorado pikeminnow in the main-stem of the Green River because there are naturally reproducing populations there (Tyus 1991). The success of the hatchery program may take several years to determine, but some promising discoveries have been made. Ripe hatchery stocked razorbacks were found in spawning bar near Jenson, Utah in the Green River and the presence of larvae collected later might indicate that these individuals spawned successfully. Bonytail that were stocked into the Green River have been recaptured. This shows that they are surviving, however no reproduction has been documented (Valdez and Muth 2005).

Public Awareness

The UCRRP has a large public relations program that increases awareness of the big-river fishes through interactive exhibits. In addition, they post signs throughout the Upper Colorado River basin to alert anglers to the possible presence of endangered fishes and produce educational materials. They even issue an annual publication, *Swimming Upstream,* which chronicles their recovery efforts (Valdez and Muth 2005).

General Research

Additionally, on-going research is a key component of the UCCRP. Investigations involving critical habitat designation, levee removals to aid floodplain access, studies on the general life histories of fishes, and the effects of high selenium levels on reproduction are just a few examples of the diverse range of research undertaken by this group. Tying together all of these components into an integrative package will undoubtedly be necessary for management policy in the future.

Conclusion

Human-induced alterations to the Green River have had an undeniably negative impact on the integrity of native fish populations. The synergistic combination of environmental modifications downstream from Flaming Gorge Dam and the introduction of non-native fishes have placed some species dangerously close to extinction. While the restoration of native fish populations to pre-dam conditions is likely impossible, a focused, integrated plan will have the most success in establishing stable, self-sustaining populations of native fishes. The coordinated activities of the groups forming the UCRRP support the broad research and implementation platform necessary for preserving fishes whose life histories are intimately tied to all facets of the natural system. The catch-22 of this broad research plan is the great deal of time required for its development – something that the native fishes of the Green River are quickly running out of.

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