Effects of Temperature, Fish Length, and Exercise on Swimming Performance of Age-0 Flannelmouth Sucker

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Abstract. --The flannelmouth sucker *Catostomus latipinnis* is one of the few native tish that persists in the lower Colorado River basin. Little is known about the effects of hypolimnetic releases of cold, swift water from Colorado River dams on flannelmouth sucker populations. We conducted fatigue velocity tests on age-0 flannelmouth suckers in the laboratory to evaluate the effects of water temperature and fish size on swimming ability. Fish of 25-114 mm total length (TL) were subjected to incremental increases in water velocity until the upper limit of their swimming ability was reached. Swimming tests were conducted at 10, 14, and 20°C. Swimming ability increased with fish length and was directly related to water temperature at all fish sizes. A decrease in water tempcrature from 20°C to 10°C resulted in an average decreas in swimming ability of 40%. Mean swimming ability of wild-caught flannelmouth suckers was 7 cm/s higher than that of captive-reared flannelmouth suckers of similar size at 20°C and 14°C. Flannelmouth suckers subjected to an abrupt 10°C temperature drop did not have significantly different swimming ability than flannelmouth suckers acclimated to 10°C over 4 d.

The construction and operation of hydroelectric dams have transformed the Colorado River from a warm, turbid. and highly dynamic stream into a system dominated by large reservoirs and cold tailwaters. These changes have dramatically affected the abundance of many native fishes. including the flannelmouth sucker *Catostomus latipinnis.* Reduced summer water temperature has been implicated in the decline of native fish in Glen and Grand canyons (Kaeding and Zimmerman 1983: Childs and Clarkson 1996: Robinson et al. 1998; Clarksoii and Childs 2000). After completion of Glen Canyon Dam in 1963. maximum summer river temperatures were reduced from 25-30°C to a nearly constant temperature of 10°C, and nonnative rainbow trout *Oncorynchus mykiss* and brown trout *Salmo trutta* were introduced. As a result, native fish now experience colder water temperatures and predation from the introduced trout, conditions that may result in a low survival rate for young, native fish.

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Flannelmouth suckers spawn in the Paria River, a tributnry of the Colorado River located *25* km below Glen Canyon Dam (Wciss 1993). Young flannelmouth suckers use the mouths of tributaries as nursery arcas until they move into the Colorado River main stem in late summer (Thiemeet al. 2001). Large numbers of age-0 flannelmouth suckers are commonly captured at the mouth of the Paria River (Hoffnagle 1999). but catch data from a variety of sampling methods indicate that low numbers of juvenile flannelmouth suckers are present in the Colorado River in Glen and Grand canyons (Valdez and Rye1 1995; McKinney et al. 1999a). This lack of recruitment may lead to population declines and extirpation of flannelmouth suckers below Glen Canyon Dam. Three other species of fish endemic to the Colorado River—the Colorado pikeminnow *Ptychocheilus lucius,* the bonytail chub *Gila elegans,* and the razorback sucker *Xyrauchen* texanus-have already been extirpated or are exceedingly rare downstream of Glen Canyon Dam (Minckley 1991).

Probable explanations for the rarity of age-0 and juvenile flannelmouth suckers in the Colorado River in Glen and Grand canyons include (1) a cold shock that causes the direct mortality of age-0 flannelmouth suckers as they exit warm tributaries and enter the cold, swift water discharged from Glen Canyon Dam, (2) predation by introduced fishes in the main stem of the Colorado River, and (3) an impaired swimming ability caused by cold-water discharges that results in age-0 flannelmouth suckers being displaced downstream.

The, Bureau of Reclamation has proposed the installation of a modified intake structure on Glen Canyon Dam that could raise summer water temperatures downstream by 4°C (USDI 1999). The effects of these proposed modifications on native fishes, however, are unknown. We tested age-0 flannelmouth suckers in the laboratory to examine the effects of temperature, fish size, and exercise on prolonged swimming ability. The objective of this study is to test the swimming performance of age-0 flannelmouth suckers over a range of sizes and temperatures to assess their response to a change in Colorado River water temperature.

Methods

We captured adult flannelmouth suckers on May 8–9, 1999, by seining the Paria River 3.5 km from the confluence. Eggs from three ripe females were fertilized with milt from six males on site. Gametes were transported to the Environmental Research Laboratory in Tucson, Arizona. where fish were reared in 1-m^3 recirculating tanks. Water temperature was maintained at 20°C (+/-52°C)throughout hatching and rearing. Timers were used to maintain a 14 h light: 10 h dark cycle throughout the study because photoperiod may alter swimming performance (Kolok 1991).

We used a flow-through system modified from designs by Thomas et al. (1964) and Berry and Pimentel (1985) to assess swimming performance. A 0.13-hp centrifugal pump circulated water between two 152-L reservoirs, and aclear acrylic cylinder measuring 50.0 cm × 7.5 cm formed the test chamber. We controlled flow with a gate valve on the pump outlet. A flowmeter fixed near the exit of the swim chamber measured water velocity to within 1 cm/s. Fish were prevented from leaving the test chamber by a 1–7-V DC electric barrier on the upstream end of the cylinder and by a galvanized screen on the downstream end.

We tested the swimming ability of fish that ranged from 25 to 114 mm mean total length (TL) at 10-mm intervals. Fish of similar size (*n*=15-20) were selected at random from those held in rearing tanks and acclimated to test temperatures for 4 d before testing. The test temperatures used were 10°C (the current temperature of the Colorado River), 14°C (what the river temperature would be if a modified intake structure were placed on Glen Canyon Dam), and 20°C (the mean predam summer temperature). Fish were acclimated in 76-L tanks by reducing water temperature with a chiller over a 24-h period and holding fish at the test temperature for 3 d. Tests were initiated by placing individual fish in the swim chamber at 50% of the test velocity for 10 min. We then exposed fish to the full test velocity for 30 min. A fish that successfully swam for 30 min was scored as a pass; a fish that became pinned against the downstream screen and remained motionless for 10 s was scored as a failure.

We calculated 50°C fatigue velocity (FV50) as the velocity at which one-half of the fish failed to swim for 30 min. For each size-class, at least five fish were tested at each of three different velocities for each temperature. Test velocities' were chosen based on several pilot trials at each size-class. When the selected velocities did not produce failure, higher velocities were used until 50% failure occurred.

We measured the total length of each fish after testing. All tested fish were then returned to the 1-m^3 rearing tanks for about 3 weeks until the average TL had increased by 10 mm. We used logistic regression to estimate FV50 (Ruetz and Jennings 2000) and 95% confidence intervals (CIs) for each temperature and size-class separately. We used multiple linear regression and a forward stepwise selection procedure to identify the relationship and interaction between temperature, fish size, and swimming ability. Measured FV50 values from the laboratory were compared with reported river velocity measurements at U.S. Geological Survey gauging stations in Glen and Grand canyons (Garrett et al. 1993).

Effect of retesting.--Individual fish were used no more than nine times throughout the study, with at least 21 d elapsing between tests. To evaluate the effects of a prior testing event on swimming performance, we compared the swimming ability of 77 flannelmouth suckers (mean TL = 40 mm) not previously tested with that of 75 flannelmouth suckers of the same size that had been tested at least 21 d before. Using a stepwise increase in water velocity of 4 sm/every 5 min until failure occurred, we determined a velocity of failure for each of these fish. We used two-sample t-tests to compare mean failure velocity of previously tested and untested fish.

Effect of cold shock.--We tested the swimming ability of fish not acclimated to test temperatures to assess whether cold shock led to direct mortality

TABLE 1.—Fatigue velocity (FV50; 95% confidence intervals in parentheses) of age-0 flannelmouth suckers after 4 d of acclimation to test temperatures; FV50 is the velocity at which 50% of fish fail to swim for 30 min and become impinged on a downstream screen.

Temperature (°C)	Total length (mm)		Number of velocities	Number of fish	FV50(cm/s)
	Mean	Range			
20	26.2	24.0–28.0	4	23	27.3 (24.8-29.7)
14	24.1	21.3–26.7	3	16	22.1 (20.9–23.3)
10	25.1	22.4–28.0	4	23	15.7 (14.3–17.2)
20	38.9	33.4–46.0	5	36	31.7 (30.4–33.0)
14	39.3	31.0–46.3	4	36	25.8 (24.9–26.6)
10	42.5	36.0-49.6	3	30	21.0 (19.8–22.1)
20	49.6	46.2–54.1	3	18	38.6 (37.5-39.7)
14	50.4	46.0–56.3	3	16	29.5 (28.0–31.0)
10	51.3	47.1–56.3	3	15	11.9 (20.3–23.5)
20	62.0	57.7–64.9	3	15	44.8 (43.6-46.0)
14	61.4	59.1–66.1	3	18	34.0 (33.2-35.0)
10	63.0	57.6-66.0	3	15	26.4 (24.7–28.1)
20	70.2	67.3–73.6	4	17	45.8 (44.8-46.8)
14	71.1	65.9–75.7	4	17	33.7 (32.7-34.8)
10	69.9	66.7–73.8	5	27	25.8 (24.7–27.0)
20	80.7	77.8–82.9	3	15	52.3 (51.0-53.5)
14	80.5	75.7–86.2	4	20	41.6 (40.7-42.6)
10	82.1	78.6-88.9	4	16	32.0 (31.0–33.0)
20	91.0	88.4–95.8	3	15	57.9 (56.9-58.8)
14	91.3	87.3-95.2	3	15	44.5 (43.3-45.7)
10	91.5	88.4-95.7	3	16	34.9 (34.0–35.9)
20	100.0	96.3-105.3	3	16	58.8 (56.5-61.1)
14	100.1	95.0–105.3	3	15	45.3 (44.0-46.5)
10	99.7	94.9–106.4	3	15	36.3 (35.0-37.5)
20	114.1	107.4-122.7	3	15	66.3 (64.1-68.1)
14	111.2	105.0–116.6	3	16	47.0 (44.7-49.2)
10	114.0	104.6-123.2	3	17	38.3 (36.5-40.1)

or reduced swimming ability at each size. These tests simulated the 10°C temperature change flannelmouth suckers may experience as they exit warm tributaries and enter the Colorado River. We removed fish from the rearing tank at 20°C and placed them directly into the test chamber at the test temperature without an acclimation period. Cold shocked fish were returned to the rearing tank following testing and monitored for delayed mortality for 3 d. The procedures used for the cold shock tests were identical to those used for the acclimated fish in all other aspects. We used logistic regression to estimate an FV50 for each of the nine size groups at each temperature. A two-sample t-test was used to compare the differences in mean fatigue velocity of acclimated versus non-acclimated fish.

Effect of captive rearing.—Seventy-five wild flannelmouth suckers (averaging 50 mm TL) were seined from the mouth of the Paria River and subjected to fixed velocity swimming tests in the laboratory within 48 h of capture. We calculated FV50 values for these fish at each of the three tempeatures and compared those for wild and captive-reared flannelmouth suckers of similar size by comparing the 95% CIs.

Results

Fatigue velocities increased with fish size and water temperature (Table 1).The relationship between fish size, water temperature, and the FV50 of age-0 flannelmouth suckers of 25–114 mm mean TL was as follows:

$$\text{FV50} = 3.78 + 0.62\,(\text{temperature}) + 0.07\,(\text{fish length}) + 0.01\,(\text{temperature} \times \text{length interaction}).$$

Temperature, fish length, and the interaction between temperature and fish length all had a significant effect on FV50 ($P < 0.001$). With all other factors held constant, swimming ability was directly related to temperature. A decrease in temperature from 20°C to 14°C resulted in a 23.5% average decrease in mean swimming ability (range, 19.0–29.0%). A decrease in water temperature from 20°C to 10°C resulted in a 40.2%

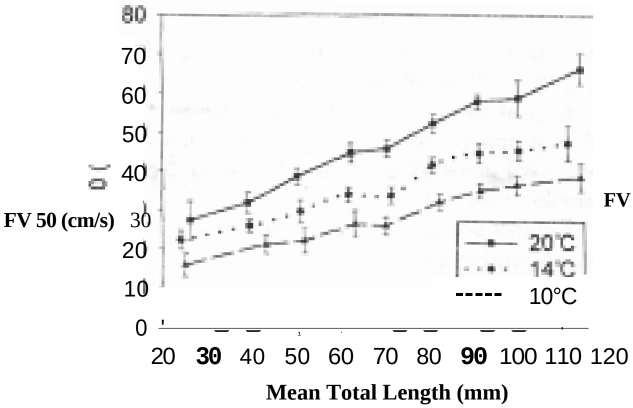

FIGURE 1.--Fatigue velocity (FVSO) and 95% confidence intervals of age-0 flannelmouth suckers (total length = 25–114 mm) at 20, 14, and 10°C following 4 d of acclimation to test temperatures; FV50 is the velocity at which 50% of fish fail to swim for 30 min.

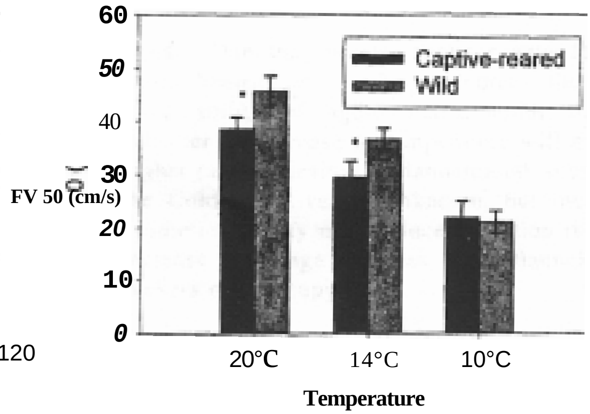

FIGURE 2.—Fatigue velocity (FV50) and 95% confidence intervals of wild versus captive-reared flannelmouth suckers (total length = 50 mm) at 20, 14, and 10°C. Asterisks denote statistically significant differences.

decrease in mean swimming ability (range, 32.3-43.7%; Figure 1).

Effect of retesting. -- The fatigue velocities of 40-mm flannelmouth suckers that had been previously tested were not significantly different from those of untested fish ($P = 0.94$). Repeated testing may alter swimming ability, but we saw no evidence of such in our two test events.

Effect of cold shock. — Flannelmouth suckers acclimated to cold temperatures for 3 d before testing did not have different fatigue velocities than cold-shocked fish ($P = 0.18$ for 20–14°C thermal shock, $P = 0.12$ for 20–10°C thermal shock). A thermal shock of 10°C or less resulted in no mortality of the 264 fish tested. Whether a 4-d acclimation period is adequate to ensure complete physiologic acclimation to test temperatures is unknown for this species.

Effect of captive rearing.—At 20°C and 14°C, wild-caught flannelmouth suckers tested within 48 h of capture showed higher fatigue velocities than captive-reared, nonexercised individuals of about the same size. At 20°C, the fatigue velocity of wild-caught flannelmouth suckers (mean = 45.7 cm/s) was 7.1 cm/s higher (95% CI = 4.6–9.6 cm/s) than the fatigue velocity of captive-reared individuals. At 14°C, the fatigue velocity of wild-caught flannelmouth suckers (mean = 36.7 cm/s) was 7.2 cm/s higher (95% CI = 4.7-9.8 cm/s) than the fatigue velocity of captive-reared fish. At 10°C, the fatigue velocities of wild-caught flannelmouth suckers and captive-reared fish were not different ($P > 0.05$; Figure 2).

Discussion

The swimming ability of flannelmouth suckers was 40% lower at 10°C than at 20°C. This reduction in swimming performance may limit the ability of age-0 flannelmouth suckers to survive in the Colorado River. The number of adult rainbow trout in the area from Glen Canyon Dam to Lees Ferry is estimated to be at least 7.800/km (McKinney et al. 1999b). The high number of trout in Glen Canyon. combined with the reduced swimming ability of young fish. may lead to a high predation mortality of young flannelmouth suckers.

Cold shock often is cited as a potential cause of mortality for age-0 native fish that exit seasonally warm tributaries and enter cold water in the Colorado River (Lupher and Clarkson 1993; Valdez and Rye1 1995: Thieme et al. 2001). In our experiments, a 10°C cold shock (which represents the temperature change age-0 flannelmouth suckers experience when exiting the Paria River) did not result in mortality. Flannelmouth sucker larvae 7–43 d posthatch also showed nu direct mortality due to cold shock (Clarkson and Childs 2000). Flannelmouth suckers therefore appear to have the ability to withstand relatively large temperature fluctuations.

The size at which flannelmouth suckers enter the Colorado River varies among years (Hoffnagle 1999). This may have important implications for recruitment because larger fish have greater swimming ability and may have a higher rate of survival. Areas with water velocity above the maximum swimming ability of small. age-0 fish are not available for use (Scheidegger and Bain 1995;

Ruetz and Jennings 2000). Midchannel water velocities in the Colorado River (Garrett et al. 1993) are several times higher than the fatigue velocities we measured in the laboratory and may block the movement of age-0 fish between low-velocity environments. In many areas, water velocity within 2.5 m of the bank exceeds the fatigue velocities we measured for age-0 flannelmouth suckers at 10°C (Converse 1996). Subyearling flannelmouth suckers that are unable to access low-velocity areas or find refuge behind instream objects may become entrained in high-velocity currents and consequently be injured or killed by turbulence or abrasion against substrates (Clarkson and Childs 2000).

Fish reared in nonmoving water have significantly reduced swimming ability compared with wild fish or exercised individuals (reviewd in Davidson 1997). Our results agree with these findings at 20°C and 14°C. Water temperature limited swimming ability at 10°C for both wild and captive-reared fish. Our estimates of swimming ability at 10°C using captive-reared fish are likely to accurately reflect the swimming ability of wild fish when they exit the Paria River and enter the Colorado River. Our estimates of swimming ability at 14°C and 20°C are likely to be low due to the greater swimming ability of exercised wild fish at these temperatures. The increased swimming ability of wild fish is consistent with swimming tests performed on wild-caught and captive-reared salnionids (Green 1964). The addition of 7 cm/s to the FV50 at 14°C and 20°C corrects for the increased swimming ability of wild fish and is more likely to accurately represent the swimming ability of wild flannelmouth suckers in the Paria River.

Information on the swimming ability of flannelmouth suckers may give insight into why the populations of other native Colorado River fish are declining. The Colorado pikeminnow, humpback chub, and bonytail chub all have thermal preferences similar to that of the flannelmouth sucker (Bulkley et al. 1981) and exhibit comparable swimming abilities for similar-sized fish (Berry and Pimentel 1985). Humpback chub spawn in tributaries to the Colorado River similar to those used by the flannelmouth sucker. Age-0 humpback chub may also experience decreases in swimming ability that result in increased predation or displacement when exiting seasonally warmed tributaries.

Low water temperature below hydroelectric dams can impair the swimming ability of age-0 flannelmouth suckers. Thus, modifications to Glen Canyon Dam that increase summer water temperatures downstream are likely to increase the swimming ability of age-0 flannelmouth suckers. Whether an increase in temperature will allow a higher rate of survival of flannelmouth suckers in the Colorado River is unknown, but increased swimming ability may reduce predation risk and increase the range of areas age-0 flannelmouth suckers may occupy.

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