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Swimming Performances of Three Rare Colorado River Fishes

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Abstract

A stamina tunnel was used to determine the prolonged swimming performance of age-0 humpback chubs *Gila cypha*, bonytail chubs *G. elegans*, and Colorado squawfish *Ptychocheilus lucius* and of subadult Colorado squawfish. The "fatigue velocity" in body lengths per second at which 50% of the test fish were fatigued (FV50) was determined at 14, 20, and 26°C. The ranges of FV50 values for the three fishes (average total length in parentheses) were: humpback chubs (95 mm), 4.4–5.7; bonytail chubs (99 mm), 4.7–5.8; small Colorado squawfish (104 mm), 4.0–4.5; large Colorado squawfish (432 mm), 2.0–2.3. Absolute speed of large Colorado squawfish was about 2.4 times that of small Colorado squawfish. Swimming ability of the subyearlings increased with increased water temperature. These rare fish had prolonged-swimming abilities similar to other fish species.

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The Colorado squawfish *Ptychocheilus lucius*, humpback chub *Gila cypha*, and bonytail chub *G. elegans* are endemic fishes of the Colorado River system that are threatened with extinction. Major causes of their decline are habitat modification caused by dams, water depletion, and introduction of exotic species (Hickman 1983). Although the biology and habitat preferences of these fishes have become better understood in recent years (Holden and Wick 1982; Valdez and Clemmer 1982), there is still a great need for biological data that can be used in planning and designing water development projects. This need has been addressed by recent field studies (Kaeding and Zimmerman 1983; Tyus et al. 1984), laboratory studies (Pimentel and Bulkley 1983; Berry 1984), and symposia (Miller et al. 1982; Adams and Lamarra 1983). However, there have been no studies of the swimming abilities of these species. Such information is needed for the proper design of fish ladders (Boyer 1961; Collins et al. 1962; Slatick 1971), culverts (Jones et al. 1974), and water intakes (Dorn et al. 1979; Hettler 1979).

Substantial literature exists on the swimming performance of many fishes (Beamish 1978), but the use of these data to predict the capabilities of unstudied species may be questionable. The objective of the present study was to determine the endurance of three rare fishes at prolonged swimming speeds. Prolonged swimming speeds are those that a fish can maintain for 15 s to 200 min, rather than burst speeds or speeds that can be sustained indefinitely (Webb 1975). We attempted to reproduce sudden velocity increases that might be encountered by a fish entering a culvert or fish ladder.

Methods

All fish were hatched and reared at Willow Beach (Arizona) National Fish Hatchery except for the bonytail chubs, which were reared at Dexter (New Mexico) National Fish Hatchery. Fish were transported to the Utah Water Research Laboratory, Logan, Utah, where they were held in circular tanks in which there were no appreciable water currents. The photoperiod was 14 h light : 10 h darkness and fish fed on commercial trout pellets ad libitum twice daily. Water quality in each tank was controlled, so that dissolved oxygen concentrations were 90–100% of saturation, pH was about 8.0, and ammonia remained below 0.2 mg/L. Temperature acclimation to 14, 20, and 26°C followed procedures recommended by Richards et al. (1977); fish were held at acclimation temperatures for at least 1 week before tests.

Fish were grouped for testing according to species and total length. Colorado squawfish were divided into groups of large (375–491 mm) and small (78–138 mm) fish. Humpback chubs were 87–107 mm; the bonytail chubs 90–107 mm. Sex of tested individuals was not determined, but because all fish were subadults, sex probably did not affect swimming performance (Brett 1965).

Swimming performance was determined in a stamina tunnel similar to that described by

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TABLE 1.—*Swimming performance of three Colorado River fishes. Swimming velocity at 2 and 120 min is expressed as body lengths (BL) per second at which 50% of the fish were fatigued (FV50) and its equivalent absolute swimming speed; the 95% confidence interval is in parentheses.*

Temperature (°C)	Total length (mm) (mean ± SD)	Number of velocities tested	Number of fish	2 min FV50 (BL/s)	2 min Absolute speed (cm/s)	120 min FV50 (BL/s)	120 min Absolute speed (cm/s)
				Bonytail chub			
14	100 ± 7	5	44	4.9 (4.7–5.3)	49 (47–53)	4.7 (4.3–5.0)	47 (43–50)
20	97 ± 7	6	59	6.4 (6.0–6.9)	62 (58–67)	5.4 (4.8–6.1)	52 (47–59)
26	99 ± 8	7	65	6.3 (6.0–6.7)	62 (58–65)	5.8 (5.3–6.4)	57 (52–63)
				Humpback chub			
14	92 ± 5	9	90	[a]	[a]	4.4 (4.1–4.7)	40 (38–43)
20	93 ± 5	7	71	6.8 (6.2–7.5)	63 (58–70)	5.5 (5.0–6.1)	51 (47–57)
26	99 ± 8	8	85	7.1 (6.1–8.4)	70 (60–83)	5.7 (5.1–6.3)	56 (50–62)
				Colorado squawfish (large)			
14	411 ± 31	4	19	2.6 (2.1–3.2)	107 (86–132)	2.3 (2.2–2.5)	95 (90–103)
20	451 ± 28	4	15	2.4 (1.7–3.4)	108 (76–153)	2.1[b]	95[b]
26	433 ± 19	4	14	2.4 (1.9–2.9)	104 (82–126)	2.0 (1.5–2.7)	87 (65–117)
				Colorado squawfish (small)			
14	88 ± 10	10	76	4.4 (4.2–4.7)	39 (37–41)	4.0 (3.6–4.4)	35 (32–39)
20	121 ± 17	6	60	4.1 (3.9–4.3)	50 (47–52)	3.9 (3.7–4.0)	47 (45–48)
26	104 ± 13	7	67	5.0 (4.7–5.3)	52 (49–55)	4.5 (4.3–4.7)	47 (45–49)

[a] Only 40% of the fish were fatigued in 2 min at the highest velocity tested (5.7 BL/s).
[b] No fatigue data between 0 and 100% were obtained.

Thomas et al. (1964). The apparatus consisted of two 500-L reservoirs connected by two pipes, a return-flow pipe, and the swimming chamber, a plexiglas tube 2 m long and 20 cm in diameter. Blocking forces (Webb 1975) were probably insignificant because the largest Colorado squawfish's cross-sectional diameter was 9.9% of the diameter of the tunnel. An electromagnetic current meter recorded flow velocities, and a downstream barrier was electrified with 5–10-V alternating current to encourage tiring individuals to swim. The tunnel was wrapped with black plastic at the upstream end to isolate the fish but to allow the entrance of light from above.

A standard testing protocol was used. The apparatus was filled with water at the acclimation temperature of the fish. One large or two small fish were acclimated to the tunnel for 5 min at a water velocity of 15 cm/s. Preliminary tests indicated no difference in prolonged swimming performance between fish acclimated for 5 and 20 min. Fish that did not swim in the tunnel during the acclimation period were excluded from the tests. After the acclimation period, fish were rapidly subjected to a selected test velocity when a stop-door was removed at the rear of the tunnel. An observer shocked tiring fish as needed and recorded the time when fish became impinged on the electrified screen as the fatigue time. Tests continued for a chosen period of 120 min or until fish fatigued.

Tests with two to four fish were first conducted at selected velocities to find a range over which the percent of fish fatigued at 2 and 120 min varied from 100% to 0%, respectively. Then, at selected fixed velocities within the range, sample size was increased to 9–14 small fish or 4–6 large fish, depending on the number available. Tested fish were measured, returned to holding tanks, and monitored for mortality. Tested fish were not reused.

The method used for estimating swimming ability was basically that used by Brett (1967): the fatigue times of individuals in a group were determined at a constant water velocity. Analysis of covariance (covariate equals fish length) was used to evaluate the effects of water temperature and velocity on fatigue times. We used a "dose–response" curve to characterize the relation between velocity and percent fatigued. The curve was plotted as straight-line connections of three-point moving averages. The FV50 (velocity at which half the fish fatigued) at 2 and 120 min was determined algebraically by linear interpo-

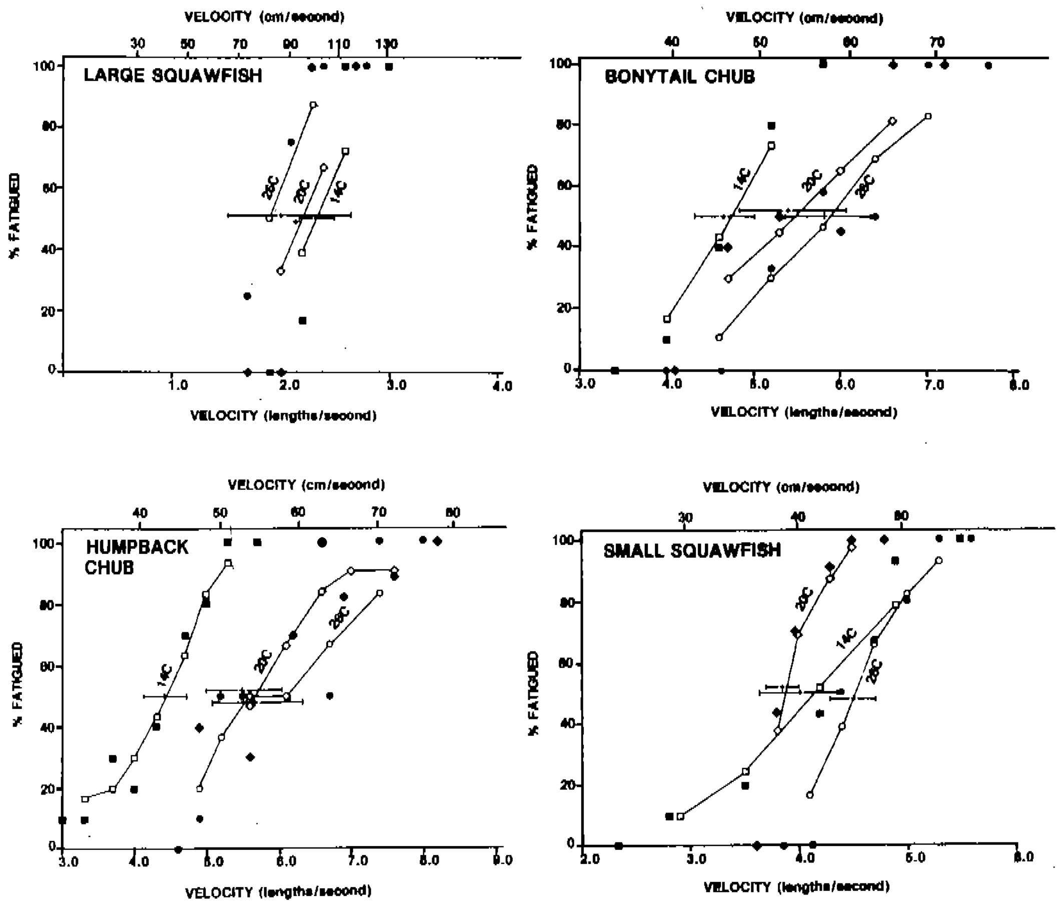

FIGURE 1.—*Relation between percentage of fatigued fish and water velocity at 14, 20, and 26°C for three species of rare Colorado River-fishes. Points on lines (open symbols) are the moving averages of three experimental data points (solid symbols). The 120-min FV50, or velocity at which 50% of the fish were fatigued in 120 min, is shown with 95% confidence intervals. The values on the upper velocity axis are based on the average length of all fish tested in each group.*

lation (Thompson 1947). Standard deviations and the *t* statistic were used to form 95% confidence intervals.

Results

The 2-min FV50 values for each test group were slightly larger than the 120-min values (Table 1), findings that agree with Brett's (1967) data for sockeye salmon *Oncorhynchus nerka*. As expected, the FV50 values in body lengths/s for large Colorado squawfish were lower than those for small ones, but when expressed in absolute speeds, the fish-length–speed relation was positive. The humpback and bonytail chubs performed similarly and had higher FV50 values than Colorado squawfish of about the same size.

Analysis of variance showed that water velocity significantly affected the mean fatigue time for all species ($P < 0.01$). Fish-length ranges covered 116 mm for large Colorado squawfish and only 17–60 mm for other groups, but these differences had no significant effect on fatigue time ($P > 0.01$).

Temperature significantly affected the performance of small fish (analysis of covariance, $P < 0.01$), but not of large fish. Increasing temperatures usually reveal some optimum at which the swimming ability of fish is maximum (Brett et

TABLE 2.—*Prolonged swimming performance of several freshwater fishes, expressed as body lengths (BL) per second and its equivalent absolute swimming speed.*

Species	Total length (cm)	Temperature (°C)	Prolonged speed BL/s	Prolonged speed cm/s	Source
Atlantic salmon *Salmo salar*	23	15	2.1–3.2	50–76	Kutty and Saunders (1973)
Largemouth bass *Micropterus salmoides*	14–27	20	2.3–3.0	45–63	Beamish (1970)
Smallmouth bass *Micropterus dolomeiu*	5–6	20	3.3–5.4	19–31	Larimore and Duever (1968)
Coho salmon *Oncorhynchus kisutch*	6–9	20	4.6–5.4	31–41	Brett et al. (1958)
Rainbow trout *Salmo gairdneri*	6	20	4.1–7.1	25–43	Butler and Milleman (1971)

al. 1958). Our data for the humpback and bonytail chubs are consistent with this generalization (Fig. 1). The small Colorado squawfish performed better at 26°C than at 20°C, but their intermediate performance at 14°C confounded the trend. Large Colorado squawfish did not improve performance with increase in temperature—an unexpected result that may have been related to the small sample size or to the possible inaccuracy of estimates made without fatigue data between 0 and 100% (Stephan 1977).

We noticed great variation among individuals in swimming ability, especially at intermediate velocities. Such variability has been noted by others (McNeish and Hatch 1978; Kovacs and Leduc 1982) and probably represents different levels of motivation, stress, and ability within each species.

Discussion

These rare Colorado River fishes have biological traits that may confer survival advantages in swift, sometimes turbulent waters (Minckley 1973). The narrow caudal peduncle and high aspect ratio (square of the maximum fin height divided by the fin area) of the caudal fin of the humpback and bonytail chubs suggest superior swimming ability compared with that of other species (Lighthill 1969). Although the ability of these two species was greater than that of the Colorado squawfish of similar size, their prolonged swimming performance at 20°C was similar to that of some other fishes (Table 2). A downward bias to our data may have resulted from the use of unexercised fish (Webb 1975) and from our use of a sudden velocity increase, instead of the gradually increasing velocities used in other tests.

The final temperature preferendum for these species is 24–25°C (Bulkley et al. 1981). It is generally assumed that the final preferendum is the optimum temperature for most physiological functions of fish. Hence, the swimming performance of these species at 26°C was probably near maximum, although this conclusion is speculative because stamina was not evaluated at higher temperatures. Maximum prolonged swimming of other eurythermal species usually occurs at temperatures between 25 and 30°C (Beamish 1978).

Hydroelectric plants and other industrial complexes remove water at structures that are potential sites for entrainment and impingement of young fish. Recommended approach and screen-face velocities at intakes are about 15 cm/s (Barnes 1976). The 120-min FV50 for small fish exceeded 35 cm/s at all temperatures; consequently the fish tested in our study should be able to avoid entrainment. However, larvae may be the most vulnerable life stage, and there is no published information on their swimming ability.

Fish passage must be provided to preserve migrating species such as the potamodromous Colorado squawfish, which undertakes spawning migrations of several hundred kilometres (Tyus 1983). Fish ladders have been suggested as a possible conservation measure because the northern squawfish *Ptychocheilus oregonensis* readily uses fish ladders on the Columbia River (Clay 1961;

Zimmer and Broughton 1965). Our data should partially define one of a dozen biological criteria needed to design an experimental fish ladder (Truebe and Drooker 1982). Additionally, data such as ours are required in formulas used to design culverts for fish passage (Watts 1974; Evans and Johnston 1980).

We attempted to simulate conditions that these fish might encounter after hydrologic alterations in stream habitat; however, our data are incomplete for most engineering and construction planning. Many other aspects of the swimming performance and behavior of each life stage must be examined before developers can adequately consider fish preferences. Our data are probably conservative because of the limitations of the test apparatus and the use of unexercised fish. The effect of fish length, water velocity, and water temperature on swimming ability could have been predicted from existing literature (Beamish 1978). Unique to our study was the opportunity to evaluate the specific abilities of these rare fishes and the finding that their abilities were similar to those of other fishes of similar size. This is encouraging because existing data for other species can augment our data in solving fish-passage and entrainment problems.

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