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Energetics, Salinity and Temperature Tolerance in the Mohave Tui Chub, *Gila bicolor mohavensis*

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Metabolic performance at various temperatures and maximal swimming speeds, critical thermal maxima and minima, as well as salinity tolerance were examined in the Mohave tui chub, *Gila bicolor mohavensis*. Maximal metabolic rates, ca. 0.1 cc O^2/g h were attained at 24 and 30 C at swimming speeds of 87 cm/sec. At 18 C fish could attain swimming speeds of only 45 cm/sec and consumed 0.1 cc O_2/g h. Factorial metabolic scope dropped from 3.3 at 18 C to 1.57 at 30 C. The mean critical thermal maxima at three acclimation temperatures (18, 24, 30 C) were 33.5, 34.9 and 36.2 C, respectively. Mean critical thermal minima were 2.8, 4.8 and 7.2 C, respectively, for fish acclimated at 18, 24 and 30 C. Mohave chubs osmoregulate well up to salinities of 237 mOsm/1. Higher salinities induce weight loss and antidiuresis.

Based on these experimental results it appears that the Mohave chub is not as adaptable to desert conditions as other desert fish, such as the pupfish (*Cyprinodon*). Therefore, careful consideration must be given to micro-environments when new refugia are sought for this endangered species.

THE Mohave tui chub, *Gila bicolor mohavensis*, is native to the Mojave River Basin in San Bernardino County, California. In the 1930's mass hybridization occurred between the Mohave chub and the related coastal species, *G. orcutti* (arroyo chub) in the portions of the Mojave River drainage where water was still present (Hubbs and Miller, 1943). Subsequent collections by Miller (1968) indicated that *G. b. mohavensis* had been eliminated from the river system through introgressive hybridization with the arroyo chub. A small population of Mohave chubs persisted at Soda Springs, southwest of Baker, California, near the terminus of the Mojave River. In 1971 fish from this population were introduced into a small lagoon formed by runoff from Lark Seep on the China Lake Naval Weapons Center. This transplant was successful and the chub population is thriving at this time. Another successful transplant was made into a small pond near the town of Hinkley, California. These populations of the Mohave chub are listed as endangered by the State of California and the US Department of the Interior, US Fish and Wildlife Service.

Fry (1947) first pointed out the importance of understanding the physiology of fishes in predicting ecological success. Very little is known about the physiology of the Mohave chub and it is difficult to predict potential success in transplantation efforts. If future management decisions are to be made for this species, it is important to have some understanding of habitat requirements in terms of environmental tolerance and physiological performance.

Therefore, in this study we looked at three physiological parameters that could limit the success of transplanted populations, or could, in fact, directly affect present adult populations. We examined metabolic performance at various temperatures and water current speeds, critical thermal maximum and minimum and salinity tolerance. These studies were conducted under the authority of an endangered species permit No. PRT2-10291 issued by the US Fish and Wildlife Service May 26, 1983.

MATERIALS AND METHODS

Twenty-five Mohave chubs were collected from China Lake's Lark Seep system on June 6, 1983. The fish were captured in an umbrella net and transported to the laboratory at California State University at Fullerton in a 200 liter fish box oxygenated with a paddle-type aerator (Breeder Goldfish Co.). In the laboratory the fish were maintained in Instant Ocean 120 liter aquaria at a density no greater than 1 fish per 4 liters of water. The aquaria were provided with gravel filters, aeration and temperature control. The fish were fed Tetramin fish food three times daily. These fish were used for met-

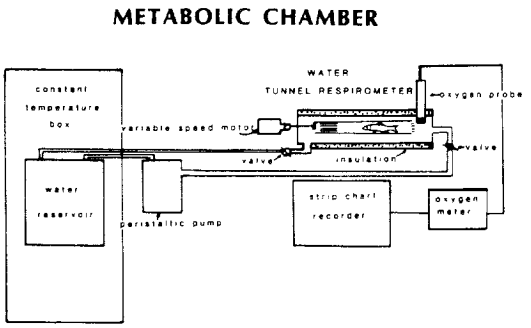

Fig. 1. Diagram of metabolic chamber and associated equipment used in this study.

abolic, and thermal tolerance studies. Five fish died during these studies and they were preserved and donated to the fish collection in the Department of Biology at California State University at Los Angeles. The 20 remaining fish were returned to Lark Seep on Aug. 8, 1983. All the fish were healthy and had grown during the experiments. Just before these fish were released, 14 more chubs were collected at Lark Seep. Of these 14, plasma samples were collected from five fish. Three of the five survived the sampling procedure (see details below) and were held for observation for approximately two h before they were released back into Lark Seep. The remaining nine fish were transported back to the laboratory as described above. On Aug. 9, 1983 31 fish were collected at Lake Tuendae, Soda Springs, located 10 km southwest of Baker, California. Six of the fish were subjected to heart puncture for blood samples and all died. The remaining 25 fish were transported and maintained in the laboratory as described above. Salinity studies were performed on these fish and 18 were killed in order to obtain blood samples. All of the remaining fish were released back into their respective habitats in a healthy state. All killed fish were preserved and placed in the fish collection at California State University at Los Angeles.

Metabolic studies.—Energy metabolism was measured in resting and swimming Mohave chubs using a Blazka-type water tunnel respirometer (Fig. 1). Water was circulated by a peristaltic pump to the respirometer from a water reservoir maintained at constant temperature. The respirometer was insulated by means of a styrofoam jacket and water temperature was monitored with a Bailey digital thermocouple thermometer (Model BAT-8). Water current was produced by means of a propeller driven by a variable speed motor. The propeller circulated water through an inner tunnel (diam. 4.8 cm) within the respirometer. Standard curves for water speed were determined by measuring the speed of particulate movement in the water. At least 10 determinations were made for each potentiometer reading governing propeller speed. When water current speeds were regressed against potentiometer readings governing propeller speeds, the data had high repeatability (correl. coeff. = 0.92). The respirometer had a total water capacity of 1.8 liters. The fish used in the respirometer ranged from 80–120 mm standard length and were placed in the inner tunnel of the respirometer. The inner tunnel contained plastic veins which minimized water turbulence. The fish swam smoothly and were not buffeted from side to side. When the fish were swimming in the inner tunnel, water velocity appeared normal, judging from particulate movement and blockage of normal water flow apparently was minimal. A polarographic oxygen probe (YSI Model 57) was sealed by an O-ring in the outer jacket of the respirometer and the membrane of the probe was exposed to the effluent of the inner tube. Changes in the partial pressure of oxygen within the respirometer were transmitted to an oxygen meter and recorded on a Sargent 30 cm strip chart recorder.

Maximum sustained swimming speeds for fish were determined at three acclimation temperatures (18, 24, 30 C) by observing the swimming ability of fish. The chubs were acclimated for a minimum of one week at each temperature before metabolic determinations were made. After these acclimation periods metabolic rates were determined only at acclimation temperatures. These temperatures were chosen to duplicate seasonal temperatures at which the fish are active. Metabolic determinations were made during the daytime hours, corresponding to the normal activity of fish in the field. A small section of the chamber insulation could be removed to visually observe the fish. The maximum swimming speed was defined as the maximum water speed the fish could sustain swimming activity for periods up to 30 min and not be pushed to the end of the inner tunnel of the respirometer. Metabolism at intermediate swimming speeds (10 cm/sec for fish at 18 C and 20 cm/sec for fish at 25 and 30 C) was also measured.

In order to determine routine metabolic rates

fish were placed in the respirometer for a minimum of 2 h. It was visibly obvious when the fish had become accustomed to the respirometer by viewing them through the window in the styrofoam. The fish appeared calm and swimming activity was at a minimum. During equilibration periods water was circulated from the reservoir into the respirometer via the peristaltic pump. The speed at which the water was circulated was sufficient to maintain a constant partial pressure of oxygen within the chamber, but not excessive enough to cause the fish to expend energy above resting, e.g., the fish could move freely within the inner tunnel of the respirometer. After equilibration the peristaltic pump was shut off, the valves to the respirometer closed and initial partial pressure of oxygen was recorded. The propeller was set at a very low speed to allow circulation of water within the respirometer. At the end of 20 min the propeller speed was increased for a few seconds to maximize water flow over the oxygen probe and a final reading was taken after probe stabilization. In this period of time the partial pressure of oxygen never dropped more than 3–4 parts per million in the chamber. At the end of the measurement the respirometer valves were opened, the peristaltic pump turned on and the system was flushed for at least 20 min. At least three duplicate measurements were performed for each fish at each acclimation temperature. The means of these duplicate measurements for 10 fish at each acclimation temperature are reported in Fig. 2.

Metabolism at maximum swimming speeds was determined as above except that after equilibration the valves to the respirometer were closed, desired water velocity was attained and the decrease in partial pressure of oxygen recorded.

Oxygen polarographic probes use oxygen themselves; therefore, control runs with no fish in the respirometer were performed at all water speeds and all experimental temperatures. Changes in partial presssure of oxygen were recorded for controls and subtracted from experimental determinations. In any given determination probe oxygen consumption amounted to between 20 and 25% of the total oxygen consumption, depending on the size of the fish in the respirometer and was very consistent and repeatable. The data are expressed as weight specific oxygen consumption (ml oxygen/g h) and were corrected to Standard Temperature and Pressure.

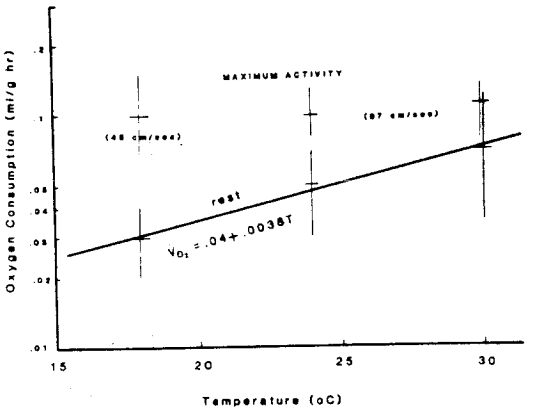

Fig. 2. Oxygen consumption of the Mohave tui chub during routine activity and at maximum swimming activity (corrected to STP). Vertical lines represent ranges and horizontal lines means for 10 fish at each temperature.

Temperature tolerance.—Chubs were acclimated for a minimum of one week at each of three temperatures, 18, 24, 30 C. Critical thermal maximum and minimum were determined for fish at each acclimation temperature by transferring individual fish to a test chamber at room temperature and then raising or lowering the temperature at a rate of 0.14 C per min. Five fish were used for high and low temperature tolerance from each acclimation temperature, e.g., 10 fish total from each acclimation temperature. Water in the test chamber was heated and cooled by a Bronwill thermoregulator. The water was mixed by a jet of water coming from the thermoregulator, in the case of heating, or by a magnetic stirbar in the case of cooling. The water was constantly aerated in both heating and cooling trials by means of air stones connected to an aquarium pump. Water temperatures were recorded immediately adjacent to the fish by means of a thermocouple and a Bailey Digital thermal recorder (Model BAT-8). Thermal maxima and minima were determined on the basis of loss of equilibrium and swimming ability of the chub. When the fish rolled on its side and swam abnormally, the water temperature was recorded. The fish was immediately placed in water at room temperature and allowed to recover. All fish used in these studies recovered.

Salinity tolerance.—Fish were acclimated at 159

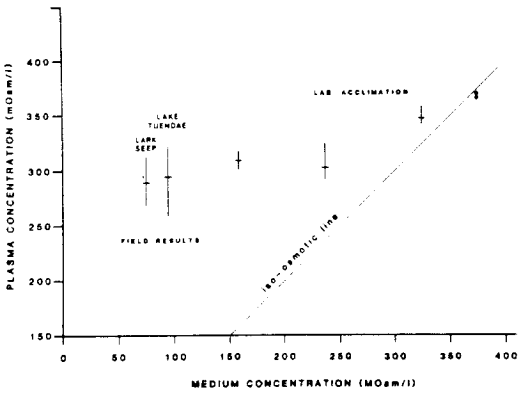

Fig. 3. Plasma concentrations for Mohave chubs in the field and acclimated in hypersaline media. Vertical lines represent ranges and horizontal lines means. (N = 5). Dots at 372 mOsm/l represent individual fish.

mOsm/l, 24 C, for at least a week. Plasma samples were taken from five fish at this concentration. This salinity was chosen as a starting point because the chub routinely survive at this concentration in the field during hot, dry months. Since the principal electrolytes accounting for increased salinities in the field are sodium and chloride, hypersalinities in the laboratory were produced by adding NaCl to the fish tanks. From 159 mOsm/l fish were sequentially moved into higher salinities of 237, 323, 372 and 519 mOsm/l. Salinities of all tanks were checked daily and the pH of the tanks was adjusted to 7.5. Blood samples were taken from fish at all salinities except 519 mOsm/l where fish showed signs of extreme stress after 24 h. Body weights were recorded for marked (fin clipped) fish at 237, 319, 372 and 519 mOsm/l.

Blood samples were taken either by heart puncture or by surgically exposing the ventricle and then removing blood. Generally no more than 50 μl of whole blood could be obtained. Samples were collected in heparinized (ammonia heparin) capillary tubes. One end of each capillary tube was heat sealed and the samples were centrifuged in a hematocrit centrifuge. Hematocrits were recorded for field animals as well as experimental animals. Most of the large fish survived after blood samples were taken by heart puncture. Smaller fish had to be killed to obtain sufficient blood samples. Urine samples were collected whenever possible by cloacal cannulation. Total osmolarity of blood, urine and water samples was determined using a Wescor Model 5100 vapor pressure osmometer (sample size 5–10 μl). Sodium and potassium concentration were determined by means of a Gilford microflame photometer (sample size 10 μl). Chloride was not determined because of insufficient plasma sample. It is assumed that most of the sodium and potassium in the plasma were bound to chloride.

Results

Metabolic rates.—The routine metabolic rate ($\dot{V}_{O_2}$) for Mohave chubs was temperature dependent and ranged from a mean of 0.03 cc O_2/g h at 18 C to 0.07 cc O_2/g h at 30 C (Fig. 2). The equation for the regression line for these metabolic data was

$$\dot{V}_{O_2} = 0.04 + 0.0038\ T.$$

Fish acclimated to 18 C, swimming at 10 cm/sec consumed a mean of 0.04 cc O_2/g h, which is not significantly different from the routine metabolic rate at that temperature. However, fish swimming at a maximal speed of 45 cm/sec at 18 C used significantly greater ($P < 0.001$) quantities of oxygen ($\bar{x} = 0.10$ cc O_2/g h). Thus, the factorial metabolic scope at 18 C was 3.3.

The mean routine ($\dot{V}_{O_2}$ for fish acclimated at 24 C was 0.05 cc O_2/g h and was not significantly different from the $\dot{V}_{O_2}$ for fish swimming at 20 cm/sec at that temperature ($\bar{x} = 0.06$ cc O_2/g h). Maximum $\dot{V}_{O_2}$ was attained at 24 C at a swimming speed of 87 cm/sec ($\bar{x} = 0.10$ cc O_2/g h). This was significantly different from the routine $\dot{V}_{O_2}$ at this temperature ($P < 0.001$) and represents a factorial metabolic scope of 2.00. Mean routine $\dot{V}_{O_2}$ at 30 C for chubs and chubs swimming at 20 cm/sec was 0.07 cc O_2/g h. Maximal $\dot{V}_{O_2}$ was attained at 30 C at a swimming speed of 87 c/sec ($\bar{x} = 0.11$ cc O_2/g h) and this represents a factorial metabolic scope of 1.57. Therefore, the scope for activity in the Mohave chub decreases from 3.3 at 18 C to 1.57 at 30 C.

Temperature tolerance.—The mean critical thermal maximum (CTMax) for chub acclimated at 18 C was 33.5 C with a range of 33.0–33.7 C. The mean CTMax for chub acclimated at 24 C was 34.9 C with a range of 34.7–35.2 C. Chub acclimated at 30 C had a mean CTMax of 36.2 C with a range of 35.8–36.5 C. The CTMax's for fish at these acclimation temperatures were

significantly different from each other ($P < 0.001$; one way ANOVA).

The mean critical minimum (CTMin) for fish acclimated at 18 C was 2.8 C with a range of 2.6–3.2 C. Fish acclimated at 25 C had a CTMin of 4.8 C (range 4.6–5.1) while fish acclimated at 30 C had a CTMin of 7.2 C (range 7.0–7.7 C). The CTMin for fish at these acclimation temperatures were significantly different from each other ($P < 0.001$).

Salinity tolerance.—Chub plasma samples from Lake Tuendae, Soda Springs, were not significantly different from plasma samples taken from fish at Lark Seep Lagoon ($\bar{x}$ = 289 mOsm/l vs $\bar{x}$ = 285 mOsm/l (Fig. 3). The osmolarity of water from these two locations was 95 and 77 mOsm/l, respectively. Plasma samples from fish acclimated at 159 and 237 mOsm/l were not significantly different from field plasma samples and the fish hyper-regulated well up to 237 mOsm/l (Fig. 3). Urine samples were obtained from two fish acclimated at 237 mOsm/l and they were essentially iso-osmotic with the plasma samples. The samples were not large enough to determine ionic composition. Plasma samples from fish acclimated at 323 mOsm/l and 372 mOsm/l were significantly higher ($\bar{x}$ = 347 and 360 mOsm/l, respectively; $P < 0.001$) than plasma samples from fish acclimated at 159 and 237 mOsm/l and from field plasma samples. Urine samples were obtained from two fish acclimated at 323 mOsm/l and they were slightly hypo-osmotic to plasma samples (e.g., fish 4—plasma 348 mOsm/l, urine 292 mOsm/l; fish 5—plasma 341 mOsm/l, urine 309 mOsm/l.

Plasma sodium and potassium concentrations from fish in the field were as follows: Lake Tuendae, $\bar{x}$ Na^+ = 143 meq/l, $\bar{x}$ K^+ = 6.4 meq/l; Lark Seep $\bar{x}$ Na^+ = 143 meq/l, $\bar{x}$ K^+ = 5.7 meq/l. Plasma sodium and potassium concentrations were not significantly different in these two field populations. Concentrations of sodium and potassium from water samples were: Lake Tuendae, Na^+ = 52 meq/l, K^+ = 1.3 meq/l; Lark Seep Lagoon, Na^+ = 39 meq/l, K^+ = 2.4 meq/l. Plasma sodium and potassium concentrations from fish acclimated at 159 and 237 mOsm/l were not significantly different from each other, nor from field plasma samples, e.g., 159 mOsm/l, $\bar{x}$ Na^+ = 151 meq/l, $\bar{x}$ K^+ = 5.2 meq/l; 237 mOsm/l, $\bar{x}$ Na^+ = 149 meq/l, $\bar{x}$ K^+ = 7.2 meq/l. Plasma sodium concentrations from fish acclimated at 323 and 372 mOsm/l were significantly higher ($P < 0.001$) than plasma sodium concentrations for fish in the field and fish acclimated at 159 and 237 mOsm/l (e.g., 323 mOsm/l, $\bar{x}$ Na^+ = 166 meq/l; 323 mOsm/l, $\bar{x}$ Na^+ = 165 meq/l). Plasma potassium concentrations from fish acclimated at 323 mOsm/l were not significantly different from field plasma samples and plasma samples from fish acclimated at 159 and 237 mOsm/l, $\bar{x}$ K^+, 323 mOsm/l = 5.2 meq/l. Plasma K^+ concentrations from fish acclimated at 372 mOsm/l were greater than 10 meq/l. There were insufficient plasma samples for further dilution and precise measurement. From these data it is clear that increased plasma osmolarities at higher salinities can be accounted for by increased plasma electrolytes.

Weights were recorded on two fish held at 323 mOsm/l for two days. One fish lost 2% of its original body mass and another lost less than 1% of its original body mass after three days of acclimation.

Hematocrits from field plasma samples had a mean of 29% red blood cells. Hematocrits from chubs acclimated at all test salinities were significantly higher than field hematocrits ($P < 0.001$). The hematocrits were : 159 mOsm/l—35%; 237 mOsm/l—35%; 323 mOsm/l—39%; 372 mOsm/l—37%.

Three fish transferred from 323 mOsm/l–519 mOsm/l survived overnight but were extremely stressed the following morning. They lost an average of 11% of their body mass. One of the three fish lost 13% of its original body mass and did not survive when placed at a lower salinity. The other two fish survived.

Discussion

Fish that inhabit aquatic habitats in xeric environments such as the Mojave Desert can potentially be exposed to a seasonal temperature range of 0–40 C, which nearly represents the entire temperature range found in aquatic ecosystems. Most of these aquatic habitats are small remnants of a once extensive system of streams, marshes and shallow playa lakes which existed during the pluvial periods of the Pleistocene. When the ice caps retreated approximately 11,500 years ago, these shallow lakes disappeared and lake species such as the Mohave chub became restricted to much more confined habitats.

The Mohave chub is a subspecies of the tui chub species, *G. bicolor* that inhabited the large pluvial lakes of the Great Basin during the Pleis-

tocene. It is a relatively large fish that apparently lived in open water situations and gill raker structure suggests it fed mainly on zooplankton (Miller, 1973). As the large lake habitats diminished *G. bicolor* became isolated and various subspecies have been described (Miller, 1973). The native habitat for the Mohave chub (*G. b. mohavensis*) was the Mojave River which originally flowed continuously from its headwaters in the San Bernardino Mountains through the present cities of Victorville and Barstow and out into Soda Lake near the southern end of Death Valley.

Many desert fishes have adapted to tolerate high temperatures. For example, many species of desert pupfish (*Cyprinodon*) show a remarkable ability to tolerate high temperatures. Lowe and Heath (1969) found that *Cyprinodon macularius* tolerate temperatures as high as 43 C in a pond at Quitobaquito in southern Arizona. Thermal tolerances this high have also been found in *C. nevadensis* from the Death Valley region (Brown and Feldmeth, 1971; Soltz and Naiman, 1978; Feldmeth, 1981). In these environments a high air temperature in summer can warm shallow pool habitats to 40 C or greater. Hence, it is imperative that fish occupying these habitats tolerate high temperatures.

It is initially surprising that *G. b. mohavensis* has a CTMax of only 36 C when acclimated at 30 C. Their thermal scope (difference between upper and lower lethal temperatures) is 30 C, whereas the thermal scope for the desert pupfish is 40 C.

These data indicate that the Mohave chub is not capable of tolerating the thermal regimes characteristic of many desert aquatic habitats. As a relict species of large playa lakes the Mohave chub probably never experienced great thermal extremes. Since the end of the Pleistocene this species has been confined to flowing stream portions of the Mojave River, as in Afton Canyon in the Mojave Desert. In these streams they could seek deep flowing cooler water. At both Soda Springs and Lark Seep Lagoon the chub always choose deeper water when water surface temperatures become heated during the day. It is possible in the case of the chub that there has been insufficient time for genetic changes (physiological) to occur to accommodate higher thermal tolerance. Hirshfield et al. (1980) found that two subspecies of pupfish (*C. nevadensis*) isolated for at least 1,000 years in habitats with differing thermal regimes, showed very slight divergence in temperature tolerance. Turner (1974, 1984) found minimal genetic divergence in biochemical characteristics for several species of Death Valley pupfish that may have been isolated since the end of the Pleistocene.

Although Mohave chubs acclimated at 18 C can tolerate reasonably low temperatures ($\bar{x}$ = 2.8 C) ,they do not perform well at low temperatures. In the winter they become inactive. Water temperatures may fall to 5 C during the coldest months and the chub disappear, presumably to the bottom of the ponds. They feed voraciously during the late spring, summer and early fall and most likely store enough energy reserves to carry them through this inactive period.

During the metabolic studies we tried to acclimate fish to 12 C and 15 C, but the fish had trouble swimming at any speed even after a week of acclimation. Therefore, it appears that the Mohave chub have a relatively narrow thermal window in which they can operate.

The water tunnel experiments are further evidence that the chub were adapted for open water habitats. The ability of these fish to swim 87 cm/sec for extended periods of time with no apparent fatigue clearly attests to their ability to survive in a large lacustrine environment.

The aerobic metabolic scope (scope for activity) for the Mohave chub narrows sharply as temperatures increase so that even if the chub were able to survive temperatures much above 30 C, there would be only minimal energy available for activity. If the line for routine metabolism (Fig. 2) is extrapolated to higher temperatures, it would intersect with the line for maximal metabolic activity of 0.1 cc O_2/g h at about 35 C. Thus, at 35 C there would be little energy available for activity beyond minimal metabolic requirements. It is interesting to note that the critical thermal maximum for the chub is between 35 and 36 C.

Slower swimming speeds at low temperatures seem to correlate well with the observed inactivity of the Mohave chub during the winter.

Maximum oxygen consumption for Mohave chubs (0.1 cc O_2/g h) is less than what has been measured for active sockeye salmon (*Oncorhynchus*), 0.63 cc O_2/g h (Brett, 1964) and for the goldfish (*Carassius*), 0.3 cc O_2/g h (Fry and Hochachka, 1970). The aerobic metabolic scope is also less in the Mohave chub when compared to goldfish and sockeye salmon. Because of the low metabolic rate at relatively high swimming speeds in the Mohave chub, the metabolic cost

of transport is also low, 0.15 kcal/kg km. The metabolic cost of salmon is 0.39 kcal/kg km (Tucker, 1970). Low metabolic cost of transport would serve a great energetic advantage to a fish such as the Mohave chub that had to cover a large territory feeding on zooplankton. Similarly, low metabolic rates would be advantageous in an environment where the partial pressure of O_2 drops as a result of plant respiration. We have routinely measured dissolved O_2 in certain locations at Lark Seep Lagoon as low as 3 parts per million in the early morning hours. A dissolved oxygen concentration of 1.1 parts per million was measured at 0550 h on June 30, 1983, in the channel just above Lark Seep Lagoon. In the laboratory we observed the chub to tolerate low O_2 tension when an air hose failed in one of the fish tanks over a weekend. The O_2 tension in the tank, before aeration was resumed, was <1 part per million.

The Mohave chub lives in a habitat where salinities may fluctuate as a consequence of flooding or excessive evaporation of water during the summer months. For example, at Soda Springs water salinities have been measured (personal measurements) as high as 285 mOsm/l in the summer and as low as 40 mOsm/l after winter rains. Water samples taken from Lake Tuendae, Soda Springs and Lark Seep Lagoon in the summer of 1983 demonstrate the diversity of salinities that is observed in these desert aquatic habitats (Lark Seep, 77 mOsm/l; Lake Tuendae, 95 mOsm/l).

The Mohave chub osmoregulated well up to salinities of 237 mOsm/l, but at 323 mOsm/l plasma osmolarity increased significantly. Although plasma osmolarities increased, the fish continued to feed and lost little weight. It appeared that they could survive indefinitely at 323 mOsm/l. Hematocrits at this salinity were not significantly different from those at lower salinities suggesting that plasma volume was regulated. Fish transferred to 372 mOsm/l had plasma osmolarities essentially iso-osmotic with the medium. Although fish held at this concentration lost 3% of their body mass in 3 d they continued to feed and appeared in good health. Hematocrits were not significantly different from those at lower salinities implying that plasma volume regulation was occurring despite the weight loss (water loss) of the fish. The experiment at 372 mOsm/l was halted after 3 d because the fish were unable to maintain body mass. Thus, it appears that the osmoregulatory mechanism of the Mohave chub starts to break down at around 370 mOsm/l. No urine could be obtained from the fish held at 372 mOsm/l, indicating antidiuresis and salt stress. Fish transferred to 519 mOsm/l for overnight became totally incapacitated.

The Mohave chub regulated plasma Na^+ and K^+ up to an external salinity of 237 mOsm/l. At higher salinities the regulatory mechanism failed and plasma sodium concentration increased. Plasma potassium levels increased after 323 mOsm/l and may be indicative of a failure in cellular regulatory mechanisms and/or a loss of extracellular body water.

Although *G. b. mohavensis* shows an ability to osmoregulate at salinities below 250 mOsm/l, it is not as euryhaline as the desert pupfish. Some species of *Cyprinodon* can tolerate salinities up to 10 times as high as the Mohave chub (Naiman et al., 1976; Stuenkel and Hillyard, 1981; Gunter, 1956).

From these data it appears that *G. b. mohavensis* must be highly selective in choosing proper micro-environments where salinity and temperature fluctuate minimally. These conditions should be a primary consideration for both the US Fish and Wildlife Service and the California Department of Fish and Game who are involved in the management plan for the Mohave chub in their present habitats and who are also seeking new refugia for this rare and endangered species.

Acknowledgments

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