Survival of Red Drum Fingerlings In Fresh Water: Dissolved Solids And Thermal Minima

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Abstract: Laboratory bioassays were conducted to estimate lower dissolved solids and temperature thresholds of red drum (*Sciaenops ocellatus*) fingerlings. Tolerance to low total dissolved solids (TDS) was measured by subjecting fingerlings to various test concentrations for 240 hours at 21° ±1° C. Higher mortality in fresh water than in diluted sea water with similar TDS suggested that concentration of individual ions may be more important than TDS to survival of red drum in fresh water. Survival in solutions of increasing sodium chloride concentrations, but constant TDS, increased and was greater than 80% at chloride levels above 130 mg/liter. Tolerance to low temperature was measured by exposing fingerlings to different temperature regimes in fresh water adjusted to a concentration of 150 ± 5 mg/liter chloride. Lower lethal temperatures ranged from 3.0° to 0.8° C when water temperature was reduced 1° C per day. When temperature was reduced 1° C every 3 days and maintained at 4° C, time to death was between 48 and 168 hours. Regardless of rate of temperature decrease, feeding ceased between 9° and 5° C. Stocking of red drum fingerlings should be successful in fresh waters that have chloride concentrations exceeding 130 mg/liter and temperature above 9° C.

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The red drum is a marine predatory fish occurring off the Atlantic Coast from Massachusetts to Florida and along the Gulf of Mexico south to northern Mexico. As juveniles they occupy estuarine environments, but occasionally enter inflowing freshwater streams (Pearson 1929, Simmons and Breuer 1962). Upon reaching maturity they inhabit primarily salt water. Rapid growth characteristics (Bearden 1967,

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Theiling and Locayano 1976, Wakefield and Colura 1982) have established the red drum as an economically important sport and commercial fish (Deuel 1973, U.S. Dep. Comm. 1975).

During the 1950s and 1960s, red drum collected in coastal waters of Texas were stocked in several state reservoirs and the Pecos River. Stocking rates were low because of difficulties of capture. However, exceptional survival, growth, and gameness in fresh water (Henderson 1972) prompted further research. During the early 1970s, culture techniques were developed for spawning red drum and rearing their larvae (Arnold et al. 1977, Lasswell, et al. 1977). By 1983, red drum had been cultured at several aquaculture facilities and fingerlings stocked into 16 Texas reservoirs.

Survival of fingerlings has been irregular in both recreational and commercial ventures, although greater returns have been observed from waters with high ionic concentrations and mild temperatures. Quantitative information on tolerance to low dissolved solids and low temperature is scarce, and would be important in establishing guidelines for freshwater culture and stocking.

We conducted bioassays to measure the lower dissolved solids and temperature thresholds of red drum fingerlings. Preliminary experiments using fresh water and diluted sea water that had similar total dissolved solids (TDS) suggested survival might not be directly related to TDS. The fresh water used in these bioassays contained large amounts of bicarbonate and calcium while sea water had more chloride and sodium ions. Since red drum have been successfully stocked in fresh waters with greater bicarbonate content (e.g., Pecos River, Texas) and calcium has been reported to inhibit diffusion of water across biological membranes, thereby enhancing survival of marine fish in fresh water (Hulet et al. 1967), additional testing was conducted in solutions with various sodium chloride concentrations.

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Methods

Red drum fingerlings (25 mm average TL) used in these experiments were supplied by the TPWD Marine Fisheries Research Station, Palacios, Texas. Fingerlings were transported to the TPWD Heart of the Hills Research Station, Ingram, Texas, and maintained in 1,800-liter indoor tanks containing sea water (20–30 ppt and 21° ± 1° C). Initially, they were fed live brine shrimp (*Artemia* sp.) nauplii, but as they grew the diet was gradually switched to commercial pellets (5% body weight/day) and live fathead minnows (*Pimephales promelas*). Water quality was maintained with a recirculating gravel filter and periodic siphoning of particulates.

Experimentation started when fingerlings reached average lengths approaching 50 or 100 mm TL. Freshwater reservoirs in Texas are normally stocked with fingerlings averaging 30–50 mm TL, but 100-mm fish could be stocked in large numbers if the additional expense does not outweigh benefits. Therefore, tests of tolerance to low ionic concentrations were conducted on fingerlings averaging near 40 and near 100 mm. Tolerance to cold temperature was measured using fingerlings 150–200 mm TL, the size expected at the onset of the cold season in north Texas reservoirs.

Low Dissolved Solids Bioassays

Tolerance to low dissolved solids was measured by exposing separate groups of fingerlings (15 fish/group) to fresh water and diluted sea water solutions of decreasing concentrations (Table 1). Fresh water was supplied by a local spring, and diluted sea water was prepared by mixing Ocean 50 Seamix (Jungle Laboratories Corp., Sanford, Fla.) with deionized water to obtain desired concentrations of TDS. Different amounts of Ocean 50 Seamix were mixed with equal volumes of deionized water, and TDS and specific conductance of each solution were measured (U.S. Environ. Protection Agency 1983). A regression equation was then derived to relate specific conductance to TDS, and solutions of deionized water and Ocean 50 Seamix were prepared to check a specific conductance predicted for a desired TDS. Ionic makeup of the dilutions were calculated from the specified ratio of elements in Ocean 50 Seamix and weight per volume of deionized water.

Testing also involved solutions of various sodium choloride concentrations with TDS held relatively constant (Table 2). These solutions were prepared by diluting fresh water with appropriate amounts of deionized water and adding enough sodium chloride (agricultural grade, 99% pure) to attain the needed TDS concentration. Chloride levels were monitored according to procedures described by the U.S. Environmental Protection Agency (1983). Concentrations of sodium and other ions were calculated from the initial ionic concentration of fresh water, dilution factor, and amount of sodium chloride added. Results are given as response to chloride.

Fish were acclimated to various experimental solutions by diluting sea water (20–26 ppt) with deionized water. Acclimations were conducted in an 18-liter aerated container. Salinity was reduced within 5 minutes to 10.0 ppt, and within 4 hours, at equal decrements, to 0.5–1.0 ppt. Four hours was considered a realistic

Table 1. Concentration (mg/liter) of major ions and total dissolved solids (TDS) in experimental solutions of diluted sea water and fresh water used to determine mortality responses of red drum fingerlings.

Ion	Diluted sea water (ppt)					Fresh water
	0.1	0.3	0.5	0.7	0.9	
Chloride	57	171	290	407	523	41
Sodium	32	94	160	225	289	23
Calcium	1	4	6	9	11	82
Magnesium	4	12	26	29	37	20
Sulfate	8	24	41	57	73	5
Potassium	1	3	6	8	10	2
Bicarbonate	<1	1	2	3	4	263
TDS	100	300	500	700	900	310

Table 2. Concentration of major ions in experimental solutions prepared to have similar total dissolved solids (approximately 300 mg/liter) but dissimilar ionic composition for use in determination of mortality responses of red drum fingerlings.

Ion	Concentration (mg/liter)					
Chloride	41	75	100	125	150	175
Sodium	23	45	60	79	94	110
Calcium	82	66	55	44	33	23
Magnesium	20	16	13	11	8	6
Sulfate	5	4	3	3	2	1
Potassium	2	2	1	1	1	1
Bicarbonate	263	210	175	142	107	74

tempering period for practical applications. Once acclimation was completed, fish were randomly distributed to aquaria containing experimental solutions.

Tests were conducted in aquaria supplied with 30 liters of experimental solution. Water temperature was maintained at 21° ± 1° C to resemble natural conditions at typical stocking times (spring and fall). Each aquarium was stocked with 15 fish when fingerlings averaged near 40 mm or 10 fish when fingerlings averaged 100 mm TL; biomass in aquaria never exceeded 1 g/liter. Water quality was maintained by continuous aeration and daily siphoning to remove wastes and by replacing at least 50% of the water. Fish were fed daily shortly after aquaria were refilled. Tests were conducted for a period of 240 hours, and dead fish were removed from aquaria as soon as observed. Criteria used to determine death were lack of respiratory movement and response to touch (Otto and Rice 1977). A control aquarium (20–26 ppt sea water) accompanied each series of experimental solutions.

Low-Temperature Bioassays

Red drum were acclimated to a temperature of either 15° or 25° C by placing freshwater-acclimated red drum into each of 2 800-liter tanks and changing temperature from ambient (21° ± 1° C) to 15° or 25° C at a rate of 1° C/day. Tanks contained fresh water (Table 1) supplemented with enough agricultural grade salt to produce a solution of 150 ±5 mg/liter chloride. Fish were maintained at desired acclimation temperature for at least 2 weeks prior to experimentation.

Tolerance to low temperature was measured by 2 methods involving separate 800-liter test tanks, each divided with netted frames into 2 compartments. With the first method, water in a test tank was warmed to 25° C, and 15 fish acclimated to 25° C were transferred into 1 of the compartments. Then, temperature was reduced by 1° C per day to 15° C, 15 of the fish acclimated to 15° C were placed into the adjacent compartment, and temperature continued to be lowered 1° C per day until all fish died. The second method was similar to the first, except that 10 fish were placed in each compartment, more time was allowed for physiological adjustment by reducing temperatures 1° C every 3 days, and temperature reductions were ended at 4° C. This temperature was maintained and time to death recorded for each fish.

Acclimation and testing temperatures were controlled with an electrical system modified from Abell et al. (1977) consisting of electrically-timed, gear-driven thermoregulators that controlled heating or chilling units. Fish were fed live fathead minnows ad libitum once or twice per day, and water quality was maintained with a recirculating gravel filter and periodic siphoning of wastes.

Data Analysis

Tolerance of red drum fingerlings to low ionic concentrations and temperatures were expressed as lethal dose (LD) to 50% (LD_{50}) and 20% (LD_{20}) of the population. LD_{50} is customarily reported in the literature and LD_{20} was felt to represent acceptable survival from a practical perspective. LD's were determined from regression equations fitted to the mortality responses using the method of least squares. Mortality responses were linearized by logit transformations (Neter and Wasserman 1974) before computing the regressions. The proportion of mortality (p) observed for each dose was converted to logits (p'), and the logits regressed against dose. Logits were computed as

$$p' = \log_e \frac{p}{1 - p},$$

with 0 and 100% mortalities interpreted as 1% and 99%, respectively.

Results

Low Dissolved Solids Mortality Responses

Bioassays using diluted sea water and fresh water indicated mortality of red drum fingerlings (47 mm average TL) increased as TDS decreased. However, at similar TDS mortality in diluted sea water (TDS = 300 mg/liter; mortality = 13%) was much lower than in fresh water (TDS = 310 mg/liter; mortality = 100%). Moreover, all fish in fresh water died between 6 and 51 hours after the start of the experiment, while mortalities in the sea water dilution with similar TDS occurred between 98 and 160 hours. These results suggested mortality may not have been directly related to TDS, but rather to concentration of specific ions.

Fingerling mortality was inversely related to chloride concentration (Fig. 1). Neither 49-mm nor 99-mm fish survived in solutions having 41 mg/liter chloride (23 mg/liter sodium), but survival improved at higher concentrations. Lethal concentrations to 20% and 50% of the fish were 128 and 107 mg/liter chloride for the 49-mm fish, and 101 and 80 mg/liter chloride for 99-mm fish. No mortalities occurred in control tanks. Larger fingerlings appeared to be more tolerant to low ionic concentrations (Fig. 1), but the increase in tolerance was not statistically significant; at calculated LDs, 95% confidence intervals around predicted mortality for 49-mm and 99-mm fish overlapped.

Low Temperature Mortality Responses

Effects of low temperature on red drum fingerlings were evident prior to death. When temperature was reduced 1° C per day, feeding ceased at 9°–7° C, regardless

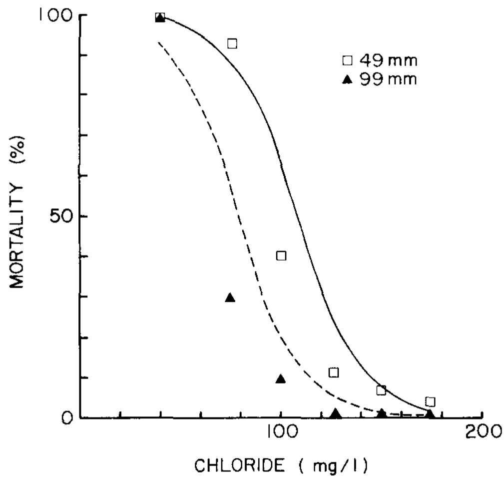

Figure 1. Mortality responses of red drum fingerlings averaging 49 and 99 mm total length and held for 240 hours at 21° ±1° C in solutions of various concentrations of chloride.

of acclimation temperature. With the reduction of 1° C every 3 days, fish acclimated to 25° C stopped feeding at 9°–5° C, while those acclimated to 15° C discontinued feeding at 7°–5° C.

Lethal temperatures to 20% and 50% of the fish acclimated to 15° C were 2.4° and 1.9° C, respectively, and 2.9° and 2.4° C, respectively, when fish were acclimated at 25° C (Fig. 2). Lethal periods to 20% and 50% of the fish were 76 and 97 hours when acclimated at 15° C, and 54 and 74 hours when acclimated at 25° C (Fig. 3). Acclimation temperatures did not affect lethal doses significantly; at calculated LDs, 95% confidence intervals around predicted mortality for fish acclimated to 15° and 25° C overlapped. Between acclimation temperatures, lethal temperatures differed by only 0.5° C and lethal periods had less than 24 hours difference.

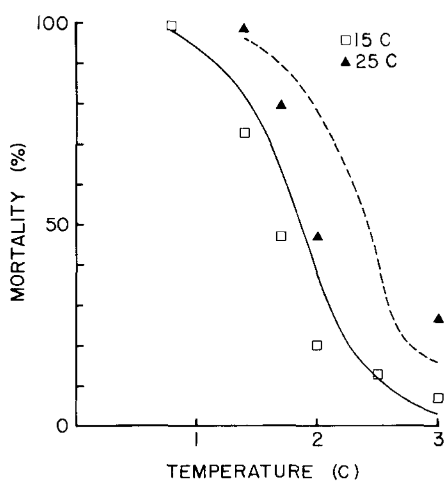

Figure 2. Mortality responses of red drum fingerlings acclimated to 15° or 25° C, and then exposed to 1° C per day temperature reductions in freshwater solutions containing 150 ±5 mg/liter chloride.

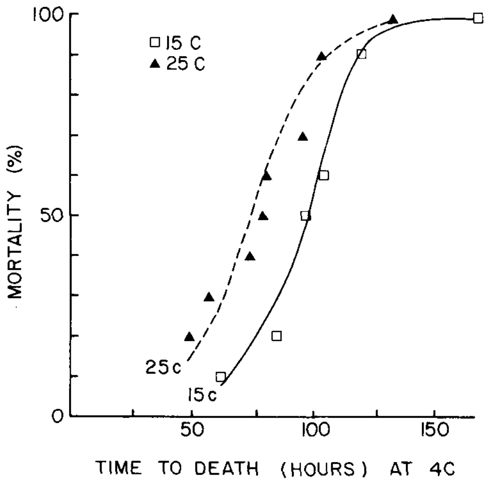

Figure 3. Mortality responses of red drum fingerlings acclimated to 15° or 25° C, exposed to 1° C every 3 days temperature reductions, and then maintained at 4° C until death in freshwater solutions containing 150 ±5 mg/liter chloride.

Rates of death between acclimation temperatures, as indicated by the slope of the lines, were also similar within lethal temperature and lethal period determinations (Fig. 2 and 3).

Discussion

Successful entrance of marine fishes into fresh water depends on their ability to maintain the proper proportion and concentration of ions in the body fluids. An inverse relationship exists between concentration of ions in the environment and the work required to neutralize diffusion losses. When ions reach certain minimum environmental concentrations, active replacement by absorption cannot compensate for the rate of diffusion losses and death occurs. Data compiled by Holmes and Donaldson (1969) showed that sodium and chloride account for approximately 40% and 50%, respectively, of the total concentration of ions (roughly, 10,000 mg/liter) in the body fluids of euryhaline fishes. Our experiments described threshold environmental concentrations of chloride at which the active replacement mechanisms of red drum fingerlings are unable to balance ionic losses due to diffusion.

Quantification of the minimum environmental chloride concentration required for effective ionic regulation may have practical value for predicting success of marine fish introductions into fresh waters. Our experiments showed good survival of both 49-mm and 99-mm fingerlings at chloride levels above 130 mg/liter (Fig. 1). Larger fingerlings may be expected to have greater tolerance because of their smaller ratio of gill to body surface, but no statistically significant increase in tolerance was observed in our study.

Concentrations of sodium and chloride needed for survival of red drum occur in certain fresh waters and tend to reflect local geological and hydrological conditions. For example, fresh waters in some sections of Florida are rich in sodium chloride as a result of leaching from sediment deposits. Surface waters contiguous to the St. Johns River system may attain 1,000 mg/liter chloride, apparently due to salts added by springs (Odum 1953). In semi-arid regions, evaporation exceeds precipitation and chloride levels increase. This is the case in most of the western half of Texas, where some surface waters average over 1,000 mg/liter of chloride (Rawson 1974). Similarly, most power-plant cooling lakes have higher evaporation rate leading to above average chloride concentration. Suitable conditions can also be found in lakes where some sodium chloride may be added by runoff from sewage and industrial wastes. A more detailed discussion on the geochemistry and location of areas with high sodium chloride are provided by Kaufmann (1960). In general, inland lakes capable of supporting red drum are not abundant. However, in areas where suitable conditions exist, red drum can dramatically add trophy fish to existing predator-gamefish communities and angling harvest.

Culture of red drum in freshwater ponds has potential for economic development. In addition to some inland lakes and streams, sufficiently high concentrations of sodium chloride may be found in portions of Alabama, Arkansas, Louisiana, Mississippi, and Texas lying over the Gulf Coast Salt Basin (Lefond 1969). Required chloride levels may be obtained artificially in natural waters low in salinity. The addition of 1,650 kg of agricultural grade salt to 1 ha-m of pond water would increase chloride by 100 mg/liter, at a cost of $90–$100 (agricultural grade salt priced at $50–$60/907 kg, in 1985). Salt would need to be added periodically to compensate for seepage losses, but concentrations could possibly be reduced as fish grow larger. Feasibility and profitability of such a venture have not been investigated.

As a poikilothermous organism, the red drum must passively adjust its body temperature to that of the surrounding water. The capacity to adjust to cold temperature is primarily determined by inherited traits. Tolerance is in part based upon enzyme diversity, relative to kinetic properties, that are temperature dependent. As temperatures change, different molecular forms of the same enzyme (isozymes) may be activated. The ability to produce isozymes with a wide range of catalyzing temperatures is an evolutionary product of the temperature extremes encountered by the organism in its natural habitat. Coastal waters have less severe temperature fluctuations than inland waters. Therefore, capacity of the red drum to make biochemical adaptations to extreme temperatures was probably limited.

Lethal temperatures of 4° to 7° C were reported for red drum on the Texas coast by Moore (1976). During the 1983 winter freeze on the Texas coast, red drum were found dead in water at 3° C (pers. comm., H. Hegen, TPWD, Rockport, Texas). Conversely, live specimens have been collected in waters as low as 2° C in Florida (Springer 1960) and Texas (Simmons and Breuer 1962). In South Carolina, no mortalities were observed when a cold front rapidly reduced the temperature of saltwater ponds to 1° C (Bearden 1967). Discrepancies in reported lethal temperatures to red drum may be due to variations in the physiological state of the fish which is influenced by factors such as photoperiod, geographic variation, age, diet, and previous history of sublethal exposure.

Lethal temperatures determined in these experiments do not differ greatly from those observed in salt water, suggesting salinity may not have a large effect on the thermal tolerance of red drum. In general, mortality is likely to occur in fresh waters that reach temperatures of 4° C or below for several days. In fresh waters that drop to 9°–7° C for prolonged periods of time, feeding may cease and growth may be adversely affected. Withstanding chloride concentrations, successful stocking of red drum into fresh water would be limited by the thermal regime of the stocked water.

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