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EFFECTS OF COLD WATER ON SUSCEPTIBILITY OF AGE-0 FLANNELMOUTH SUCKER TO PREDATION BY RAINBOW TROUT

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ABSTRACT—We conducted laboratory tests to evaluate the effects of an abrupt 10°C decrease in water temperature on ability of age-0 flannelmouth suckers (*Catostomus latipinnis*) to escape predation by rainbow trout (*Oncorhynchus mykiss*). Juvenile flannelmouth suckers (58 mm mean total length) were maintained at 20°C and introduced individually, without acclimation, into tanks containing a single adult rainbow trout (246 mm mean total length) at 10 or 20°C. Rainbow trout attacked suckers more often at 20°C, but were more likely to capture them at 10°C. Age-0 flannelmouth suckers experience an abrupt temperature decrease when they exit warm tributaries and enter cold hypolimnetic water released from Glen Canyon Dam on the Colorado River. This temperature change might increase susceptibility of young flannelmouth suckers to predation by rainbow trout, which are abundant in the Colorado River in Glen, Marble, and Grand canyons.

RESUMEN—Realizamos experimentos en el laboratorio para evaluar los efectos de la baja brusca de 10°C en la temperatura del agua con relación a la habilidad de los alevines (edad-0) del pez gato *Catostomus latipinnis* para escapar de la depredación por la trucha arcoiris (*Oncorhynchus mykiss*). Alevines (un promedio de 58 mm LT) se mantuvieron a 20°C y fueron introducidos individualmente, sin aclimatización en tanques que contenían una trucha arcoiris (un promedio de 246 mm LT) a 20 o 10°C. Los ataques de la trucha fueron más frecuentes a 20°C, pero fueron menos efectivos capturando a su presa a 10°C. Peces recién eclosionados (edad-0) sufren una baja de temperatura brusca cuando salen de los tributarios cálidos y entran en el agua hipolimnética que fluye de la presa del Cañon Glen en el Río Colorado. Este cambio de temperatura podría incrementar la suceptibilidad a la depredación de los alevines por la trucha arcoiris, que es abundante en los cañones de Glen, Marble, y Grande del Río Colorado.

Hydroelectric dams have modified flow regimes and temperatures in the Colorado River, causing loss of native fish fauna and creating conditions that allow nonnative fishes to proliferate (Johnson and Rinne, 1982). The continued decline of many native fishes in the American Southwest is largely because of adverse interactions with these nonnative fish species (Miller et al., 1989; Minckley et al., 1991; Blinn et al., 1993). Nonnative fishes harm native Colorado River fishes, primarily through predation (Tyus and Saunders, 2000). In the Little Colorado River, diet analysis of predatory nonnative rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), yellow bullhead (*Ameiurus natalus*), and black bullhead (*Ameiurus melas*) revealed that these species might be a threat to the persistence of humpback chub (*Gila cypha*) and other native fishes in the Colorado River (Marsh and Douglas, 1997). Relative abundance of rainbow trout in the 26-mile reach of the Colorado River from Glen Canyon Dam to Lee's Ferry has more than tripled since 1991 (McKinney et al., 2001). Predation by increased numbers of rainbow trout on flannelmouth sucker (*Catostomus latipinnis*) might be responsible for the low number of juvenile flannelmouth suckers currently found in the Colorado River in Glen, Marble, and Grand canyons.

Flannelmouth suckers spawn in several tributaries of the Colorado River (Paria River; Bright Angel, Shinumo, Kanab, and Havasu creeks) within Glen and Grand canyons and use these tributaries as nursery areas before

moving into the Colorado River (Thieme et al., 2001). Age-0 flannelmouth suckers can experience an abrupt temperature decrease when they exit warm tributaries and enter the main stem. The large volume and swiftness of the Colorado River cause mixing zones to be small, and fluctuating water levels make warm backwaters and shallow inshore areas transitory (Converse et al., 1998). In late summer, differences in water temperature between the Colorado River and its tributaries commonly exceed 10°C (Kaeding and Zimmerman, 1983). A decrease in water temperature from 20°C to 10°C does not cause mortality of age-0 flannelmouth suckers in laboratory experiments, but does reduce swimming ability (Ward et al., 2002). Reduced swimming ability in cold water might contribute to limited recruitment of young flannelmouth sucker in the Colorado River.

The combination of cold water and high densities of rainbow trout in modified areas, such as Glen and Grand canyons, might lead to high predation of native fishes, such as flannelmouth sucker. We performed laboratory tests to evaluate the effects of an abrupt 10°C temperature reduction on vulnerability of age-0 flannelmouth suckers to predation by rainbow trout.

MATERIALS AND METHODS—We captured 40 age-0 flannelmouth suckers (mean = 58 mm total length; range 51 to 70 mm) in August 2000 by seining the mouth of the Paria River, a tributary to the Colorado River, 26 km below Glen Canyon Dam. We transported the fish to the Environmental Research Laboratory in Tucson, Arizona and maintained them in a circular 1,000-L fiberglass tank at 20°C. Ten adult rainbow trout (246 mm mean total length; range 235 to 270 mm), maintained at 20°C in a 1,000-L tank, were obtained from Bubbling Ponds State Fish Hatchery in Arizona. Trout were fed live goldfish for 3 weeks before testing to accustom them to eating live fish.

We conducted laboratory predation tests with rainbow trout held at 10 and 20°C. Tests at 10°C simulated conditions that exist when young flannelmouth suckers exit warm tributaries and enter the cold Colorado River. Tests at 20°C simulated conditions where no temperature difference exists. Procedures for each series of tests were identical, with 2 trials performed on each of the 10 trout, at each temperature, over a period of 2 months (n = 20/treatment). We acclimated trout to 10°C by circulating chilled water from a 300-L reservoir into the holding tank with a $^1/_{10}$-horsepower submersible pump. In this fashion, water temperature was reduced to 10°C in 24 h and subsequently maintained at 10°C (±2°C) for 5 days. We withheld food from all trout for 4 days before testing to motivate them to feed.

In all predation tests, a randomly selected flannelmouth sucker was placed in a perforated 18-L bucket suspended within the flannelmouth holding tank. One trout was randomly selected from the rearing tank and placed in an adjoining 1,000-L circular tank supplied with a continuous flow of water. Fish were held for a minimum of 8 h to allow them to recover from being moved. From behind a canvas blind, we placed each flannelmouth sucker into the experimental tank by slowly pouring the sucker into a funnel attached to the end of a 25-mm PVC pipe. This method allowed the flannelmouth sucker to be placed into the test tank without disturbing the trout. An observer recorded the number of attack events and whether the flannelmouth sucker was consumed during a 10-min trial. No refuge or cover was provided within the test tank.

We defined an attack event as burst swimming (Hoar and Randall, 1978) of the rainbow trout in the direction of the flannelmouth sucker. If a flannelmouth sucker avoided predation for 10 min, the test was terminated and the flannelmouth sucker was removed. We returned trout to a separate holding tank following testing.

We used a 2 × 2 contingency table and a two-tailed Fisher's exact test to evaluate differences in the proportion of successful captures at each temperature. The 40 flannelmouth suckers available for use as prey restricted the number of trials we could complete.

RESULTS—There were twice as many attacks on flannelmouth suckers at 20°C (n = 52) than at 10°C (n = 23; Table 1), but the proportion of successful attacks on flannelmouth suckers was significantly higher at 10°C (9 captures in 23 attacks) than at 20°C (3 captures in 52 attacks; P = 0.007). Although no refuge was provided within the test tank, flannelmouth suckers often avoided detection by remaining motionless in a shadow cast by the standpipe or swimming at the edge of the tank near the surface. Flannelmouth suckers always exhibited an escape response when approached by a trout and often jumped out of the water to avoid the pursuing trout. Flannelmouth suckers showed no visible signs of abnormal swimming behavior at either temperature. Trout either attacked the flannelmouth sucker immediately or did not attack for the entire trial.

TABLE 1—Number of rainbow trout attacks on flannelmouth sucker and number of prey consumed during 10-min predation tests following an abrupt 10°C temperature decrease.

Temperature °C	Number of trials	Number of trout initiating attacks	Total number of attacks	Number of suckers consumed	Successful attacks (%)
20	20	15	52	3	5.8
10	20	10	23	9	39.1

Activity level of individual trout was highly variable and several trout did not attempt to attack prey that swam directly in front of them at either temperature.

DISCUSSION—The combination of reduced water temperature and large numbers of nonnative predators might contribute to the decline of native fishes in the Colorado River in Glen and Grand canyons. Temperature affected both the number of times rainbow trout attacked age-0 flannelmouth suckers and the number of flannelmouth suckers that were consumed. The greater number of attacks by rainbow trout at 20°C than at 10°C was likely the consequence of increased metabolism of the trout at warmer water temperatures (Myrick and Cech, 2000), but the greater number of attacks in warm water did not result in increased predation success. Predation success of rainbow trout was significantly lower at 20°C than at 10°C. This suggests that cold water might be responsible for the difference in predation success.

Young flannelmouth suckers that exit warm tributaries and enter the cold Colorado River might be more susceptible to predation than they would be if a temperature difference did not exist. In prolonged swimming performance tests, flannelmouth suckers average a 40% reduction in swimming ability at 10°C compared with 20°C, even after 4 days of acclimation to 10°C (Ward et al., 2002). A reduction in swimming ability of this magnitude because of cold water temperature might limit the ability of flannelmouth suckers to escape predation.

Abrupt temperature changes also might result in reduced responsiveness or elusiveness of prey to predators, even if no visible loss of equilibrium occurs (Coutant, 1973). Goldfish subjected to abrupt increases in water temperature showed reduced reaction distances to rainbow trout (Webb and Zhang, 1994). Although young flannelmouth suckers showed no visible signs of abnormal swimming behavior in our tests, reaction distance or elusiveness might have been affected by cold shock (Berry, 1988).

Results of our study suggest that age-0 flannelmouth suckers exposed to a rapid temperature decrease of 10°C have an increased risk of predation. Young flannelmouth suckers or other native fish that exit warm tributaries and enter cold water released from hydroelectric dams might experience reduced swimming ability or behavioral responses that cause them to be highly susceptible to predation. The existing combination of unnaturally cold water released from Glen Canyon Dam and high numbers of introduced salmonids might limit recruitment of native fishes in Glen, Marble, and Grand canyons.

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