Non-native fish removal in the Green River, Lodore and Whirlpool canyons, 2002-2006, and fish community response to altered flow and temperature regimes, and non-native fish expansion

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EXECUTIVE SUMMARY

Non-native fish removal was conducted in the Green River, Utah and Colorado, downstream of Flaming Gorge Dam in Browns Park, Lodore and Whirlpool canyons, and Island-Rainbow Park. Non-native fish abundance and fish community responses in the reach were evaluated relative to non-native fish removal as well to different flow and temperature regimes that are influenced by Flaming Gorge Dam. We place emphasis on comparisons between the 1994 to 1996, 2002 to 2004, and 2005 to 2006 periods. We also make recommendations for attempting to understand non-native predator abundance and fish community change in relation to multiple potential driving variables including fish removal and Flaming Gorge flow and temperature regimes.

Four major dam-related events affected physical habitat and the fish community of the upper Green River: dam installation in 1962, penstock modification in 1978, flow re-regulation beginning in 1992, and higher peak flows, and lower base flows, and drought events since 2000. The impacts of construction and operation of Flaming Gorge Dam on physical habitat in the highly regulated reach of the Green River from the dam downstream to the Yampa River and in Whirlpool Canyon downstream of the Yampa River included lowering peak flows, increasing base flows, lowering summer water temperatures, and reducing sediment transport and turbidity. Regulation effects were partially remediated by thermal modifications implemented in 1978, discharge re-regulation in 1992, and 2002 to 2006 drought-period changes to base flow levels and patterns. Relatively higher releases in 1997, 1999, 2005, and 2006, and drought-induced high water temperatures created conditions that more closely resembled pre-dam conditions. Peak flows were lower in most other years and at the relatively low power plant capacity including those from 2002 to 2004. Flows in the 2002 to 2006 study period also had a more stable, albeit slightly higher than historical, summer-winter base flow pattern because power

generation fluctuations at Flaming Gorge Dam were minimized. In Lodore Canyon, drought in 2002 to 2006 resulted in low base flows (2005 base flows were moderate level), and thermal regimes in the study area were more similar to those in the pre-dam era than during any other post-impoundment period. This ensured a close match of Green and Yampa River water temperatures during drought years when Colorado pikeminnow larvae were drifting downstream from the Yampa River in summer.

Green River peak flows in Whirlpool Canyon in the pre-impoundment period showed a typical dome-shaped hydrograph, with low late-summer, autumn, winter, and early-spring base flows, rising to a peak in late spring and early summer. Post-impoundment Green River peak flows in Whirlpool Canyon were lower and arrived earlier than historically, an effect of Flaming Gorge Dam. Whirlpool Canyon flow peaks during 2002 and 2004 were lower than the historical average while the 2003, 2005, and 2006 peak flow exceeded the average historical condition (1946 to 1962). Base flows in Whirlpool Canyon in the 2002 to 2006 period matched the historical average pattern reasonably closely. Thermal regimes in 2002 to 2006 were similar to historical ones because dam-related cooling was probably overwhelmed by enhanced warming during low flows, although 2005 water temperatures were cooler.

We used raft-based electrofishing gear, seines, drift nets, and trammel nets to sample Green River fishes from Browns Park downstream to Island-Rainbow Park. A total of 209,466 specimens representing 9 native and 19 non-native species and 7 hybrid combinations were captured by all sampling gears during 2002 to 2004. When data obtained with all gears were combined, native fishes in the 2002 to 2004 period comprised only 10.3% of total catch and non-natives were 89.3%; the remaining 0.4% were hybrids. In the 2005 to 2006 period, an additional 68,466 specimens representing 11 native and 21 non-native species and 6 hybrid combinations were captured by all sampling gears. Native fish abundance increased to 26.4% and non-native fishes were 72.8%; the remaining 0.8% were hybrids.

All told, 238,316 non-native fishes were captured during this study (2002-2006), and most of those were removed. We removed 1,176 potentially problematic large-bodied fishes captured by electrofishing in 2005 (another 411 brown trout or other salmonids were released), and another 1,124 in 2006 (another 410 brown trout or other salmonids were released). Totals for both years included 299 smallmouth bass, 24 northern pike, and 894 channel catfish.

Relative abundance of non-native fishes in Browns Park and Lodore Canyon in 2002 to 2004 increased since 1994 to 1996 sampling, but declined in 2005-2006. Increases in 2002-2004 were throughout the study area and were particularly evident for small-bodied cyprinids, channel catfish, and smallmouth bass in the upper portions of Lodore Canyon. Declines in 2005-2006 were mostly for small-bodied species such as red shiner and fathead minnow. Smallmouth bass abundance increased in the 2005 to 2006 period, mostly because of increased abundance of small-bodied (< 100 mm total length [TL]) individuals. Northern pike abundance remained similar between the two periods, although northern pike recently expanded upstream where reproduction was detected in Browns Park. White sucker and channel catfish abundance also increased. Smallmouth bass reproduction, which was not observed in Lodore Canyon prior to this study, increased through the 2002 to 2004 period, and expanded to Browns Park in 2006. Salmonid abundance temporarily declined in 2002, but increased in 2003 to 2006, and were similar in abundance to that observed in 1994 to 1996. Abundance of predaceous fishes in the Green River study area has increased.

Trammel net sampling in Whirlpool Canyon detected a small population of humpback chub. The relatively large population of roundtail chub present in 2003 may be declining based on sampling conducted in 2006. Hatchery-stocked bonytail were also captured.

Drift net sampling detected reproduction by Colorado pikeminnow in Lodore Canyon in 2006, along with a possible razorback sucker. Reproduction by Colorado pikeminnow was not noted in other years. Drift net sampling revealed that fish, including early life stages of smallmouth bass, were displaced in response to turbidity and higher flow events in 2003 and particularly, 2004.

We were able to link displacement of smallmouth bass in 2004 in the Green River with reduced year-class strength and population abundance in 2005. The abundance reduction was documented in this study with catch-effort statistics. The decline was also observed in a study designed to remove smallmouth bass from the Green River downstream of the Yampa River, where a 58% reduction in abundance was observed from 2004 to 2005. Only a portion of the reduction was due to removal. Sampling and length-frequency histograms indicated a near complete failure of the 2004 year class as age-1 fish in 2005, an age group that made up about 40% of the population sampled by electrofishing in 2004. Reductions of this magnitude are rarely observed or persist in removal studies between years. These data suggested that flow manipulations from Flaming Gorge Dam may be useful to disadvantage survival and recruitment by early life stages of smallmouth bass. Additional information is needed on smallmouth bass early life history to understand when flow manipulations may be most useful. Effects of flow fluctuations on native fishes should also be considered.

Colorado pikeminnow continued to use Lodore Canyon heavily in summer in 2002 to 2006, based on captures we made and those in a concurrent companion study. Ripe male Colorado pikeminnow were detected there in 2001 and 2003, which in concert with detection of larvae in 2006, indicates conditions suitable for reproduction in some years.

Based on our 2002 to 2006 sampling, the net effect of non-native fish predators and flow and temperature regimes on the native fish community, was mixed. During this study, we were able to obtain reliable information on the response of the fish community to flow and temperature effects, but only at the lower end of the flow spectrum and the high end of the temperature spectrum. Flow and temperature conditions observed in 2002 to 2006 fell within the bounds for recommendations that would be implemented in years with low or moderately low water availability, which happen in only 30% of flow years. Average, moderately high, and high flow years, which occur the other 70% of the time, were not evaluated because those conditions were not realized during this study period. Additional years of sampling when those flow conditions are available are needed to fully assess the combined effects of non-native fish removals as well as flow and temperature recommendations for Flaming Gorge Dam on the fish community of the Green River.

We recommend additional monitoring of water temperatures, flows, and the fish community of the Green River in Browns Park, Lodore and Whirlpool canyons, and Island-Rainbow Park. Comparisons of fish community response to different levels of fish removal in the study area (Green River up and downstream of the Yampa River) and flow and temperature regimes from Flaming Gorge Dam may enhance understanding of factors that may limit invasive species, particularly predators, and enhance native fishes. Care needs to be taken when implementing these studies so that effects of fish removal and concurrent effects of flow and temperature regimes from Flaming Gorge Dam on native fishes are not inextricably confounded. We offer some suggestions for that, perhaps including additional sampling in the lower Yampa River. We also recommend PIT-tagging and scanning all chubs captured, including roundtail chubs, and continued removal of predaceous and other non-native fishes from the study area.

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KEY WORDS

Fish removal, non-native predators, smallmouth bass, northern pike, channel catfish, Colorado pikeminnow, roundtail chub, humpback chub, razorback sucker, river regulation, restoration, endangered fishes, longitudinal abundance patterns, drift net sampling, fish community change, water temperature

INTRODUCTION

Introduction and establishment of non-native fish in western rivers of the USA is a major threat to conservation of native fish assemblages (Minckley and Deacon 1968, Stanford and Ward 1986, Moyle et al. 1986, Carlson and Muth 1989, Minckley and Deacon 1991, Olden et al. 2006). In the upper Colorado River Basin, non-native fish invasions began over 100 years ago, with introduction of channel catfish *Ictalurus punctatus*, common carp *Cyprinus carpio*, and salmonids for sport fishery purposes. In the 1960's, small-bodied species such as red shiner were relatively rare in the Green River sub-basin of the Upper Colorado River Basin (Vanicek et al. 1970), but by the 1970's were expanding rapidly (Holden and Stalnaker 1975a and 1975b). By the 1980's, red shiner was a dominant species in low-velocity habitat used by early life stages of native fishes, and potential negative effects of that species and other small-bodied fishes have been documented (Haines and Tyus 1990; Dunsmoor 1993; Ruppert et al. 1993; Muth and Snyder 1995; Bestgen et al. 1997; 2006). More recently, piscivores such as smallmouth bass *Micropterus dolomieu* and northern pike *Esox lucius* have established and are common in the lower Yampa River and the upper and middle Green River basins (Anderson 2002; 2005, Bestgen et al. 2006, Finney 2006). The predatory threat of these large-bodied taxa is substantial and control programs have been initiated to reduce their abundance and negative effects on native fishes.

Altered flow, sediment, and temperature regimes in regulated rivers have also been implicated as factors responsible for reduced distribution and abundance of native aquatic biota in the Colorado River Basin (Petts 1984, Ward 1989, Ward and Stanford 1995, Stanford et al. 1996, Poff et al. 1997). In these snow-melt dominated streams, dams reduce spring discharge maxima, which disrupts channel-flood plain interactions and channel forming processes. Deep-releases from reservoirs reduce spring, summer, and autumn water temperature downstream from dams and cause shifts in composition of fish and invertebrate communities from warm stenothermic native species to non-indigenous cold-tolerant eurytherms (Holden 1979, Ward and Stanford 1979, Stanford et al. 1996). Remnant populations of native fishes may persist as longlived adults, but reproduction is often reduced or eliminated by cold spring and summer water temperatures and other effects of regulation.

In the regulated reach of the Green River downstream from Flaming Gorge Dam, native fishes are affected both by expanding populations of non-natives fishes and by altered flows and thermal regimes. Flow and temperature regimes in the Green River have recently been re-regulated at Flaming Gorge Dam for the benefit of native fishes downstream (Muth et al. 2000, Record of Decision, U. S. Bureau of Reclamation, 2006). Protocols used for river restoration embraced re-establishment of natural physical processes in streams with hypothesized benefits for native biota, including fishes (Stanford et al. 1996, Poff et al. 1997). Re-establishment of annual flow maxima to maintain channel geomorphology and flood plain connectedness, reduction of base flow fluctuations to enhance stability and food web functioning of low velocity nearshore areas, and restoration of more natural seasonal temperature patterns are examples of key processes that may facilitate recovery of native biota (Stanford et al. 1996, Poff et al. 1997). However, re-regulated flow and thermal regimes may also influence non-native fish populations in affected reaches and may result in uncertainty about whether such management actions provide a net positive benefit for native fishes (Propst and Gido 2004, Bestgen et al. 2006). For example, it is difficult to isolate effects of flow or temperature regimes on native fishes when distribution and abundance of invasive species are expanding, perhaps through interactions with variable environmental conditions (Bestgen et al. 2006). Thus, a main challenge of testing river restoration hypotheses is linking population measurements such as fish abundance to a driving variable or set of flow or temperature variables with reasonable certainty, while also considering the potentially large effect that non-native predaceous fish populations may have on native fishes.

The goal of this study is to report on non-native fish removal efforts in the Green River in Lodore and Whirlpool Canyon. We examine trends in distribution and abundance of selected non-native fishes, from 2002-2004 (Bestgen et al. 2006) and 2005-2006 when flows were relatively low and water temperatures in summer were warm, and compare those trends with abundance levels estimated from 1994-1996, a period prior to introduction or expansion of several non-native species and when summer flow levels were relatively higher and cooler. We then compare trends in native fish abundance over the same time periods. We attempt to sort out the relative effects of expanding populations of non-native fishes on native ones as well as changes in flow and temperature regimes between the periods 1994-1996 and 2002-2006, particularly in 2005 and 2006 when non-native fish removals were increased (Christopherson et al. 2005, this study). We also discuss means, in part, to understand the overlapping and potentially confounding effects of simultaneous fish removal and flow and thermal regimes on non-native and native fishes.

The reach of the Green River, Utah and Colorado, downstream of Flaming Gorge Dam offers an opportunity to evaluate effectiveness of actions to re-establish native fishes. This is an ideal study area because more natural hydrologic and temperature regimes designed to benefit native fishes have been implemented over a series of years. The Green River also has a source pool of native fishes downstream, including the mostly unregulated and tributary Yampa River and regulation-attenuated downstream reaches of the Green River, to re-colonize upstream reaches. Furthermore, descriptions of the fish community are available from immediate pre-dam (pre-1962) and post-dam (1964-1966) periods, as well as before and after installation of a temperature control device (1978-1980). Additional sampling was conducted from 1994 to 1996 and in 2002-2004 that further evaluated changes in the fish community following implementation of flow and temperature recommendations contained in biological opinions on operation of Flaming Gorge Dam (U. S. Fish and Wildlife Service 1992, Bestgen and Crist 2000, Muth et al. 2000, Bestgen et al. 2006).

The newest set of flow and temperature recommendations for the Green River was developed (Muth et al. 2000) and those recommendations were officially implemented in 2006 (Record of Decision, U. S. Bureau of Reclamation, 2006). Annual peak and base flow recommendations were developed for each of five hydrologic conditions that ranged from dry to wet, based on exceedance probabilities: dry (90 to 100% exceedance), moderately dry (70 to 90% exceedance), average (30 to 70% exceedance), moderately wet (10-30% exceedance), and wet (0-10% exceedance). Flaming Gorge Dam spring peak release recommendations range from

130 m^3/s (full power-plant capacity) in dry years to > 244 m^3/s in wet years. Base flow (August to February) release recommendations were also scaled to hydrologic conditions and ranged from 23 to 28 m^3/s in dry years to 79 to 85 m^3/s in wet years. Warmer releases (up to 15°C) and lower summer base flows were also recommended to improve downstream water temperature conditions for native fishes in the Green River. Specifically, water temperatures of 18 to 20°C were targeted for two to five weeks in summer in Lodore Canyon. Another goal of warmer summer water temperatures was to ensure that the Green River was no more than 5°C cooler than the Yampa River, to reduce the possibility of cold shock to Colorado pikeminnow *Ptychocheilus lucius* larvae as they drift downstream from the Yampa River. The range of flow and temperature recommendations were expected to benefit all life stages of native, endangered fishes and further their recovery. Muth et al. (2000) recognized "uncertainties" regarding effects of recommended flow and temperature regimes. A primary uncertainty was whether hypothesized negative effects of increased distribution and abundance of certain non-native fishes may offset benefits from recommended flow and temperature regimes to native or endangered fishes. This summary of the recommendations is provided so the reader understands the operational history of Flaming Gorge Dam on the Green River and the fish community changes that have been documented over time. Study goals and specific objectives were:

Goal. Assess if recent non-native predator fish removal and changes in Green River flow and thermal regimes since 1996 are associated with changes in distribution and abundance patterns of native and non-native fishes in Browns Park and Lodore Canyon. Information will be used to evaluate if flow and temperature regimes from Flaming Gorge Dam are benefitting endangered fishes without causing detrimental increases in abundance of non-native fishes.

Objective 1. Remove non-native fishes in the study area. Effects of this action will be evaluated by determining if shifts in distribution and abundance of large-bodied fishes occurred in Browns Park and Lodore Canyon by comparing results of shoreline electrofishing and trammel net surveys with results of previous studies, particularly Bestgen and Crist (2000) and Bestgen et al. (2006).

Objective 2. Determine if shifts in distribution and abundance of small-bodied fishes occurred in Browns Park and Lodore Canyon by comparing results of seining low-velocity, nearshore areas with results of previous studies, particularly Bestgen and Crist (2000) and Bestgen et al. (2006).

Objective 3. Determine if Colorado pikeminnow spawn in the Green River upstream of the Yampa River confluence by establishing a larval drift station in lower Lodore Canyon, and by summer sampling to determine presence of ripe adults.

Objective 4. Collect data from the hydrological records for two time periods (WY 1992-1996 vs. 1997-2006) as recorded by the U. S. Geological Survey at the Greendale, Utah gaging station (09234500).

Objective 5. Collect main channel temperatures in Browns Park and Lodore Canyon in coordination with other ongoing efforts.

Objective 6. Compare and contrast the summer thermal regime of the Green River through Browns Park and Lodore Canyon for two time periods (WY 1991 to 1996 vs. 1997 to 2006). Temperature models will be used to generate thermal regimes, where empirical data are lacking.

Goal: Continue to monitor the effect of fish removal efforts and Flaming Gorge operations on the fish community in Lodore and Whirlpool canyons.

Objective 7. Conduct non-native fish removal and fish community sampling into Whirlpool Canyon.

Objective 8. Collect flow data in Whirlpool Canyon USGS stations at the Deerlodge Park gage on the Yampa River, and the Greendale, Utah and Jensen, Utah gages on the Green River.

Objective 9. Collect water temperature data in Whirlpool Canyon.

Objective 10. Based on the conclusions of these investigations (Obj. 1-9), recommend a process to monitor future effects of operations at Flaming Gorge Dam on the downstream fish community.

Goal. Characterize the humpback chub *Gila cypha* population in Whirlpool Canyon.

Objective 11. Gather preliminary information to describe the distribution, relative abundance, and size structure of *Gila spp*. in Whirlpool Canyon through the fish community sampling methodologies.

Objective 12. Characterize morphology of the *Gila spp*. collected in Whirlpool Canyon (Douglas et al. 1989; 1998).

Objective 13. Develop program to monitor the humpback chub population in Whirlpool Canyon.

STUDY AREA

The Green River Basin drains mountainous and high desert portions of southern Wyoming, eastern Utah, and northwestern Colorado (Fig. 1) and is the largest tributary of the Colorado River. The study area encompassed the Green and Yampa rivers in and above Dinosaur National Monument and included highly regulated and regulation-attenuated river reaches. The Green River below Flaming Gorge Dam downstream to near Jensen, Utah, was the primary focus of the study. The river below Flaming Gorge Dam flows for 22 km through Red Canyon, enters the 48-km-long low gradient Browns Park valley, and then flows for 32 km through high-gradient Lodore Canyon before entering Echo Park at the Yampa River confluence. From Echo Park, the Green River flows 18 km mostly through Whirlpool Canyon, another 11 km through Island-Rainbow Park, and another 13 km through Split Mountain Canyon before emerging into the alluvial Uintah Basin valley reach near Jensen.

Extent of river meandering (river plan form) and habitat types in the major reaches of river are controlled by local geology. In Lodore, Whirlpool, and Split Mountain canyons the Green River is generally confined to a single, relatively narrow channel. Canyon river reaches constricted by debris fans form riffles and rapids with cobble and boulder substrate. These river reaches generally have higher current velocities and deeper runs and pools than lower gradient areas without debris fans. In lower gradient alluvial reaches such as Browns and Island-Rainbow parks, river plan form is characterized by restricted meanders (Grams 1997), and the channel is relatively wide, shallow, and sometimes interspersed with islands. Lower velocity runs with sand and cobble substrate predominate.

Flaming Gorge Dam in northeastern Utah impounds the mainstem Green River at the upstream end of the study area. With a storage capacity of 3.74 million acre-ft (4,624 million m^3), it is the largest reservoir in the Green River Basin. Upstream Fontenelle Reservoir, the only other mainstem Green River reservoir, does not appreciably affect releases from Flaming Gorge Dam. Flaming Gorge Dam was closed in 1962 as part of the Colorado River Storage Project (CRSP) to store water so that states of the Upper and Lower Colorado River basins (Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona, California) could develop their respective water entitlements. The dam and reservoir also produce hydropower and provide fish and wildlife benefits. Mean annual discharge in the Green River upstream of the Yampa River has not changed appreciably as a result of dam closure (59 m^3/s post-dam versus 56 m^3/s pre-dam). However, seasonal flow variability has been considerably reduced. Since Flaming Gorge Dam was closed in 1962, June mean maximum flow of the Green River has been reduced from 381 m^3/s to 139 m^3/s (Tyus and Karp 1991, Muth et al. 2000). Flows at all other times of the year have increased. In addition, releases for peaking power production were made up to twice per day, resulting in short-term daily fluctuations much greater than historically occurred. Annual volume of sediment transported by the Green River below Flaming Gorge Dam has decreased by 54% as a result of deposition in the upstream reservoir (Andrews 1986).

The relatively unregulated Yampa River, a major tributary of the Green River, exhibited greater seasonal variability and more stable daily flows than the Green River below the dam. During the period 1963 to 2004, annual flow maxima in the Yampa River occasionally reached 566 m^3/s, but sometimes declined to < 2 m^3/s in late summer (U. S. Geological Survey et seq.; Maybell Gauge, 09251000).

METHODS

Methods of fish collections used in this study were essentially identical to those reported in Bestgen et al. (2006). Collections of small-bodied (< 150 mm TL, most were 25 to 75-mm TL) and large-bodied (150- mm TL or greater) fishes were made from 2002 to 2006 to describe current distribution and abundance patterns of fishes in the Green River from Swinging Bridge in Browns Park to the downstream end of Island-Rainbow Park, portions of which were reported in Bestgen et al. (2006). Water temperature and discharge data were used to understand the relationship of physical factors to longitudinal distribution and abundance patterns of fishes in the regulated portion of the Green River. Discharge and temperature regimes associated with specific dam operations were compared to changes in fish distribution and abundance patterns.

Collection of small-bodied fish.—Low-velocity channel margins in Browns Park, Lodore and Whirlpool canyons, and Island-Rainbow Park were sampled with seines (1.3 and 4.6 m length, 1.6 and 4.7-mm mesh). Seine sampling was conducted in spring, summer, and autumn in each year from 2002 to 2004, and during summer and autumn in 2005 and 2006. Habitat types sampled were mostly backwaters, but channel margin eddies, low velocity runs and pools, and a few riffles were also sampled. More effort was expended in larger habitat areas and less in smaller ones so that the proportion of the habitat sampled was approximately equal across different-sized areas. Riffles were occasionally “kick-seined”, whereby substrate was vigorously disturbed and dislodged fish were captured in a stationary downstream seine. Some vouchers were preserved in 10% formalin and identified at the Larval Fish Laboratory, Colorado State University. We scrutinized all young chubs captured and preserved in 2002 to 2006 by counting dorsal and anal fin rays, and characterizing shape characteristics of the snout and mouth (mouth terminal in roundtail chub *Gila robusta*, slightly subterminal in humpback chub), body depth, fin lengths, and the line of the angle of the anal fin base relative to the upper lobe of the caudal fin, which assisted with identifications (Muth 1990, Douglas et al. 1989, Snyder et al. 2006).

Drift net samples collected in the Green River just upstream of the Yampa River in 2002 to 2006 were used to describe species composition and abundance patterns of fish larvae transported downstream and to determine if upstream spawning of Colorado pikeminnow had occurred. Samples were collected daily in the morning (beginning ca. 0630 to 0900 h) with conical drift nets (0.15 m^2 mouth diameter, 4 m long, 560 μm mesh) set near shore in water 30 to 50-cm deep. Three nets were set on each sampling occasion for up to 2 h, but sampling ceased if debris load exceeded 3.8 L/sample. Water depth at which a white object disappeared from sight was recorded as a measure of water turbidity. General Oceanics flow meters (model 2030) suspended in each net mouth recorded water velocity. Samples were fixed immediately in 100% ethanol and fish were removed from debris within 4 h and preserved in 100% ethanol. Ethanol was used to ensure that fish otoliths or other tissues were useful for later analysis, if desired.

Collection of large-bodied fish.—Most collections of large-bodied fishes were by electrofishing and (mostly in Whirlpool Canyon) trammel nets; angling was used on a limited basis. Two electrofishing sampling trips were made each year from 2002 to 2006, one in mid to late July and one in mid to late September. Inflatable raft-based Smith-Root electrofishers were employed. Water conductivity was 300 to 700 microsiemens and electrofishing units usually produced 3-6 amperes with about 350 volts. Generally, 1.5 to 3 km reaches were electrofished before fish were identified, and lengths and weights taken on about every other sample. Electrofishing effort was continuous throughout the reach and concentrated along river banks, in deep pools, riffles, eddies, or near cover. We attempted to capture all fishes that were stunned. Electrofishing samples collected in 2002 in summer (both rafts) and autumn (one raft) were potentially biased downward compared to samples collected in 2003 to 2006 because the anode and cathode plugs were switched. This caused the relatively small surface area dropper sphere in the front of the raft to become the cathode and the relatively large surface area cables positioned mid-raft to become the anodes. The result was fewer fish were attracted to the anode and sometimes came up at the side of the raft rather than the front, which resulted in less efficient sampling. However, mean capture rate of all species combined over the study period was only slightly higher when the 2002 data was excluded (2.65 fish/h average per all species, 95% CI = 2.43 to 2.89, compared to 2.42 fish/h, 95% CI = 2.24 to 2.61 with 2002 data included). Also, of nine species most often captured by electrofishing, five increased in mean abundance when 2002 data were excluded and four decreased. Since inclusion of that data appeared to have little effect on overall abundance values, we retained 2002 data in all analyses.

Trammel net sampling was mostly confined to Whirlpool Canyon, because that reach contained deep eddy habitat most likely to support humpback chub. A few trammel net samples were collected in Mitten Park and Lodore Canyon. Multi-filament trammel nets (23 m long x 1.8 m deep; 25-cm outer mesh, 2.5-cm inner mesh) were set in late summer or autumn when water temperatures were relatively low so that fish mortality would be minimized. In autumn 2003 we conducted three consecutive sampling trips (passes) in an attempt to obtain an abundance estimate for chubs in Whirlpool Canyon, but sampling of that intensity was not conducted in other years. The main sampling sites for trammel nets were in upper Whirlpool Canyon just upstream and downstream of Rain Camp (river kilometer (RK) 550.8), at a large eddy pool about 1 km upstream of Jones Hole Creek (RK 546.4), and at Compromise Camp (RK 544). Trammel nets were usually fished during crepuscular and nighttime hours, and lesser amounts in day time, and were set in low velocity habitats and in the separation zone of the main channel current and eddy pools (eddy lines). The number of nets set (up to six) was contingent on habitat availability and accessibility. Nets were cleared of fish every 2 h. Fish captured by electrofishing and trammel nets were measured (total length [TL]) and sex and reproductive condition was noted, if discernable. Large samples of small-bodied fish captured by electrofishing were counted. In addition, endangered fishes and roundtail chubs were individually weighed and scanned for a passive integrated transponder (PIT) tag. If none was detected, a PIT tag was implanted and the fish was released. Special care was taken to identify potential catostomid hybrids. We identified these based on morphological characteristics of the mouth and body that were intermediate between putative parental types and on intermediate squamation patterns and scale counts in the lateral series (Hubbs and Miller 1953). Vouchers of some specimens, including catostomid hybrids, were preserved in 10% formalin and are housed at the Larval Fish Laboratory, Colorado State University.

Browns Park habitat reconnaissance and fish sampling.—In response to finding the first age-0 northern pike in upstream portions of the Green River in Browns Park in 2005 (2005 annual report, RIP project 115), we made additional observations of habitat and conducted additional fish sampling in Browns Park in 2006, to better understand habitat availability and the distribution and abundance of northern pike. Maps and communications with area wetlands managers were used to identify locations of potential wetlands and the extent of connections of off-channel areas with the Green River. In late May, during the period when high releases (up to 193 m^3/s) were made from Flaming Gorge Dam, one of us (CTW) surveyed the Green River from just upstream of the Utah/Colorado state line downstream to Lodore Canyon to assess whether connections existed between the river and potential flood plain wetlands that may support spawning populations of northern pike and other non-native fishes. The type of connection and the method of wetland filling (pumped, gravity canal, direct connections, etc.) at each site was noted, with special attention given to accessibility (up or downstream) of riverine fishes to wetlands, and vice versa, and whether fishes were observed in wetlands. Potential for connection at flows higher than those observed were also made, in the event that future hydrologic conditions merit even higher releases from Flaming Gorge Dam. Observations were supplemented with communication with wetland managers about modes of operation, connections, and potential presence of fishes. We hypothesized that this information may be useful to understand if newly discovered (2005) age-0 northern pike in the Browns Park reach of the Green River were being produced in wetlands that connect with the river during higher spring flows or if pike were spawning in inundated vegetation within the active channel.

Using information gained from May 2006 habitat surveys, we then sampled the Green River in Browns Park at 18 locations, mostly from river kilometers 613.6 to 585.9 on 19-21 August 2006; most sites were in upstream areas but a few were near the Lodore Canyon boat ramp. This sampling was designed to provide further information on the distribution and abundance of northern pike in the reach especially relative to observations of potential pike habitat in spring surveys, and was focused in an area up- and downstream of locations where pike had been collected in 2005 (Beaver Creek confluence and Hog Lake). Sampling was conducted with a 9.1-m-long electric seine. Sampling effort was focused mostly in near shore areas or backwaters with low velocity and sand or silt substrate, locations known to support age-0 northern pike. Such areas in this reach of the Green River are typically heavily vegetated with submerged or emergent macrophytes. Sampling effort focused on capture of northern pike and centrarchids, potentially predaceous fishes, although other species detected during sampling were noted and their qualitative abundance was recorded. The northern pike and centrarchids were counted, measured, weighed, and then preserved. Predaceous fishes (pike and smallmouth bass) were preserved in ethanol so that additional information could be gathered via otolith analysis.

Stream flow and water temperature data collection and presentation.—Most temperature data were from lower Lodore Canyon and Mitten Park (pers. comm., G. Smith, U. S. Fish and Wildlife Service, Denver, Colorado). Flow data were from U. S. Geological Survey gauges. First, we describe the major changes in flow and temperature regimes in Lodore and Whirlpool canyons as a result of construction and operation of Flaming Gorge Dam. We characterized flow differences in the historical period (Lodore Canyon, Greendale gauge, # 09234500, RK 660, 1951 to 1962; Whirlpool Canyon, Jensen gauge # 09261000, RK 486.2, 1946 to 1962), a post-impoundment period (1962 to 1991), a post-Biological Opinion period (1992-1996), and a recent (1997 to 2006) period which was thought to represent conditions that affected the fish communities during this investigation. We used the gauge near Jensen, Utah, to characterize Whirlpool Canyon and Island-Rainbow Park flows because the few small tributaries present between Whirlpool Canyon and the downstream gauge will not affect flow estimates appreciably.

Fish sample data analysis and presentation.—Composition of the fish community in the study area (Fig. 1) was calculated for samples collected in the 2002 to 2004 period for each gear type, and also for the 2005 to 2006 period. We grouped samples in this manner because 2002-2004 data were reported previously (Bestgen et al. 2006), and it made sense to compare those findings with more recent data collected in 2005 and 2006. Longitudinal and temporal shifts in community composition were characterized by partitioning samples into reaches for large-bodied fishes captured primarily by electrofishing in the periods 1994 to 1996, 2002 to 2004, and 2005 and 2006. Seine sampling data was used to supplement observations gathered for large-bodied fishes, but that data is not extensively featured here. In some cases, we cite the recent and extensive analyses in Bestgen et al. (2006) rather than duplicate those results here. Samples were from eight contiguous Green River reaches: a Browns Park reach, four 8-RK Lodore Canyon reaches, upper and lower Whirlpool Canyon reaches (9 and 8 RK) and the Island-Rainbow Park reach (10 RK); electrofishing was conducted only in Lodore and Whirlpool canyons.

Change in numerically dominant native and non-native fishes in reaches was compared among study periods 1994 to 1996, 2002 to 2004, and 2005 and 2006, and reaches to facilitate detection of longitudinal shifts in community composition. We defined relative abundance as the percent composition that a particular species represented in a sample. For electrofishing samples, CPUE was number of fish captured per amount of time sampled. In general, relative abundance and CPUE indices tracked each other closely so we present mostly relative abundance data here.

RESULTS AND DISCUSSION

Effects of Flaming Gorge Dam on Green River discharge and temperature patterns, Lodore Canyon.—We present extensive information on historical and present-day streamflow and temperature patterns of the Green River because we believe they are a significant influence on fish distribution and abundance patterns for the associated time period. Further, detailed understanding of dam operations may also allow predictions to be made about effects of flow and temperature regimes to the extent that such may be useful to manage distribution and abundance of fishes. Summaries are also available in Bestgen and Crist (2000) and Bestgen et al. (2006), but are brought up to date and presented here for the convenience of the reader. Four major dam-related events affected physical habitat and the fish community of the upper Green River: dam installation in 1962, penstock modification in 1978, flow re-regulation beginning in 1992, and higher peak flows, lower base flows, and drought events since 1997. Prior to construction of Flaming Gorge Dam, discharge patterns of the Green River exhibited high spring peaks followed by lower, stable base flows in other seasons, particularly winter (Fig. 2). Water temperature ranged from a low of 0°C in winter to over 22°C in summer (Fig. 3) and turbidity increased seasonally from inputs of fine inorganic silts (Vanicek et al. 1970). Immediate dam effects included inundation of riverine habitat in the reservoir zone. Downstream, naturally variable and relatively high spring discharge maxima were reduced (Fig. 4). Power plant operations increased base flow levels and daily discharge fluctuations. Naturally turbid water was cleared when virtually all sediment was trapped behind the dam. Water drawn from the hypolimnion of the reservoir reduced temperature of summer releases to about 6°C after reservoir filling was completed in 1967. Downstream warming occurred but mean monthly summer water temperatures reached a maximum of about 14°C in the post-dam period in Lodore

Canyon compared with > 20°C in the pre-impoundment period (Fig. 3 in Bestgen and Crist 2000). Post-dam winter water temperatures in the tailwater were increased compared to pre-impoundment conditions from near 0°C to about 4°C.

Cold tailwater releases begun after 1967 dramatically reduced trout growth in the fishery that established after dam closure, which prompted the second major Green River change due to Flaming Gorge Dam (Holden and Crist 1981). A multi-level penstock was installed and became operational in June 1978 (mean daily water temperature was 5°C on 19 June, increased to 13°C on 22 June) to allow water to be drawn from warmer upper layers of the reservoir in summer. Temperature of multi-level penstock releases during summer operations were targeted at about 13°C, a level thought to maximize growth of rainbow trout *Oncorhynchus mykiss* and maximize downstream extent of the tailwater fishery. Effects of penstock modifications on native fishes in reaches further downstream were assessed from 1978 to 1980 by Holden and Crist (1981). Penstock modifications raised water temperature in the Green River upstream of the Yampa River, but summer maxima rarely exceeded 17°C in the period 1978 to 1991 (Fig. 3 in Bestgen and Crist 2000).

The third major dam-related operation event occurred in 1992 in response to a Biological Opinion on operation of Flaming Gorge Dam (Tyus and Karp 1991, U. S. Fish and Wildlife Service 1992). Spring release levels from the dam were increased in an attempt to simulate a more natural runoff pattern and enhance floodplain inundation downstream of Jensen, Utah (Fig. 2). The spring through autumn flows implemented in 1992 were designed to enhance physical habitat in the Green River downstream of the Yampa River confluence; habitat enhancement in the regulated Green River reach upstream of the Yampa River was not a priority because few endangered fishes were thought to occur there. Releases up to maximum power plant levels (130 m^3/sec, Fig. 4) were made for up to six weeks in spring around the time when unregulated Yampa River discharge peaked. During summer, release levels were designed to maximize nursery habitat for Colorado pikeminnow near and downstream of Jensen, Utah (Tyus and Karp 1991). To achieve the desired stable base flow of 51 m^3/sec ($\pm$ 12.5%, Pucherelli et al. 1990, Tyus and Karp 1991, U. S. Fish and Wildlife Service 1992), releases were usually decreased to as low as 22.3 m^3/sec soon after prescribed high spring flows ended because Yampa River discharge was usually high. Dam releases were increased later in summer after Yampa River discharge declined and when Green River discharge at Jensen fell below target levels.

Water temperatures in the Green River upstream of the Yampa River in the period 1992 to 1996 showed a slightly warmer summer pattern than for the previous 1978 to 1991 period as summer maxima typically peaked at about 18°C or less for a short period (Bestgen and Crist 2000). Summer discharge manipulations altered thermal regimes in the regulated reach because flow level and water temperature were inversely correlated in the Green River downstream of Flaming Gorge Dam (Vanicek et al. 1970, Bestgen and Crist 2000). This is because reservoir releases that are cold relative to air temperature progressively warm via solar insolation downstream from the dam, but warm faster in upstream reaches if flows are lower and slower. Thus, under lower drought flows, relatively warm water can be expected well upstream into Browns Park if air temperatures are warm. Dynamics of flow and water temperatures and regression models to predict downstream warming were discussed in detail in Bestgen and Crist (2000) and Muth et al (2000). Because flows typically increased from Flaming Gorge Dam in summer during 1992 to 1996 to meet downstream flow requirements near Jensen, Utah, maximum temperatures in the reach upstream (e.g., Lodore Canyon) of there were sometimes achieved in late June but often declined by mid July.

Flow and temperature regimes in the Green River downstream of Flaming Gorge Dam since 1997 followed elements of both the 1992 Biological Opinion and newer proposed recommendations. Higher spring releases were realized in 1997 and 1999 (Fig. 5), but spring peaks during study years 2002 to 2004 were at or below power plant capacity (about 130 m^3/sec, Fig. 4). Compared to earlier post-regulation periods, in 1997 to 2004, and particularly for the 2002 to 2004 period (and in 2000 and 2001), base flows (August to February) were lower, stable, and more closely approximated the historical hydrograph (Fig. 6, Table 1). Baseflows were slightly higher in 2004 than in 2002 or 2003. Flows that resulted from the 1992 Opinion recommendations were more variable. For example, summer base flows more than doubled from about 23 m^3/sec in June to nearly 50 m^3/sec in August in the low flow year 1994.

In 2005 and 2006, spring releases were higher than powerplant capacity in each year, 195 m^3/sec in 2005 and 173 m^3/sec in 2006 (Fig. 4). Higher flows were released mostly to enhance peaks of the Green River downstream of Jensen, Utah, to facilitate estimation of entrainment rates of buoyant beads and razorback sucker larvae into flood plain wetlands. Base flows were relatively high at about 41.6 m^3/sec in 2005 but in 2006 were comparable to 2002 and 2003 at about 25 m^3/sec (Fig. 7).

In all periods, regulated flows showed large differences in hydrograph shape. Historical flows had a longer duration peak, increased to peak and declined from peak more gradually, and base flows were lower (Fig. 2). In 1992 to 1996, flow peaks were lower than historically, had higher base flows, and were of moderate duration. In 2002 to 2006 drought years, flow peaks were low (slightly higher in 2005 and 2006), had very limited duration even compared to 1992-1996, and declined to base flow relatively early in summer. Additionally, timing of peak flow from the regulated Green River upstream of the Yampa River exhibited peak flows several weeks earlier than was historically seen, peaking now in late May rather than mid or late June (Fig. 2), as dictated by the 1992 Biological Opinion and the new Flaming Gorge Dam flow recommendations (Muth et al. 2000, Record of Decision, U. S. Bureau of Reclamation, 2006).

As a result of relatively low base flows in 1997 to 2004, summer water temperatures in Lodore Canyon increased to levels likely not observed since Flaming Gorge Reservoir filled in 1967 (Fig. 3), and that trend continued in 2005 and 2006 (Fig. 8). Summer water temperatures were particularly warm in the Green River upstream of the Yampa River in 2002 and 2006, when daytime highs reached 25°C in late July, and matched the summer maxima observed in the limited 1957 to 1962 historical period. In years 2005 and 2006, and perhaps portions of 2004, it appears that penstock level at Flaming Gorge Dam was manipulated to achieve release temperatures below the dam as high as 15°C in summer (in part, Fig. 9), whereas in 2002 and 2003, penstock levels were manipulated to limit releases to a temperature of 13°C or sometimes less (e.g., 2002). Mean temperature of releases in the June through August period were 11.9, 12.0, 13.0, 12.7, and 13.8°C, for years 2002 to 2006 respectively.

In lower Lodore Canyon, Green River mean daily water temperature reached 16°C at a relatively consistent time each year: 31 May, 6 June, 29 May, 17 June, and 5 June, in the years 2002 to 2006, respectively. That 16°C temperature level may be consistent with the onset of smallmouth bass spawning activities (Carlander 1977, KRB, unpublished Yampa River data). The relatively low 2005 temperatures that occurred relatively late in the year were consistent with higher and cooler base flows released from Flaming Gorge Dam. Mean daily water temperatures for the main June-August fish growing season was 19.4°C in 2002, 19.8°C in 2003, 18.6°C in 2004, 17.6°C in 2005, and 19.7°C in 2006.

Effects of Flaming Gorge Dam on Green River discharge and temperature patterns, Whirlpool Canyon.—Annual peak flows in the pre-impoundment period (1946-1962) showed a typical dome-shaped hydrograph, with low late summer, autumn, winter, and early spring base flows, rising to a peak in later spring and early summer (Fig. 10). Post-Flaming Gorge peak flows in the 1992 to 1996 and 2002 to 2006 periods were, on average, lower than historical, from a standpoint of mean daily annual flow, peak flow, and maximum May-June flows (Table 1). However, peak flows in each of years 2003, 2005, and 2006 were higher than occurred in the 1946-1962 pre-impoundment period, and timing of flow peaks more closely approximated those that occurred historically (Figs. 11 and 12). Base flows in the period August to February were typically lower in the pre-impoundment period than post. Mean July-August summer base flows were lower in 1992 to 1996 than historical flows, and mean July-August base flows in the 2002 to 2006 period approximated historical conditions.

Water temperatures of the Green River in Whirlpool Canyon (Mitten Park station, just upstream of Whirlpool Canyon), in the 1992 to 1996 were substantially cooler than in the period 2002 to 2006 (Fig. 13). Mean daily temperature of the Green River from June through August at Mitten Park in 1992 to 1996 was 18.0°C compared to 19.8°C from 2002 to 2006. The primary difference was a period from mid-May to mid-July, when water temperatures were up to 4°C cooler in the 1992 to 1996 period compared to 2002 to 2006. This was due to relatively high and cold flows observed in 1993 and 1995. Green River water temperatures in lower Lodore Canyon and Mitten Park in the period 2002 to 2006 were similar except for a slightly elevated mid-July maximum temperature in downstream Mitten Park, reflecting relatively little influence of the warmer but relatively low Yampa River in those drought years (Fig. 14).

Thus, three actions subsequent to dam closure in 1962 have incrementally modified flows and temperatures in the Green River upstream and downstream of the Yampa River to a state that more closely resembles historical, unregulated conditions. The flow and thermal regimes observed in 2002 to 2006 likely will reflect those that would be realized in low or moderately-low flow years, under new Flaming Gorge Dam flow and temperature recommendations (Muth et al. 2000), especially if Flaming Gorge Dam penstock releases are warmer such as in 2006. Therefore, studies conducted in the five years from 2002 to 2006 (albeit, 2005 baseflows were average) offered an opportunity to assess fish community response to flows that were at the lower end of the recommendations spectrum. A more complete assessment of fish community response will be possible only with additional years of sampling conducted in average, moderately-high, or high flow years.

During 2002 to 2006, warmer temperatures in Lodore Canyon resulted in minimal water temperature differences between the Green River upstream of the Yampa River and the Yampa River (Table 2), which was a goal of flow and temperature recommendations of Muth et al. (2000). Minimizing temperature differences may reduce the likelihood of temperature shock when Colorado pikeminnow larvae are carried from the warm Yampa River flows into the colder Green River (Berry 1988, Tyus 1991). This problem may be more pronounced when Yampa River flows are very low and warm and flows in the regulated Green River are higher and colder.

Composition of the fish community in Browns Park, Lodore Canyon, Whirlpool Canyon, and Island-Rainbow Park reaches, 2002-2004 and *2005-2006*.—A total of 209,466 specimens representing 9 native and 19 non-native species and 7 hybrid combinations were captured by all sampling gears during 2002 to 2004 (Table 3). An additional 68,466 specimens representing 11 native and 21 non-native species and 6 hybrid combinations were captured by all sampling gears during the 2005-2006 period (Table 4).

All told, 238,316 non-native fishes were captured during this study, most of those being removed. Since 2005 when removal was permitted for all potentially predaceous species except salmonids, we removed 1,176 potentially problematic large-bodied fishes captured by electrofishing in 2005 (Table 5, another 411 brown trout or other salmonids were released), and another 1,124 in 2006 (another 410 brown trout or other salmonids were released). Totals for both years included 299 smallmouth bass, 24 northern pike, and 894 channel catfish.

In the 2002-2004 period, flannelmouth sucker *Catostomus latipinnis* was the most common native fish captured by all sampling gears, followed by bluehead sucker *Catostomus discobolus*, mountain whitefish *Prosopium williamsoni*, speckled dace *Rhinichthys osculus*, roundtail chub, mottled sculpin *Cottus bairdi*, Colorado pikeminnow, bonytail *Gila elegans*, and humpback chub. In 2005-2006, bluehead sucker was the most abundant native fish captured by all gears, followed by flannelmouth sucker, speckled dace, roundtail chub, mountain whitefish, mountain sucker, Colorado pikeminnow, bonytail, humpback chub, and razorback sucker. Most changes were due to differences in the number of native fish captured in seine samples. No razorback suckers or mountain suckers *Catostomus platyrhynchus* were captured during 2002-2004 but each was captured in the 2005-2006 period; one razorback sucker adult was captured by electrofishing in 2006 in lower Whirlpool Canyon, and many mountain sucker were seined in tributary Vermillion Creek in 2005. Both taxa were previously collected in the study area (Holden and Crist 1981; Bestgen and Crist 2000).

Composition of the fish community in Browns Park, Lodore Canyon, Whirlpool Canyon, and Island-Rainbow Park reaches by gear type, 2002-2004 and *2005-2006*.—In 2002-2004, electrofishing captured nine native fishes, 16 non-natives, and seven hybrids. The most abundant non-native taxa were brown trout, common carp, and channel catfish (Table 6). In 2005-2006, channel catfish, brown trout, and common carp were most abundant in electrofishing samples. Smallmouth bass were less abundant in 2005-2006 than in 2002-2004.

In both periods, the three most abundant native fish species captured by electrofishing were flannelmouth sucker, bluehead sucker, and mountain whitefish. All other native taxa were relatively rare in electrofishing samples. In 2005-2006, roundtail chub declined notably in electrofishing samples as did bonytail, and no humpback chub were collected by electrofishing. The percent of native fishes increased during 2005-2006 due mostly to increased abundance of flannelmouth sucker and mountain whitefish.

Seining yielded eight native and 17 non-native species, and four hybrids in 2002-2004 (Table 7). Red shiner, sand shiner, fathead minnow, and redside shiner, in descending order of abundance, were the most abundant non-native taxa collected in 2002-2004. Red shiner, sand shiner, white sucker, redside shiner, and fathead minnow were the most abundant non-native taxa collected in 2005-2006.   Although relatively uncommon, smallmouth bass increased in abundance in seine samples from 0.2% in 2002-2004 to 2.0% 2005-2006, an order of magnitude change in relative abundance. Flannelmouth sucker, bluehead sucker, mountain whitefish, and speckled dace, in descending order of abundance, were the most common native fishes collected in the Green River in 2002-2004. In 2005-2006, bluehead sucker, flannelmouth sucker, speckled dace, roundtail chub, and mottled sculpin, in descending order of abundance, were the most common native fishes.

Non-native fishes were 92.4% of all fishes captured in seine samples in 2002-2004, but declined to 76.5% in 2005-2006, due mostly to increased abundance of native bluehead and flannelmouth sucker and roundtail chub. High non-native fish abundance in each period in seine samples reflected the dominance of small-bodied red shiner, sand shiner, and fathead minnow in the low-velocity habitats where most samples were collected. Those taxa dominated the fish community in low-velocity habitats in other areas of the Colorado River Basin (Haines and Tyus 1990; Propst and Gido 2004) such as in backwaters of the middle and lower Green River, where Haines and Tyus (1990) found that those species comprised about 90% or more of the fish community. However, higher native fish abundance in seine samples collected in low-velocity nearshore areas was documented in portions of the Yampa River in Little Yampa Canyon as recently as 1999, when native fishes including roundtail chub, speckled dace, and flannelmouth sucker comprised 59% of samples and smallmouth bass were 2.5% (Wick et al. 1985; Anderson 2002; 2005). A population explosion by smallmouth bass in the Yampa River began about 2001 (Anderson 2002; 2005), when smallmouth bass comprised 67% of seine samples and native fishes (roundtail chub only) were 1.4% of samples. In four years of sampling similar areas from 2003 to 2006, native fishes were 1% or less of the fish community in samples collected in riverine habitat (Bestgen et al., Yampa River Native fish response evaluation, RIP project 140). Native fish abundance was higher in isolated pools where smallmouth bass abundance was lower.

Increased abundance of native fishes in seine samples in the period 2005-2006 may be due to a number of factors. This is discussed further below.

Presence and severity of turbidity events in the Green River may also be an explanation for the relatively high variability in abundance of native fishes observed in seine samples collected from 2002-2004 compared to 2005-2006 (Bestgen et al. 2006, in part). We observed relatively high native fish abundance in seine samples in summer 2002 when no severe turbidity events were observed. Alternatively, in 2003 and 2004 we observed low native fish abundance in summer and two severe turbidity events occurred in each year. Similar to 2002, higher relative abundance of native fish in 2005 and 2006 was also associated with absence of extreme turbidity events. High turbidity may cause fish to lose orientation and be transported downstream. This hypothesis was supported by high catch rates of fish in drift net samples in the Green River in 2003 and 2004 after flood events (Fig. 43, in Bestgen et al. 2006). This also occurred in the Yampa River, when Colorado pikeminnow (and other taxa) abundance in drift samples typically increased when turbidity events occurred (Bestgen et al. 1998). Because such events in the Green River happened after native fish reproduction occurred, no additional larvae were available for re-colonization and their abundance remained low through autumn. Non-native fish were likely similarly reduced by turbidity events (e.g., red shiner and sand shiner in Whirlpool Canyon, summer 2003) but, because many of those taxa spawn into late-summer, populations could recover by autumn to achieve high population levels we observed. Fish transport may be particularly high from canyon reaches, because few shallow, channel margin backwaters occurred where fish could find refuge.

In 2002-2004, trammel net samples yielded six native and eight non-native species, and three hybrids, and captured the highest proportion of native fish (about 2/3) of any sampling gear (Table 8). In 2005-2006, trammel net samples yielded five native and six non-native species, and one hybrid and percent native fishes declined to about 50%. The overwhelming majority of non-native fish captured during both time periods was channel catfish, which showed a large increase in 2005-2006 (47%) compared to 2002-2004 (28%). The most common native fishes captured in trammel nets in 2002-2004 were flannelmouth sucker and roundtail chub, but chub abundance (relative and absolute) declined dramatically from 24% of captures in 2002-2004, to 12.7% in 2005-2006.

Drift net sampling.—Drift net sampling was also conducted in 1994 and 1995 (Bestgen and Crist 2000). Few fish species and individuals were captured in drift net samples in 1994 to 1995, diversity and number of fish captured increased substantially in the period 2002 to 2004, and then number of fish captured declined again in 2005 and 2006 (Table 9 this report, and Fig. 43 in Bestgen et al. 2006). In 1994 to 1995, six species were captured and > 90% of those individuals were native. Up to 16 species were captured in a single year (2003) in the 2002 to 2004 period, when substantially more non-native taxa were captured than in previous years (33% native fishes captured). Fewer taxa and individuals were captured in 2005 and 2006, but native fish increased to 46% of the sample. Notably, two Colorado pikeminnow larvae were captured in summer 2006, and one likely early life stage razorback sucker (Bestgen et al. 2006 annual report, project reports 115 and 22f).

Based on spawning ecology of Colorado pikeminnow and water temperatures that were present in the Green River in Lodore Canyon, pikeminnow should have been able to spawn there in all years of this study (Nesler et al. 1988, Bestgen et al. 1998). We are not sure why spawning was not detected in other years, but the presence of ripe fish suggested that perhaps we did not detect it if spawning occurred.

We did not collect young smallmouth bass in drift net samples in 2002, but captured a few in 2003 (N = 6, 10 to 24 mm TL), and greater numbers in 2004 (N = 93, 8 to 28 mm TL, Bestgen et al. 2006). In 2005 and 2005, 16 small smallmouth bass were captured in drift net samples. In 2003, most fish of all species (60%) were captured the day of and the day following two turbidity events, one on 22 July and one on 6 August. The 22 July 2003 event was especially severe, as water clarity was reduced to zero and silt loads were extremely high from runoff in the Vermillion Creek drainage basin. Most bluehead sucker (53%) and flannelmouth sucker (66%) captured that year were taken during these events, as were most smallmouth bass (4 of 6) and sand shiner (74%). About 34% of red shiner captured that year were taken during these two events. We noted relatively high mortality of those fish in drift net samples collected on 22 July; usually fish collected in drift nets are alive upon capture and larger suckers present in mid- to late-July are noticeable. Thus, loss of visibility and outright mortality from sediment loads may be factors associated with increased transport rates.

A similar high turbidity and increased flow event occurred on 17 July 2004, when a total of 532 fish of all species (29% of all captured in 2004) were captured. All 2004 smallmouth bass specimens were captured in the period 17 to 25 July, and 87 of 93 (94%) on 17 July. Flow stage dropped 7 to 8 cm the next day, but turbidity remained high for several days. On 25 July, a similar turbidity event occurred, and only 5 fish were captured (three flannelmouth sucker, one white sucker, and one smallmouth bass). A similar situation occurred in 1994: most fish captured that year (N = 223, 72.6%) were taken on 7 July when water turbidity increased dramatically from thunderstorm runoff.

Spatial and temporal patterns of distribution, abundance, and size-structure of selected non-native and native species, from 1994 to 1996, 2002 to 2004, and 2005-2006 periods.—This section presents overall patterns of distribution, abundance, and size structure for selected species and examines changes between study periods 1994 to 1996, 2002 to 2004, and 2005 to 2006. We present data only for selected, potentially problematic, non-native species and some common native taxa. We use mostly electrofishing data to explore these trends because most of the taxa considered are large-bodied and are not commonly captured by other sampling gears.

Non-native fishes.—In general, non-native fish distribution in the study area increased between the period 1994-1996 and 2002-2004. In 2005 and 2006, distribution of smallmouth bass and northern pike further increased upstream into Browns Park. In 2005 and 2006, species abundances appeared to stabilize for the most part where they were previously established (e.g., trout, northern pike, red shiner in Lodore Canyon) or even decline slightly (smallmouth bass), although white sucker may have increased.

Northern pike were found sporadically throughout the study area from the upstream reaches of Browns Park (only since 2005) downstream through Whirlpool Canyon. Northern pike are increasing in distribution and abundance in upstream reaches of the Green River in Browns Park. This was based on the finding pike, all age-0 specimens (190-280 mm TL in 2006), in Browns Park in autumn 2005 (n = 10) and summer 2006 (n = 11). The 2005 fish were captured in regular autumn seine sampling conducted in backwaters and 2006 sampling was seining plus a special effort with an electric seine devoted to obtaining a better understanding of pike distribution in Browns Park (more discussion on that effort below).

Northern pike capture rates have been relatively low and static in the Green River downstream of Browns Park in Lodore and Whirlpool canyons in the 1994-2006 period. In all electrofishing sampling conducted from 1994-2006 (no Whirlpool Canyon sampling in 1994-1996) 7 pike were captured in reach LD3, 39 in LD4, 2 in WH1 and two in WH2. Most LD4 reach pike were captured within 1 km of the confluence of the Yampa and Green rivers. Electrofishing capture rates of northern pike in the 1994-1996 and 2002-2004 period were constant at 0.2 fish/hr, even though number of fish captured by electrofishing in each study increased over time (8 and 18, respectively). In 2005, electrofishing capture rate for northern pike remained constant at 0.2 fish/hr (N = 16 total fish), but declined to 0.09 (n = 8) in 2006. Reduced capture rates in 2006 may reflect continued upstream removal in the Yampa River, increased effort in lower Lodore Canyon where pike appear concentrated, or variation in abundance or sampling efficiency. Several captured pike had been previously tagged and had dispersed downstream from the middle Yampa River. For example, in 2003, all four recaptured pike were from the middle portion of the Yampa River (Bestgen et al. 2006). Northern pike captured averaged 644 mm TL (191 to 825 mm TL, Bestgen et al. 2006), and all were healthy and fat. Most were captured from deep eddies and pools or runs. There was evidence of reproduction by northern pike in Lodore Canyon as a 191 mm TL fish, presumably age-0, was captured in summer 2003 in lower Lodore Canyon.

Channel catfish in the study area are restricted to the Green River downstream of Browns Park. Distribution and abundance of channel catfish in Lodore Canyon in 1994 to 1996 was relatively restricted, with few fish occurring in upstream reaches and abundance overall was low (Fig. 15). In the 2002 to 2004 period, abundance increases were evident across Lodore Canyon, particularly in downstream reaches, and channel catfish was most abundant in Whirlpool Canyon. Channel catfish abundance was increased only slightly in some reaches in 2005 over 2002-2004 levels, but in 2006, was markedly higher, particularly in Whirlpool Canyon. There continues to be no direct evidence of reproduction by channel catfish in the Lodore Canyon reach of the Green River because we did not collect any channel catfish < 180 mm TL in seine or drift net samples in the Green River; channel catfish are a regular component of drift samples collected annually in the lower Yampa River.

Size structure of channel catfish in electrofishing samples in Lodore Canyon changed between the 1994-1996 and 2002-2004, mainly because of increased abundance in 2002 to 2004 (Fig. 33, in Bestgen et al. 2006). In general, during both periods larger fish (> 300 mm TL) were more common in the upper reaches of Lodore Canyon and smaller fish were more common in lower Lodore Canyon; the pattern is more obvious in 2002 to 2004. Similar to lower Lodore Canyon, channel catfish in Whirlpool Canyon in the 251 to 300 mm TL size class dominated populations, although a few very large fish were also present. No small channel catfish were sampled in Lodore Canyon, perhaps indicating absence of reproduction by that species there. Small channel catfish were present in downstream Whirlpool Canyon.

Smallmouth bass are presently distributed from upstream Browns Park, being discovered there as recently as summer 2006 upstream as far as RK 604, downstream throughout Lodore and Whirlpool canyons and Island-Rainbow Park. They were first discovered in Browns Park during the additional sampling conducted in August 2006 that was aimed at obtaining a better understanding northern pike distribution in Browns Park, and were also captured in subsequent regular seine sampling in autumn 2006 (more below).

Smallmouth bass distribution and abundance in Lodore Canyon in the 1994-1996 period was extremely restricted, as only a single smallmouth bass was collected from 1994 to 1996 by electrofishing and was found in reach LD3. Smallmouth bass distribution and abundance in Lodore Canyon increased dramatically in the 2002 to 2004 period compared to 1994 to 1996 (Fig. 16). By the 2002-2004 period, smallmouth bass occupied all Lodore Canyon reaches and increased in abundance in a downstream fashion, where they constituted > 6% of the fish community in LD4 and > 10% of the fish community in Whirlpool Canyon. In 2005 and 2006, abundance of smallmouth bass remained similar and low in upper reaches of Lodore Canyon, but was lower in lower Lodore Canyon (relative abundance reduced by nearly 50% in 2005-2006 compared to 2002-2004), and declined substantially in Whirlpool Canyon in 2005.

Seine and drift net samples showed that smallmouth bass reproduction was first detected in lower Lodore Canyon in 2002 (N = 4, 13 to 85 mm TL) and was more progressively widespread in subsequent years. This is supported by the sampling of Fuller (2005) in the nearby lower Yampa River, who found that smallmouth bass abundance increased from 0.15 fish/hr captured in 2001 to 36 fish/hr in 2004. The upstream range expansion of smallmouth bass in the Green River in Lodore Canyon continued through 2005 when small age-0 bass were noted nearly to the head of Lodore Canyon in autumn, and into Browns Park in 2006. Prior to 2001, higher base flows prevailed and temperatures were cooler. Perhaps warm water conditions promoted successful smallmouth bass reproduction and higher levels of channel catfish abundance beginning in 2002 in Lodore Canyon. Cooler and higher flow conditions in 2005 may also have prevented smallmouth bass from successfully spawning in Browns Park until the relatively warm year of 2006. Anderson (2002; 2005) also found increased abundance of young smallmouth bass in the Yampa River in 2001, 2003, and 2004 when summer water temperatures were elevated (no sampling conducted in 2002).

Size structure of smallmouth bass captured in 2002 to 2004 suggested a population invading from downstream, as the few fish present upstream were relatively large (Fig. 35, in

Bestgen et al. 2006). Upstream reaches of Lodore Canyon now have a mix of sizes, including small fish, as reproduction has been noted throughout the canyon and upstream. In Whirlpool Canyon, modal size was lower than upstream and fish in the 151 to 200-mm TL size class or smaller were most abundant (Christopherson et al. 2005; Bestgen et al. 2006).

Large numbers of fish, including smallmouth bass, in drift net samples in the Green River upstream of the Yampa River in 2003 and 2004 associated with turbidity events suggested susceptibility to displacement. Such displacement likely also occurred in the Green River downstream of the Yampa River because the Yampa contributed only about 25% of the flow downstream of the confluence during those events. The literature also suggested negative effects of flow increases on early life stages of smallmouth bass (Lukas and Orth 1995, Peterson and Kwak 1999, references therein); Winemiller and Taylor (1982) documented negative effects of turbidity and high flows on disruption of smallmouth bass spawning, nest destruction, and displacement of young. Increased flows levels via dam releases or turbidity events may be a potential controlling mechanisms for early life stages of smallmouth bass in this portion of the river.

We believe that displacement or direct mortality of early life stages of smallmouth bass by flow or turbidity events, as noted in 2004 drift net samples, reduced survival of those age-0 fish and subsequently reduced abundance of the same year class of age-1 smallmouth bass in Lodore and Whirlpool canyons in 2005 (Fig. 16). Inexplicable abundance reductions in 2005 were also noted by Christopherson et al. (2005, M. Fuller conducted sampling in The Whirlpool reach), who conducted abundance estimates for smallmouth bass associated with removal efforts in 2004 and 2005 in the Green River in Whirlpool Canyon. They could not explain the reduction in smallmouth bass abundance in 2004 from 8,000 compared to about 3,300 fish in 2005, a decline of 59%, because they only had 31% removal rate in 2004. Importantly, that decline did not account for recruitment of abundant smaller bass into the 2005 population, which is usually ample enough to replace the bass removed in the subsequent year: age-1 smallmouth bass were about 41% of the population sampled in 2004. Christoperson et al. (2005) correctly surmised that a large portion of the difference in abundance in 2004 and 2005 was due to low recruitment of fish in the 125-150 mm TL size classes into the 2005 population. They further postulated that environmental effects were playing a role, and thought that fish of that size were age-2 or the 2003 year class. We agree that the likely cause was environmental effects but believe the year-class involved was 2004 not 2003. We believe this because smallmouth bass in this area grow to an average size of about 75 mm TL by the end of their first growing season; that size may even be conservative because upstream populations in the Yampa River where water temperatures are cooler and bass hatch later are of similar size. By the time Christopherson et al. (2005) conducted removal sampling in August 2005, the now age-1 bass hatched in 2004 could easily have grown to 125 to 150 mm TL by August 2005 in the almost two full growing seasons; growth rate estimates from otoliths of smallmouth bass collected in the Yampa River just upstream corroborate growth rates postulated here (pers. comm. P. Martinez, Colorado Division of Wildlife). In 2004, smallmouth bass in that age-1 size class were about 41% of all fish in the population susceptible to electrofishing (based on size frequencies in Fig. 1, Christopherson et al. 2005). Near-complete absence of that generally abundant size-class from the 2005 Whirlpool Canyon population could be the difference between abundances expected in 2005, based on 2004 estimates and removal levels. This, of course, assumes that the abundance and removal estimates of Christopherson et al. 2005 are unbiased. We believe those abundance estimates are essentially correct (no differential bias among years) and the decline shown in 2005 is real, because our own 2005 sampling showed a similar decline in relative abundance for smallmouth bass in Whirlpool Canyon of approximately 50%; we also showed the expected and similar reduction in Lodore Canyon. Further, the lower Yampa River smallmouth bass removal sampling effort in 2005 showed that a large year-class of the 125-150 mm TL fish were present: no large floods or turbidity events were documented there in 2004 based on observations during drift net sampling. Thus, high displacement of age-0 smallmouth bass by a flood or floods in the upper Green River in 2004 may be responsible for a significant reduction in larger bass abundance in 2005 and perhaps a lasting effect into the future. This is important because even relatively substantial removal efforts in most portions of the Upper Colorado River Basin (Hawkins 2005, middle Yampa River; Fuller, 2005 in the lower Yampa) rarely show any sustained reductions in abundance levels between years, much less a reduction of > 50%. This reduction also occurred in a year, 2005, when large numbers of smallmouth bass and other species escaped from Elkhead Reservoir and were found in the middle and lower Yampa River (Fuller 2005; Hawkins 2005) and may have supplemented bass numbers in the study area.

The literature also supports the idea that cooler, higher flows, flow fluctuations, or turbidity events may limit growth and reproductive success by smallmouth bass (Winemiller and Taylor 1982; Lucas and Orth 1995, Peterson and Kwak 1999), and potentially recruitment. Effects of flow and temperature regimes on smallmouth bass in Lodore Canyon and downstream will require additional monitoring in years when higher flows and cooler water temperatures prevail. High flows and turbidity events are known to displace young smallmouth bass from nests (Winemiller and Taylor 1982, Lukas and Orth 1995, Peterson and Kwak 1999). Use of flow manipulations from Flaming Gorge Dam to disadvantage smallmouth bass appear promising, but will require additional information so that effects can be optimized if implemented. Minimal information needs are onset and duration of the spawning season of smallmouth bass in relation to water temperature and other important environmental variables, and flow levels needed to cause the desired negative effect. Flow management activities to disadvantage selected species need to consider potential effects on other fishes in the system, and in this situation, would likely be effective in Whirlpool Canyon and downstream only in years when Yampa River flows were relatively low. Potential negative effects of high or cold releases during the smallmouth bass spawning period (June and early July?) on native fishes include higher flows when native fish are reproducing or when early life stages are present, and abnormal environmental signals for native fish (e.g., increasing flow and declining temperature) that spawn in summer.

Trout species are most abundant in upstream reaches of the study area including Lodore Canyon, are less common in Whirlpool Canyon except in the vicinity of Jones Creek where they are abundant, and are rare in downstream Island-Rainbow Park (based on seine sampling, Bestgen et al. 2006). All trouts were combined to illustrate the general abundance pattern for salmonids (excluding whitefish) because those cold-water taxa were thought to respond similarly to environmental conditions. Brown trout constituted about 85% or more of all trouts captured, with rainbow trout and rainbow x cutthroat trout hybrids (plus a few cutthroat trout, Snake River subspecies, and a single brook trout captured in 2006) constituting the other 15% (Bestgen et al. 2006). In 1994-1996, 2002-2004, and 2005 and 2006, salmonid abundance patterns based on electrofishing captures were remarkably similar among reaches and periods (Fig. 17). Trout abundance was lower in reach LD1 but increased in LD2. Trout abundance (and other species as well) was low in LD1 because habitat is mostly shallow and sand-bottomed, whereas in LD2, more deep pools and rocky substrate occur. Trout abundance declined rather rapidly downstream and by reach LD4 trout were < 10% of the fish community. Salmonid abundance increased slightly in WH2 because of fish dispersing from the abundant Jones Creek population. Similarity of trout abundance over time was surprising because we expected shifts in response to differences in the widely variable thermal regimes present over the study period, 1994-2006. We did observe a decline in trout abundance in summer 2002 when water temperatures were very warm (25C or more) in Lodore Canyon, but abundance levels quickly recovered in autumn 2002 and in 2003 (Bestgen et al. 2006). Lack of sustained changes in trout abundance over time suggest a hyper-stable population that is not affected by the vagaries in flows and temperatures of the magnitudes observed during the study period and because no removals were conducted in any of those years.

Red shiner distribution and abundance has changed over the 1994-2006 period in the study area apparently in response to variable flow and temperature regimes. Although this is not a large-bodied species that is typically captured by electrofishing, we discuss it here because recent changes in distribution and abundance offer insights into response of warm water species to variations in thermal regimes. In 1994 to 1996, red shiner was absent from Browns Park and Lodore Canyon reaches LD1 to LD3, but were common in LD4 (Fig. 18, reproduced from Bestgen et al. 2006). Red shiner expanded their distribution and were more abundant in the upper portions of the study area in the 2002 to 2004 sampling period. Red shiners were not present in the upper extent of the study area in 2002, but invaded Browns Park in 2003, and further increased in abundance in all Lodore Canyon reaches. Relative abundance and density of red shiner was high in Whirlpool Canyon reaches and in Island-Rainbow Park in 2002 to 2004.

In spring and summer 2003, red shiner was abundant in lower Lodore Canyon, rare or not present in upper Lodore Canyon, and in low abundance in newly invaded Browns Park, with two specimens captured in spring and four in summer 2003. By autumn 2003, we documented red shiner throughout Browns Park from just upstream of Swinging Bridge (RK 612.8) downstream through Lodore Canyon. Red shiner was often the most abundant species in seine samples in Browns Park in autumn 2003, particularly in backwater habitat. Adult and juvenile size classes were present, which suggested successful reproduction by that species in that reach. In 2004 and 2005 (one captured), red shiners were rare or non-existent upstream of Lodore Canyon in any season, a pattern similar to that observed in 2002 and from 1994 to 1996. However, in summer 2006, they were found again in Browns Park. Upstream range of red shiners is apparently expanding and contracting in response to differences in thermal regimes among years in the period 2002-2006 because temperature of releases and those downstream in summer were highest in 2003 and 2006 when red shiner expanded upstream. In years of slightly lower water temperatures or higher base flow releases from Flaming Gorge Dam (e.g. 2005), red shiner distribution and abundance was reduced. These changes in red shiner distribution and abundance patterns illustrate the powerful role that water temperature, perhaps interacting with stream flow (higher flows result in lower water temperatures in this reach when releases are of like temperature, Bestgen and Crist 2000), can have on fish distribution and abundance. These patterns and species responses also suggest that releases from Flaming Gorge Dam may be managed to purposefully alter the distribution and abundance of other problematic species in the Green River.

White sucker was found throughout the study area and its abundance in electrofishing samples declined from upstream to downstream (Fig. 19), a pattern expected for a species that is more common in cooler upstream reaches than warmer downstream ones. However, white sucker has also increased in abundance over time and may yet be expanding downstream. White sucker abundance in electrofishing samples was highest in upper Lodore Canyon; CPUE data showed a large increase in white sucker abundance in the 2002 to 2004 period compared to 1994 to 1996. White sucker also increased in abundance in 2005 but declined back to 2002-2004 levels in 2006. The large increase in white suckers in 2005 in reaches LD1 and LD2 may be, in part, a function of cooler water temperatures present in that year that increased survival of fish produced in 2004. Most white suckers found in those reaches are smaller age-1 fish in the 101-150 mm TL size class (Bestgen et al. 2006).

Native fishes.—In contrast to non-native fishes, native fishes captured in electrofishing samples generally declined between the periods 1994-1996 and 2002-2004. In 2005 and 2006, native fishes showed a mixed abundance response, with some species continuing to decline, and others remaining at lower levels or increasing slightly.

Mountain whitefish was found throughout the study area but was most common in upstream Browns Park, was moderately abundant in Lodore Canyon reaches, and was comparatively uncommon in Whirlpool Canyon and Island-Rainbow Park. Relative abundance of mountain whitefish in Lodore Canyon electrofishing samples was relatively high in the 1994 to 1996 period, declined substantially in 2002 to 2004 period (Fig. 20), increased dramatically in 2005, but declined again in 2006. Expanded distribution in 1994 to 1996, and 2005 was likely the result of higher flows and cooler temperatures of releases from Flaming Gorge Dam, which promoted higher dispersal and survival of mountain whitefish throughout the study area. This scenario is supported because mountain whitefish, an autumn spawner, would have hatched and grown to a size that is susceptible to electrofishing gear by summer and autumn in 2005. The most common size of fish captured in those summer and autumn samples are in the 101-150 mm TL size class, a size expected from fish produced in the previous autumn (Fig. 13, in Bestgen et al. 2006, pers. comm., P. Martinez, Colorado Division of Wildlife). As discussed previously, annual abundance fluctuations of some fishes in the Green River indicate a strong role of water temperature and stream flows on controlling fish distribution and abundance.

Adult Colorado pikeminnow were found in all Lodore Canyon reaches in all time periods and in Whirlpool Canyon and Island-Rainbow Park in 2002 to 2006; none have been collected in Browns Park but pikeminnow are known to use that area (Kitcheyan and Montagne 2006).

Relative abundance of Colorado pikeminnow in electrofishing samples declined in 2002 to 2004 and in 2005 and 2006 compared with the period 1994 to 1996 (Fig. 21). Colorado pikeminnow in Lodore and Whirlpool canyons were a mix of sizes including a single fish in each period in the 351 to 400-mm TL size class (Fig. 15, in Bestgen et al. 2006).

Roundtail chub was found in every reach of the study area except Browns Park. Roundtail chub showed increased downstream abundance in electrofishing samples in most periods, with a peak in abundance in 2002-2004 in reach WH1. However, roundtail chub abundance in electrofishing samples declined in 2002 to 2004 compared to the 1994 to 1996 period (Fig. 22), and that decline continued in 2005 and 2006, particularly in Whirlpool Canyon. Abundance declines were also evident in trammel net samples collected in 2005 and 2006, compared to the period 2002-2004 (Table 8), when a relatively large population of roundtail chub (about 2000) apparently inhabited Whirlpool Canyon (Bestgen et al. 2006). Roundtail chub abundance was higher in seine samples in the 2005-2006 period compared to 2002-2004. However, even though small chubs were present in summer 2006 seine samples, few remained in autumn samples suggesting poor survival. Roundtail chub abundance in seine samples was similarly low in all Lodore Canyon reaches in 2002 to 2004, had declined relative to samples collected in 1994 to 1996 (Bestgen et al. 2006), and only a few were captured in lowermost Lodore Canyon in 2005 and 2006.

Flannelmouth sucker was found throughout the study area from Browns Park downstream to Island-Rainbow Park. Abundance of adults increased slightly in a downstream direction while young fish in seine samples declined in abundance downstream (Fig. 23, also Fig. 19 in Bestgen et al. 2006). Flannelmouth sucker relative abundance in electrofishing samples declined by nearly 40% in all Lodore Canyon reaches in 2002 to 2004, compared to the 1994 to 1996 period; CPUE data demonstrated a significant decline (Bestgen et al. 2006). Sampling in 2005 and 2006 indicated increased abundance of flannelmouth suckers in Lodore Canyon compared to 2002-2004 (but less than in 1994 to 1996), and continued to increase in downstream reaches WP1 and WP2. Flannelmouth sucker typically represented 20 to 45% of electrofishing samples in all Lodore and Whirlpool Canyon reaches in 2005 and 2006. Relative abundance of flannelmouth sucker in seine samples was also increased in 2005 and 2006 compared to the 2002 to 2004 period, but remained substantially lower than abundances in 1994-1996 in Lodore Canyon (Bestgen et al. 2006).

Bluehead sucker was also distributed throughout the study area, and similar to flannelmouth sucker, large juveniles and adults in electrofishing samples increased in abundance downstream (Fig. 24). Similar to trout and flannelmouth sucker abundance patterns, bluehead sucker abundance in Lodore Canyon was moderately high in LD1, highest in LD2, and declined in LD3 and LD4. Similar to flannelmouth sucker, bluehead sucker abundance increased in downstream WP1 and WP2 reaches. These patterns are likely due to differences in habitat available in each reach. Reaches with more sand substrate and are relatively shallow support fewer fish (e.g., LD1), while reaches with deeper water with more riffles and large rocky substrate support more fish (LD2, Whirlpool reaches). Bluehead sucker relative abundance in electrofishing samples declined in all Lodore Canyon reaches in 2002 to 2004 compared to 1994 to 1996. On average, bluehead sucker abundance in 2005 and 2006 remained at levels similar to those found in 2002-2004. Bluehead sucker abundance ranged from 5 to 10% of the electrofishing sample in upper Lodore Canyon in all sampling periods and represented 25-35% of the electrofishing sample in lower Whirlpool Canyon in 2002 to 2006. Relative abundance of bluehead sucker in seine samples declined dramatically in Browns Park and all Lodore Canyon reaches and constituted < 5% of the fish community in 2002 to 2004, but increased in 2005 and 2006 to 10.1%.

Increased reproduction by native fishes in 2005 and 2006, as observed by their abundance in summer seine samples, was associated with increased spring flow peaks downstream of Flaming Gorge Dam in each year. Perhaps spawning or backwater habitat was enhanced that increased survival and abundance to summer. Unfortunately, abundance of native fishes in seine samples was much reduced in autumn, particularly in 2006, such that few or no native fishes could be found in that season.

Browns Park habitat and fish community sampling, 2006.—Habitat and river connectivity surveys of the Green River from 633 to 588 RK were completed from 23-25 May

2006, when Flaming Gorge flows were between 129 and 187 m^3/sec. Map observations and high bluffs along the river offered opportunities to view possible wetlands and river connections along the river corridor and a total of 22 sites were inspected and described in more detail (Appendix I). Additional details regarding pike habitat suitability and connectivity were added to site descriptions from observations in August to verify findings from May surveys.

Surveys indicated that all managed wetlands were disconnected from the river at the flow levels observed and that there was little opportunity for fish to access wetlands from the river or vice versa. Wetlands are typically filled via pumping from the river but absence of overflow from wetlands limits fish colonization of the river from ponds. Further, fish were not observed in any managed wetlands. The likelihood of connection at higher flows was also assessed and few if any would be likely to connect with the river at flows up to 227 m^3/sec. One wetland, Hog Lake, was apparently connected to the river by high flows in 1983, but it does not support fish. Our conclusions from these surveys were that the age-0 northern pike observed in the Green River in 2005 were unlikely to originate from managed wetlands in Browns Park.

Other locations such as confluences of streams (e.g., Beaver Creek, Vermillion Creek) supported wetlands connected to rivers. These areas were noted so that they could be sampled in later summer to assess presence of northern pike. In general, the areas that were assessed as potentially good habitat for pike when observed during high flows tended to not support extensive pike habitat at base flow levels in summer. This was because flows retreated much further than expected, leaving shallow, vegetated areas dry in summer.

Based on findings of habitat surveys, sampling in the reach was focused on near shore, in channel habitat rather than flood plain wetlands. Sampling was focused in the vicinity of previous pike sampling locations (Beaver Creek and Hog Lake backwater) and on downstream areas.

The eighteen sites sampled yielded 11 age-0 northern pike (ten were captured from 2 sites in 2005). Samples 1-5 were taken through the reach of RK 613.6 to 609.8. About 950 m of shoreline was sampled for 1.42 hr. Shoreline areas had dense mats of emergent and submerged vegetation, which grew several m from the bank in some cases, and was more extensive than at most other sites. Presence of vegetation reduced water velocity significantly and improved habitat for northern pike. Seven of the 11 pike caught during all sampling were caught in this reach. Six of the seven pike in this reach were caught in the upper two samples. All pike at this site were caught in the main river channel associated with vegetation and outside of backwaters, which were often clogged with vegetation. Two green sunfish were also caught in this reach.

Samples 6-12 were taken between RK 608 and 603. In this reach, 1,099 m of shoreline were sampled for 1.7 hr. In general, this reach had less in-channel vegetation than upstream. The vegetation was restricted to a narrow nearshore band. One location that held a pike in this reach had slower flowing water due to a wider buffer of vegetation on the shoreline. The other sample site that held a pike was a large backwater, approximately 30 x 60 m in area, with large amounts of vegetation and a variety of depths. This backwater also held smallmouth bass, the first known capture of that species in Browns Park, and red shiner, another sporadic non-native species, and a large number of green sunfish. Other areas in this reach, which appeared to be good pike habitat, were difficult and ineffectively sampled due to deep water.

Samples 13-15 were collected between RK 603 and 600. About 404 m of river was sampled for 0.74 hr. The areas sampled were all backwaters or shorelines leading into backwaters. Large backwaters seemed to be more common than elsewhere. Shoreline vegetation was not prominent in this reach. All backwaters were relatively shallow and had deep silt substrate. Two of the backwaters had deep mouths which restricted sampling, but may support adult pike. Several smallmouth bass and green sunfish were taken from these backwaters. No pike were caught in this reach.

The final reach sampled was upstream of and across from the Gates of Lodore boat ramp. Samples 16-18 spanned RK 585.9 to 585.4 and the area was sampled for 0.56 hr. The braided channel area in the lower portion of this section held more instream vegetation than the previous two reaches sampled and one pike was captured here. Upstream of the braided channels the river was much the same as above and only had a narrow strip of vegetation on the very edge of the shoreline. Few fish were caught anywhere other than in the vegetation.

All northern pike captured in Browns Park in 2006 were age-0 fish (188 to 280 mm TL), and were slightly smaller than fish collected in 2005 due to earlier sampling (August 2006 vs. September2005). Smallmouth bass captured during these surveys were the first ever from Browns Park and all were age-0 fish (47 to 73 mm TL). Smallmouth bass likely first reproduced in lower Lodore Canyon in 2002, and apparently it took this length of time to colonize Browns Park from downstream. Reasons that we do not believe smallmouth bass came from Flaming Gorge Reservoir were discussed in Bestgen et al. (2006). Red shiners were captured in restricted localities as well. They had not been collected in Browns Park prior to 2003 (Bestgen and Crist 2000), and have been taken sporadically since (Bestgen et al. 2006).

While northern pike sampling localities were broadly distributed, pike and smallmouth bass were found at just a few localities. Northern pike were most common in areas where inundated macrophytes were common in the margins of the stream channel or in backwaters. Such areas could provide adult spawning habitat at even the lowest flow levels because rooted macrophytes are well established and apparently were little affected by spring flows up to 227 m^3/sec. Rooted macrophytes are typically rare in unregulated western rivers because areas that are regularly wetted at a stable elevation are uncommon. Their abundance in this reach may be a combined function of relatively low magnitude flows that do not scour deeply, and also presence of stable base flows and fine-grained substrate, which provides a reliable wetted habitat area for macrophyte establishment for the entire year. Northern pike spawning likely occurred in the main channel margins or backwaters and may have occurred in close proximity to where age-0 fish were collected. Further efforts to remove northern pike from this reach should focus on locations where age-0 pike were most abundant. Use of boat or raft sampling may improve efficiency and should be timed to capture pike in spawning habitat where they are accessible but before they spawn. Otolith analysis may guide estimation of spawning times, but that work is yet to be completed.

Reasons for restricted distribution of smallmouth bass in Browns Park are not known. A main reason may be that smallmouth bass only recently invaded the area and may not yet have established a regular distribution pattern. Smallmouth bass are also generally found in areas where rocky substrate is common. The mostly sand-bottomed Green River in our Browns Park study area may be a poor habitat for smallmouth bass and may restrict their abundance. However, areas of larger substrate near creek mouths, or in upstream reaches, may provide better habitat for smallmouth bass. The relatively large size of these age-0 smallmouth bass (mean TL about 60 mm) suggested relatively early spawning or fast growth. Otolith analysis may be useful to further understand spawning periodicity of smallmouth bass here and in the lower Green River, and would be useful to time additional releases from Flaming Gorge Dam that may disrupt spawning. Non-native fish suppression activities (e.g., additional removal, flow management) should begin as soon as possible while populations are still relatively restricted in distribution and abundance.

SUMMARY

Efforts to reduce problematic non-native fishes in the Colorado River Basin are undertaken so that status of native fishes, particularly endangered ones, will be improved. Similarly, a main tenet of dam re-regulation to create more natural flow and temperature regimes is that native fishes will benefit (Stanford et al. 1996, Poff et al. 1997, Muth et al. 2000). The data sets presented here were used to evaluate whether those activities are useful to improve the status of native fishes in the study area.

Flow and temperature effects on the Green River fish community between 1994 to 1996, 2002 to 2004, and 2005-2006.—Evaluating biotic response to fish control programs and to simultaneous changes in flow and temperature recommendations is a considerable challenge given the multitude of factors that can affect the distribution and abundance of natural populations. A first challenge is obtaining reliable measurements of the population parameters of interest so that inferences can be made with confidence. We think we did a reasonable assessment of the fish community because our sampling was spatially and temporally intensive and we used a variety of gears to sample nearly all life stages of fish present in the system.

Linking population measurements such as abundance levels to a driving variable or set of variables with certainty is another major challenge.

These difficulties not withstanding, we believe reasons for some observed changes in the fish community in the period 2002-2004 and 2005-2006, as compared to previous periods, were associated with changes in flow and temperature regimes. Expanded distribution and abundance of red shiner, sand shiner, channel catfish, and smallmouth bass were almost certainly a product of low flows and, particularly, warm temperatures. Water temperature in mid-summer in Browns Park and upper Lodore Canyon may be 2 to 3°C cooler than in lower Lodore Canyon (Bestgen and Crist 2000). However, upstream observations of 22°C or more were recorded in our study, conditions which likely promoted upstream expansion by warm water species. Distribution and abundance of most other non-native fishes also increased.

Warmer summer base flows may also have benefitted Colorado pikeminnow. Although our electrofishing data from 2002 to 2004 indicated a slight decline in Colorado pikeminnow, Kitcheyan and Montagne (2006) detected large numbers of Colorado pikeminnow in Lodore Canyon in 2002 and 2003, when flows were low in the rest of the basin. We also detected reproduction based on capture of larvae in drift nets in 2006, and we collected ripe Colorado pikeminnow in Lodore Canyon in 2003 and there was a similar report in 2001 (T. Modde, pers comm., U. S. Fish and Wildlife Service, Vernal, Utah). Further, Kitcheyan and Montagne (2006) also reported small aggregations of Colorado pikeminnow during summer at two locations in Lodore Canyon, which may represent spawning groups. These data support the contention that lower and warmer summer base flows in Lodore Canyon may be a benefit to Colorado pikeminnow.

We did not anticipate reduced abundance of most other native fish of all life stages in the study area during 2002 to 2004, but some increased in 2005-2006. Earlier declines in relative abundance of young native fishes may be a function of the influx of large numbers of non-native cyprinids that were captured in seine samples. The subsequent effect may be that they comprise a smaller portion of a larger sample, but do not actually decline in abundance. However, density and relative abundance trends for 2002 to 2004 data often tracked each other closely, suggesting that relative abundance measures often reflect density as well, and that reductions were real. Continued density difference comparisons will allow us to track such changes more closely.

Increased abundance of native fishes, particularly in summer seine samples, was noted in 2005 and 2006. Increased abundance could be due to higher reproductive success after relatively high spring flows from Flaming Gorge Dam in 2005 and 2006. Increased abundance of native fishes in backwater habitats in the lower Yampa River in years with higher spring flows has been noted in other studies (Muth and Nesler 1993). Increased native fish abundance in 2005 and 2006 could also be due to reduced abundance of young smallmouth bass, particularly in 2005. During our study, native fish abundance declined precipitously from summer to autumn. This was also the pattern in 2002 to 2004 (Bestgen et al. 2006). Potential reasons for abundance reduction in autumn are many and could be due to movement to other habitats, increased abundance of age-0 bass to a size capable of predation between summer and autumn, or some combination of those and other factors.

Evaluation of the high flows in 1997 and 1999 was difficult because those events were relatively far removed, on a temporal scale, from our sampling. Those flows no doubt had positive benefit for physical habitat, including channel scouring and reworking, and associated removal of invasive tree species in Lodore Canyon and downstream reaches (Muth et al. 2000). Benefits to biota would be best evaluated in a time frame closely associated with the event. Potential measures of effects of high flows would be sampling of fish in low-velocity areas in summer and autumn such as was done in this study. With such data collected over a relatively long time frame, differences in reproductive success and abundance of native and non-native fishes could be evaluated. Escapement of smallmouth bass from Flaming Gorge Reservoir during spills is a potential downside of high flows, especially if release elevation levels coincide with vertical distribution of fish in the reservoir. As noted above, increased abundance of native fishes in the study area in 2005-2006 was associated with increased spring peak flows in each year. Higher flows may have created better conditions for reproduction or survival of small native fish.

The net effect of flow and temperature regimes on the native fish community in this river reach, based on our 2002 to 2006 sampling, was mixed. During this study, we were able to obtain information on the response of the fish community to flow and temperature effects, but only at the lower end of the flow spectrum. Flow and temperature conditions observed in 2002 to 2006 (except 2005) fell within the bounds for recommendations that would be implemented in years with low or moderately low water availability, which happen in only 30% of years. Average, moderately high, and high flow years, which occur the other 70% of the time, were not evaluated because those conditions were not realized during this study period. Additional years of sampling when those flow conditions return are needed to fully assess the effects of pending flow and temperature recommendations for Flaming Gorge Dam on the fish community of the Green River. Because components of the fish community may be changing regardless of changes in flow and temperature conditions, monitoring should be on an annual basis. This would allow for documentation of fish community changes, such as new or ongoing species invasions that may otherwise be attributed to flow or temperature changes. Once additional years of sampling data are accumulated under different flow and temperature regimes, managers can make informed decisions about the effects of Flaming Gorge recommendations on the native fish community, including endangered fishes.

Smallmouth bass reductions in the study area in 2005-2006 were apparently a result of both bass removal as well as environmental effects including flow-turbidity displacement of age-0 bass and reduced water temperatures in 2005. It may be possible to replicate flow and temperature effects associated with reduced bass abundance via altered operation of Flaming Gorge Dam. Additional information is needed to understand the timing and potential utility of those prior to using Flaming Gorge Dam as a management tool to reduce smallmouth bass. Effects on native fishes also need to be considered.

Results of sampling conducted in the study area will be asked to address several objectives, including evaluation of flow and temperature recommendations (e.g., draft Green River study plan) as well as effects of continued non-native predator removal. Simultaneous implementation of factors that affect native fish populations, such as various annual flow and temperature regimes, as well as changes in abundance levels of non-native fishes that are affected by removal and other factors, has potential to confound response of native fish to managed factors and explanations of those changes. This is always the case in unreplicated large river systems, where it is difficult to change only a single factor in any given year and equally difficult to measure relevant driving variables.

We feel as though the current sampling program may still be able to answer many of the questions posed of it in the future. This is especially true if continued careful sampling of a variety of life stages is conducted. For example, summer seine sampling should continue to yield reasonable estimates of the relative strength of native fish reproduction in any given year. Continued sampling of adult life stages should provide a longer view of the status of the species in the area and should, over time, reflect status of species in view of variable recruitment across years. Effects of substantially increased smallmouth bass removals in the Green River downstream of the Yampa River (Whirlpool Canyon and downstream) beginning in 2007 (8 passes?) on the native fish community should be discernable if the moderate levels of fish removal (2-3 annual passes) are maintained in Lodore Canyon. This would allow comparisons of differential (low vs. high) effects of fish removal across reaches (e.g., Lodore compared to Whirlpool in 2007 and beyond), and also allow comparisons over time among the reaches (e.g., Whirlpool reaches in 2002-2006 compared to 2007 and beyond). Differences in background fish communities in Lodore and Whirlpool canyons, and differences in the flow and thermal regimes in each reach, due to the effects of the Yampa River on Whirlpool Canyon, are potential confounding factors. Continued careful measurement of some of those covariate effects will reduce confounding somewhat, which when combined with a weight-of-evidence approach (Beyers 1998), should provide suitable information. Better native fish community information from the Yampa River directly upstream of the Green River (e.g., Yampa Canyon) would be useful to disentangle some of those effects.

Recommendations for temperature and fish community monitoring in the Green River downstream of Flaming Gorge Dam.

Temperature monitoring.—We recommend continued collection of water temperature data at Echo Park in the lower Yampa River and in the Green River just upstream and downstream of the Yampa River.

Large-bodied fish sampling recommendations.—We recommend two electrofishing sampling passes in the study area, one in summer and one in autumn. Samples collected during those times had the highest species richness and fish density and will result in the highest removal rates on non-native fishes. A main advantage of summer sampling may be to demonstrate use of Lodore Canyon by spawning Colorado pikeminnow, when water temperatures are warm. Monitoring of potential spawning by Colorado pikeminnow in Lodore Canyon may also be accomplished by drift net sampling in lower Lodore Canyon. Autumn electrofishing sampling is useful because capture rates were high. Using both summer and autumn sampling increases the likelihood that at least one sampling pass will have conditions conducive to high sampling efficiency.

We also recommend a several-day effort of sampling in Browns Parks with boat or raft electrofishing to control abundance of adult northern pike and smallmouth bass in that reach. Sampling could be conducted in spring (boat) or summer (raft) and should focus on areas where small northern pike and bass have been captured.

Whirlpool Canyon chub sampling recommendations.—Confirmation of a small population of humpback chub in Whirlpool Canyon and capture of stocked bonytail and substantial numbers of roundtail chub suggest that additional monitoring should occur to document status of those populations and response to operational changes at Flaming Gorge Dam. One sampling pass of three to four days with trammel nets under low flow conditions in late summer or autumn sampling is recommended because water temperatures are relatively low and may reduce sampling mortality. More intensive capture-recapture sampling to document population abundance of chub species would be useful on a less than annual basis. This sampling is particularly relevant in light of 2006 trammel-netting efforts, which showed a much reduced abundance of adult chubs in Whirlpool Canyon. All chubs should be PIT tagged to better understand abundance, survival, and movement of those species.

Small-bodied fishes.—We recommend two seine sampling passes, one in each of summer and autumn. Native fish abundance and species richness was usually high in summer, so sampling then is needed to document annual reproductive success. Autumn sampling for monitoring is also advantageous because non-native fish abundance and species richness is high and fish are larger and easier to identify.

Drift net sampling is one means to detect reproduction by adult Colorado pikeminnow in the Green River upstream of the Yampa River. It has also been useful to document patterns of abundance of invading smallmouth bass and to document effects of increased flow and turbidity events on fish drift rates. This sampling is relatively easily accomplished when associated drift net sampling occurs in the lower Yampa River.

Sampling of any kind is not recommended in spring, with the exception of possible sampling in Browns Park. Fish activity may be reduced when water temperatures are cold, and higher flows may limit sampling efficiency. Higher flows in spring due to elevated runoff from the Yampa River especially limits effectiveness of sampling in Whirlpool Canyon and downstream. This is because eddies that are sampled with trammel nets and backwaters that are sampled by seines are mostly washed out at higher flows.

We also recommend collection of additional information on early life history stages of smallmouth bass. Collections from appropriate areas and times will permit a better understanding of timing of spawning and the potential use of Flaming Gorge Dam to disrupt smallmouth bass reproductive success and recruitment.

CONCLUSIONS

- ♦ The impacts of construction and operation of Flaming Gorge Dam on physical habitat in the highly regulated reach of the Green River from the dam downstream to the Yampa River and in Whirlpool Canyon downstream of the Yampa River were partially remediated by thermal modifications implemented in 1978, discharge re-regulation in 1992, and 2002 to 2006 drought-period changes to baseflow levels and patterns.
- ♦ Thermal enhancement of the regulated reach via penstock modification in 1978 had a large restorative effect because reproduction by most native fishes in the Green River upstream of the Yampa River was restored. Low-flow conditions in drought years 2002 to 2006 (except 2005) increased water temperatures in the Green River to levels that likely mimicked pre-dam conditions. This ensured a close match of Green and Yampa River water temperatures during drought years when Colorado pikeminnow larvae were drifting downstream from the Yampa River in summer.
- ♦ The Green River upstream of the Yampa River supported nine native fishes (ten if bonytail is included) in 2002 to 2006, and only bonytail did not reproduce. Native fishes in Lodore Canyon declined in abundance in electrofishing, seine, and drift net samples in 2002-2004 compared to those collected in 1994 to 1996, but recovered somewhat in 2005-2006. Ten native fishes were collected in the Green River downstream of the Yampa River. Native fishes were numerically dominant in electrofishing and trammel net samples; seine samples were dominated by non-native taxa but native ones increased in abundance in 2005 and 2006.
- ♦ Abundance of non-native fishes in Browns Park and Lodore Canyon increased in 2002 to 2004 compared to 1994 to 1996, but some stabilized in 2005 and 2006. Increases were throughout the study area and largest in the upper portions of

Lodore Canyon for small-bodied cyprinids, channel catfish, and smallmouth bass. Smallmouth bass reproduction, which was not previously observed in Lodore Canyon, was widespread and northern pike reproduction was also observed. Increased distribution of northern pike and smallmouth bass was noted in 2005 and 2006 in Browns Park. Salmonids were temporarily reduced in abundance in 2002, but increased in 2003 to 2006, and remained similar in abundance to that observed in 1994 to 1996. The overall predator load in the Green River study area has increased.

- ♦ Diversity and abundance of other non-native fishes increased since 1994 to 1996. For example, species not detected in 1994 to 1996 but found in 2002 to 2006 included creek chub, brook stickleback, bluegill, and black crappie. Abundance of green sunfish and black bullhead increased in 2002 to 2006 compared to the 1994 to 1996 sampling period.
- ♦ A strong water temperature gradient played a role in controlling distribution and abundance of fishes in Lodore Canyon. Further upstream expansion of several warm-water fishes was restricted to upper Lodore Canyon because of relatively cool upstream water temperatures in most years. Previously, this limitation was observed in lower Lodore Canyon but moved upstream because of elevated temperatures in 2002 to 2006 (excepting 2005).
- ♦ Abundance of several hybrid combinations of suckers was high and increased since 1980 and again since the 1994 to 1996 period. Particularly common were hybrids that had white sucker as one parental type. Occurrence of cool water white suckers and hybrids declined in a downstream direction in Lodore Canyon, presumably in response to warmer water temperatures.
- ♦ Trammel net sampling detected a small population of humpback chub in Whirlpool Canyon and a relatively large population of roundtail chub in 2003. Hatchery-stocked bonytail were also captured. Trammel net sampling was a useful technique to sample chubs. Stocked bonytail were susceptible to predation

and infections and survival rates were low based on absence of recaptures of fish more than a few weeks after stocking. Sampling as recently as autumn 2006 indicated a decline in chub populations in Whirlpool Canyon, as few individuals of any taxa were collected.

- ♦ Drift net sampling detected reproduction by Colorado pikeminnow for the first time in Lodore Canyon in 2006; a likely early life history stage razorback sucker was also collected. Drift sampling revealed important patterns of increased downstream transport rates of fish in response to turbidity events.
- ♦ Colorado pikeminnow continued to use Lodore Canyon heavily in summer, based on captures we made and those in a companion study. Ripe male Colorado pikeminnow were detected there in 2001 and 2003, indicating suitable conditions for reproduction, which was substantiated by capture of larvae in 2006.
- ♦ More complete evaluation of the response of the fish community to flow and temperature regimes from Flaming Gorge Dam will require additional years of sampling in conditions other than the low and warm summer flows we observed.

RECOMMENDATIONS

- ♦ Continue removal of predaceous and other non-native fishes from Lodore Canyon for maintenance levels of control. This will allow comparisons of fish community response in downstream areas where removal effort is higher.
- ♦ Continue removal efforts with exploratory sampling in Browns Park, similar to that conducted in 2006 and 2007. Removal of adult northen pike and smallmouth bass may be most beneficial to reduce the spread of those taxa.
- ♦ Continue to monitor water temperature, flows, and the fish community of the Green River in Browns Park, Lodore and Whirlpool canyons, and Island-Rainbow Park, as outlined.

- Compare fish community response to different flow and temperature regimes from Flaming Gorge Dam to better understand factors that may limit invasive species, particularly predators.
- Gain a better understanding of smallmouth bass reproduction and early life history by conducting otolith analyses of specimens in collections and future field-captured specimens.
- Begin PIT-tagging and scanning all chubs captured, including roundtail chubs.
- Investigate reasons for low survival of stocked bonytail in the Green River.

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Appendix I.

Northern Pike Habitat Reconnaissance- High Flow Observations
Browns Park, Colorado, May 2006

23 May 2006

Beaver Creek Backwater 16:45- 12 665453E 4521921N, River kilometer (RK) 612.4

At a flow of approximately 187 m^3/sec, the main channel of the Green River inundates the lower peninsula of the backwater (archived pictures 5&9). The backwater extends up the Beaver Creek channel ending at a service road (archived picture 6), which forms a dam for a small pond above the backwater (archived picture 7). There is no opportunity for fish to reach this pond from the river. However, fish are able to reach the river from the pond on Beaver Creek. The pond outlet is a vertical culvert, which drops over a meter to a horizontal culvert running beneath the road and dumping into the backwater. The entire margin of the backwater is made up of up to a 3-m-wide band of submerged rooted vegetation. A small pod of common carp was observed feeding deep into these margins. At this flow, the backwater forms approximately 90 m of suitable habitat for northern pike. Two days later at flows of 129 m^3/sec, habitat area was greatly reduced (archived picture 41&42) and was about 70 m in length. The river left margin above and below the backwater also offers habitat to pike in the form of submerged vegetation. As flows decrease these types of habitat will become less available. Releases of 227 m^3/sec would likely not effect the connectivity of the pond to the river, but would likely eliminate much of the lower end of the backwater. Summer sampling at low flow is recommended for the backwater with use of seine net, fyke net and trammel net. Pond sampling is not necessary due to the lack of connectivity.

Summer sampling with electric seine was conducted in the river channel and in the backwater at this location. Very little habitat was left in the backwater during the summer base flows. The main channel of the river held submerged vegetation where most of the pike were captured. During the spring reconnaissance trip all good pike habitat was thought to be on the margins of the river and in backwaters, however, during sampling in this area the best habitat was found 10 meters from the shore.

Hog Lake Backwater 18:30- 12 669877E 4522378N, RK 608

At flows of 187 m^3/sec, this backwater is flow through (archived picture 10). However, upstream vegetation forms a barrier on the upstream and peninsula sides so that water velocity was very low (archived picture 11). Low flow and large amounts of submerged macrophytes provide near-lentic conditions for fish, though none were observed. One day later at 129 m^3/sec, the backwater was less of a flow through and submerged cattails and rushes at the upstream end re-emerged (archived picture 30). At flows of 388 m^3/sec, the entire area would likely be inundated and of high velocity. This backwater should be seined in the summer and possibly fyke and trammel netted if water depth is found adequate at the time.

During base flows in late summer this backwater was dense with vegetation making it difficult to sample. Portions of the river below the backwater appeared to be good habitat, but sampling was impeded due to water depth.

Hog Lake 19:00- intake 12 668302E 4521773, RK 608.8

This lake is filled via pumping direct from the river at the above UTM coordinates (archived pictures 14&15). The water travels through pipe or ditch to the inlet of the lake. No water flows out of the lake; water either evaporates or is lost through seepage. Water flow out of the lake would only occur if the lake rose 1.5-2 m, which Browns Park National Wildlife Refuge (BPNWR) refuge personal stated has never happened. Much of the lake is filled with thick mats of aquatic vegetation, possibly making poor fish habitat (archived picture 13). Observations of Hog Lake in 2002 did not suggest fish occupied the lake, possibly because of it was shallow and macrophyte-filled conditions, poor conditions for overwintering. Most BPNWR lakes, which are managed primarily for waterfowl, function in this manner and receive water only irregularly. Managers stated Hog Lake was inundated by the river in a very wet year in the early 1980s, which was likely 1983 (388 m^3/sec) . Only in a scenario like this would Hog Lake become connected with the river making it unlikely that fish populations could be linked between the lake and the river. Even flows of 227 m^3/sec would not connect with the lake.

This lake was not sampled during summer sampling, but still held water.

24 May 2006

Grimes Bottom 11:00- UTM location unsure, RK 591.5

Bottom is dry and appears to have been for several years. Managers said many of these impoundments don’t hold water very well and are not used anymore. If the bottom was used, filling would be by a pump and ditch system, but no outlet could be found.

Water was not present during summer sampling.

Vermillion Creek Mouth 11:45- 12 678363E 4514529N, RK 589.5

The mouth of Vermillion Creek forms a wide backwater greater than 100 m long; the upstream portion of the backwater was not observed (archived picture 16&17). Flow through the backwater was minimal and velocity was negligible. Comparisons at flows of 227 m^3/sec to 129 m^3/sec suggested that this backwater remains and at higher flows would only grow in size. At 129 m^3/sec, approximately 70% of the backwater margin was inundated willows and vegetation (archived picture 18). The backwater is attractive to fish as the 50 or more common carp observed. The water in the backwater was noticeably more turbid than that of the river, perhaps due to fish activity. This backwater likely retains water at base flow and should be sampled. Trammel or fyke netting may be the most effective way to sample without boats and electricity. Seining may be limited to the upper end of the backwater where it may be shallower.

Predictions of finding pike habitat in the mouth of the creek during summer sampling turned out to be incorrect. During base flow the river level is below the mouth of the creek and there is very little standing water in the creek.

Island Backwater 12:20- 12 676814E 4516628N, RK 594.7

This moderately-sized island 80-90 m long is an example of shallow downstream area of inundated vegetation offering suitable habitat to pike at the flow of 129 m^3/sec (archived picture 19). Nearly every island in the Browns Park reach offers this type of habitat and may be suitable for use by pike at higher powerplant flows. At mid-summer base flows we don=t believe that these inundated island habitats will exist any longer and therefore wouldn=t recommend their sampling except at high flow with boat electro fishing. At flows of 227 m^3/sec, many of these islands would probably be covered with water.

Island backwaters such as this held no habitat for fish during base flows. The level of the river allowed for only a small amount of instream vegetation.

Harry Hoy Bottom 13:00- intake 12 675661E 4518995N, RK 598.1

This area is filled with water that is pumped at an upstream site into a ditch that runs to the impoundment (archived picture 21&22). At this time, only the lower elevation edge along the dyke holds open water (archived picture 20). The outlet would be a low point in the downstream end of the dyke that leads into a ditch to the river. It does not appear that water has ever inundated the outflow. Instead, water is lost either through evaporation or seepage. Given the way the bottom is filled and water is lost, it seems unlikely that flows of 129-227 m^3/sec would create connectivity with the river. Fish could be pumped into the wetland, but lack of river connectivity makes it unnecessary to sample this in the summer.

This impoundment was not sampled in the summer and held even less water than what was seen in the spring.

Backwaters above Crook Campground 14:00- 12 674349E 4519439N, RK 599.5

About 0.8 km upstream of Crook Campground is a river-left silted oxbow with a large upstream backwater (archived picture 24) and a shallower and smaller one downstream (archived picture 23). The downstream backwater is heavily vegetated at 127 m^3/sec, but still appears to be good pike habitat. The upstream flow through backwater has an inlet at top of the oxbow and an outlet 60 m downstream. Both the inlet and outlet appear to be much more shallow than the center of the backwater suggesting that this could become an isolated pool at lower flow. Both backwaters have little to no flow and entire margins of inundated vegetation making them possible pike habitats. Summer sampling of these backwaters is recommended mainly with use of seine and potentially trammel and fyke nets on the upper backwater.

The upper backwater was sampled during the summer and fall. The mouth was very deep and couldn't be sampled. The upper portion quickly became more shallow with submerged vegetation and held smallmouth bass. The lower backwater was nonexistent.

Horseshoe Bottom 14:40- intake 12 673233E 4519330N, RK 602.2

This area appears perennially dry due to the non-aquatic vegetation present. This area would also be pump filled if needed and no outlet was apparent, suggesting that water is lost through evaporation and seepage. Like the other wetland basins, this one has little chance of river connectivity even at flows of 227 m^3/sec. A photo taken at the pump site for this bottom shows submerged vegetation on island and bank margins giving a perspective of the difference of 127 and 187 m^3/sec (archived picture 25). The brown on the willows shows the depth at which the vegetation was submerged the previous day.

The area was still dry in the summer and was not sampled.

Goodman Gulch Island Complex 14:50- 12 672923E 4520270N, RK 603.2

Islands and gulch mouth hold several backwaters, some that may become to shallow for large fish at low flows, but at 187 m^3/sec look to be excellent pike habitat (archived picture 27). The entire complex is submerged inundated vegetation making it potentially attractive to pike. The flooded mouth of the gulch looks as though it would remain as a backwater even at low flows making this area a good place for summer base flow sampling with seine. Another potential large backwater is river right and just below this complex (archived picture 26). This backwater is entirely inundated by the river at flows of 129 m^3/sec but may become good pike habitat at lower flow and would be a good area to attempt to seine or set nets during summer sampling.

In the upper portion of the complex a large backwater persisted during base flows. The backwater held pike as well as smallmouth bass and red shiners. During the peak spring flows this backwater would have been a side channel. Much of the habitat within the complex that was predicted to remain as good base flow habitat no longer appeared as such during summer sampling.

Spitzie Bottom 15:10- intake 12 671064E 4521937N, RK 605.8

Spitzie Bottom is a very long wetland directly adjacent to the hill leading out of the river bottom (archived picture 28). Spitzie Bottom is also pump filled (archived picture 29). The outlet would be a ditch on the downstream end of the bottom. Like others this lake releases water through evaporation and seepage. This system provides little opportunity for connectivity and fish access from the river. Flows of 227 m^3/sec would not connect it with the river.

The wetland still held water through the summer and no summer sampling was conducted.

Flynn Bottom 16:20- intake 12 668894E 4521835N, RK 608.4

This property is no longer part of the Browns Park National Wildlife Refuge; the lease was lost two days prior. Water for Flynn Bottom is pumped from the river nearly directly across the river from Hog Lake. The outflow is a vertical culvert in the dyke with boards added or removed to regulate wetland height. During overflow, water pours over the boards dropping 3-4 feet into a horizontal pipe running under the dyke and exits into a ditch running into Warren Bottom. Three boards were removed from the culvert by the new lessee and water levels in the bottom dropped nearly 1 m. The remnants of released water could scarcely be seen in Warren Bottom. This was the only bottom on the refuge where water was typically released over a spillway; water elevation is otherwise controlled by pumps or through evaporation or seepage. Even after water was drained, Flynn Bottom remained one of the largest lakes (archived picture 31). The drain setup on Flynn would allow for fish populations to escape into Warren Bottom, but would be impossible for the reverse to occur. Due to the low possibility of fish connecting between the river and the lake summer sampling is not recommended.

The impoundment was not observed nor sampled during the summer sampling trip.

Warren Bottom 16:40- intake ~ 12 670738E 4521834N, RK 606.1

Other than a couple of desiccating puddles from the Flynn Bottom releases, Warren Bottom was dry and apparently was for some time. In addition to out flow from Flynn, Warren Bottom is filled by pump. The outflow of Warren is from a drain called a beaver-proof drain. The drain may limit movement of fish as well. The device is much like a vertical pour-over culvert, however that same system is contained in a upright, square box. A culvert leads into the base of the box imbedded in the dyke. Inside the tall vertical box, separating the inflow from the outflow is a dividing wall of aluminum boards that can be added or removed to regulate water depth in the lake (archived picture 37). Water depth in the lake side of the box then pours over about 3 m into the outflow culvert leading into a ditch to the river. Finding a water filled ditch led me to the connection of the ditch to the river where a small amount of water was flowing from the river back upstream into the half mile long ditch (archived picture 33). Flows higher than 129 m^3/sec could turn this ditch into a very long backwater and be accessible by large fish. At flows lower than 129 m^3/sec, the ditch would become disconnected from the river. Sampling of this ditch could easily be accomplished if water remains in summer months.

Warren Bottom was not observed or sampled during the summer trip.

Nelson Bottom 18:15- intake UTM location unsure, RK 599.2

Wetland is dry and appears to have been that way for two or more years due to the lack of riparian vegetation. The bottom is pump filled from river and the outflow is the same beaver-proof device described in Warren Bottom, but does not have a ditch with inflow from the river.

Nelson Bottom Backwater 18:50- 12 675538E 4517410N, RK 596.1

Long, wide backwater intersected by inundated willows in two places near the middle of backwater, approximately 100 m long by 20 m wide (archived pictures 35&36). Narrow island forms peninsula at flow of 129 m^3/sec and at higher flows, water would flow over top of the peninsula. This backwater would be a very good area for pike spawning when flow is equal to 129 m^3/sec or lower. Summer sampling is recommended with use of seines and possibly fyke or trammel nets. The best access to this backwater is by parking on Nelson Bottom dyke 200 m past outlet.

This backwater was not observed during summer sampling. Future efforts should look at the presence of this backwater during base flow.

25 May 2006

Flynn Bottom Side Channel and Backwater 10:10- mouth 12 670234E 4522104N, RK 607.4

Side channel is about 1 km long with little to no flow through it. Inlet to channel is densely vegetated with willows and cottonwoods. Flows of 129 m^3/sec push small amounts of water into the inlet. At flows of 227 m^3/sec and greater, flow through would be much higher and would likely function more as a side channel. Most of side channel is heavily vegetated and very shallow making poor habitat for most large fish, however for small fish and juveniles, this could be very good habitat (archived picture 40). The mouth of the side channel forms a deeper (~1 m) and still heavily vegetated backwater with good connectivity to the river at all flows (archived pictures 38 & 39). Sampling of the backwater and possibly side channel is recommended. Seining at the mouth and backpack electoshocking the shallow vegetation will be the most effective.

The side channel was not investigated during summer sampling, however the mouth was found to provide no backwater habitat and it could be assumed that the side channel was also dry.

Butch Cassidy Lake 11:50- outlet 12 664600E 4522440N, RK 613.2

Inflow to the lake comes from Beaver Creek, which is inaccessible to fish from the river. The outflow for the lake is north of the inflow, near the state border and seems to continually be in use. The lake is large and has open water, likely supporting fish from the Beaver Creek drainage. The drain for the lake is a homemade beaver-proof device that could, if conditions were right, have connectivity between river and lake (archived picture 44). Flows of 227 m^3/sec in the Green River would submerge the outflow culvert. In combination with high inflow from Beaver Creek there is a possibility that fish could travel up the horizontal riverside culvert into the water filled vertical culvert with access to the lakeside horizontal culvert, which is unlikely. Sampling the lake is not a high priority because of the remote chance of river access.

The lake held water during summer sampling, but was not sampled.

Butch Cassidy Backwater 11:50- 12 664600E 4522440N, RK 613.2

The outlet of Butch Cassidy Lake spills into the middle of a 200-m-long heavily vegetated backwater with depths of 1-2 m. Several schools of small-bodied fish and small pods of carp were observed in the pool directly below the outflow culvert. Flows of 129 m^3/sec provide no flow into the backwater, but flows of 227 m^3/sec would likely make this backwater the outer edge of the river. The number of fish in this backwater makes it a good site to sample for the presence of pike in the summer. Seining and possibly backpack electrofishing would be the best methods for sampling the upper pools of the backwater and trammel and fyke nets may be utilized at the mouth of the backwater.

This backwater is very small and shallow during base flows. The main channel outside of the backwater did have a large amount of submerged vegetation and pike were captured in it.

Bridgeport Unit Ponds, UT 14:00- pump12 656376E 4529142N, RK 630.9
outlet 12 655746E 4527699N, RK 629.0

These ponds are pump filled and fed into a ditch running to the upper most pond, which then drains into two lower ponds (archived picture 49). The lower ponds each have a pour over vertical culvert into a horizontal culvert spilling into a side channel of the river (archived picture 45&46). This design does not keep these ponds a closed system. Fish can escape from them if they are pumped in. A trickle pours from the ditch into the upper pond and almost no water pours into the drains, leading to the assumption that most of the water in the system is lost as seepage. The ponds are 0.5 m or less deep and have very little riparian vegetation growing from their edges. A fourth pond is at riverbank level and is just 10 m from the river (archived picture 47). Outflow from the upstream lower pond is designed to drain into this pond. At 129 m^3/sec the small fourth pond overflows a small trickle directly into the river. Flows of 187 m^3/sec may have had a larger connection and at 227 m^3/sec the pond would have river flow through. The pond is brimming with rooted aquatic vegetation, which may make for poor fish habitat. Of all the wetlands observed, this one offers the best chance for fish connectivity at higher Green River flows. This area should be sampled in summer, but the depth of the pond is uncertain and may require use of a boat.

No observations were made in Utah during the summer sampling trip.

Bridge Hollow Campground Ponds, UT 15:30- 12 654232E 4529111N, RK 633.3

The Ponds are isolated pools in an oxbow with a backwater at the bottom of the side channel (archived picture 48). The ponds were isolated from the river even at 129 m^3/sec. At 227m^3/sec they would probably become connected with the river. Fish populations could survive in the ponds from one flood event to the next due to the ground water and deeper water. The backwater does not reach more than 20 m up the side channel and is very wide at the mouth. Willows and other wetland vegetation fill most of the area. Sampling of the ponds with fyke nets is one option, even though boats may be required to be effective.

Parson Unit Ponds, UT 16:30- inlet 12 654908E 4528974N, RK 632.3
outlet 12 656218E 4526428N, RK 626.1

Managers stated that these ponds hold pretty much every fish that the river has and that none of them were stocked, they all came in on their own. In the fall of 2005 fyke nets were set in these ponds to detect northern pike and no pike were captured. The inlet to the ponds is entirely gravity fed. The ditch off the river is approximately 1.6 km downstream of the Bridge Hollow Campground (archived picture 51). The ditch runs parallel with the river to a vertical culvert with depth regulating boards on it. At visitation, approximately 2.5 cm of water was pouring over the top board into the ditch leading to the upper Parson pond (archived picture 52). The water pouring over the boards drops 1 or more m to the ditch level making it difficult for fish to escape out of the ditch with this design. About 4 km downstream, the ditch enters the upper pond of the unit. Water then runs from one pond to the next until reaching the outlet drain on the dyke of the most downstream pond (archived picture 50). The drain is another vertical culvert with metal grill covering the area facing the lake (archived picture 53). As algae and vegetation are trapped on the grill the water level in the lake would rise. Very little water trickles out of this drain and most is probably lost through seepage. Only small fish could escape out this drain and no fish could come up through it. Even though fish can get in and small ones can get out, this system is unlikely to support northern pike. Only system failure would permit connectivity. At Green River flows of 227 m^3/sec, the system would not be in jeopardy. These ponds should still be sampled to see if they do begin to harbor pike. Electro fishing boats would be the best means to sample these ponds, but intensive fyke netting would also be a possibility.

Crouse Creek Pond, UT 18:30- intake 12 662369E 4522718N, RK 614.8

Water for this pond is gravity fed off of Crouse Creek. The outflow for this pond was not investigated. The possibility of fish travel from the Green River up Crouse Creek to the inlet should also be further researched. The pond is long and apparently shallow with grasses making up most of the flooded vegetation. Flows of 129 to 227 m^3/sec are not believed to be a threat to connect with the river, but more observations should be made if circumstances permit.

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Table 1. Flow characteristics (mean daily flow in m^3/sec)for the Green River upstream of the Yampa River (Greendale, gauge # 09234500, RK 660), and the Green River downstream of the Yampa River (Jensen gauge # 09261000, RK 486.2). Mean August-February flow is considered the base flow period for the Green River.

Location	Period	Mean daily	Annual low	Annual high	Mean May-June	Mean July-August
Greendale	2002	26.9	22.4	112.5	40.5	23.4
	2003	28.8	21.3	130.0	47.2	22.9
	2004	30.7	22.5	128.9	43.2	32.6
	2005	46.0	24.6	195.2	89.9	44.6
	2006	37.4	23.3	173.1	62.7	25.4
	1992-1996	51.4	35.0	110.4	81.0	41.5
	2002-2006	34.0	22.8	147.9	56.7	29.8
	1951-1962	59.7	15.0	220.4	160.5	71.0
Jensen	2002	46.8	22.8	201.7	96.3	24.4
	2003	80.0	27.2	538.2	253.0	38.4
	2004	67.3	28.3	322.9	151.8	44.0
	2005	111.6	38.0	552.4	330.5	79.3
	2006	99.5	27.1	521.2	265.2	39.0
	1992-1996	110.1	47.0	400.6	298.6	79.7
	2002-2006	81.0	28.7	427.3	219.3	45.0
	1946-1962	124.5	24.3	469.6	391.9	111.6

Table 2. Average daily summer water temperature (maximum) of the Green and Yampa rivers, Echo Park, Dinosaur National Park, Colorado, 2000 to 2006. The number of days when Green River water temperature was 5°C or more cooler than the Yampa River is also shown. None of those days were in the period when Colorado pikeminnow larvae were drifting from the Yampa River.

	Mean summer water temp C (maximum)		
Year	Green River	Yampa River	Number of days difference exceeded 5^{o}C
2000	17.0 (20.7)	19.7 (24.1)	2 (2)
2001	19.0 (23.4)	20.5 (25.6)	1 (0)
2002	18.6 (24.5)	20.4 (25.3)	1 (0)
2003	18.7 (23.2)	20.1 (25.9)	0
2004	17.9 (21.9)	19.0 (24.4)	0
2005	17.1 (22.0)	18.8 (25.5)	0
2006*	19.5 (23.7)	21.1 (25.6)	0

Table 3. Fish community composition (% relative abundance) from electrofishing, seining, trammel nets, and drift nets in the Green River, 2002 – 2004. Electrofishing was conducted in Lodore and Whirlpool canyons (RK 585.3-537.7). Seining was conducted in Browns Park, Lodore and Whirlpool canyons, Island and Rainbow parks (RK 611.7-528.0). Most trammel net samples were from Whirlpool Canyon. Drift net samples were from lower Lodore Canyon (RK 566).

	% Relative Abundance				
Species	Electrofishing	Seine	Trammel	Drift	Total
mountain whitefish	1.0	1.7	0	0.2	1.7
humpback chub	<0.1	0	0.6	0	<0.1
bonytail	0.7	<0.1	0.7	0	<0.1
roundtail chub	0.5	0.2	24.0	0.1	0.3
Colorado pikeminnow	0.3	<0.1	0.3	0	<0.1
speckled dace	0.2	1.0	0	1.9	1.0
bluehead sucker	18.2	1.3	12.9	14.4	2.5
flannelmouth sucker	24.9	3.1	27.4	16.8	4.7
mottled sculpin	0.9	0.1	0	0	0.1
cutthroat trout	<0.1	0	0	0	<0.1
rainbow trout	2.1	<0.1	0.3	0	0.1
cutthroat X rainbow trout	<0.1	0	0	0	<0.1
brown trout	12.6	<0.1	0	0	0.7
red shiner	0.7	43.6	0	42.0	41.1
common carp	11.3	0.3	0.7	0.5	0.8
fathead minnow	0	10.4	0	0.4	9.6
sand shiner	<0.1	26.2	0	12.5	24.4
redside shiner	<0.1	6.7	0	<0.1	6.2
creek chub	0	<0.1	0	0	<0.1
non-native cyprinids	0	0	0	1.7	<0.1
unidentified minnow	0	<0.1	0	0	<0.1
white sucker	5.4	4.4	1.9	6.3	4.5
bluehead X white sucker	0.4	<0.1	0.2	0	<0.1
flannelmouth X bluehead sucker	0.9	<0.1	0.1	0	0.1
flannelmouth X white sucker	1.9	0.1	1.2	0	0.2
flannelmouth X bluehead X white sucker	0.1	0	0	0	<0.1
razorback X flannelmouth sucker	<0.1	0	0	0	<0.1
razorback sucker hybrid	0	<0.1	0	<0.1	<0.1
unidentified sucker	0	0.1	0	0.7	0.1
black bullhead	<0.1	<0.1	0	0	<0.1
channel catfish	10.2	<0.1	27.9	0	0.7
northern pike	0.1	<0.1	0.1	0	<0.1
plains killifish	0	<0.1	0	0	<0.1
brook stickleback	0	<0.1	0	0	<0.1
green sunfish	0.2	0.6	0	0.2	0.5
bluegill	<0.1	<0.1	0	0	<0.1
green sunfish X bluegill	<0.1	0	0	0	<0.1
smallmouth bass	7.0	0.2	0.8	2.3	0.6
black crappie	0.1	<0.1	0.7	0	<0.1
walleye	<0.1	0	0.1	0	<0.1
Total fish	10725	193264	1206	4269	209464
Effort (hours or samples)	151.9	800	535.5	420	
# native species	9	8	6	5	9
% native species	46.8	7.4	66	33.3	10.3
# non-native species	16	18	8	8	20
% non-native species	49.8	92.4	32.5	65.9	89.3
# hybrid combinations	7	4	3	1	9
% hybrid combinations	3.4	0.2	1.5	<0.1	0.3

Table 4. Fish community composition (% relative abundance) from electrofishing, seining, trammel and drift nets in the Green River, 2005 – 2006. Electrofishing was conducted in Lodore and Whirlpool canyons (RK 585.3-537.7). Seining was conducted in Browns Park, Lodore and Whirlpool canyons, Island and Rainbow parks (RK 611.7-528.0). Most trammel net samples were from Whirlpool Canyon. Drift net samples were from lower Lodore Canyon (RK 566).

	% Relative Abundance				
Species	Electrofishing	Seine	Trammel	Drift	Total
mountain whitefish	3.0	<0.1	0	0	0.4
humpback chub	0	0	0.6	0	<0.1
bonytail	0.1	0	12.3	0	<0.1
roundtail chub	0.2	0.9	12.7	0	0.8
Colorado pikeminnow	0.2	<0.1	0	0.5	<0.1
speckled dace	0.3	4.2	0	3.1	3.7
bluehead sucker	16.6	10.3	4.6	16.9	11.0
flannelmouth sucker	30.0	7.4	19.4	25.6	10.0
mountain sucker	0	0.3	0	0	0.2
razorback sucker	<0.1	0	0	0.2	<0.1
mottled sculpin	0.8	<0.1	0	0	0.2
cutthroat trout	0	0	0	0	0
rainbow trout	1.2	<0.1	0.3	0	0.1
cutthroat X rainbow trout	0	0	0	0	0
brown trout	11.4	<0.1	0.3	0	1.2
brook trout	<0.1	<0.1	0	0	<0.1
red shiner	0.6	28.3	0	2.7	25.0
common carp	7.8	0.2	1.5	0.2	1.0
fathead minnow	0	4.4	0	0.2	3.9
sand shiner	<0.1	27.6	0	7.7	24.4
redside shiner	<0.1	4.5	0	0	4.0
creek chub	0	<0.1	0	0	<0.1
non-native cyprinids	0	0	0	1.4	<0.1
unidentified minnow	0	0	0	0	0
white sucker	6.6	9.1	0.6	36.0	9.0
bluehead X white sucker	0.5	<0.1	0	0	<0.1
flannelmouth X bluehead sucker	0.7	<0.1	0	0	<0.1
flannelmouth X white sucker	2.7	0.3	0.6	0.5	0.6
flannelmouth X bluehead X white sucker	<0.1	<0.1	0	0	<0.1
razorback X flannelmouth sucker	<0.1	0	0	0	<0.1
razorback sucker hybrid	0	0	0	0	0
unidentified sucker	0	<0.1	0	0.7	<0.1
black bullhead	0	<0.1	0	0	<0.1
channel catfish	12.3	0	46.6	0	1.5
northern pike	0.3	<0.1	0	0	<0.1
plains killifish	0	<0.1	0	0	<0.1
brook stickleback	0	<0.1	0	0	<0.1
green sunfish	0.1	0.1	0	0	0.1
bluegill	0.2	0.2	0	0.2	0.2
green sunfish X bluegill	0	0	0	0	0
smallmouth bass	4.1	1.9	0.3	3.9	2.1
black crappie	<0.1	<0.1	0	0	<0.1
walleye	<0.1	0	0	0	<0.1
Total fish	7249	59301	324	414	67288
Effort (hours or samples)	85.2	365	229.4	168	
# native species	8	8	5	5	11
% native species	51.3	23.2	49.7	46.4	26.5
# non-native species	15	18	6	8	21
% non-native species	44.7	76.4	49.7	52.4	72.7
# hybrid combinations	5	4	1	1	5
% hybrid combinations	4.0	0.3	0.6	0.5	0.7

Table 5. Selected non-native fishes removed from the Green River, Lodore and Whirlpool canyons (RK 585.3-537.7), 2005-2006, with comparison of electrofishing capture rates (fish/hr electrofshing, number of fish removed parenthetically). Brown trout were not removed but shown to represent their abundance relative to the other species captured.

	2005	2006
Bluegill	0.09 (7)	0.04 (4)
Brown trout	5.2 (411)	4.6 (410)
Northern pike	0.20 (16)	0.09 (8)
Common carp	3.7 (288)	2.7 (242)
White sucker	3.4 (269)	1.7 (151)
Channel catfish	4.3 (339)	6.2 (555)
Green sunfish	0.70 (55)	0.02 (2)
Smallmouth bass	1.8 (140)	1.8 (159)
Walleye	0	0.03 (3)

Table 6. Fish community composition (% relative abundance) from electrofishing samples collected in the Green River, Lodore and Whirlpool canyons (RK 585.3-537.7), in the periods 2002-2004 and 2005 - 2006.

	% Relative Abundance	
Species	2002-2004	2005-2006
mountain whitefish	1.0	3.0
humpback chub	<0.1	0
bonytail	0.7	0.1
roundtail chub	0.5	0.2
Colorado pikeminnow	0.3	0.2
speckled dace	0.2	0.3
bluehead sucker	18.2	16.6
flannelmouth sucker	24.9	30.0
mountain sucker	0	0
razorback sucker	0	<0.1
mottled sculpin	0.9	0.8
cutthroat trout	<0.1	0
rainbow trout	2.1	1.2
cutthroat X rainbow trout	<0.1	0
brown trout	12.6	11.4
brook trout	0	<0.1
red shiner	0.7	0.6
common carp	11.3	7.8
fathead minnow	0	0
sand shiner	<0.1	<0.1
redside shiner	<0.1	<0.1
creek chub	0	0
non-native cyprinids	0	0
unidentified minnow	0	0
white sucker	5.4	6.6
bluehead X white sucker	0.4	0.5
flannelmouth X bluehead sucker	0.9	0.7
flannelmouth X white sucker	1.9	2.7
flannelmouth X bluehead X white sucker	0.1	<0.1
razorback X flannelmouth sucker	<0.1	<0.1
razorback sucker hybrid	0	0
unidentified sucker	0	0
black bullhead	<0.1	0
channel catfish	10.2	12.3
northern pike	0.1	0.3
plains killifish	0	0
brook stickleback	0	0
green sunfish	0.2	0.1
bluegill	<0.1	0.2
green sunfish X bluegill	<0.1	0
smallmouth bass	7.0	4.1
black crappie	0.1	<0.1
walleye	<0.1	<0.1
Total fish	10725	7249
Effort (hours or samples)	151.9	85.2
# native species	9	9
% native species	46.8	51.3
# non-native species	16	15
% non-native species	49.8	44.7
# hybrid combinations	7	5
% hybrid combinations	3.4	4.0

Table 7. Fish community composition (% relative abundance) from seine samples collected in the Green River, Browns Park downstream through Island-Rainbow Park (RK 611.7-528.0), in the periods 2002-2004 and 2005 - 2006.

	% Relative Abundance	
Species	2002-2004	2005-2006
mountain whitefish	1.7	<0.1
humpback chub	0	0
bonytail	<0.1	0
roundtail chub	0.2	0.9
Colorado pikeminnow	<0.1	<0.1
speckled dace	1.0	4.2
bluehead sucker	1.3	10.3
flannelmouth sucker	3.1	7.4
mountain sucker	0	0.3
razorback sucker	0	0
mottled sculpin	0.1	<0.1
cutthroat trout	0	0
rainbow trout	<0.1	<0.1
cutthroat X rainbow trout	0	0
brown trout	<0.1	<0.1
brook trout	0	<0.1
red shiner	43.6	28.3
common carp	0.3	0.2
fathead minnow	10.4	4.4
sand shiner	26.2	27.6
redside shiner	6.7	4.5
creek chub	<0.1	<0.1
non-native cyprinids	0	0
unidentified minnow	<0.1	0
white sucker	4.4	9.1
bluehead X white sucker	<0.1	<0.1
flannelmouth X bluehead sucker	<0.1	<0.1
flannelmouth X white sucker	0.1	0.3
flannelmouth X bluehead X white sucker	0	<0.1
razorback X flannelmouth sucker	0	0
razorback sucker hybrid	<0.1	0
unidentified sucker	0.1	<0.1
black bullhead	<0.1	<0.1
channel catfish	<0.1	0
northern pike	<0.1	<0.1
plains killifish	<0.1	<0.1
brook stickleback	<0.1	<0.1
green sunfish	0.6	0.1
bluegill	<0.1	0.2
green sunfish X bluegill	0	0
smallmouth bass	0.2	1.9
black crappie	<0.1	<0.1
walleye	0	0
Total fish	193264	59301
Effort (hours or samples)	800	365
# native species	8	8
% native species	7.4	23.2
# non-native species	18	18
% non-native species	92.4	76.4
# hybrid combinations	4	4
% hybrid combinations	0.2	0.3

Table 8. Fish community composition (% relative abundance) from trammel net samples collected in the Green River, Whirlpool Canyon (RK 551.3-540.9), in the periods 2002-2004 and 2005-2006.

	% Relative Abundance	
Species	2002-2004	2005-2006
mountain whitefish	0	0
humpback chub	0.6	0.6
bonytail	0.7	12.3
roundtail chub	24.0	12.7
Colorado pikeminnow	0.3	0
speckled dace	0	0
bluehead sucker	12.9	4.6
flannelmouth sucker	27.4	19.4
mountain sucker	0	0
razorback sucker	0	0
mottled sculpin	0	0
cutthroat trout	0	0
rainbow trout	0.3	0.3
cutthroat X rainbow trout	0	0
brown trout	0	0.3
brook trout	0	0
red shiner	0	0
common carp	0.7	1.5
fathead minnow	0	0
sand shiner	0	0
redside shiner	0	0
creek chub	0	0
non-native cyprinids	0	0
unidentified minnow	0	0
white sucker	1.9	0.6
bluehead X white sucker	0.2	0
flannelmouth X bluehead sucker	0.1	0
flannelmouth X white sucker	1.2	0.6
flannelmouth X bluehead X white sucker	0	0
razorback X flannelmouth sucker	0	0
razorback sucker hybrid	0	0
unidentified sucker	0	0
black bullhead	0	0
channel catfish	27.9	46.6
northern pike	0.1	0
plains killifish	0	0
brook stickleback	0	0
green sunfish	0	0
bluegill	0	0
green sunfish X bluegill	0	0
smallmouth bass	0.8	0.3
black crappie	0.7	0
walleye	0.1	0
Total fish	1206	324
Effort (hours or samples)	535.5	229.4
# native species	6	5
% native species	66.0	49.7
# non-native species	8	6
% non-native species	32.5	49.7
# hybrid combinations	3	1
% hybrid combinations	1.5	0.6

Table 9. Fish community composition (% relative abundance) from drift net samples collected in the Green River, lower Lodore Canyon (RK 566.0), in the periods 2002-2004 and 2005-2006.

	% Relative Abundance	
Species	2002-2004	2005-2006
mountain whitefish	0.2	0
humpback chub	0	0
bonytail	0	0
roundtail chub	0.1	0
Colorado pikeminnow	0	0.5
speckled dace	1.9	3.1
bluehead sucker	14.4	16.9
flannelmouth sucker	16.8	25.6
mountain sucker	0	0
razorback sucker	0	0.2
mottled sculpin	0	0
cutthroat trout	0	0
rainbow trout	0	0
cutthroat X rainbow trout	0	0
brown trout	0	0
brook trout	0	0
red shiner	42.0	2.7
common carp	0.5	0.2
fathead minnow	0.4	0.2
sand shiner	12.5	7.7
redside shiner	<0.1	0
creek chub	0	0
non-native cyprinids	1.7	1.4
unidentified minnow	0	0
white sucker	6.3	36.0
bluehead X white sucker	0	0
flannelmouth X bluehead sucker	0	0
flannelmouth X white sucker	0	0.5
flannelmouth X bluehead X white sucker	0	0
razorback X flannelmouth sucker	0	0
razorback sucker hybrid	<0.1	0
unidentified sucker	0.7	0.7
black bullhead	0	0
channel catfish	0	0
northern pike	0	0
plains killifish	0	0
brook stickleback	0	0
green sunfish	0.2	0
bluegill	0	0.2
green sunfish X bluegill	0	0
smallmouth bass	2.3	3.9
black crappie	0	0
walleye	0	0
Total fish	4269	414
Effort (hours or samples)	420	168
# native species	5	5
% native species	33.3	46.4
# non-native species	8	8
% non-native species	65.9	52.4
# hybrid combinations	1	1
% hybrid combinations	<0.1	0.5

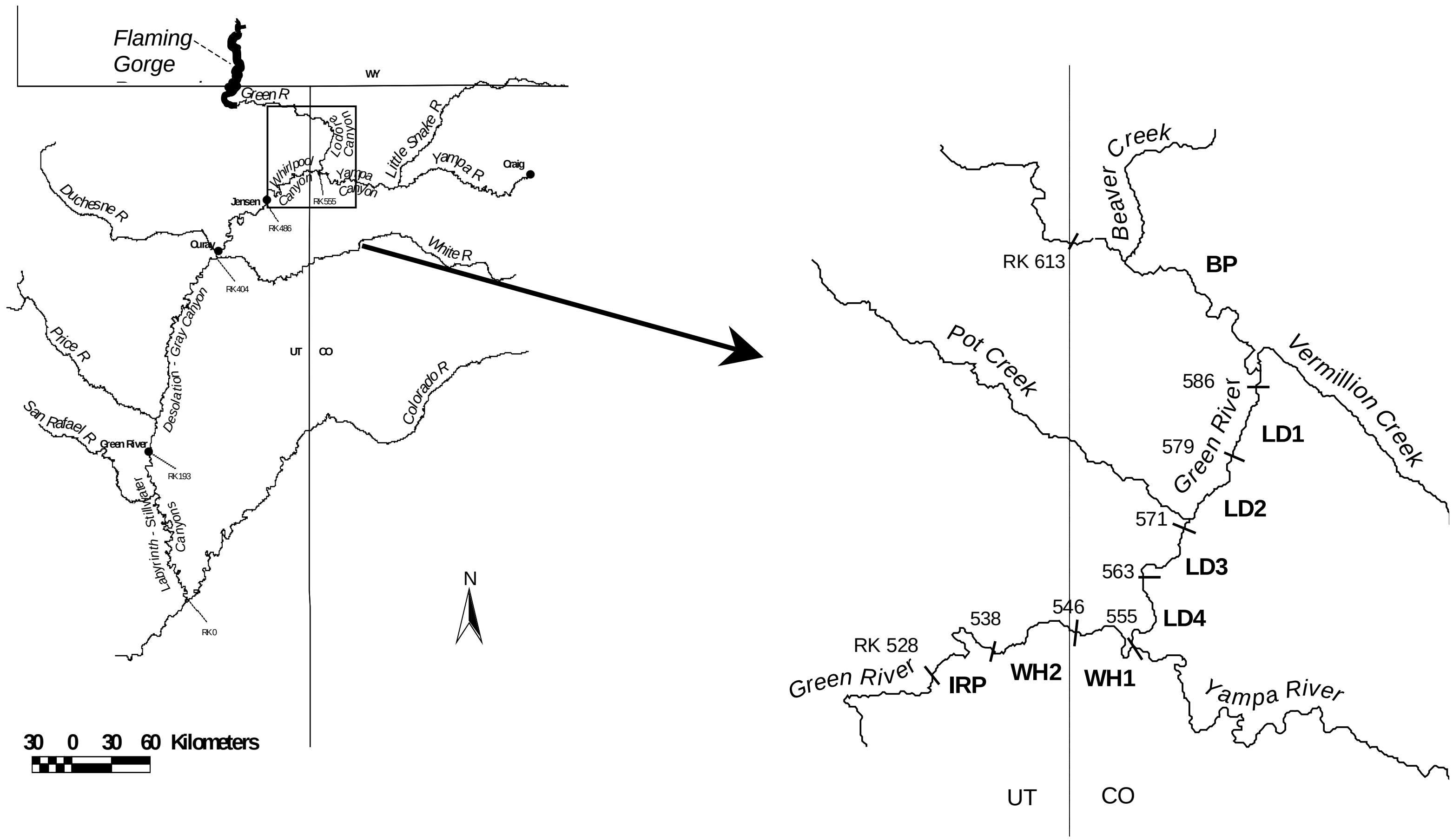

Figure 1. Map of study area. Reach BP is Browns Park, reaches LD1 to LD4 correspond to Lodore Canyon reaches 1 to 4, WH1 and WH2 are Whirlpool Canyon reaches 1 and 2, and IRP is the Island-Rainbow Park reach. RK = river kilometer.

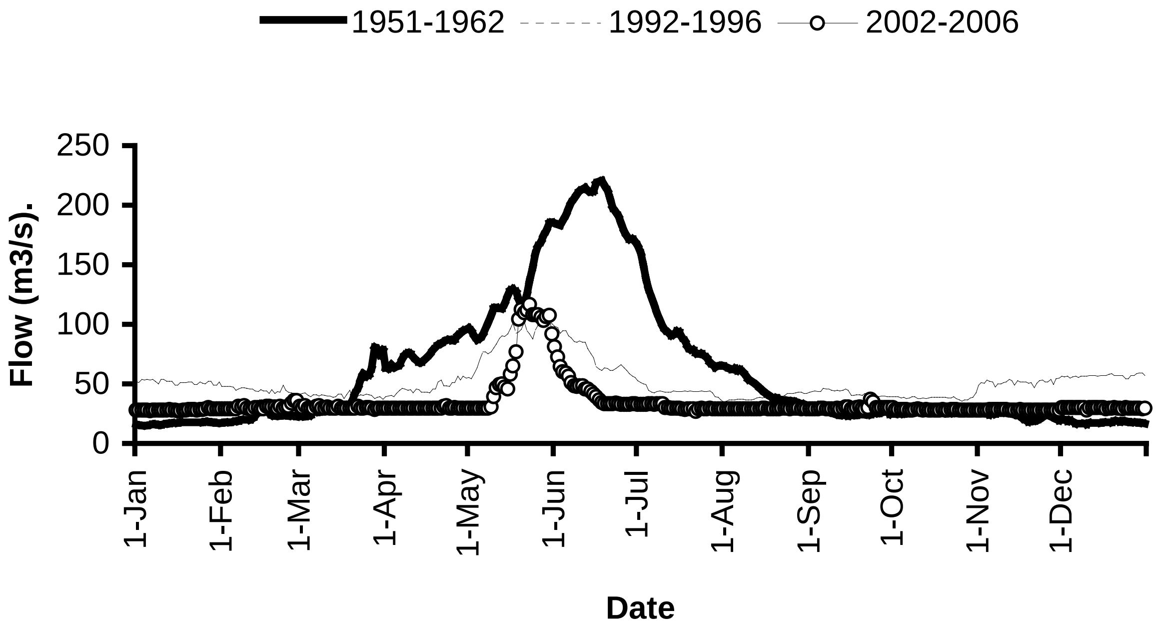

Figure 2. Mean daily flows for the Green River upstream of the Yampa River in the pre-Flaming Gorge Dam period (1951 to1962, Greendale gauge # 09234500, RK 660), compared to post- regulation 1992 to 1996 and 2002 to 2006 periods.

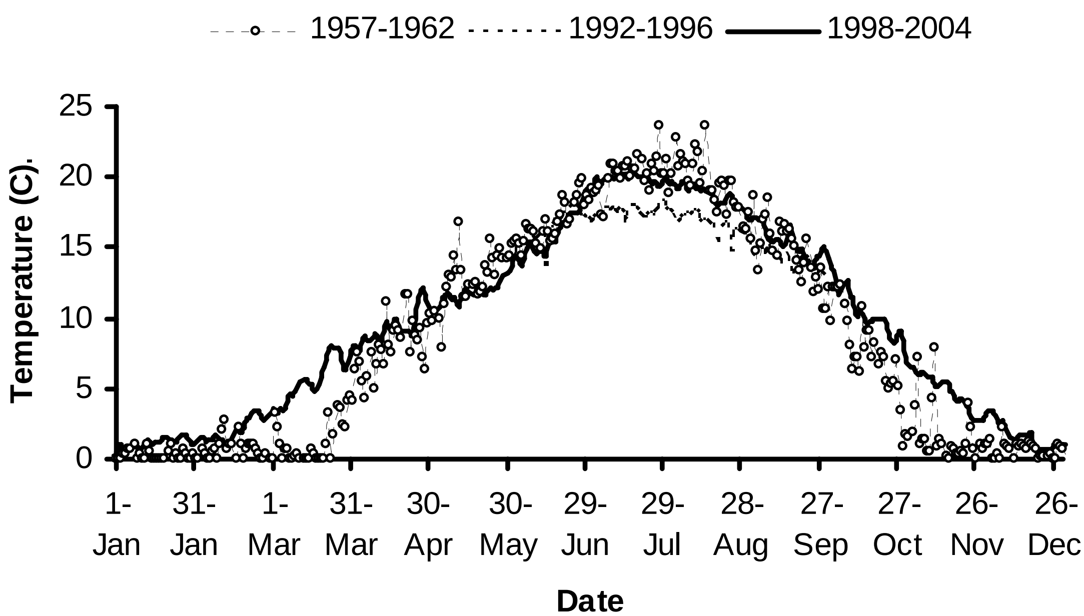

Figure 3. Mean daily water temperatures for the Green River upstream of the Yampa River in the pre-Flaming Gorge Dam period (1957 to1962, Greendale gauge # 09234500, RK 660), compared to post-1992 Biological Opinion (1992-1996, only June through Sept. portrayed), and recent (1998 to 2004) periods.

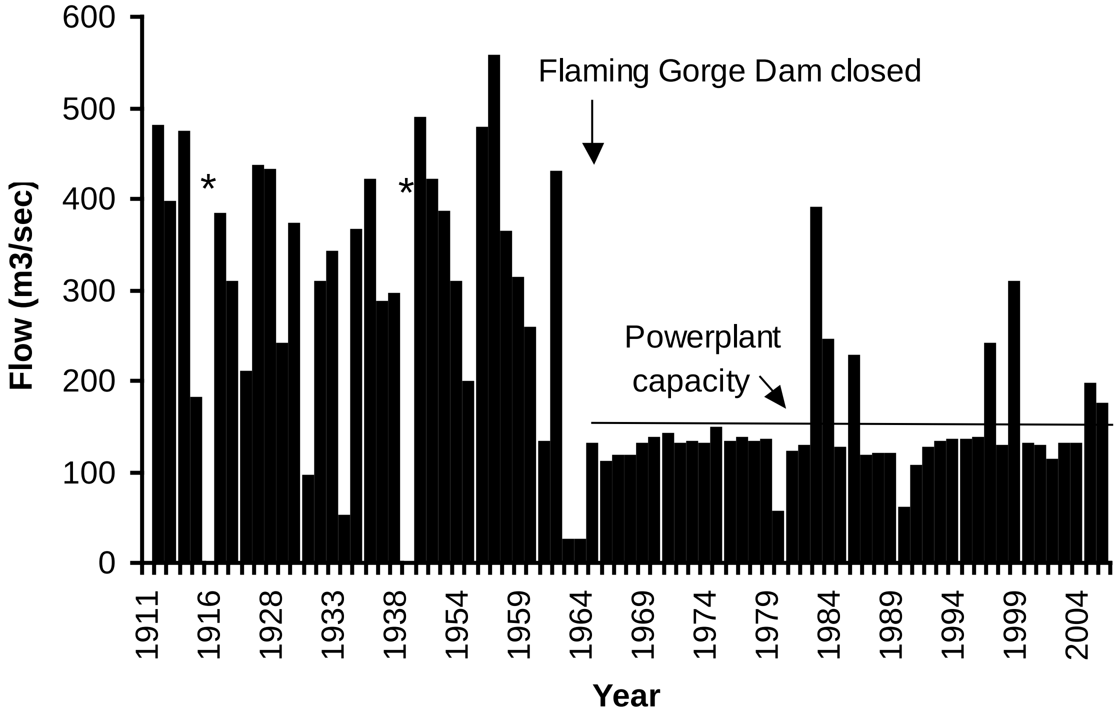

Figure 4. Variation in annual peak flow maxima (mean daily) for the Green River near present-day Flaming Gorge Dam in pre-impoundment (1911 to 1962) and post-impoundment (1963 to 2004) periods. Discharge records are from the following localities: near Bridgeport, Utah (upper Browns Park, 1912 to 1915, gauge # 09235000); near Linwood, Utah (1924 to 1938, submerged by Flaming Gorge Reservoir, gauge # 09230500); near Greendale, Utah (1951 to 2004, gauge # 09234500, RK 660), asterisks denote breaks in record.

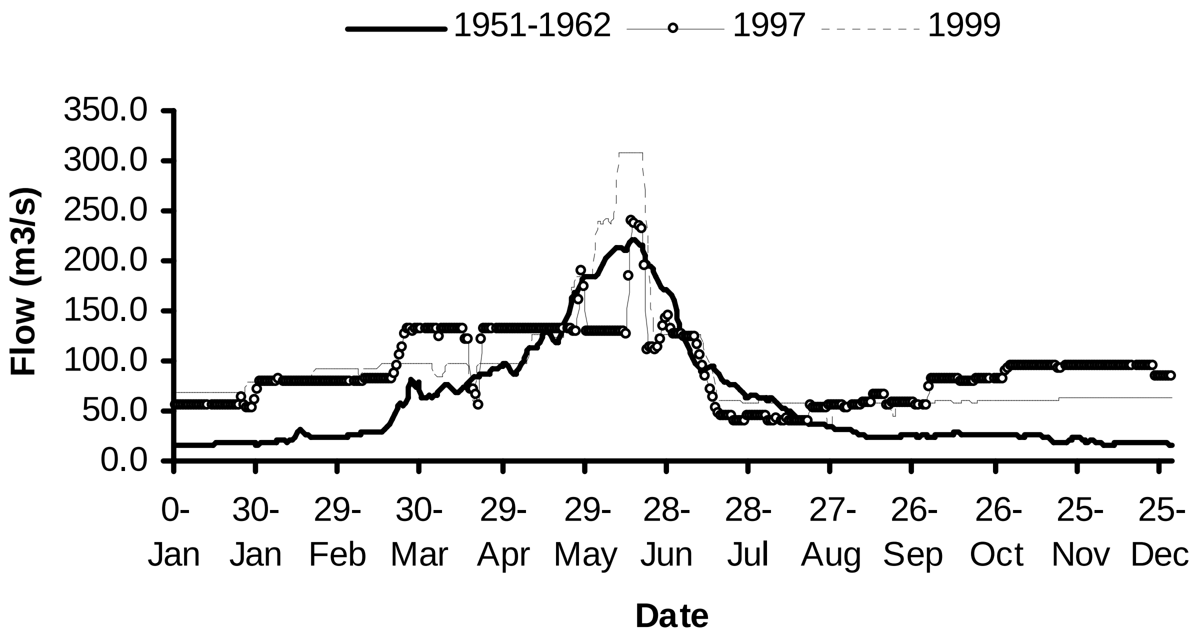

Figure 5. Mean daily flows for the Green River upstream of the Yampa River in post-Flaming Gorge Dam in years1997 and 1999 years compared to mean daily flows in the pre-regulation period (1951 to1962, Greendale gauge # 09234500, RK 660).

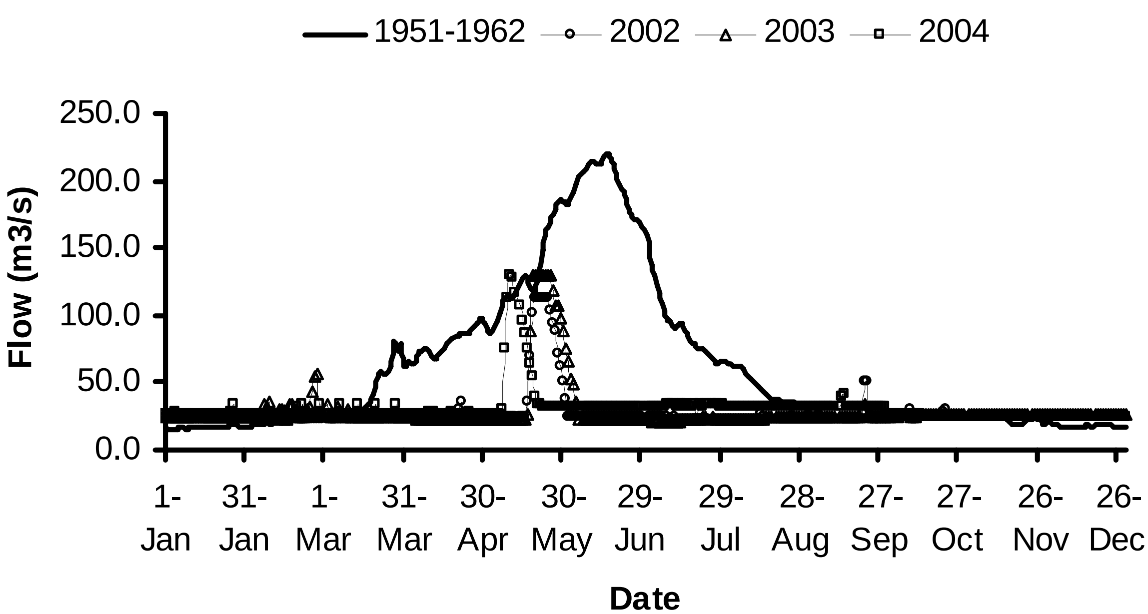

Figure 6. Mean daily flows for the Green River upstream of the Yampa River in the pre-Flaming Gorge Dam period (1951 to1962, Greendale gauge # 09234500, RK 660), compared to 2002 to 2004 hydrographs.

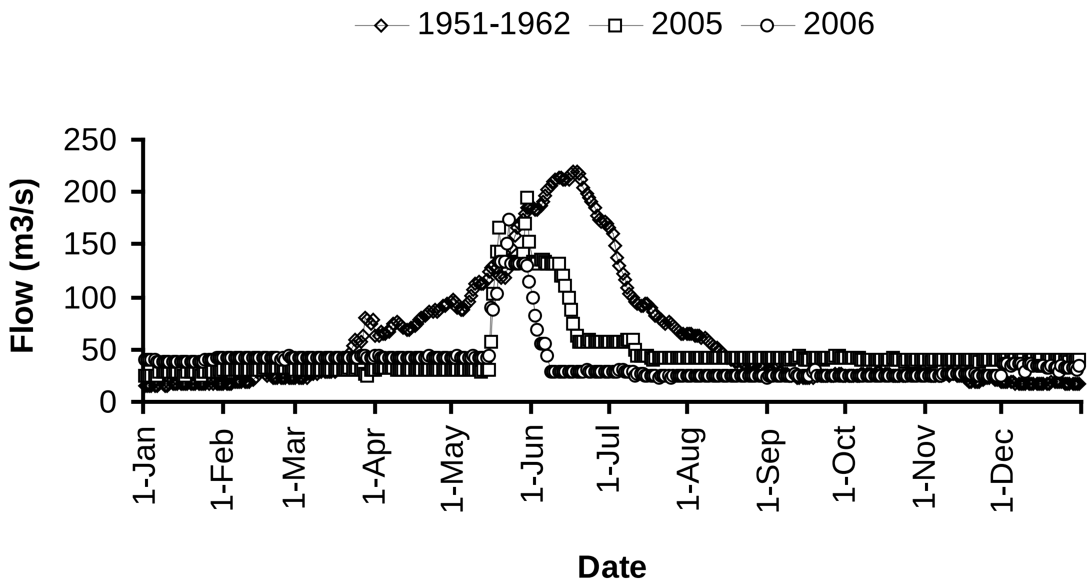

Figure 7. Mean daily flows for the Green River upstream of the Yampa River in the pre-Flaming Gorge Dam period (1951 to1962, Greendale gauge # 09234500, RK 660), compared to 2005 to 2006 hydrographs.

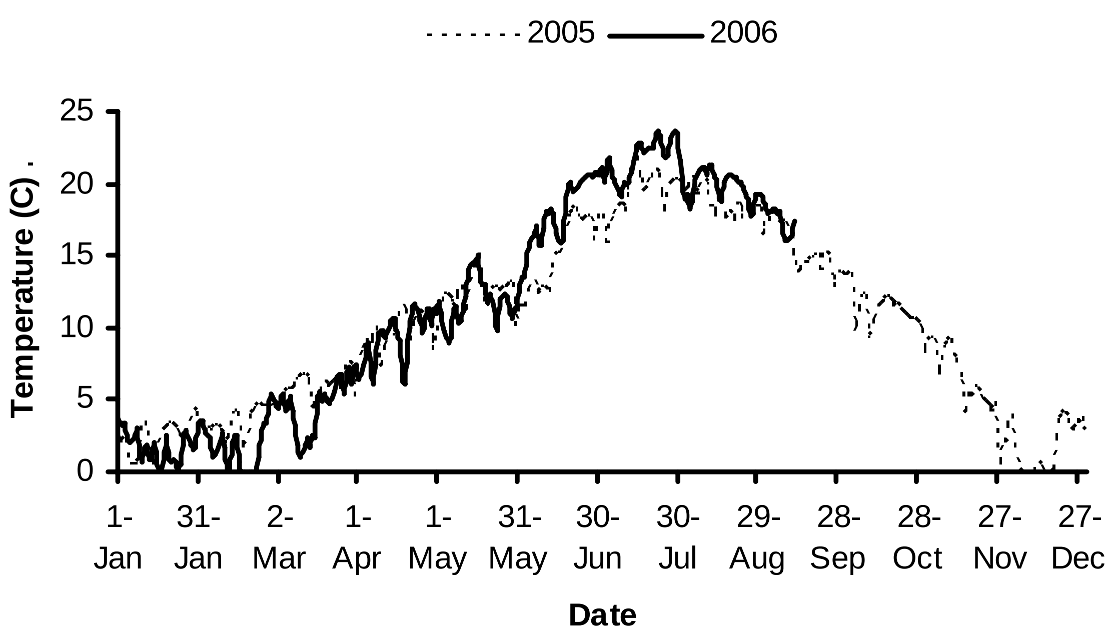

Figure 8. Mean daily water temperatures for the Green River (RK566.5), just upstream of the Yampa River in 2005 to 2006.

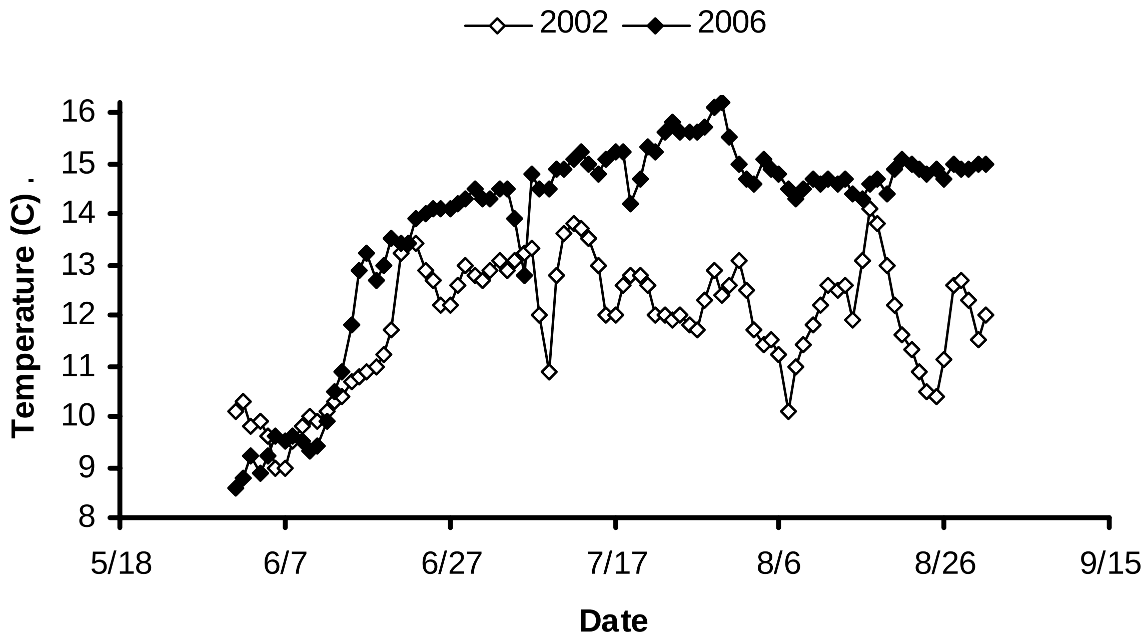

Figure 9. Mean daily water temperature of releases from Flaming Gorge Dam penstocks to the Green River, 2002 and 2006 (RK660).

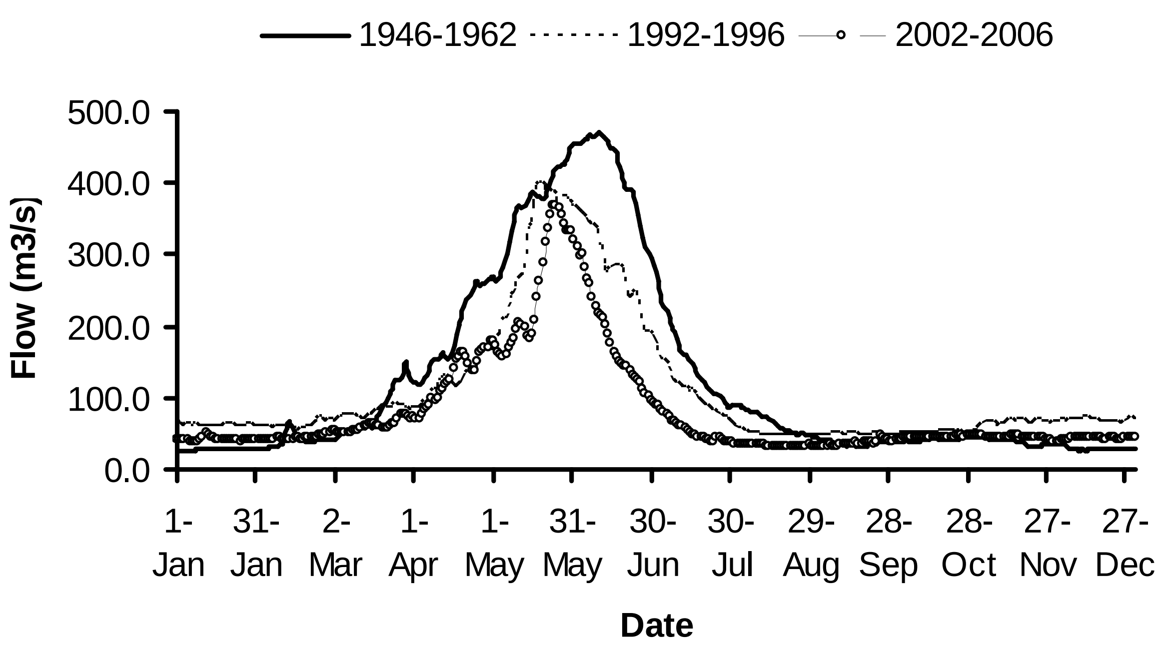

Figure 10. Mean daily flows for the Green River in Whirlpool Canyon downstream of the Yampa River in the pre-Flaming Gorge Dam period (1946 to1962, Jensen gauge # 09261000, RK 486.2), compared to post- regulation 1992 to 1996 and 2002 to 2006 periods.

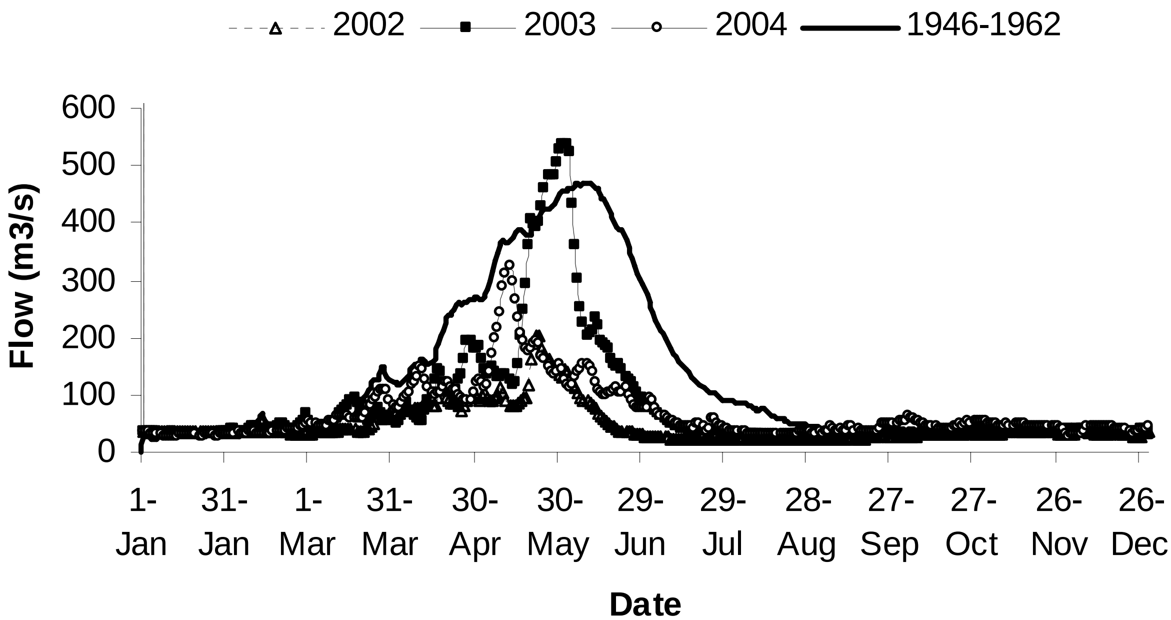

Figure 11. Mean daily flows for the Green River in Whirlpool Canyon downstream of the Yampa River in the pre-Flaming Gorge Dam period (1946 to1962, Jensen gauge # 09261000, RK 486.2), compared to post- regulation daily flows in the 2002 to 2004 study period.

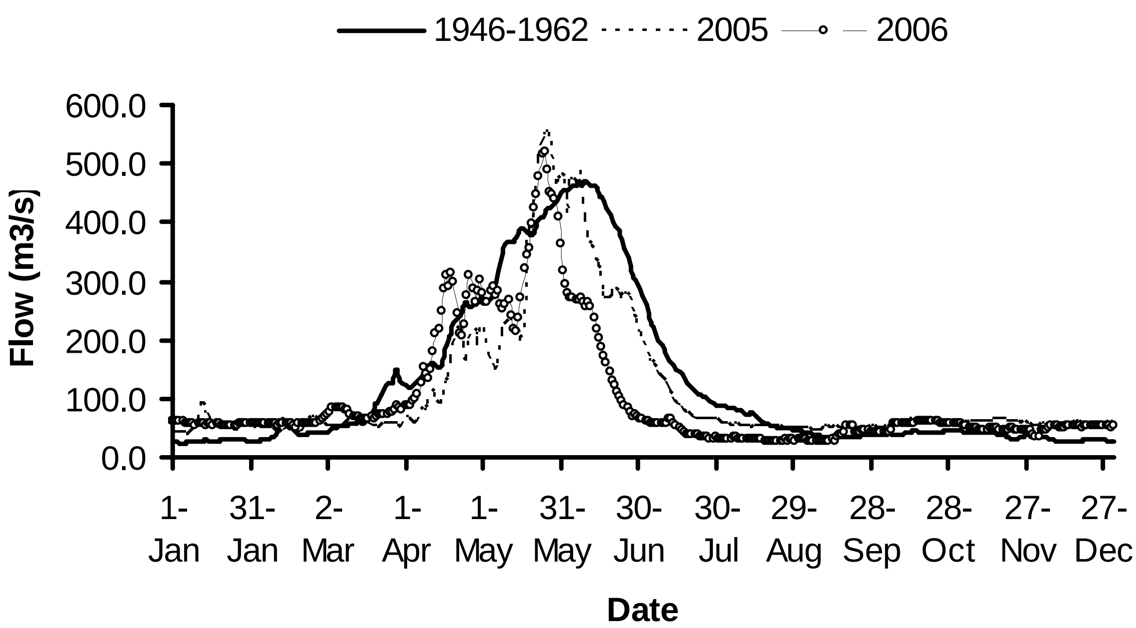

Figure 12. Mean daily flows for the Green River in Whirlpool Canyon downstream of the Yampa River in the pre-Flaming Gorge Dam period (1946 to1962, Jensen gauge # 09261000, RK 486.2), compared to post- regulation daily flows in 2005 and 2006.

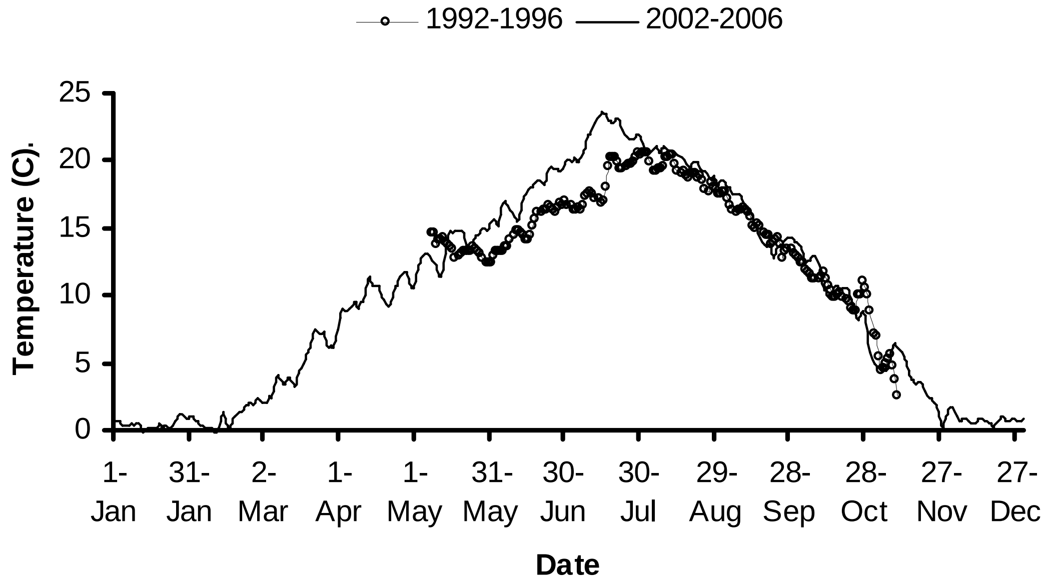

Figure 13. Mean daily water temperatures for the Green River (RK 552.5) in Whirlpool Canyon downstream of the Yampa River in the post-1992 Biological Opinion (1992-1996, partial year only available), and recent (2002 to 2006) periods.

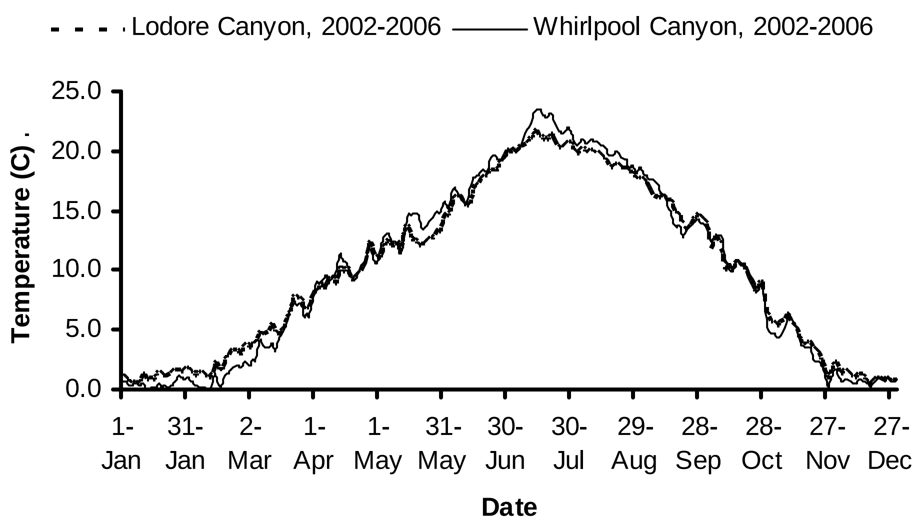

Figure 14. Mean daily water temperatures for the Green River in lower Lodore Canyon just upstream of the Yampa River (RK 566.5) and Whirlpool Canyon (Mitten Park portable gauge, RK 552.5) downstream of the Yampa River in 2002 to 2006 period.

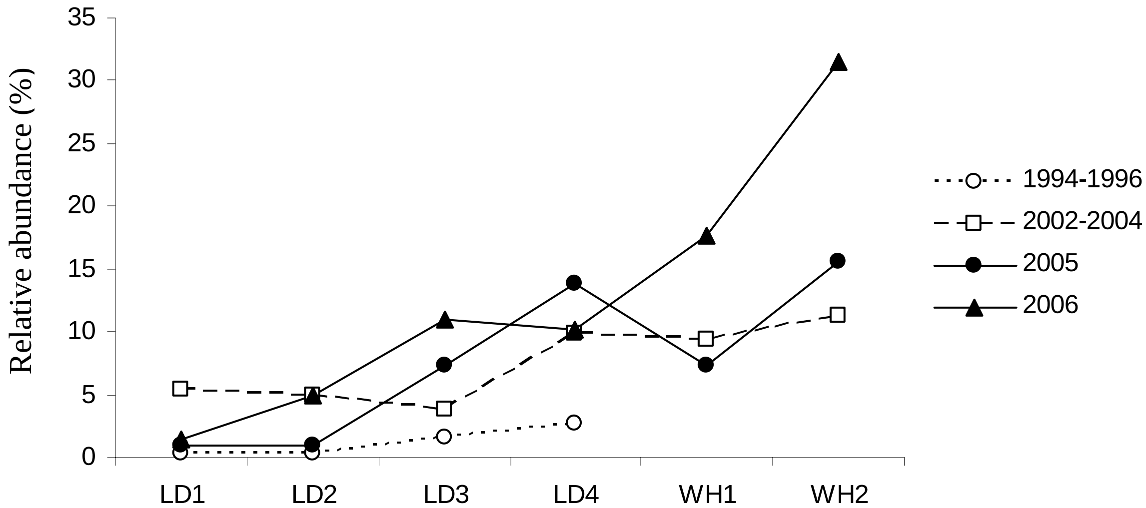

Figure 15. Distribution and % relative abundance of channel catfish in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

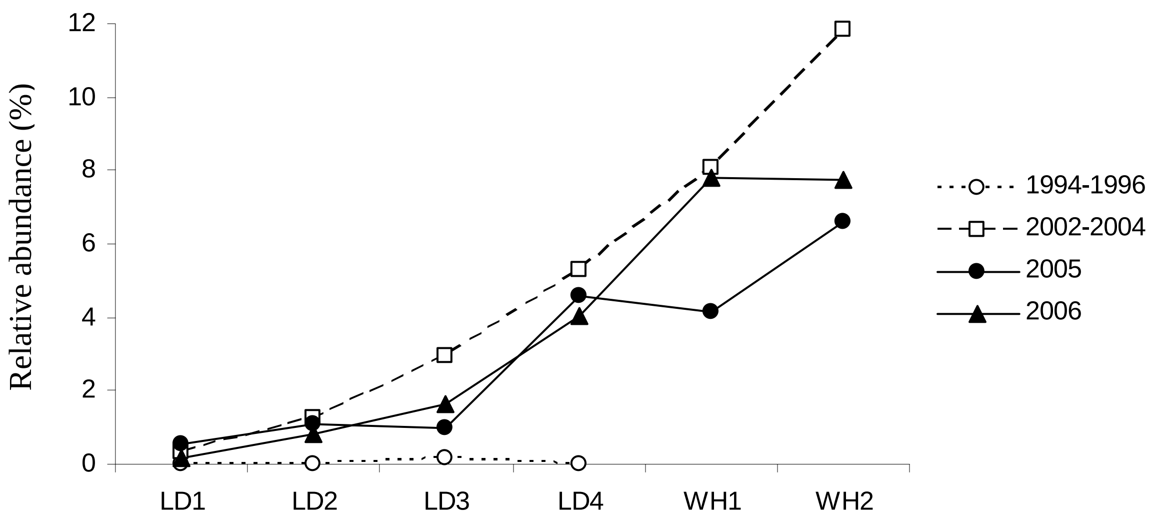

Figure 16. Distribution and % relative abundance of smallmouth bass in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

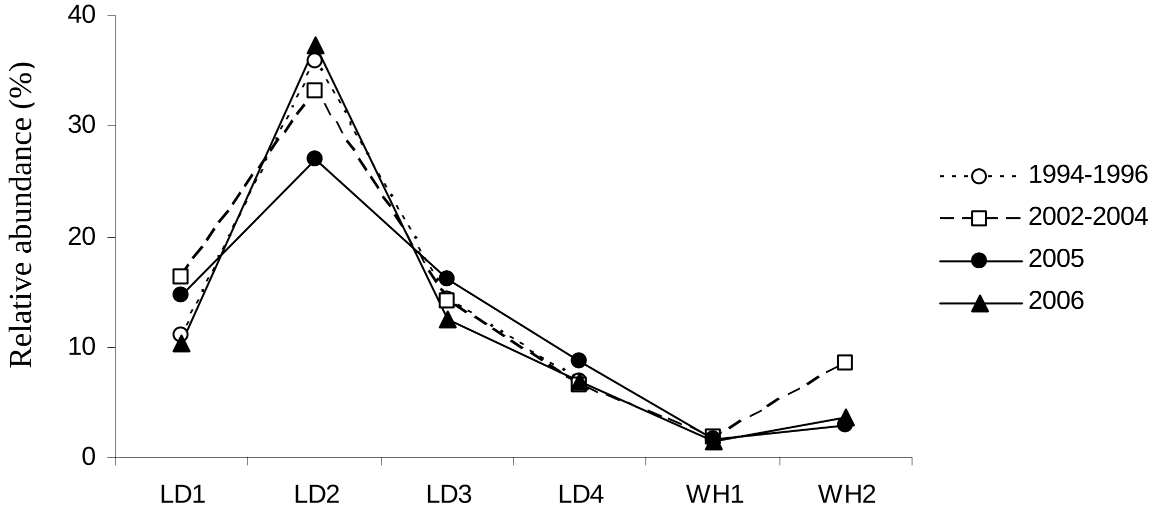

Figure 17. Distribution and % relative abundance of trout (mostly brown trout) in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

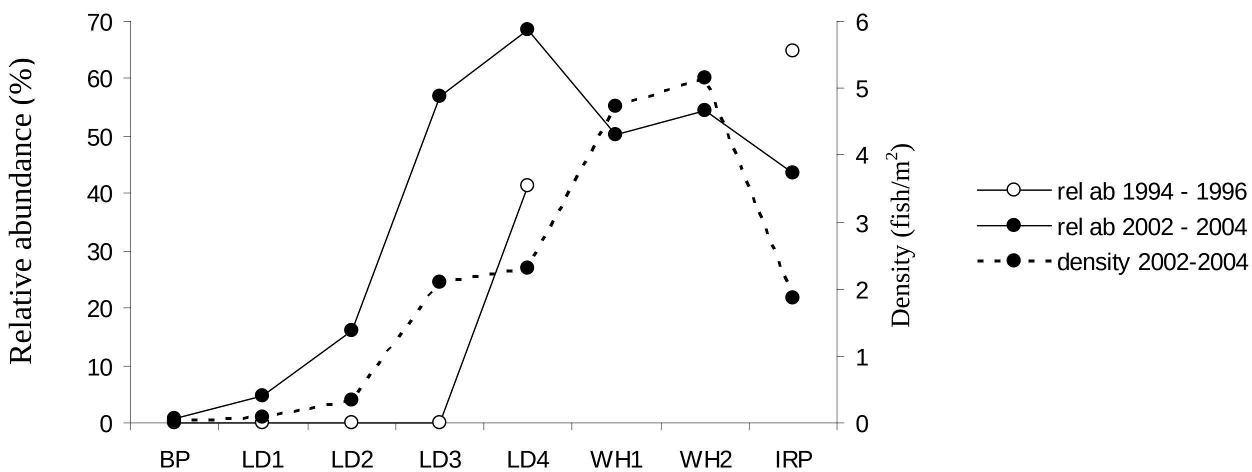

Figure 18. Distribution and abundance of red shiner in seine samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996 and 2002-2004. Only relative abundance data are available for seine samples in the 1994-1996 period. Sampling areas include Browns Park (BP, RK 613.0-586.0), four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3), two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1), and Island-Rainbow Park (IRP, RK 538.0-528.0).

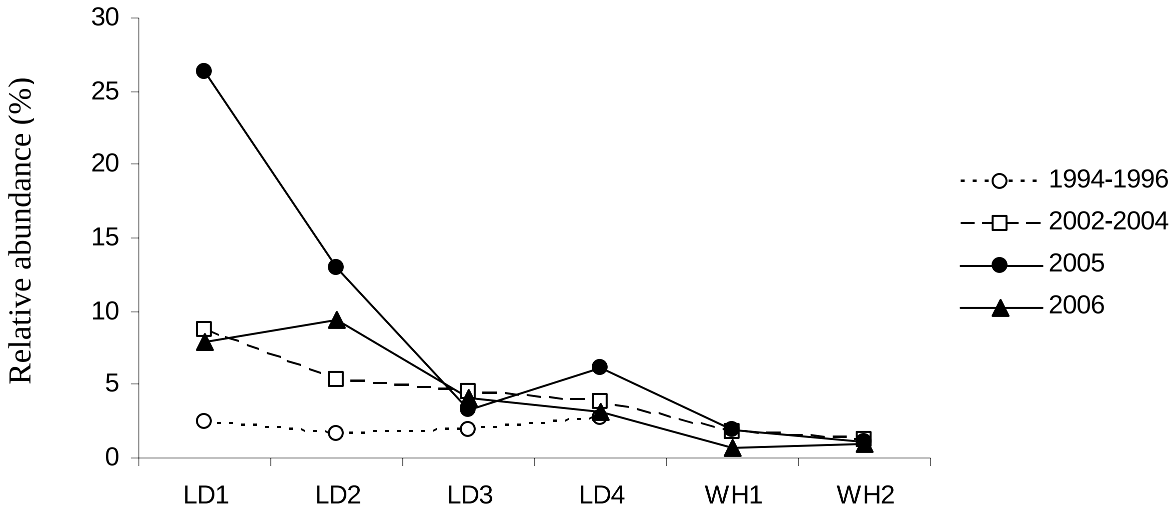

Figure 19. Distribution and % relative abundance of white sucker in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

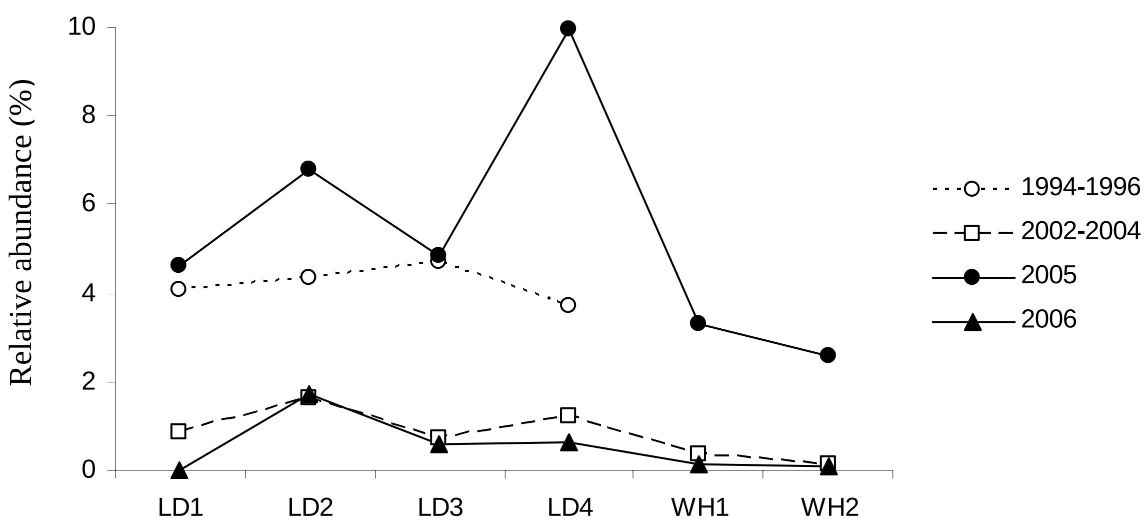

Figure 20. Distribution and % relative abundance of mountain whitefish in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

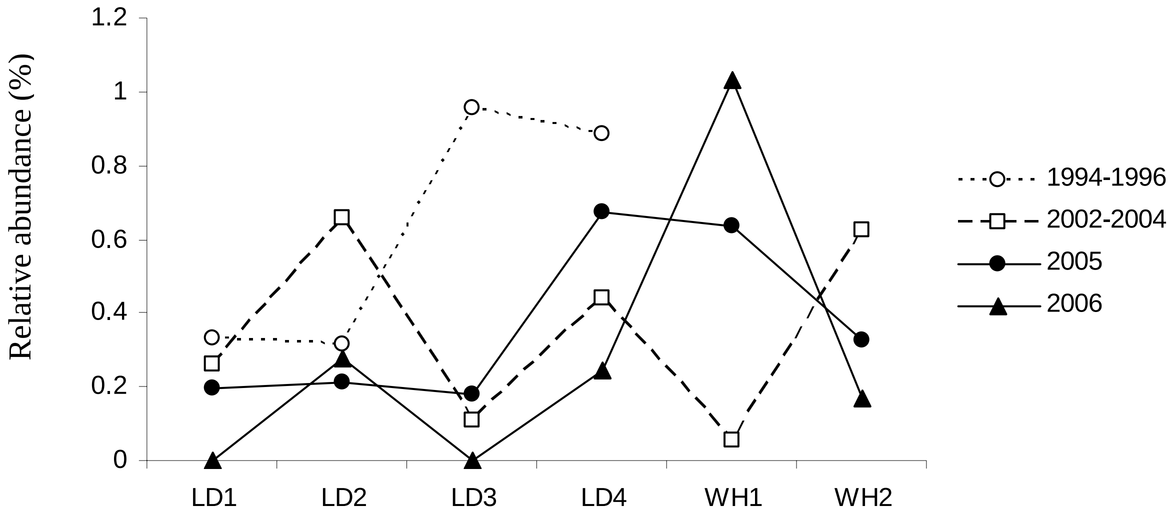

Figure 21. Distribution and % relative abundance of Colorado pikeminnow in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

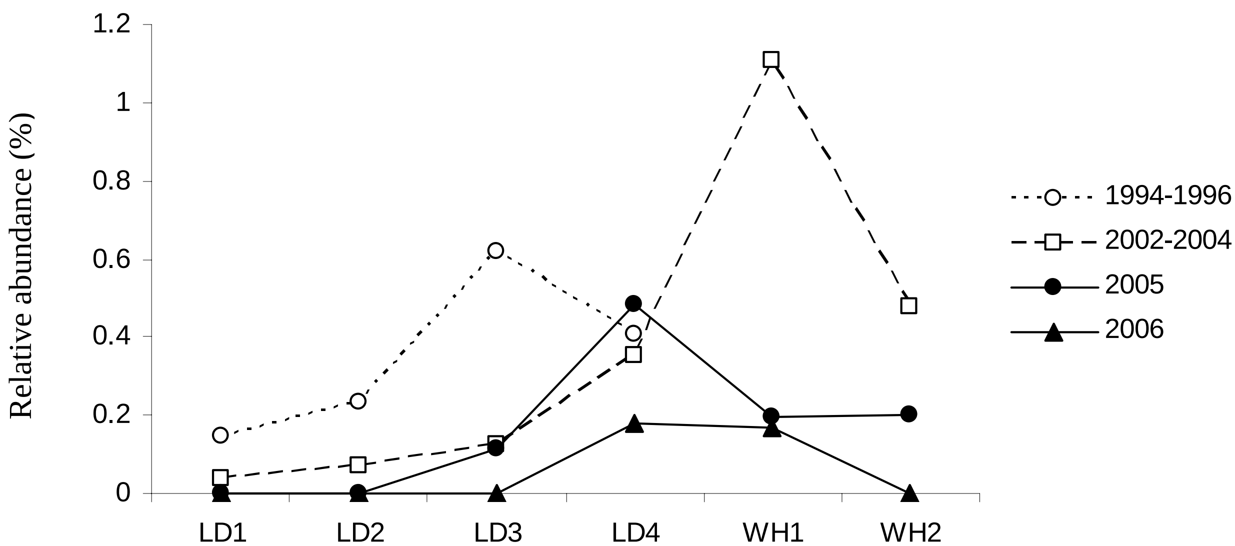

Figure 22. Distribution and % relative abundance of roundtail chub in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

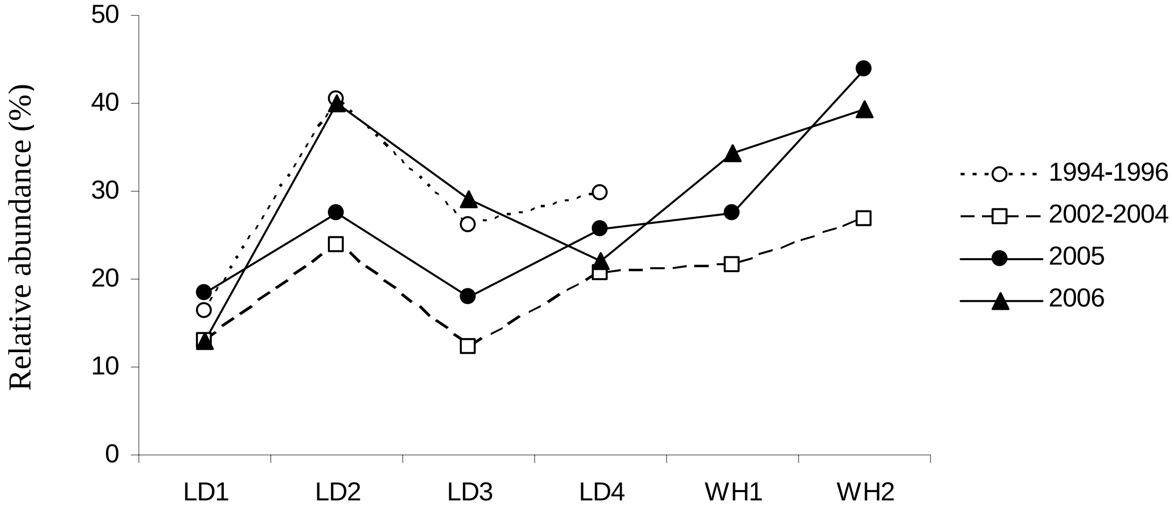

Figure 23. Distribution and % relative abundance of flannelmouth sucker in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).

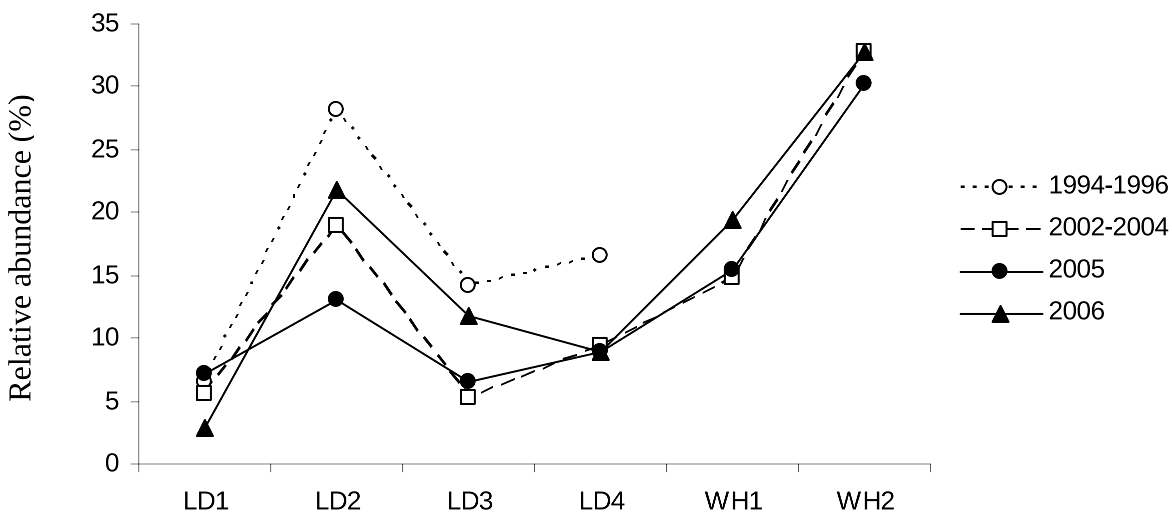

Figure 24. Distribution and % relative abundance of bluehead sucker in electrofishing samples from the Green River downstream of Flaming Gorge Dam, Colorado and Utah, in periods 1994-1996, 2002-2004, and 2005 and 2006. Sampling areas include four Lodore Canyon reaches (LD1, RK 585.9 to 579.0; LD2, RK 578.9 to 571.0, LD3, RK 570.9 to 563.0; LD4, RK 562.9 to 555.3) and two Whirlpool Canyon reaches (WH1, RK 555.2 to 546.6; WH2, RK 546.5 to 538.1).