DISPERSAL OF NONNATIVE FISHES AND PARASITES IN THE INTERMITTENT LITTLE COLORADO RIVER, ARIZONA

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ABSTRACT—We sampled nonnative fishes stranded in isolated pools near Grand Falls in the Little Colorado River (LCR), Arizona, after the river ceased flowing (21 June and 12 July 2005) to evaluate whether nonnative fishes can invade the perennial, lower 21 km of the LCR from upriver sources. The encroachment of nonnative fishes could jeopardize resident populations of endangered humpback chub, *Gila cypha*, and other native fishes in the lower LCR. We captured red shiner, *Cyprinella lutrensis*; common carp, *Cyprinus carpio*; fathead minnow, *Pimephales promelas*; black bullhead, *Ameiurus melas*; and plains killifish, *Fundulus zebrinus*, all of which have been captured >132 km downriver in the lower LCR and >127 km upriver in the closest perennial sources. Moreover, we detected Asian tapeworm, *Bothriocephalus acheilognathi*, in 9 of 30 common carp examined. Our findings suggest that nonnative fishes, including those hosting parasites, can invade the lower LCR from upriver sources >250 km away during freshets and provide a mechanism for the dispersal of invasive aquatic species in intermittent river systems.

RESUMEN—Muestreamos peces no nativos atrapados en cuerpos de agua aislados cerca de Grand Falls en el Little Colorado River (LCR), Arizona, después de que cesó la corriente (21 de junio y 12 de julio 2005) para determinar si peces no nativos son capaces de invadir desde la parte alta del río hasta los 21 km bajos perennes del LCR. La invasión de peces no nativos puede perjudicar poblaciones locales del charalito (*Gila cypha*), y otros peces nativos en la parte baja del LCR. Capturamos sardinita roja, *Cyprinella lutrensis*, carpa común (*Cyprinus carpio*), carpita cabezona (*Pimephales promelas*), bagre torito negro (*Ameiurus melas*) y sardinilla de las planicies (*Fundulus zebrinus*), los cuales han sido capturados >132 km más abajo en la parte baja del LCR y >127 km más arriba en las fuentes de agua perennes más cercanas. Por otra parte, detectamos el cestodo asiático, *Bothriocephalus acheilognathi*, en 9 de 30 carpas comunes examinadas. Nuestros hallazgos sugieren que peces no nativos, incluyendo aquellos que mantienen parásitos, pueden invadir la parte baja del LCR desde las partes altas >250 km de distancia durante crecimientos de corriente y proporcionan un mecanismo para la dispersión de especies acuáticas invasoras en sistemas intermitentes de ríos.

The largest population of endangered humpback chub, *Gila cypha*, inhabits the Colorado River below Glen Canyon Dam within Grand Canyon National Park and the lower Little Colorado River (LCR) on Navajo tribal lands, Arizona (U. S. Fish and Wildlife Service, 1990; Douglas and Marsh, 1996; Fig. 1). Presently, adults from both rivers spawn and their progenies grow and recruit primarily within the warm LCR (Kaeding and Zimmerman, 1983; Gorman and Stone, 1999). The LCR was once perennial, but now only flows intermittently throughout most of its 573-km corridor (Colton, 1937; Miller, 1961) and is subject to episodic floods

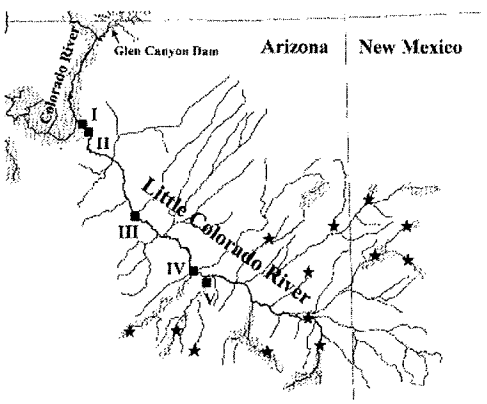

FIG. 1—The Little Colorado River (LCR) basin in Arizona and New Mexico: I) Chute Falls, a barrier to upriver fish migrations; II) beginning of perennial, lower corridor of the LCR; III) Grand Falls, the area surveyed for stranded fishes; and IV) Clear Creek Reservoir and V) lower Chevelon Creek, both likely sources of nonnative fishes displaced downriver. Stars denote some reservoirs that contain nonnative fishes and commonly spill into the LCR Basin. Shading denotes perennial stream reaches.

after spring thaws and summer rains that drain the 69,870-km^2 river basin (Johnson, 1975). Perennial flows are maintained in the lower 21 km by spring discharges that cumulatively result in a mean baseflow of 6.3 m^3/s near the mouth (Cooley, 1976).

Native fishes have numerically dominated 2 distinct lower LCR fish communities at least since 1980. These communities are separated by Chute Falls, a large travertine dam located 14 km upriver of the mouth that obstructs fish from moving further upstream (Kaeding and Zimmerman, 1983; Robinson et al., 1996; Fig. 1). Below Chute Falls, humpback chub are typically most common, followed by speckled dace (*Rhinichthys osculus*), bluehead sucker (*Catostomus discobolus*), and flannelmouth sucker (*C. latipinnis*) (Kaeding and Zimmerman, 1983; Stone and Gorman, 2006). Above Chute Falls, speckled dace are ubiquitous and were the only native fish captured (Kaeding and Zimmerman, 1983; Mattes, 1993) before young-of-the-year (YOY) humpback chub were translocated above the falls on 1 August 2003 to extend the range of this species (DMS, pers. observ.). However, 9 nonnative fish species have been captured both above and below Chute Falls (Table 1). Some of these nonnative fishes are rarely captured (e.g., green sunfish, *Lepomis cyanellus*), others are captured in seasonal, cyclical patterns (e.g., red shiner, *Cyprinella lutrensis*), and some might have become permanently established (e.g., channel catfish, *Ictalurus punctatus*). Concerns have been raised over the potential detrimental impacts to humpback chub and other native fishes by nonnative fishes resulting from piscivory, oophagy, resource competition, and introductions of parasites (Kaeding and Zimmerman, 1983; Marsh and Douglas, 1997; Oberlin et al., 1999; Heckmann, 2000; Choudhury et al., 2004).

The source of nonnative fishes in the lower LCR is unresolved. This remote area has never been stocked, and recreational fishing, especially using live fish for bait, has been prohibited for decades. Nonnative fishes can enter the mouth of the LCR from the Colorado River (Fig. 1). However, most nonnative fishes captured in the LCR are warm-water species, and the Colorado River was converted into a cold-water, rainbow trout (*Oncorhynchus mykiss*) dominated system following the closure of Glen Canyon Dam in 1963 (Minckley, 1991). Moreover, if Chute Falls imposes a physical barrier to upriver fish migrations, then the Colorado River cannot be the source for nonnative species captured above the falls. We hypothesize that many of these nonnative species might invade the lower LCR from various upriver water sources during freshets. Determining sources of nonnative fishes that enter the lower LCR is critical to the development of appropriate remedial actions to control nonnative encroachment and associated parasite introductions into the lower LCR.

To examine whether nonnative fishes and their parasites can migrate into the lower LCR from upriver locations during freshets, we surveyed for fishes stranded in isolated pools located within 1 km above and below Grand Falls after the river ceased flowing (Figs. 1, 2a-d). Grand Falls is located on Navajo tribal lands about 132 km above the perennial, lower 21-km of the LCR, and about 127 km below Clear Creek Reservoir and about 141 km below Chevelon Creek, presumably, the closest permanent sources of nonnative fishes (Fig. 2e, 2f). Grand Falls (56.4 m) is even higher than Niagara Falls (53.6 m) and, therefore, obstructs all fishes from moving upriver but not downriver (Colton, 1930). This area has never been stocked, and even the deepest pools have occasionally become totally dry during intervening droughts over the

TABLE 1—Native and nonnative fishes caught in the Little Colorado River (LCR) basin, Arizona since 1993. Survey locations include: 1) below and above Chute Falls (14 km above mouth) in the perennial, lower 21-km LCR corridor; 2) pools sampled just below and above Grand Falls on the 21 June and 12 July 2005, respectively, in the intermittent LCR corridor (about 132 km upriver of perennial, lower corridor); 3) near Winslow, Arizona in (a) Clear Creek Reservoir and (b) lower Chevelon Creek (about 127 km and about 141 km upriver of Grand Falls, respectively); and 4) in all other areas of the LCR watershed. The numbers of fishes captured are given for Grand Falls surveys, and an X denotes fish presence in other areas. Species protected under the U. S. Endangered Species Act (E = endangered, T = threatened, and C = candidate for listing) and sportfishes (S) are superscripted. Information was compiled from U. S. Fish and Wildlife Service, Navajo Fish and Wildlife Department, and Arizona Game and Fish Department unpublished stocking and survey data files and reports.

	Chute Falls		Grand Falls		Winslow	Other
Families and species	below	above	below	above	area	areas
Native fishes						
Cyprinidae						
Gila cypha, humpback chub [E]	X	X[1]				
G. robusta, roundtail chub [S]						X
Lepidomeda vittata, Little Colorado spinedace [T]					X (b)	X
Rhinichthys osculus, speckled dace	X	X			X (b)	X
Catostomidae						
Catostomus discobolus, bluehead sucker	X				X (b)	X
C. discobolus yarrowi, Zuni bluehead sucker [C]						X
C. latipinnis, flannelmouth sucker	X				X (a, b)[2]	X[2]
Salmonidae						
Oncorhynchus apache, Apache trout [T, S]						X
Nonnative fishes						
Clupeidae						
Dorosoma petenense, threadfin shad						X
Cyprinidae						
Carassius auratus, goldfish						X
Cyprinella lutrensis, red shiner	X	X	1		X (b)	X
Cyprinus carpio, common carp [S]	X	X	71	~500	X (a, b)	X
Notemigonus crysoleucas, golden shiner					X (a, b)	X
Pimephales promelas, fathead minnow	X	X	3	~100	X (b)	X
Ictaluridae						
Ameiurus melas, black bullhead [S]	X	X		1	X (a, b)	X
A. natalis, yellow bullhead [S]	X	X			X (b)	X
Ictalurus punctatus, channel catfish [S]	X	X			X (a, b)	X
Esocidae						
Esox lucius, northern pike [S]						X
Salmonidae						
Oncorhynchus clarki, cutthroat trout [S]						X
O. mykiss, rainbow trout [S]	X	X			X (a)	X
Salmo trutta, brown trout [S]						X
Salvelinus fontinalis, brook trout [S]						X
Thymallus arcticus, Arctic grayling [S]						X
Poeciliidae						
Gambusia affinis, western mosquitofish						X
Cyprinodontidae						
Fundulus zebrinus, plains killifish	X	X		6	X (b)	X
Centrarchidae						
Ambloplites rupestris, rock bass [S]					X (a)	X
Lepomis cyanellus, green sunfish [S]	X	X			X (a, b)	X
L. macrochirus, bluegill [S]					X (a)	X
Micropterus dolomieu, smallmouth bass [S]						X
M. salmoides, largemouth bass [S]					X (a, b)	X

TABLE 1—Continued.

Families and species	Chute Falls below	Chute Falls above	Grand Falls below	Grand Falls above	Winslow area	Other areas
Pomoxis nigromaculatus, black crappie [S]						X
Percidae						
Perca flavescens, yellow perch [S]						X
Sander vitreus, walleye [S]						X

[1] Humpback chubs were only captured after being translocated on 1 August 2003.

[2] Proposed as distinct from flannelmouth sucker and commonly referred to as the Little Colorado sucker (Minckley, 1973).

past 50 y (G. G. Fisk, U. S. Geological Survey, pers. comm.). Therefore, fishes above Grand Falls (or their parents) likely originated >127 km upriver, which is presumably also the case for fishes below Grand Falls, because upriver fish migrations from the perennial, lower LCR are obstructed by Chute Falls. We sampled for fishes in 2 pools below Grand Falls on 21 June 2005 with hoop nets, and in 3 clay-bottomed pools above Grand Falls on 12 July 2005 by seining. Thirty young-of-year (YOY) common carp (*Cyprinus carpio*) from above Grand Falls were retained and later examined for Asian tapeworm, *Bothriocephalus acheilognathi*. We identified all fish to species and measured representative samples for total length (TL).

We captured 5 fish species in pools at Grand Falls (Table 1). Only fathead minnows, *Pimephales promelas* (range = 18 to 71 mm TL, n = 42), and YOY common carp (23 to 65 mm TL, n = 101) were captured both above and below Grand Falls. We also captured an adult red shiner (62 mm TL) below Grand Falls and a black bullhead, *Ameiurus melas* (168 mm TL), and 6 plains killifish, *Fundulus zebrinus* (40 to 65 mm TL), above Grand Falls. Whereas seine samples provided a relatively complete inventory of fishes in the pools above Grand Falls, the hoop net samples provided only a glimpse of the actual age structure and species composition of fishes in the pools below Grand Falls. For example, we also observed another red shiner, multiple schools of unidentifiable fish, and 2 fairly large fish (>230 mm TL) jump out of the water and found the skeletal remains of a large-bodied fish (>400 mm TL) on the bank. Historically, Miller (1963) collected common carp, channel catfish, yellow bullhead (*Ameiurus natalis*), plains killifish, and green sunfish in the isolated plunge pools below Grand Falls on 13 June 1959, but these pools have occasionally dried since that survey. There were also other pools above and below Grand Falls that we did not sample, but in which we could see fish. Nine of the 30 YOY common carp examined (30%) were infected with Asian tapeworm, which extends the known distribution of this deleterious parasite into the upper LCR watershed.

Our findings suggest a mechanism allowing nonnative fishes and their parasites to invade the lower LCR from upriver locations during freshets. Any reservoir, tributary, stock tank, or other water source that contains nonnative fishes and occasionally spills into the LCR drainage is a potential source. Some of the nonnative fishes residing at Grand Falls, or at least their parents, probably originated in Clear Creek Reservoir and lower Chevelon Creek, which both flow into the LCR (Fig. 2e, 2f) and contain all 5 nonnative fishes we caught at Grand Falls (8 nonnatives with collections by Miller, 1963) and all 9 nonnative species historically captured in the lower LCR (Table 1). If these fishes had successfully moved >127 km downriver to Grand Falls, then some individuals might likewise migrate another 132 km to the perennial, lower LCR with ensuing freshets (e.g., Figs. 1, 2a). Conceivably, fishes drifting downstream in the main current can travel from Clear Creek to the perennial, lower LCR in about 4 d (about 260 km) during a 28.3-m^3/s freshet (D. J. Topping, U. S. Geological Survey, pers. comm.); however, many fishes probably linger in the intermittent corridor and become stranded when the LCR stops flowing. After flows cease, pools containing displaced fishes are likely scattered throughout the intermittent corridor. During extremely hot, drought years, most pools can desiccate or become thermally-chemically unsuitable for fish survival (Chapman and Kramer, 1991; G. G. Fisk,

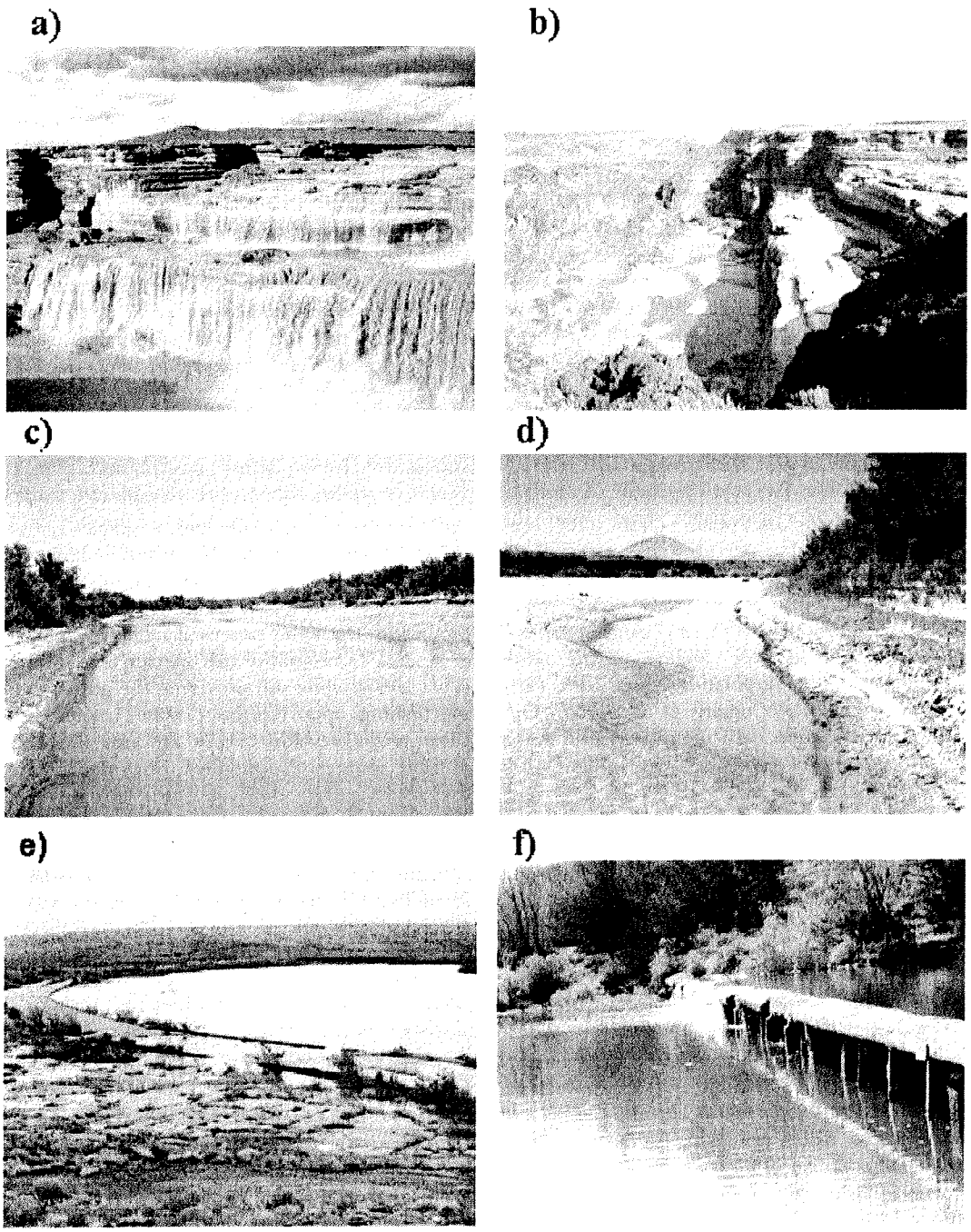

FIG. 2—Photographs of a) Grand Falls in the Little Colorado River (LCR), Arizona, flowing on 19 February 2005; b) pools sampled for nonnative fishes below Grand Falls on 21 June 2005; c) a clay-bottomed pool above Grand Falls on 21 June 2005 and d) on 12 July 2005 (when seined); and e) Clear Creek Reservoir on 11 August 2005 and f) lower Chevelon Creek on 21 February 2006 spilling water (and likely nonnative fishes) to the LCR corridor.

pers. comm.), while in cooler, monsoonal years, many pools likely contain sufficient depth and water quality to allow fish to survive, even spawn, until ensuing freshets allow for further downriver migrations (Matthews and Hill, 1977; Ostrand and Wilde, 2004).

Nonnative fishes have introduced at least 10 new parasite species into the lower LCR fish assemblage (Choudhury et al., 2004). Most of these parasites are species specific and not currently a major concern. However, Asian tapeworm, which was first documented in the lower LCR in 1990 (Minckley, 1996), has been found in all lower LCR fish species in varying degrees of infestation, with a clear predilection for cyprinids, especially humpback chub (Choudhury et al., 2004), and can cause high fish mortality in new host species (Hoffman and Schubert, 1984; Heckmann, 2000). Asian tapeworm parasitizes humpback chub after they consume infected copepods (i.e., intermediate hosts; Choudhury et al., 2004) and other fishes via postcyclic transmission (Stone and Gorman, 2006; Hansen et al., 2007), and likely contributed to the 30 to 60% decline of the adult humpback chub population since the early 1990s estimated by Coggins et al. (2006). Our finding of common carp parasitized with Asian tapeworm above Grand Falls, coupled with Choudhury et al. (2004) documenting Asian tapeworm (and other parasites) above Chute Falls, provide evidence that this parasite has and will continue to invade the lower LCR from the upper watershed. Moreover, the common carp hosting Asian tapeworm above Grand Falls were likely infected in Clear Creek, Chevelon Creek, or both, suggesting that the resident native fishes (e.g., Little Colorado spinedace, *Lepidomeda vittata*) are likewise infected. Parasite studies and surveys must be implemented in the upper LCR watershed to delineate where Asian tapeworm (and other parasites) currently exists and what native fishes are being impacted before remedial actions can be considered.

Native fishes still numerically dominate the lower LCR fish community despite decades of encroachment by nonnative fishes (Miller, 1961, 1963; Kaeding and Zimmerman, 1983; Stone, 2005; Stone and Gorman, 2006). Presumably, LCR native fishes possess adaptations that make them more resilient to flash floods than nonnative fishes (Miller, 1946; Meffe, 1984; Minckley and Meffe, 1987). Thus, LCR floods might not only be instrumental in displacing nonnative fishes downriver into its perennial, lower corridor, but also in flushing them out of the LCR and into the Colorado River. Other physicochemical water properties, such as warm water temperatures, high salinity, conductivity, and dissolved carbon dioxide, likely curtail the colonization of some nonnative fishes in the lower LCR (e.g., cold-water trout; Kaeding and Zimmerman, 1983; Minckley, 1991). Conversely, some warm-water nonnative fishes have already become permanently established in the lower LCR, and other nonnative colonizers might eventually invade from the upper LCR watershed (Table 1, Fig. 1).

Many reservoirs, lakes, and stock tanks were built throughout the LCR basin and, along with perennial tributaries, haphazardly stocked with nonnative fishes before detrimental ramifications to native fishes were considered (Miller, 1961) and the U. S. Endangered Species Act of 1973 was enacted. Currently, resource managers of the LCR watershed are responsible for protecting 8 native fish species (4 are federally protected) from the potential negative impacts of at least 25 nonnative fish species (e.g., Moyle et al., 1986), while still providing the public with sportfishing opportunities (Table 1). Although Clear and Chevelon creeks are not the only possible sources of nonnative fishes that invade the lower LCR, they are probably leading contributors. However, these creeks and their tributaries also contain some of the largest concentrations of Little Colorado spinedace, flannelmouth sucker, bluehead sucker, roundtail chub (*Gila robusta*), and speckled dace existing in the upper watershed and could have historically contained Apache trout, *Oncorhynchus apache*, (Miller, 1972) and Zuni bluehead sucker, *C. discobolus yarrowi* (Propst et al., 2001). Therefore, we suggest that both Clear Creek and Chevelon Creek drainages be declared native fish sanctuaries, whereby perennial waters in these creeks, their tributaries, reservoirs, and even stock tanks are renovated with fish barriers, nonnative fishes eradicated, and native fishes reestablished. The historically established nonnative sportfisheries of multiple species could be transformed into premier native Apache trout and roundtail chub fisheries. Ultimately, this should drastically reduce the number of warm-water nonnative fishes (and their parasites) that invade the lower LCR and help secure the future existence of native fishes in the upper watershed.

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