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Michael C. Quist
University of Wyoming, Laramie

Wayne A. Hubert
University of Wyoming, Laramie

Frank J. Rahel
University of Wyoming, Laramie

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FISH ASSEMBLAGE STRUCTURE FOLLOWING IMPOUNDMENT OF A GREAT PLAINS RIVER

Michael C. Quist[1,3], Wayne A. Hubert[1], and Frank J. Rahel[2]

ABSTRACT.—Understanding the upstream and downstream effect of impoundments on stream fish assemblages is important in managing fish populations and predicting the effects of future human activities on stream ecosystems. We used information collected over a 41-year period (1960–2001) to assess changes in fish assemblage structure resulting from impoundment of the Laramie River by Grayrocks Reservoir. Prior to impoundment (i.e., 1960–1979), fish assemblages were dominated by native catostomids and cyprinids. After impoundment several exotic species (e.g., smallmouth bass [*Micropterus dolomieu*], walleye [*Sander vitreus;* formerly *Stizostedion vitreum*], yellow perch [*Perca flavescens*], brown trout [*Salmo trutta*]) were sampled from reaches upstream and downstream of the reservoir. Suckermouth minnows (*Phenacobius mirabilis*) were apparently extirpated, and hornyhead chubs (*Nocomis biguttatus*) and common shiners (*Luxilus cornutus*) became rare upstream of Grayrocks Reservoir. The lower Laramie River downstream from Grayrocks Reservoir near its mouth retains habitat characteristics similar to those prior to impoundment (e.g., shallow, braided channel morphology) and is the only downstream area where several sensitive species persist, including suckermouth minnows, hornyhead chubs, and bigmouth shiners (*Notropis dorsalis*). Grayrocks Reservoir serves as a source of exotic piscivores to both upstream and downstream reaches and has altered downstream habitat characteristics. These impacts have had a substantial influence on native fish assemblages. Our results suggest that upstream and downstream effects of impoundment on fish assemblage structure are similar and that downstream reaches which retain habitat characteristics similar to pre-impoundment conditions may serve as areas of refuge for native species.

Key words: impoundment, conservation, exotic species, Great Plains, Wyoming.

Reservoirs are regarded as one of the most significant threats to aquatic biodiversity at global and regional scales (Richter et al. 1997, Rosenberg et al. 1997). Over 39,000 large dams (≥15 m in height) throughout the world (Dynesius and Nilsson 1994) and approximately 5500 large dams and 75,000 smaller dams (<15 m in height) in the United States have been constructed to provide agricultural, hydropower, flood control, and recreational benefits (Rosenberg et al. 2000). Although the rate of reservoir construction has declined during the last 20 years (Postel et al. 1996, Rosenberg et al. 2000), projects such as the Three Gorges development in China and various small projects in northern Canada indicate continued interest in reservoir construction (Rosenberg et al. 1997).

Extensive development of water resources has instigated a variety of studies on the effects of impoundments to lotic ecosystems. Regulated discharge from impoundments results in an altered hydrograph, often with reduced peak flows during spring and augmented flows during summer and winter (Ward and Stanford 1979, Pringle et al. 2000). Discharge from reservoirs can alter thermal regimes, with colder summer temperatures and warmer winter temperatures than occurred prior to impoundment (Rosenberg et al. 1997, Poff and Hart 2002). Water velocity is reduced upon entering a reservoir, and this allows sediment to settle from the water column. Thus, water discharged from reservoirs is relatively free of sediment. Reduced sediment transport, coupled with regulated flow regimes, can alter channel morphology and substrate characteristics. For example, reduced peak flows and continual discharge of sediment-free water commonly result in reduced width and increased depth (i.e., channel incision), and selective transport of smaller sediments causes armoring of the substrate (Ward and Stanford 1979, Poff and Hart 2002). All of these factors, in isolation or in concert, influence the composition of native fish assemblages, especially with regard to

[1]U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, WY 82071-3166.
[2]Department of Zoology and Physiology, University of Wyoming, Laramie, WY 82071-3166.
[3]Corresponding author.

species adapted to dynamic river systems characteristic of the western Great Plains (Cross and Moss 1987, Fausch and Bestgen 1997).

Most studies that have investigated the influence of reservoirs on biotic communities have focused on anadromous species. Reservoirs may act as barriers to movements and contribute to the decline of species dependent on extensive spawning migrations, such as Pacific salmonids (Li et al. 1987, Gregory et al. 2002). Like anadromous species, many resident fishes are dependent on upstream or downstream movements for spawning or for an escape from harsh environmental conditions (Geist et al. 1996, Matthews 1998). In addition to blocking movements, altered habitat conditions, loss of channel-floodplain connectivity, and introduction of exotic species may influence fish assemblage structure. Understanding how impoundments influence fish assemblages is important for both managing stream fish populations and predicting the effects of future human activities (e.g., dam construction or removal; Hart et al. 2002). Although the effects of impoundments on fish assemblages have received detailed investigation in the northwestern (Gregory et al. 2002) and southwestern (Carlson and Muth 1989) United States, the effects of reservoirs on stream systems in the Great Plains are not well documented. Therefore, the purpose of this study was to assess the upstream and downstream effects of an impoundment on the fish assemblage of a Great Plains river. Specifically, we examined changes in fish assemblage structure upstream and downstream of Grayrocks Reservoir on the Laramie River, Wyoming, using information collected before and after reservoir construction.

METHODS

The Laramie River, one of the largest tributaries to the North Platte River, originates in the mountains of northern Colorado and flows northeasterly to its confluence with the North Platte River at Fort Laramie, Wyoming (Fig. 1). The Laramie River has experienced extensive water development since the early 1900s, including diversion of water for agricultural use and construction of large storage reservoirs. Two large reservoirs have been constructed on the Laramie River: Wheatland Reservoir Number 2 and Grayrocks Reservoir. Grayrocks Reservoir, located 40 km east of Wheatland, Wyoming, was constructed in 1980 by the Missouri River Basin Power Company. The reservoir was built to provide cooling water for a coal-fired power-generation facility. No heated effluent is returned to Grayrocks Reservoir or the Laramie River. At capacity the reservoir has a surface area of 1435 ha and a maximum depth of approximately 23 m. The fish community in the reservoir includes native species (e.g., channel catfish [*Ictalurus punctatus*], river carpsucker [*Carpiodes carpio*]) and a variety of exotic species introduced to provide recreational angling opportunities (e.g., smallmouth bass [*Micropterus dolomieu*], walleye [*Sander vitreus;* formerly *Stizostedion vitreum*]) and prey for sport fishes (e.g., gizzard shad [*Dorosoma cepedianum*]; Hubert and O'Shea 1991).

Prior to settlement by Europeans, the Laramie River was characteristic of other Great Plains rivers having well-developed pool and riffle habitats in middle reaches (e.g., near Chugwater Creek, North Laramie River) and a shallow, braided channel with dynamic substrate in lower reaches (Patton and Hubert 1993, Baxter and Stone 1995). The Laramie River from Grayrocks Reservoir to its confluence with the North Platte River (approximately 20 km) has changed from a braided channel to a single, incised channel with few remaining side-channel and backwater habitats (Patton and Hubert 1993).

We used historic data collected during 1960–1979 by University of Wyoming (UW) and Wyoming Game and Fish Department (WGFD) personnel to characterize the fish assemblage prior to construction of Grayrocks Reservoir (Fig. 1). Fish assemblage structure after reservoir construction was determined using information collected by UW, WGFD, and Montana State University personnel during 1980–2001. All fish were sampled using either electrofishing or seining. The reaches sampled during 1960–1979 were the same as those we sampled during 1980–2001, allowing us to compare changes in fish assemblages before and after construction of Grayrocks Reservoir. Twelve additional reaches (4 upstream and 8 downstream of Grayrocks Reservoir) were also sampled during 1980–2001 to provide further evidence of changes to the fish assemblage following impoundment.

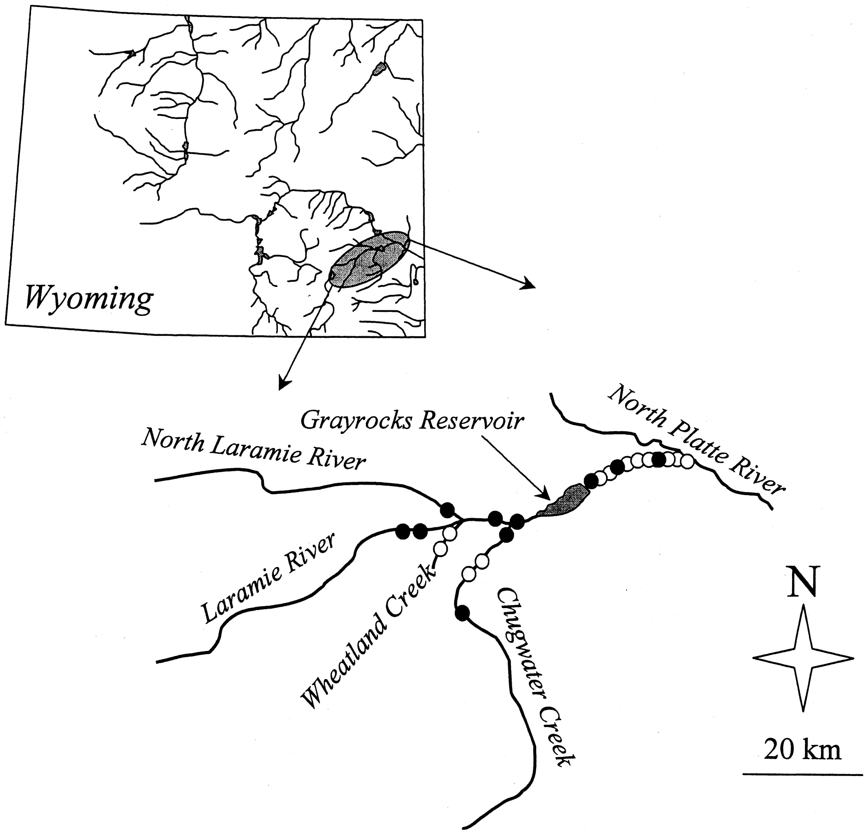

Fig. 1. Map of reaches sampled in the Laramie River drainage near Grayrocks Reservoir, Wyoming. Solid symbols represent reaches sampled both before (1960–1979) and after (1980–2001) impoundment, and open symbols represent additional reaches sampled after impoundment.

Similarity in fish assemblage structure among reaches was evaluated using Jaccard's index of assemblage similarity (Jongman et al. 1995). Jaccard's index values were calculated for all possible pairs of upstream and downstream reaches sampled before and after impoundment. The resulting matrix of similarity indices was clustered using the unweighted pair-group method (UPGMA; Jongman et al. 1995, Matthews 1998) to produce a dendrogram depicting clusters of reaches with similar fish assemblage structure. The similarity analysis was conducted using NTSYS (Rohlf 1990).

Using the number of species by family (i.e., clupeids, salmonids, native cyprinids, catostomids, ictalurids, fundulids, centrarchids, and percids), we assessed changes in fish assemblage structure sampled from reaches before and after impoundment. If a reach was sampled more than once (i.e., post-impoundment), then we used the most recent year of data in the analysis. Differences in the number of species by family were examined using a paired t test (Ott 1993). Because the effects of impoundment may differ depending on the location of the reach (i.e., upstream versus downstream), tests were conducted on reaches upstream and downstream of Grayrocks Reservoir. Furthermore, a Bonferroni adjustment was used to avoid type-I errors associated with multiple statistical tests (Ott 1993). Paired t tests were performed using SAS (SAS Institute, Inc. 1996).

In addition to examining changes in assemblage structure across reaches, we obtained a chronology of changes in the fish assemblage from a reach downstream from Grayrocks Reservoir. The sampling reach, 8 km downstream from Grayrocks Reservoir, was sampled repeatedly from 1979 to 1991. Similar

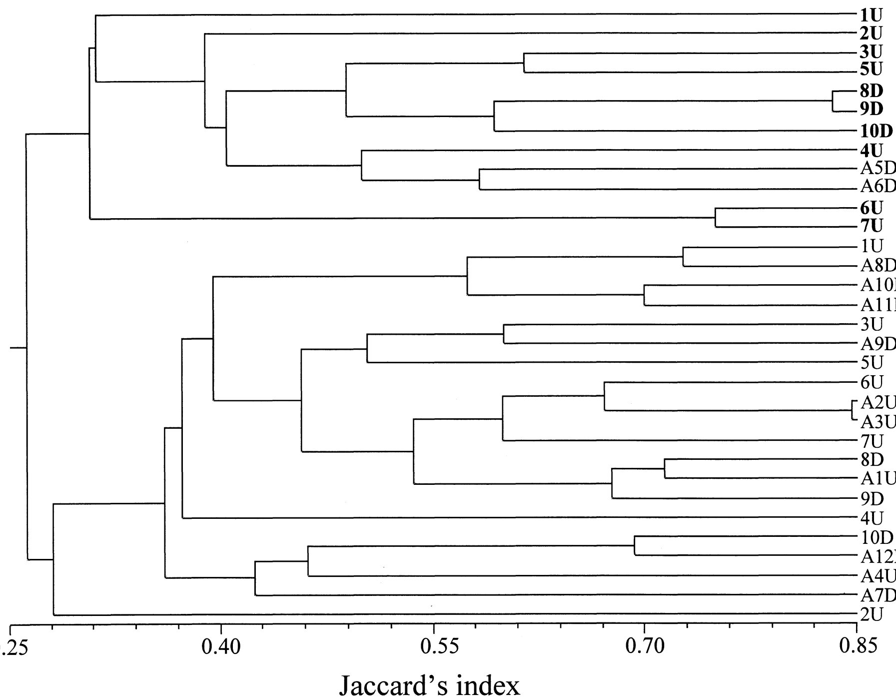

Fig. 2. Dendrogram depicting fish assemblage similarity among reaches sampled in the Laramie River, Wyoming, before and after construction of Grayrocks Reservoir. Reach labels that begin with the same number indicate that the same reach was sampled before (bold text) and after (normal text) impoundment. Additional reaches that were sampled only after impoundment are labeled with an "A". Reach labels also designate whether the reach was located upstream (U) or downstream (D) of Grayrocks Reservoir.

data were unavailable for reaches upstream of the reservoir.

RESULTS

Cluster analysis of similarity index values illustrated changes in fish assemblage structure following construction of Grayrocks Reservoir (Fig. 2). For example, 2 broad clusters were identified (separating at a Jaccard's index value of approximately 0.28; Fig. 2), with reaches sampled prior to impoundment in 1 cluster and reaches sampled after impoundment in the other. Two reaches (i.e., reaches A5D and A6D in Fig. 2) sampled after impoundment clustered with those sampled before impoundment. Both reaches were located near the confluence with the North Platte River and had assemblages similar to those found prior to construction of the reservoir. In addition, these 2 reaches were the only downstream ones where sensitive species (e.g., suckermouth minnow, hornyhead chub) have been recently collected. Within the cluster of reaches sampled prior to impoundment, some clustering of the downstream reaches was observed (i.e., reaches 8D, 9D, and 10D in bold; Fig. 2). Conversely, upstream and downstream reaches within the cluster of post-impoundment samples did not exhibit any evident patterns or consistent clustering. This suggests that fish assemblages were different before and after impoundment and that after impoundment, fish assemblages were similar in upstream and downstream reaches.

Prior to construction of Grayrocks Reservoir, fish assemblages were dominated by native cyprinids and catostomids (Table 1). Native cyprinids were sampled from all reaches, and catostomids were found at 80% of upstream and 67% of downstream reaches. However, after completion of Grayrocks Reservoir, salmonids, centrarchids, catostomids, and percids became more frequent both upstream and downstream of the reservoir. The number of species in

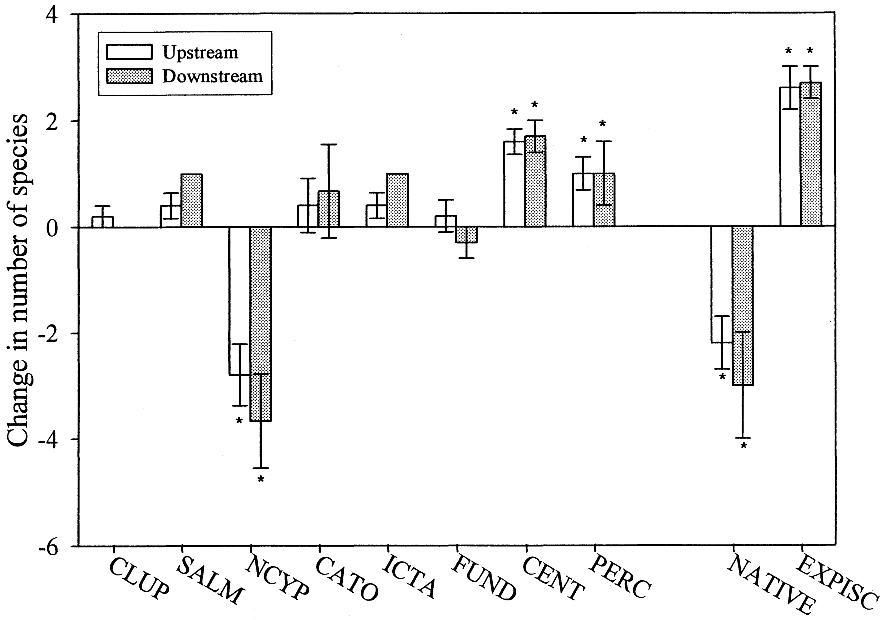

Fig. 3. Change in the number of species sampled by taxa (CLUP = clupeidae, SALM = salmonidae, NCYP = native cyprinidae, CATO = catostomidae, ICTA = ictaluridae, FUND = fundulidae, CENT = centrarchidae, PERC = percidae, NATIVE = all native species, and EXPISC = exotic piscivorous species) from reaches following construction of Grayrocks Reservoir, Wyoming. Positive values represent the addition of species to a taxonomic group, while negative values represent the loss of species. An asterisk represents a significant change in the mean number of species ($P < 0.001$; paired t test with a Bonferroni adjustment).

nearly all families increased following impoundment except for native cyprinids where 3 fewer species were generally collected following impoundment (Fig. 3). Most changes in the number of species were similar between reaches sampled upstream and downstream of the reservoir, but for some families (e.g., native cyprinids, ictalurids) downstream changes were greater (Fig. 3). Furthermore, significantly fewer native and more exotic species were sampled following impoundment from both upstream and downstream reaches.

Species-specific occurrences at reaches sampled before and after impoundment identified further changes to fish assemblages. The decline of native cyprinids upstream of Grayrocks Reservoir was associated with reduced frequency of occurrence of bigmouth shiners, creek chubs, common shiners, hornyhead chubs, and suckermouth minnows (Table 1). Although the frequency of occurrence of several species declined in downstream reaches, other cyprinids (e.g., creek chubs, central stonerollers) were more common following impoundment. Catostomids were common in all reaches after impoundment. Several species were introduced to the system following impoundment including gizzard shad, channel catfish, rainbow trout, smallmouth bass, and walleye.

Temporal trends in the fish assemblage were observed for a reach downstream from Grayrocks Reservoir (Fig. 4). Prior to construction of Grayrocks Reservoir in 1980, over 90% of the fish collected were native catostomids and cyprinids. One year after the reservoir was completed, brown trout, rainbow trout, and yellow perch were sampled in the reach. Walleyes were relatively abundant in the reach 5 years after impoundment, and smallmouth bass were first sampled 11 years after impoundment. Catostomids and cyprinids were common in the reach after impoundment, but brassy minnows, common shiners, fathead minnows, longnose dace, and longnose suckers were not collected after 1981.

DISCUSSION

The most notable change in the fish assemblage upstream of Grayrocks Reservoir was

TABLE 1. Number of reaches where each species was sampled upstream and downstream of Grayrocks Reservoir, Wyoming. Reaches were sampled before and after completion of the reservoir in 1980.

		Same reaches				Additional reaches	
		Upstream ($N = 7$)		Downstream ($N = 3$)		Upstream ($N = 4$)	Downstream ($N = 8$)
Common name	Scientific name	Before	After	Before	After	After	After
Native species							
CYPRINIDAE							
Brassy minnow	*Hybognathus hankinsoni*	1	2	0	1	1	0
Bigmouth shiner	*Notropis dorsalis*	4	2	1	0	3	2
Central stoneroller	*Campostoma anomalum*	1	2	1	3	2	3
Creek chub	*Semotilus atromaculatus*	5	3	1	3	2	3
Common shiner	*Luxilus cornutus*	4	1	2	1	1	2
Fathead minnow	*Pimephales promelas*	3	4	3	3	2	3
Hornyhead chub	*Nocomis biguttatus*	3	1	1	0	0	0
Longnose dace	*Rhinichthys cataractae*	2	2	3	3	4	1
Red shiner	*Cyprinella lutrensis*	2	1	3	2	3	4
Sand shiner	*Notropis stramineus*	4	3	3	2	3	1
Suckermouth minnow	*Phenacobius mirabilis*	1	0	2	0	0	1
CATOSTOMIDAE							
Longnose sucker	*Catostomus catostomus*	1	1	2	2	3	3
Quillback	*Carpiodes cyprinus*	1	1	1	1	0	2
River carpsucker	*Carpiodes carpio*	1	0	0	0	0	0
Shorthead redhorse	*Moxostoma macrolepidotum*	2	2	1	2	0	5
White sucker	*Catostomus commersoni*	4	4	2	3	4	8
ICTALURIDAE							
Channel catfish	*Ictalurus punctatus*	0	2	0	2	1	3
Stonecat	*Noturus flavus*	1	1	2	2	1	0
FUNDULIDAE							
Plains killifish	*Fundulus zebrinus*	1	1	0	1	1	0
Plains topminnow	*Fundulus sciadicus*	1	1	0	0	0	0
PERCIDAE							
Iowa darter	*Etheostoma exile*	1	0	0	0	0	1
Johnny darter	*Etheostoma nigrum*	2	2	0	0	3	4

TABLE 1. Continued.

		Same reaches				Additional reaches	
		Upstream ($N = 7$)		Downstream ($N = 3$)		Upstream ($N = 4$)	Downstream ($N = 8$)
Common name	Scientific name	Before	After	Before	After	After	After
Piscivorous exotic species							
SALMONIDAE							
Brown trout	*Salmo trutta*	0	2	0	2	1	2
Rainbow trout	*Oncorhynchus mykiss*	0	0	0	1	0	1
CENTRARCHIDAE							
Green sunfish	*Lepomis cyanellus*	2	4	0	3	2	3
Smallmouth bass	*Micropterus dolomieu*	0	0	0	3	0	5
PERCIDAE							
Walleye	*Sander vitreus*	0	0	0	2	0	1
Yellow perch	*Perca flavescens*	0	1	1	2	0	5
Non-piscivorous exotic species							
CLUPEIDAE							
Gizzard shad	*Dorosoma cepedianum*	0	1	0	0	0	0
CYPRINIDAE							
Common carp	*Cyprinus carpio*	3	4	2	3	2	7

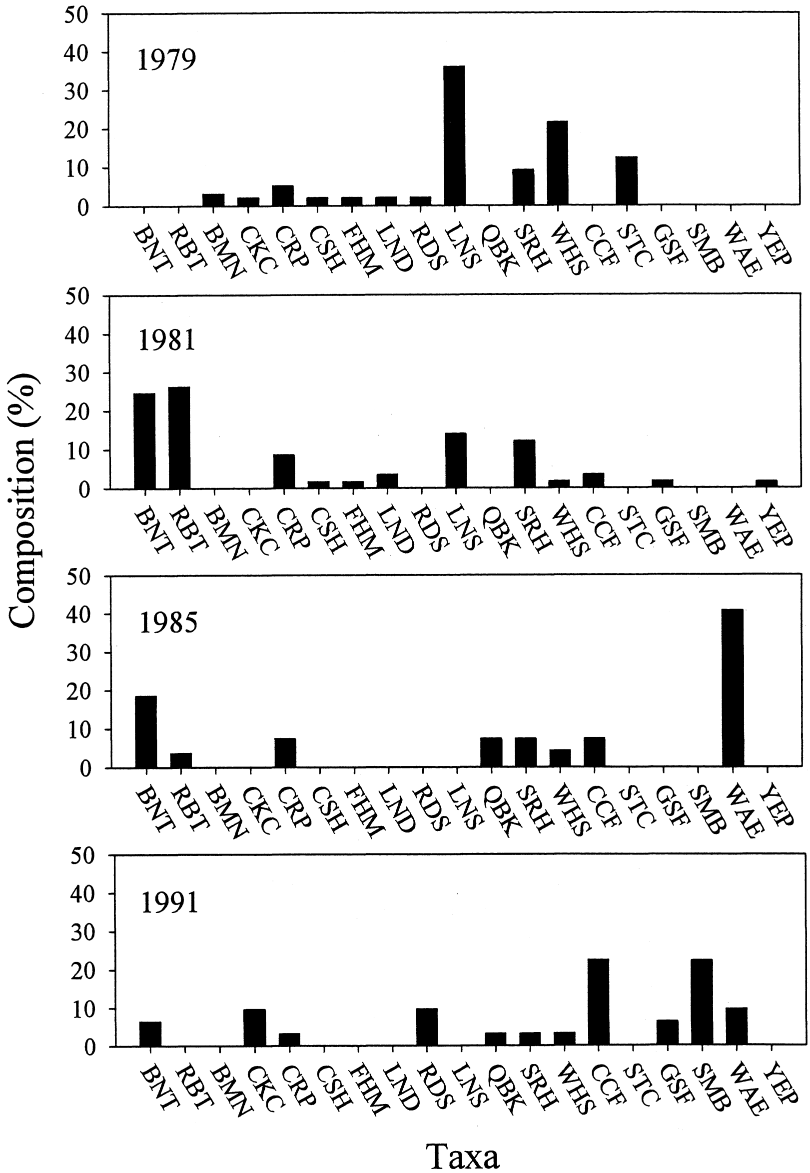

Fig. 4. Composition of species (BNT = brown trout, RBT = rainbow trout, BMN = brassy minnow, CKC = creek chub, CRP = common carp, CSH = common shiner, FHM = fathead minnow, LND = longnose dace, RDS = red shiner, LNS = longnose sucker, QBK = quillback, SRH = shorthead redhorse, WHS = white sucker, CCF = channel catfish, STC = stonecat, GSF = green sunfish, SMB = smallmouth bass, WAE = walleye, and YEP = yellow perch) sampled from a reach 8 km downstream of Grayrocks Reservoir on the Laramie River, Wyoming. Samples collected after 1980 represent post-impoundment fish assemblages.

the reduced frequency of occurrence or loss of native cyprinids and the occurrence of exotic piscivores after impoundment. Many introduced species are thought to be highly successful in reservoir systems because of the relatively stable lentic habitat and limited competition with other fishes (Moyle 1986). Gido et al. (2002) suggested that Tuttle Creek Reservoir, an impoundment on the Big Blue River, Kansas, has served as a source for the dispersal and subsequent establishment of introduced species to upstream reaches. Although Gido et al. (2002)

found that only a single species, speckled chub (*Macrhybopsis aestivalis*), had been extirpated upstream of Tuttle Creek Reservoir, other studies have reported substantial changes in upstream fish assemblages resulting from impoundment and introduction of exotic species. Taylor et al. (2001) reported that the fish assemblage in an Illinois stream upstream from a reservoir shifted from a cyprinid-dominated to a centrarchid-dominated assemblage following impoundment. Winston et al. (1991) reported similar results wherein the construction of a small impoundment on an Oklahoma stream resulted in the extirpation of native cyprinids from upstream reaches. The decline or extirpation of species upstream from reservoirs could be due to a variety of mechanisms, including the inability of fish to move to downstream refuge areas during environmental stress, predation by introduced piscivores that move upstream from the reservoir, predation on eggs and larvae that drift into the reservoir, or disruption of recolonization dynamics from downstream source populations (Winston et al. 1991, Luttrell et al. 1999).

We did not determine the specific mechanism for changes in fish assemblage structure upstream of Grayrocks Reservoir, but the presence of exotic piscivores may explain some of the observed trends. For example, several species such as suckermouth minnows, hornyhead chubs, and common shiners are known to be sensitive to biotic interactions (Baxter and Stone 1995, Pflieger 1997) and are now absent or rare in upstream reaches. In addition, invasive species in reaches upstream of Grayrocks Reservoir (i.e., green sunfish, yellow perch, brown trout) have been shown to be important predators when introduced to new systems (Tabor and Wurtsbaugh 1991, Winston et al. 1991, Johnson and Hines 1999). For instance, Lohr and Fausch (1996) reported that introduced green sunfish have had a negative influence on stream fish assemblages in the Great Plains region of Colorado. Green sunfish were present in a few upstream reaches prior to construction of Grayrocks Reservoir, but were more frequent following completion of the reservoir.

The effect of Grayrocks Reservoir on downstream habitat has been substantial. Before settlement by Europeans, downstream reaches of the Laramie River were shallow and braided, and side-channel and backwater habitats were abundant (Patton and Hubert 1993, Baxter and Stone 1995). Patton and Hubert (1993) found that regulated, sediment-free flows from Grayrocks Reservoir have resulted in an incised channel (approximately 1.5 m), a dominance of run habitat, reduced availability of side-channel and backwater habitats, and reduced fine substrate. Not only are the habitat changes (i.e., stable substrate and flows) conducive to the establishment of exotic species, but the reservoir also provides a continual source of exotic species to reaches downstream of the reservoir. The direct effect of exotic species on native fish assemblages is unknown, but their role as predators, especially smallmouth bass and walleye, on fish assemblages downstream of impoundments has been well documented throughout the western United States (e.g., McMahon and Bennett 1996). In addition to providing suitable habitat for exotic species, habitat changes associated with impoundments may be beneficial for some native species. For example, catostomids and central stonerollers were more common in downstream reaches following reservoir construction. Because these species are most common in run habitats with large substrate (Aadland 1993, Pflieger 1997), their increased frequencies of occurrence are likely due to reduced fine sediment transport and regulated flows (i.e., larger substrate, increased run habitat).

Despite changes in habitat for most of the Laramie River downstream of Grayrocks Reservoir, the lower Laramie River near its confluence with the North Platte River maintains some of its historical characteristics, having a shallow, braided channel with sand and gravel substrate (Patton and Hubert 1993). Exotic species are generally absent from this lower segment, and this is the only downstream area where suckermouth minnows, bigmouth shiners, and hornyhead chubs have been collected recently. Therefore, downstream reaches that retain some historical habitat characteristics may "reset" ecological conditions (Bain et al. 1988, Stanford et al. 1996) and provide a refuge for native species sensitive to biotic interactions with exotic species.

Prior to settlement by Europeans, rivers and streams in the Great Plains were not only frequently intermittent, with extreme fluctuations in flow, temperature, and dissolved oxygen, but they also had a heterogeneous channel morphology with dynamic substrate characteristics (Matthews 1988, Fausch and Bestgen 1997). Because many species were unable to tolerate the harsh environmental conditions or could not reproduce due to the shifting substrate (e.g., nest-building centrarchids), fish assemblages were depauperate and had little or no history of co-occurrence with piscivores (Fausch and Bestgen 1997). Reservoirs have changed habitat characteristics in downstream reaches such that exotic species are able to survive, and the reservoirs provide a continual source of exotic species to upstream and downstream reaches, even if these species cannot maintain naturalized populations.

Understanding the mechanism responsible (i.e., physical habitat alterations or biotic interactions) for changes in native fish assemblages is difficult. Regardless, our results suggest that fish assemblage structure has changed in the Laramie River following construction of Grayrocks Reservoir. Compared to other reservoirs in the Great Plains, Grayrocks Reservoir is relatively new, but changes in the fish assemblage upstream and downstream of the reservoir are evident. The long-term effects on fish assemblage structure are unknown; thus, continued monitoring of this system is important to better understand the effects of stream impoundment in the western Great Plains and to develop strategies for managing stream fish assemblages.

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