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[Note]

Distribution and Movement of Humpback Chub in the Colorado River, Grand Canyon, Based on Recaptures

CRAIG P. PAUKERT,*[1] LEWIS G. COGGINS, JR., AND CHRISTOPHER E. FLACCUS

U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, 2255 North Gemini Drive, Flagstaff, Arizona 86001, USA

Abstract.—Mark–recapture data from the federally endangered humpback chub *Gila cypha* in the Colorado River, Grand Canyon, were analyzed from 1989 to 2002 to determine large-scale movement patterns and distribution. A total of 14,674 recaptures from 7,127 unique fish were documented; 87% of the recaptures occurred in the same main-stem river reach or tributary as the original captures, suggesting restricted distribution by most fish. A total of 99% of all recaptures were from in and around the Little Colorado River (LCR), a tributary of the Colorado River and primary aggregation and spawning location of humpback chub in Grand Canyon. Time at liberty averaged 394 d, but some fish were recaptured near their main-stem capture location over 10 years later. Proportionally fewer large (>300-mm) humpback chub exhibited restricted distribution than small (<200-mm) fish. However, several fish did move more than 154 km throughout Grand Canyon between capture and recapture, suggesting that limited movement occurs throughout Grand Canyon. The majority of the recaptured fish remained in or returned to the LCR or the Colorado River near the LCR. Although many large-river fishes exhibit extensive migrations to fulfill their life history requirements, most of the humpback chub in Grand Canyon appear to remain in or come back to the LCR and LCR confluence across multiple sizes and time scales. Detecting trends in the overall abundance of this endangered fish in Grand Canyon can probably be accomplished by monitoring the area in and around the LCR.

The humpback chub *Gila cypha* is a federally endangered species with only six remaining populations, the largest population located in the Little Colorado River (LCR) and Colorado River in Grand Canyon (Kaeding and Zimmerman 1983; USFWS 2002). Like many other big-river fishes in the southwestern United States, humpback chub populations are declining because predation, competition from nonnative fish, large-scale river regulation, or a combination thereof altered temperature and flow regimes (Minckley et al. 2003). Recent research on humpback chub has focused on population estimation and trends to meet recovery goals of the U.S. Fish and Wildlife Service (USFWS 2002; Coggins et al. 2006).

The LCR is the largest tributary to the Colorado River in Grand Canyon (Figure 1) and is the primary spawning location for humpback chub (Kaeding and Zimmerman 1983; Douglas and Marsh 1996), these fish inhabiting the lower 14.75 km. Recruitment of humpback chub likely does not occur (or is extremely limited) in the main-stem Colorado River because of cold water temperatures (Kaeding and Zimmerman 1983). Humpback chub from the main stem move into the LCR to spawn, some adults remaining in the LCR for extended periods of time other than spawning (Douglas and Marsh 1996; but see Gorman and Stone 1999; Coggins et al. 2006).

Humpback chub movement and distribution have been previously examined with more spatially or temporally limited data sets that recorded recaptures only in the LCR, its inflow, or both (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; Gorman and Stone 1999) or using telemetry with smaller sample sizes (Keading et al. 1990; Valdez and Hoffnagle 1999). In addition, these studies focused on short time frames (usually under 1 year or fewer seasons across 2 or fewer years). To our knowledge, no one has evaluated site fidelity over a long (>10-year) time period with sample sizes (>10,000 recaptures) as large as this study.

Large-river fishes typically migrate long distances, presumably to meet the life history requirements of adults such as spawning (e.g., Pellett et al. 1998; Paukert and Fisher 2001), and this also occurs in adult desert river fishes (Tyus 1991; Modde and Irving 1998). However, the scale at which distribution and movement is evaluated also affects how conservation and management measures are implemented (Fausch and Young 1995; Hay et al. 2001). Previous studies of endangered or threatened desert fishes in the southwestern United States have shown mixed results. Humpback chub show high fidelity (using short-term telemetry transmitters) in main-stem riverine populations (Keading et al. 1990; Valdez and Hoffnagle 1999), whereas bonytail *Gila elegans* have less fidelity during spawning (Keading et al. 1990). Colorado

* Corresponding author: cpaukert@ksu.edu
[1] Present address: U.S. Geological Survey, Kansas Cooperative Fish and Wildlife Research Unit, 205 Leasure Hall, Division of Biology, Kansas State University, Manhattan, Kansas 66506, USA.

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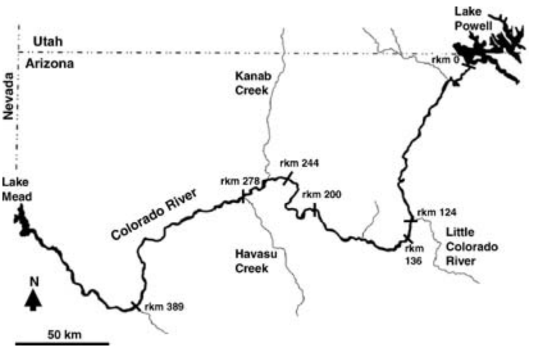

FIGURE 1.—Location of the Little Colorado River in relation to the Colorado River and Grand Canyon, Arizona. Sampling for humpback chub primarily occurs between the Paria River (rkm 27) and Diamond Creek (rkm 389).

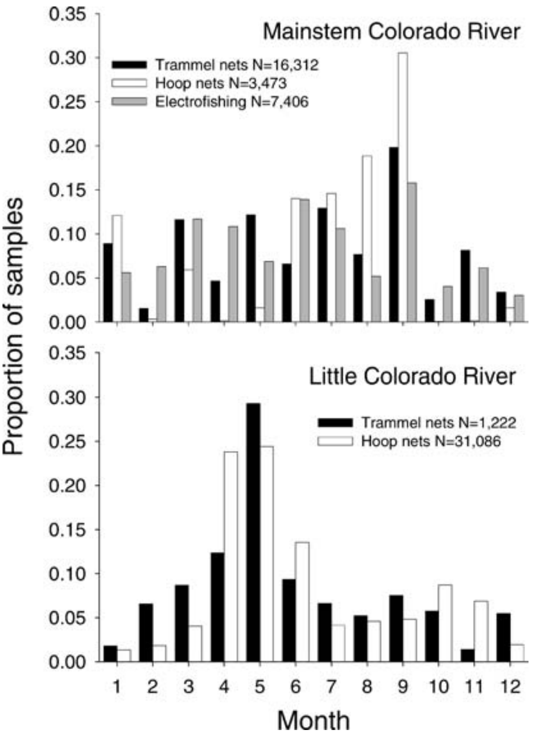

FIGURE 2.—Proportion of sampling effort by month (1 = January, etc.) for trammel nets (net sets), hoop nets (net sets), and electrofishing (stations) used to collect humpback chub in the main-stem Colorado River and Little Colorado River, May 1989 to October 2002.

pikeminnow *Ptychocheilus lucius* make substantial migrations during spawning (Tyus 1991; Irving and Modde 2000), whereas razorback sucker *Xyrauchen texanus* also migrate substantial distances but may use different spawning locations in different years (Modde and Irving 1998), emphasizing the need to evaluate distribution and movement over multiple years. Understanding the distribution and movement of humpback chub in Grand Canyon is needed before conservation and management strategies to recover this species can be fully evaluated.

The objective of this study was to summarize recaptures of passive integrated transponder (PIT)-tagged fish to determine the distribution and movement of humpback chub throughout Grand Canyon in all seasons. We wanted to determine if movement patterns and distribution differed by fish size or temporal scale, and if their distribution and movement was similar to that of other large-river fishes. Our study focused on the large-scale movement throughout Grand Canyon over a 12-year period as other studies have focused on the movement of fish within the LCR and within-year movements, including the spawning season (e.g., Kaeding and Zimmerman 1983; Douglas and Marsh 1996; Gorman and Stone 1999; Valdez and Hoffnagle 1999).

Methods

We used a long-term monitoring data set to determine the distribution and large-scale movement of humpback chub throughout 389 km of the Colorado River in Grand Canyon from the Paria River to Diamond Creek (Figure 1). Patterns in distribution and movement were evaluated to determine the extent of movement of humpback chub between the main-stem Colorado River and the tributaries (e.g., LCR). To minimize bias and pseudoreplication associated with fish recaptured immediately after capture, we used only recaptures that were at large at least 14 d between capture and recapture, which would minimize the effects of fish recaptured during the same multiday sampling events (typically 8–14 d) and would provide time for fish to allow movement among river reaches. The fish were separated into three categories by total length (average of length recorded at capture and recapture): less than 200 mm, 200–299 mm, and 300 mm or larger. The minimum size of adult humpback chub is about 200 mm (Meretsky et al. 2000; USFWS 2002).

Humpback chub were collected from 1989 to 2002 by a variety of gears in the main-stem Colorado River (e.g., trammel nets, hoop nets, and boat electrofishing), but primarily by hoop nets in the tributaries (Figure 2; Valdez and Ryel 1995; Gorman and Stone 1999; Coggins et al. 2006). Sampling effort was variable across seasons in the main-stem Colorado River and more focused during early spring in the Little Colorado River (Figure 2). Although variable, effort was substantial: over 7,000 electrofishing samples (typically 5-min stations) were collected in the main-stem Colorado River, and there were over 34,000 overnight hoop net sets in the main-stem Colorado River and LCR (Figure 2). For each fish, total length (mm) and capture location (usually to the nearest 0.1 river km) were recorded and a PIT tag was implanted in the abdominal cavity to serve as a unique fish identifier for fish larger than 150 mm total length. Each fish was then released near its capture location.

Captures and recaptures were recorded in seven main-stem Colorado River reaches that were determined based on geomorphology, logistics, and easily identifiable areas (Figure 1; Table 1). In addition, two tributaries (LCR and Havasu Creek) were also identified as reaches along with the inflow areas of these tributaries (e.g., main-stem Colorado River near the confluence of these tributaries). Restricted distribution was defined as recapture and previous capture location within the same river reach or tributary. Since other studies have suggested that the humpback chub population in the main-stem Colorado River within 12 km of the LCR (i.e., LCR inflow) is the same population (Douglas and Marsh 1996; Gorman and Stone 1999), we also analyzed distribution by combining the LCR inflow and the LCR as one river reach, thus creating six river reaches instead of seven. Logistic regression was used to determine if a size-group of fish was more likely to exhibit restricted distribution based on odds ratios (Stokes et al. 1995). Logistic regression was also used to determine if the proportion of fish that exhibited restricted distribution differed by time at liberty. In this analysis, time at liberty was separated into eight categories: 14–30 d, 31–90 d, 91–120 d, 121–365 d, 1–3 years, 3–5 five years, 5–10 years, and more than 10 years. An analysis of variance was used to determine if the mean distance between capture and recapture location (for fish that exhibited restricted distribution) differed by fish size and by river (i.e., main-stem Colorado River and the LCR) for three times between capture and recapture (14–90 d, 91–365 d, >365 d).

Results

A total of 14,674 recaptures of 7,127 unique fish were recorded in Grand Canyon from May 1989 to October 2002. Of the 7,127 unique fish, 3,322 (46%) were recaptured only once, whereas 219 (3%) were recaptured more than five times and one was recaptured 15 times. The mean number of days between captures was 394 (range = 14–4,713). However, 75% of the recaptures occurred in less than 404 d.

Of the 14,674 total recaptures, 12,868 (87.7%) were recaptured in the same tributary or area of the main-stem Colorado River (Table 1) and thus exhibited restricted distribution. For fish exhibiting a restricted distribution, the mean number of days between capture and recapture was 532 (range = 22–3,700) for the main-stem Colorado River, and 354 (range = 14–4,713) for the LCR. For fish not exhibiting a restricted distribution, the mean number of days between capture and recapture was 773 (range: 14–3,742) for the main-stem Colorado River and 515 (range = 14–3,808) for the LCR.

Of the total recaptures, 12,508 (85.2%) were captured and recaptured in the LCR, whereas an additional 241 (1.6%) were captured and recaptured in the main-stem Colorado River within 12 km of the LCR confluence (Table 1). When we considered the LCR and LCR inflow as one population, 14,526 (99.0%) of recaptures occurred in the LCR or the main stem near the LCR confluence and thus exhibited a restricted distribution to this reach. Although a high percentage of fish showed restricted distribution to the LCR and surrounding areas, there was evidence a few

TABLE 1.—Recaptures of humpback chub collected throughout the Colorado River in Grand Canyon, Arizona, 1989–2002. Values along the diagonal (bold italics) indicate that the capture and recapture locations were the same (i.e., site fidelity). Major tributaries are the Little Colorado River (LCR) and Havasu Creek; rkm = river kilometers. Values above the diagonal represent downstream movement, values below the diagonal upstream movement.

	Recapture location (rkm)									
Tag location (rkm)	0–117	124 (LCR)	117–136	136–199	199–201	201–227	227–244	278 (Havasu Creek)	244–389	Total recaptures
0–117	***26***	1								
124	1	***12,508***	868	5					4	
117–136		909	***241***	3		1	1			
136–199		2	1	***1***			1			
199–201		1			***8***					
201–227						***1***	1			
227–244						2	***77***			
278		1					1	***5***	1	
244–389									***2***	
										14,674

fish moved throughout Grand Canyon. Two fish moved to and from the main stem near rkm 72 and the LCR (rkm 124) within 1 year, and five fish moved to and from Havasu Creek (rkm 278) and the LCR with the period between capture and recapture (Table 1) ranging from 2 to 5 years.

Proportionally fewer large fish exhibited restricted distribution than small fish. Only 76.5% of fish 300 mm or larger exhibited restricted distribution compared with 93.5% of fish 200–299 mm, and 98.7% of fish smaller than 200 mm ($\chi^2 = 881$; df = 2; $P < 0.001$). Odds ratios revealed that small fish were 23 times more likely to exhibit a restricted distribution compared with large fish, and five times more likely compared with medium-sized fish. Of the fish that exhibited a restricted distribution, mean distance between capture and recapture was typically lower for smaller fish. Humpback chub 300 mm or larger had a longer displacement between capture and recapture in the main-stem Colorado River ($F = 4.39$; df = 2, 352; $P = 0.013$) and the LCR ($F = 396$, df = 2, 9,584, $P < 0.001$; Figure 3).

The percentage of fish exhibiting restricted distribution did differ by time at liberty ($\chi^2 = 592$; df = 7; $P < 0.0001$), but it was never less than 71% (for fish at liberty 5–10 years; $N = 666$). The percentage of fish exhibiting restricted distribution was greater than 90% for fish at liberty 14–30 d ($N = 1,554$), 31–90 d ($N = 3,283$, and more than 10 years ($N = 29$). When we considered the LCR and LCR inflow as one river reach, the proportion of fish that exhibited restricted distribution increased to 100% for fish at liberty 14–30 d, 31–90 d, and more than 5 years, and never was below 99.3%.

Discussion

Humpback chub showed restricted distribution within the Colorado River in Grand Canyon regardless of the spatial and temporal scale analyzed. Previous studies at shorter temporal scales demonstrated that humpback chub may remain in the same areas during spawning (Douglas and Marsh 1996; Gorman and Stone 1999), and other studies have suggested that this may occur annually as well (Keading et al. 1990; Valdez and Ryel 1995; Gorman and Stone 1999). Other large-river fishes have also shown substantial migrations to the same areas (Pellett et al. 1998; Stancill et al. 2002) and it has been suggested that this may not differ even to 5 years (Hay et al. 2001). Our study even found that fish at liberty over 10 (main-stem Colorado River) to 12 (LCR) years were recaptured near their same capture location. Other southwestern desert fishes (e.g., Colorado pikeminnow) have shown substantial migrations and a fidelity to spawning locations across long (up to 10-year) temporal scales (Tyus 1991), but others (e.g., razorback suckers) may move among several spawning locations over 3 years (Modde and Irving 1998), suggesting that some fish may not imprint to specific spawning locations.

We could not confirm that all fish exhibiting restricted distribution remained in the same area between capture and recapture. Localized movements of adult humpback chub within the LCR have been documented (Douglas and Marsh 1996; Gorman and Stone 1999), and some of these fish may remain in the LCR all year (Douglas and Marsh 1996). However, these resident LCR fish were typically smaller than 300 mm (Gorman and Stone 1999), likely explaining why this study found increased fidelity of small (<200-mm) fish.

Our study suggests that the most movement between rivers occurred at the confluence area (LCR inflow) of the LCR and main-stem Colorado River. This is not unusual, and it has been suggested that these fish are part of the same population (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; Valdez and Hoffnagle 1999; Meretsky et al. 2000). However, there were a few humpback chub that moved at least 52 km upstream and 154 km downstream of the LCR confluence, suggesting that the LCR population does extend to a large part of the Colorado River and that limited movement may occur throughout Grand Canyon.

Scale can have important influences on the management and conservation of fishes (Fausch and Young 1995; Hay et al. 2001). Since short-term tagging studies may miss important information relating to distribution and movement (Hay et al. 2001), a longer term evaluation of tag recaptures is necessary for a more complete understanding of distribution and movement in fishes. Our study involved 12 years of recaptures of over 7,000 individual fish. The determination of whether fish remained in the same area throughout the year or returned to the same area could not be evaluated in this study. However, the larger temporal scale suggests that restricted movement exists over longer periods of time. Distribution and movement of humpback chub in Grand Canyon appear to be primarily restricted to the LCR and LCR inflow area and is in contrast to other southwestern river fishes that may move long distances to meet their life history requirements.

There appears to be little to no humpback chub reproduction or recruitment occurring in the main-stem Colorado River, probably because of the regulated, stenothermic environment, the invasion by nonnatives in the main stem (Clarkson and Childs 2000), and the fact that the humpback chub population in Grand Canyon is focused in and around the LCR. Management and monitoring of the humpback chub population

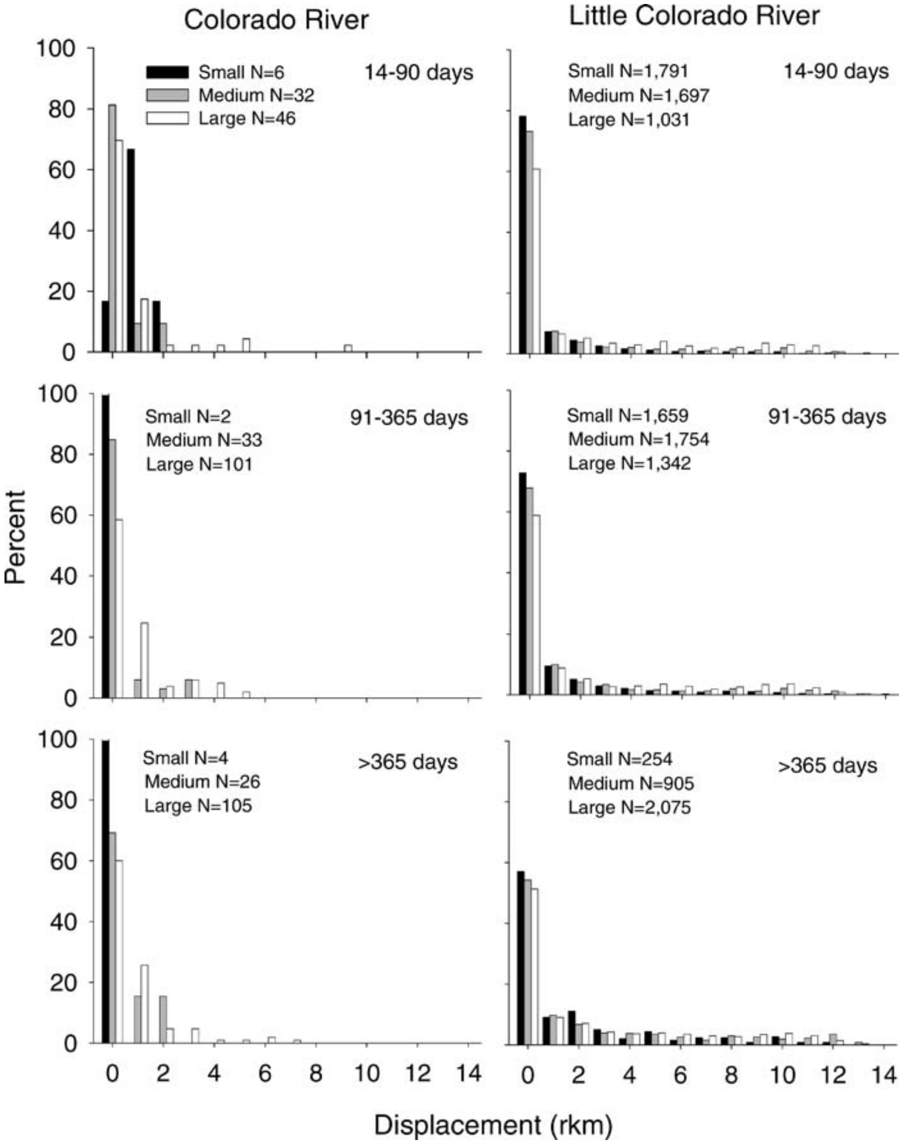

FIGURE 3.—Displacement between capture and recapture for three sizes of fish that exhibited restricted distribution in the Colorado River and its tributaries, Arizona, at three different temporal scales: 14–90 d, 91–365 d, and more than 365 d. Sizes of fish were based on the mean lengths of the fish between the capture and recapture periods and were classified as small (<200 mm), medium (200–299 mm), and large (≥300 mm).

in Grand Canyon may be most logistically feasible on a smaller scale that focuses on the LCR and its confluence with the Colorado River. Researchers need to choose the optimum sampling methodology to accomplish their goals given reduced numbers of endangered species, limited funds, and logistical constraints (Tate et al. 2003). Although main-stem Colorado River monitoring of humpback chub may be needed to meet specific objectives (e.g., influence of increased main-stem water temperature in the Colorado River; Petersen and Paukert 2005), the trends in the overall abundance of humpback chub in Grand Canyon may be accomplished by focusing efforts in the LCR.

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