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Factors Affecting Condition of Flannelmouth Suckers in the Colorado River, Grand Canyon, Arizona

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Abstract.—The impoundment of the Colorado River by Glen Canyon Dam, Arizona, in 1963 created a highly regulated environment in the Grand Canyon that altered the native fish populations, including the flannelmouth sucker *Catostomus latipinnis*. Flannelmouth suckers were sampled from 1991 to 2001 to determine seasonal, annual, and spatial trends in fish condition (i.e., relative weight [W_r]). Mean W_r peaked during the prespawn and spawning periods and was lowest in summer and fall, but it was never lower than 93. Condition was variable throughout the Grand Canyon but was typically greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased number of warmwater tributaries in this reach. Flannelmouth sucker condition in September was positively correlated with Glen Canyon Dam discharge during summer (June–August); this result may be due to the larger euphotic zone and greater macroinvertebrate abundance observed during higher water flows. Increased dam discharge that stimulates river productivity may provide benefits for this native fish.

The Colorado River in the Grand Canyon historically had eight endemic fishes (Minckley 1991), of which three are now extirpated (Colorado pikeminnow *Ptychocheilus lucius*, bonytail *Gila elegans*, and roundtail chub *Gila robusta*) and two are federally endangered (humpback chub *Gila cypha* and razorback sucker *Xyrauchen texanus*). The flannelmouth sucker *Catostomus latipinnis*, also endemic to the Colorado River, is relatively common in the Grand Canyon compared to other native fishes (Minckley 1991).

Although previous research has suggested that the Grand Canyon population of flannelmouth suckers is relatively stable (Douglas and Marsh 1998), there is concern that recruitment may be declining because of the effects of lower water temperature caused by hypolimnetic releases from Glen Canyon Dam (Weiss et al. 1998; Clarkson and Childs 2000; Ward et al. 2002), loss of suitable rearing habitat (Thieme et al. 2001), blockage of spawning migrations (Chart and Bergersen 1992; McKinney et al. 1999), and predation (Ward et al. 2002). Therefore, continued monitoring of flannelmouth sucker populations is needed to assess changes in the status of this native fish.

Fish body condition is a common fisheries assessment tool. Measures of fish condition have been linked to general fish health (Coughlan et al. 1996), fat and lipid content (e.g., Neumann and Murphy 1992), prey availability (e.g., Paukert and Willis 2003), reproductive potential (e.g., Neumann and Murphy 1992), and environmental conditions (e.g., productivity [DiCenzio et al. 1995] and water level fluctuations [Johnson et al. 1992]). In general, higher condition is associated with higher energy (fat) content, increased food base or reproductive potential, or more favorable environmental conditions.

Our objectives were to evaluate long-term (>10 years) temporal and spatial trends in flannelmouth sucker condition and to evaluate the biotic and abiotic relationships that might influence condition. The goal of the study was to assess condition on a large scale (i.e., canyonwide) to aid in the evaluation of trends in the flannelmouth sucker population in the Colorado River system.

Study Area

The study area encompassed the Colorado River from river kilometer (RKM) 26 (the Paria River

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inflow) below Glen Canyon Dam (near the Arizona–Utah border and considered RKM 0.0) downstream to Diamond Creek at RKM 363.2. The study area is strongly influenced by Glen Canyon Dam, which has reduced flood frequency, seasonal flood variation, flood magnitude, and sediment transport in the river (Stevens et al. 1997). In addition, hypolimnetic releases from Glen Canyon Dam have stabilized water temperature at about 10°C (with little warming throughout the 363-RKM-long study area), whereas pre-dam temperature conditions varied from near 0°C to 29.4°C (Stevens et al. 1997).

Several major warmwater tributaries of the Colorado River in the Glen and Grand canyons are important to native fishes, including the Little Colorado River (RKM 98.7) and the Paria River (RKM 1.4). These tributaries are known spawning locations for the flannelmouth sucker and other native species (Valdez and Ryel 1995; Weiss et al. 1998; Douglas and Douglas 2000; Meretsky et al. 2000), and unlike the main-stem Colorado River, the tributaries have remained relatively unchanged in terms of flow and temperature regimes.

Methods

Fish collection.—Flannelmouth suckers were collected with a variety of techniques, including hoop nets, trammel nets, and electrofishing (e.g., Valdez and Ryel 1995). Sampling took place from March 1991 to September 2001 in the main-stem Colorado River (Glen and Grand canyons) between the Paria River and Diamond Creek. These collections were part of continued long-term monitoring of Grand Canyon fish populations and were not sampled specifically for this study. Each fish was measured for total length (TL) to the nearest millimeter and weighed to the nearest gram. Because of the uncertainty of sex determinations, we did not distinguish between male and female flannelmouth suckers in the analysis.

Analysis.—Relative weight (W_r; Blackwell et al. 2000) was used to assess trends in condition. The standard weight (W_s) equation used to determine flannelmouth sucker W_r was described by Didenko et al. (in press). Only fish collected in 1993 were used to determine monthly (i.e., seasonal) trends in condition because this was the most complete annual data set (fish were collected throughout the Grand Canyon from January to November). To describe annual trends, we selected the two months (March and September) for which the data set was most complete from 1991 to 2001. Not all lengths of flannelmouth sucker were collected in every year, month, and river location, and therefore the analysis was limited to fish between 200 and 599 mm TL. This length range was the one most commonly collected during the study.

Because condition changes with fish length, we categorized flannelmouth suckers into 100-mm length-groups (i.e., 200–299 mm TL, 300–399 mm TL, etc.) for purposes of analysis. The Colorado River in the Grand Canyon was also categorized into 16-km river reaches (based on the upstream-most RKM) to ensure that several fish were collected in most reaches. Three separate three-way analyses of variance (ANOVAs) with interactions were conducted: (1) to determine whether mean W_r differed among length-groups, river reaches, and months during 1993, (2) to determine whether mean W_r differed among length-groups, years, and river reaches during March, and (3) to determine whether mean W_r differed among length-groups, years, and reaches during September. In all analyses, the W_r data were $\log_{10}$ transformed to better meet the ANOVA assumptions (Zar 1996).

Correlation analyses were used to determine the relation between flannelmouth sucker mean W_r and water flows recorded at three U.S. Geological Survey (USGS) gauging stations (Paria River at Lee's Ferry [RKM 1.4], Colorado River above Lee's Ferry [RKM 0.2], and Little Colorado River [RKM 98.7] near Cameron, Arizona). Correlation analysis was also used to compare mean W_r with mean macroinvertebrate density (number/m^2) determined throughout the study reach with a Hess sampler in June 1991–2001 (Benenati et al. 2002). We used only flannelmouth suckers collected in September (the most common sampling month) to avoid bias associated with seasonal differences. Mean water flows for the 3 months prior to the September fish collections (June–August) were used in correlation analyses because changes in condition might not respond instantaneously to changes in environmental factors.

Results

Monthly Differences in Condition

A total of 673 flannelmouth suckers were weighed and measured during January–November 1993. We found no significant two- or three-way interactions among length-group, month, or river reach (ANOVA, $P \geq 0.166$). However, mean W_r differed across months ($F = 4.50$; df = 10, 531; $P < 0.001$), length-groups ($F = 3.04$; df = 3, 531; $P = 0.029$), and river reaches ($F = 2.54$; df = 18, 531; $P = 0.0005$). Mean monthly W_r was greatest

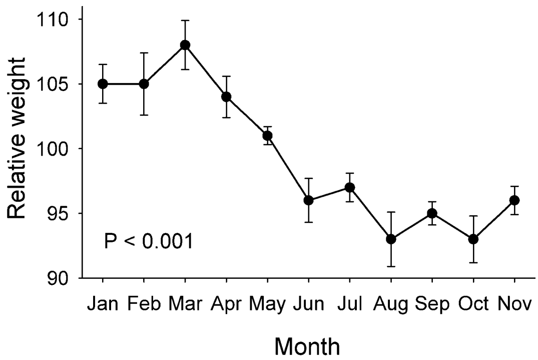

FIGURE 1.—Monthly mean relative weight (W_r) values (±SEs) for flannelmouth suckers collected in the Colorado River, Grand Canyon, Arizona, in 1993.

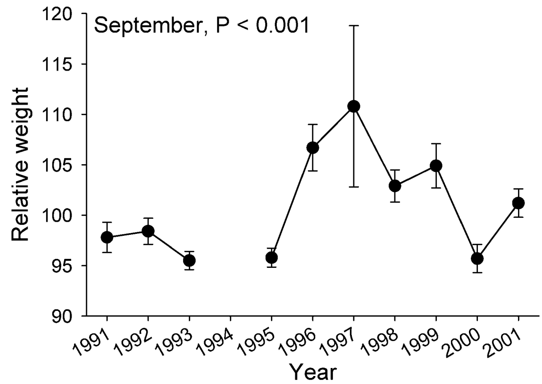

FIGURE 2.—Mean September relative weight (W_r) values (±SEs) for flannelmouth suckers collected in the Colorado River, Grand Canyon, Arizona, 1991–2001.

(>100) during January–May, peaking at 107 in March; mean W_r later decreased to 93 in August (Figure 1). Mean W_r was highly variable among river reaches. The highest mean W_r values were observed at river reaches RKM 225 (mean = 108; SE = 4.5), RKM 177 (mean = 107; SE = 2.3), and RKM 193 (mean = 107; SE = 1.9). The lowest mean values were observed at river reaches RKM 306 (mean = 94; SE = 6.1) and RKM 338 (mean = 94; SE = 3.0). Mean W_r was never lower than 94, and all reaches upstream of reach RKM 225 had mean W_r values greater than 100. Overall, mean W_r was highest for 400–499-mm fish (mean = 101; SE = 0.8) and lowest for 200–299-mm fish (mean = 97; SE = 0.8). Although significantly different (F = 3.04; df = 3, 531; P = 0.029), these two W_r values were very similar.

Annual Differences in Condition

A total of 193 flannelmouth suckers were collected in March 1991–1993 and 1995–1997, and a total of 554 flannelmouth suckers were collected in September 1991–1993 and 1995–2001. Analyses of March data indicated no significant two- or three-way interactions among length-group, year, or river reach ($P \geq 0.555$). Mean W_r did not differ significantly among years (F = 0.20; df = 5, 131; P = 0.964) or length-groups (F = 1.31; df = 3, 131; P = 0.274). Mean W_r was variable among river reaches (F = 2.20; df = 12, 131; P = 0.015), but was highest near reach RKM 177 (mean = 118; SE = 8.3) and lowest in river reach RKM 354 (mean = 94; SE = 2.7). Mean W_r exceeded 100 in all river reaches between RKM 97 and RKM 306, whereas samples collected above RKM 97 or below RKM 306 had mean W_r values less than 100.

September sampling revealed no significant two- or three-way interactions among river reach, year, or length-group ($P \geq 0.284$). Mean W_r did not differ among length-groups (F = 0.24; df = 3, 411; P = 0.869), but did differ significantly among years (F = 3.30; df = 9, 411; P = 0.0007) and among river reaches (F = 2.18; df = 17, 411; P = 0.004). In general, mean W_r decreased in downriver reaches; 9 of 10 river reaches below reach RKM 209 had mean W_r values lower than 100, and 5 of 8 river reaches above RKM 209 had mean W_r values greater than 100. Although the highest mean W_r was observed in river reach RKM 354 (mean = 106; SE = 6.4), only three fish were collected in that segment. The lowest mean September W_r occurred in 1993 and 1995 (mean = 96 for each year; Figure 2). Mean W_r increased in 1996 and 1997 and began a decline in 1998, but was never lower than 95 (Figure 2).

Correlation between Condition and Water Flows

Flannelmouth sucker condition was strongly related to water flows from Glen Canyon Dam. Mean W_r of flannelmouth suckers collected in September 1991–2001 was positively correlated with mean monthly summer flow (June–August) in the Colorado River above Lee's Ferry (r = 0.71, P = 0.02, N = 10; Figure 3A), but not with Paria River flow (r = 0.44, P = 0.20, N = 10) or Little Colorado River flow (r = 0.13, P = 0.72, N = 10). Mean September W_r of flannelmouth suckers tended to increase with mean June macroinvertebrate density between RKM 0.8 and RKM 328.8 (r = 0.57, P = 0.08, N = 10; Figure 3B).

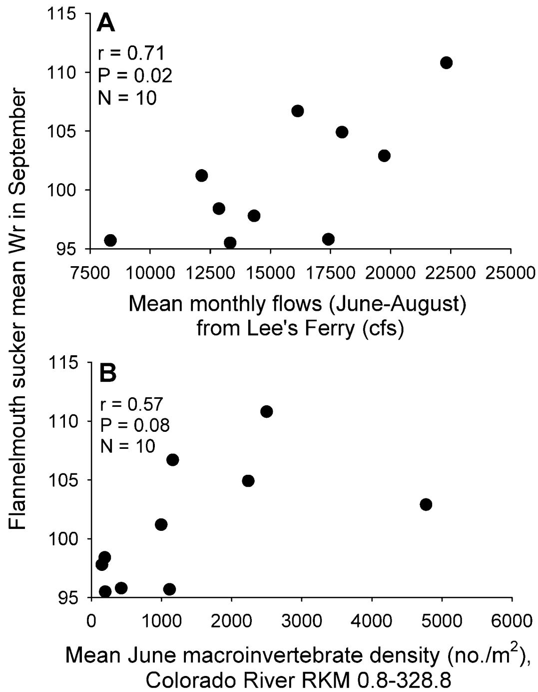

FIGURE 3.—Correlations of mean September relative weight (W_r) of flannelmouth suckers with **(A)** mean monthly summer (June–August) flows (cubic feet per second) from the Colorado River above Lee's Ferry, 1991–2001 and **(B)** mean June macroinvertebrate density in the Colorado River (river kilometers 0.8–328.8), 1991–2001 (Benenati et al. 2002). No fish were collected in September 1994.

Discussion

Flannelmouth sucker condition peaked during the prespawn period and subsequently declined. Flannelmouth suckers spawn in March and April (Weiss et al. 1998), coincident with the period of peak flannelmouth sucker condition. Similarly, McKinney et al. (1999) found flannelmouth sucker condition at Lee's Ferry also increased in spring and was lowest in summer. Decreased condition after spawning is common in fish (Pope and Willis 1996) and likely occurred in flannelmouth suckers in the Grand Canyon. Our results suggest that flannelmouth suckers do not rebound with increased condition in late summer (October or November), as has been observed for the humpback chub (Valdez and Ryel 1995; Meretsky et al. 2000). However, Douglas and Douglas (2000) documented October spawning of flannelmouth suckers in Havasu Creek (RKM 252.2). Although our results showed no evidence of increased October condition suggestive of gonadal development and possible spawning (Pope and Willis 1996), individual flannelmouth suckers may have exhibited increased condition. However, the large scale of our analysis suggests that many of the fish sampled did not spawn in the main-stem Colorado River in October.

Flannelmouth sucker condition was variable throughout the 363-RKM-long study area. However, the greatest condition values were typically observed at intermediate distances from Glen Canyon Dam for both the seasonal and annual data. Increased condition may be associated with favorable environmental conditions (Blackwell et al. 2000) occurring in these intermediate reaches. Biomass of the alga *Cladophora glomerata* peaked at RKM 104 (similar to the location of peak condition indices in our study), but macroinvertebrate drift, a common food source for flannelmouth suckers (Minckley 1991), was typically greatest in upstream segments (Shannon et al. 1996). Warmwater tributaries can be important spawning and rearing areas for native fishes (Valdez and Ryel 1995; Weiss et al. 1998; Douglas and Douglas 2000); seven major warmwater tributaries of the Colorado River occur at intermediate distances from Glen Canyon Dam (RKM 141–152). Therefore, an increased number of warmwater tributaries in a reach may be related to increased condition in flannelmouth suckers.

Flannelmouth sucker condition peaked in September 1996 and 1997, but the condition of fish sampled in March did not differ among years. In contrast, McKinney et al. (1999) found no annual difference in condition (Fulton's condition factor, *K*) of flannelmouth suckers collected from February to December 1992–1997 in the Colorado River at Lee's Ferry. Condition in our study was strongly correlated to water flows from Glen Canyon Dam. Increased flows in the Grand Canyon increase the size of the euphotic zone, particularly in the upper canyon above RKM 189 (M. Yard, USGS, unpublished data). This finding is likely related to the increased macroinvertebrate densities during peak flows, which was documented by Benenati et al. (2002).

Mean flannelmouth sucker condition never declined below 93, despite the fact that these fish inhabit a cold, stenothermic environment in which water temperatures are typically near 10°C, much lower than the species' preferred temperature of 25°C (Deacon et al. 1987). Although cold water temperatures in the main-stem Colorado River may reduce recruitment (Thieme et al. 2001), swimming performance (Ward et al. 2002), and possibly growth (Valdez and Ryel 1995), flannelmouth suckers can become tolerant of cold water (Chart and Bergersen 1992; McKinney et al. 1999) and still increase in weight. In addition, the W_s equation used to calculate W_r was likely created from populations in regulated systems. Therefore, W_r values in our study may reflect condition relative to fish in other regulated systems, but not historical (i.e., pre-dam) flannelmouth sucker condition.

Flannelmouth suckers apparently are able to tolerate the highly regulated, stenothermic conditions in the Colorado River below Glen Canyon Dam. Mean W_r values were at or near 100, corresponding to the 75th percentile of weights at a given length (Blackwell et al. 2000), which suggests that condition was moderate to high compared to that of other flannelmouth sucker populations. However, the greatest condition values were associated with periods of higher flows and productivity. Increased condition in other fishes has been associated with increased food availability (e.g., Marwitz and Hubert 1997; Paukert and Willis 2003), and this likely also occurred with flannelmouth suckers in the Colorado River. Efforts to increase dam discharge during the summer months may increase food availability and benefit the native flannelmouth suckers in this large river system.

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