INTRODUCTION

Red drum (Sciaenops ocellatus) has been a popular fish, both for food and sport, for many years along the Texas coast. Increased fishing pressure led to a ban on commercial harvests of red drum in September, 1981. This ban left Texas restaurateurs with an estimated annual demand of 1,000,000 pounds of red drum (Robert L. Colura, personal communication, 1981) and no local supply, necessitating red drum imports from nearby Gulf Coast states: Louisiana, Mississippi and Alabama. The recent Cajun cooking rage, "blackened redfish", has further intensified the demand.

The Texas Parks and Wildlife Department (TPWD) has been mass culturing red drum fry for over 10 years. The technology for spawning and larval rearing is well established (Arnold et al., 1976, 1977; Colura et al., 1976; Roberts et al., 1978a, 1978b; Gene McCarty, personal communication, 1985).

A number of TPWD red drum stockings have been successful in power plant cooling reservoirs, inland lakes with hard waters (high levels of calcium and/or magnesium) and in several low salinity impoundments of West Texas (Robert L. Colura, personal communication, 1981). These introductions have demonstrated the ability of the red drum to adapt to a diverse range of environmental conditions (marine and fresh waters); the fish have exhibited rapid growth rates. Under optimal conditions, red drum have attained sizes from 0.45 kg to 1.36 kg in one year (Bearden, 1967; Luebke and Strawn, 1973; Arnold et al., 1977; Robert L. Colura, personal communication, 1985, 1986; Gene McCarty, personal communication, 1986). Red drum
typically reach 450 g in one year on their natural feeding grounds (Pearson, 1929; Simmons and Breuer, 1962; Harrington et al., 1979).

There are three groups of euryhaline fishes: true or widely euryhaline, catadromous and anadromous. True or widely euryhaline species, such as red drum, are those which are found over wide ranges of salinity (even from freshwater to seawater concentrations). Catadromous species are those which migrate from fresh water to salt water to spawn. Anadromous species are those which migrate from salt water to fresh water to spawn. Stenohaline species are those which tolerate only fairly narrow ranges of salinity (e.g. strictly freshwater and strictly marine species typically fit this category).

Aquatic environments are often subjected to physical and chemical change. The various salinity regimes that occur in estuaries are of particular importance to euryhaline species. Freshwater environments display a diversity of ionic types and ratios and typically have substantially lower levels of total dissolved solids (ions) than marine or brackish waters. In the marine environment, ions occur in comparatively stable ratios with absolute concentrations varying as a result of freshwater dilution or evaporation. Even though teleosts may live in waters which exhibit wide ranges of salinity, they are capable of maintaining relatively stable plasma and tissue dissolved ion concentrations (Holmes and Donaldson, 1969).

The mechanism for maintaining constant internal ionic concentrations relative to external or environmental ionic concentrations is known as osmoregulation. Fish at the extremes of their salinity tolerance range often exceed their ability to osmoregulate. This causes changes in plasma osmolarity leading to stress and, eventually, death. It is for this reason that an understanding of osmoregulation is important for those interested in the culture of marine and euryhaline fishes and, to some extent, freshwater species.

Osmoregulation is a mechanism for maintaining internal homeostasis. It is primarily responsible for controlling the osmolarity or osmotic pressure of plasma. Osmotic pressure is the pressure exerted by varying the number of solute particles in a solution contained within a semi-permeable membrane, relative to external solutions. Plasma is maintained at an
osmolarity equal or similar to that of internal tissues and cells. This protects fish from the dehydrating or waterlogging effects of higher or lower external osmolarity. Osmoregulation tends to buffer fish cells and tissues against the effects of fresh water or sea water.

It has been observed that plasma osmolarity and monovalent ion concentrations remain relatively constant for a variety of teleosts. Plasma osmolarity ranges from 250 to 400 milliosmols/kg; sodium and chloride concentrations range from 120 to 180 mEq/l and 110 to 150 mEq/l, respectively (Holmes and Donaldson, 1969). Sodium, chloride, potassium, calcium and magnesium appear to occur in fish plasma at concentrations which are relatively constant for most fishes and are higher in concentration than other inorganic plasma ions (Holmes and Donaldson, 1969). It is generally recognized that sodium, chloride, potassium and calcium are primarily responsible for osmoregulation in fishes, either by exerting osmotic effects (sodium and chloride) or by affecting uptake and excretion (calcium and potassium). These elements also serve electrochemical, enzymatic and structural functions. It has been suggested that, in some fishes, free amino acids are involved in the maintenance of cell and plasma osmolarity (Jones, 1959; Love, 1970, 1980). However, evidence on this point is not conclusive.

Maintaining high or low plasma osmolarity relative to the environment is known as hyperosmoregulation and hypo-osmoregulation, respectively. The salinity of the surrounding water has pronounced, but different, effects on freshwater and marine teleosts. In freshwater fish, the internal ion concentrations are higher than the surrounding water. For marine fish, the reverse is true. These differences result in net influx and net efflux of water in freshwater and marine fishes, respectively. These fluxes occur across exposed body surfaces (i.e. skin and gills). Euryhaline fishes are subject to both effects during their lifetimes. Marine and freshwater fish have different types of kidney functions and structures in order to accommodate these differences.

Freshwater fish deal with their high water load by producing large volumes of dilute urine (relatively free of monovalent ions). The diuretic effect of excreting large volumes of water tends to draw some ions with it. In addition, the osmotic gradients present at gill and body surfaces tend to draw out monovalent and divalent ions. These are usually replaced by uptake
at the gills or by absorption from ingested foods. The kidneys in freshwater fishes are composed of filtering, secreting and absorbing elements. The glomerulii are capillary-capsule complexes responsible for filtering water, ions and metabolites from the plasma. Attached to each glomerulus is a complicated system of tubules capable of secreting divalent ions and reabsorbing monovalent ions.

Several mechanisms for extrarenal absorption of monovalent ions in the freshwater environment have been proposed. It is important to note that these were demonstrated under starvation conditions. It is most likely that the monovalent ions are maintained at constant levels by absorption from food in the intestine and renal excretion with limited gill uptake or elimination.

Krogh (1939) and Maetz and Garcia Romeu (1964) observed that Na\(^+\) could be absorbed at the gills in exchange for NH\(_4^+\). Kerstetter et al. (1970) suggested that the true mechanism was a Na\(^+\)-H\(^+\)exchange. Maetz (1973) found better correlation when Na\(^+\) uptake was coupled with the sum of NH\(_4^+\) and H\(^+\) efflux. Chloride does not appear to follow Na\(^+\) passively across the gills by electrostatic attraction. Chloride exchange seems to be related to carbonic anhydrase and is absorbed in exchange for bicarbonate (DeRenzis and Maetz, 1973; Fleming, 1974; Evans, 1975; Pic and Maetz, 1981).

Marine fish are continuously drinking sea water to replace lost body water. These animals are confronted with the problem of removing the ions absorbed in conjunction with water. Marine teleosts produce small amounts of extremely concentrated urine, containing wastes and divalent cations. Glomerular size and function have been reduced in order to conserve the energy required to filter and reabsorb monovalent ions and important organic plasma substances. This also tends to conserve water. Nearly all marine species have lost the distal and intermediate tubule segments; those areas are responsible for reabsorbing monovalent ions (Na\(^+\), K\(^+\), Cl\(^-\)). The only segment remaining in similar form to that of freshwater fish is the proximal tubule. This segment is responsible for divalent ion (Mg\(^{++}\) and Ca\(^{++}\)) secretion (Hickman and Trump, 1969).
Krogh (1939) indicated that the probable mechanism for elimination of the monovalent ion load absorbed from seawater is via extrarenal secretion; located in the gill-buccal region. Mitochondria-rich cells above the basal cells in the gill filaments are considered to be ion secretors. It is believed that they are salt inducible and form polyanionic substances which act as ion secretory compounds (Conte, 1969). There appears to be a sodium-sodium as well as a sodium-potassium exchange pump (Maetz and Pic, 1975; Pic et al., 1979). The sodium-potassium pump appears to remove only a small proportion of the total sodium load from the plasma (Maetz, 1969). These pumps exchange internal sodium for external potassium and sodium across the gills. The sodium-potassium pump may make some contribution to the maintenance of internal potassium levels.

Euryhaline species have kidneys that seem to perform well in both low and high salinity environments. In general, their kidneys are similar to those of freshwater teleosts. However, function and in some cases structure can be influenced by the salinity of the environment in which the fish are confined. It was observed by Ford (1958) that pink salmon fry reared in fresh water had more glomerulii than those reared in salt water.

When drinking sea water, marine fish consume from 0.2% to 0.5% of their body weight per hour. Seventy to 80% of the water swallowed is absorbed (Conte, 1969). The majority of monovalent ions and a small proportion of divalent ions are absorbed. What remains in the intestine is magnesium and sulfate residues and insoluble carbonate salts of calcium: These are eliminated with the feces. This was described in saltwater studies with rainbow trout (Shehadeh and Gordon, 1969). Hickman (1968) observed similar findings in southern flounder.

Calcium serves a number of functions in fish. In bony fishes, it combines with phosphorus for the deposition of bone. It is possible that bone serves as a reservoir of calcium for plasma and tissues. Additionally, calcium appears to be important in reproduction (Pang et al., 1980b; Pang and Yee, 1980) and in mitochondrial function (Lehninger, 1975). Important sites of calcium uptake are the intestine and gill (Fleming, 1974; Pang et al., 1980a; Payan et al., 1981; Mayer-Gostan et al., 1983); intestinal uptake can limit gill uptake to some extent. Calcium metabolism in teleosts and other vertebrates has been reviewed by Pang et al.
It is generally recognized that calcium has an important role in osmoregulation.

Low calcium concentrations in fresh and sea waters result in increased turnovers (passive fluxes) of water and sodium for a variety of euryhaline and fresh water teleosts. Water influx increases across the gills in calcium-free fresh water while increased efflux occurs in calcium-free or deficient sea water (Potts and Fleming, 1970; Ogawa, 1975; Isaia and Masoni, 1976; Gallis et al., 1979). The opposite occurs for sodium: efflux and influx, respectively (Pickford et al., 1966; Potts and Fleming, 1971; Bornancin et al., 1972; Fleming et al., 1974; Eddy, 1975; Carrier and Evans, 1976; Isaia and Masoni, 1976; McWilliams and Potts, 1978; Pic and Maetz, 1981). Another diffusional related phenomenon resulting from the reduction or removal of environmental calcium is a change in gill transepithelial membrane potentials (Kerstetter et al., 1970; Eddy, 1975; McWilliams and Potts, 1978). The potential changed from positive to negative in calcium deficient fresh water.

Environmental calcium concentrations also appear to affect a potassium mediated sodium exchange mechanism which is distinct from the passive processes discussed above. Sodium is actively transported against diffusional gradients producing sodium influx in fresh water and efflux in sea water. When environmental calcium is absent or reduced in concentration, the rates of influx or efflux are reduced (Bornancin et al., 1972; Fleming et al., 1974; Eddy, 1975; Isaia and Masoni, 1976; Norton et al., 1977; Pic and Maetz, 1981).

Prolactin production in sticklebacks (Wendelaar Bonga, 1978) and tilapia (Wendelaar Bonga et al., 1983) appears to be related to environmental calcium concentrations rather than sodium concentrations or osmolarity. High concentrations of calcium, as found in sea water, reduced prolactin production. Prolactin release increased epidermal thickness and the density of mucocytes. The observed effects of prolactin injection and hypophysectomy on water and sodium metabolism at the gills appears to be opposite to that of high versus low calcium environments, respectively (Potts and Fleming, 1970; Potts and Fleming, 1971; Ogawa, 1975). Prolactin apparently affects active sodium transport primarily and passive exchange indirectly (increased mucous production and thicker epidermis). These studies indicate that ambient calcium concentrations can affect prolactin production which in turn may affect both
the active and passive processes of sodium metabolism. Calcium also exerts a direct effect on both of these processes which is independent from prolactin.

Over 100 years ago, Ringer (1884) observed that the single addition of calcium chloride to distilled water was superior to sodium chloride, potassium chloride or sodium bicarbonate (singly or in combinations) for prolonging survival of sticklebacks or minnows placed in these solutions. Several researchers have reported that some marine teleosts could survive for protracted periods in freshwater to which calcium had been added (Breder, 1934; Hulet et al., 1967; Carrier and Evans, 1976; Brown, 1981). Potts and Fleming (1971) reported poor survival for the euryhaline cyprinidont, Fundulus kansae, when transferred from seawater to calcium-free seawater. Isaia and Masoni (1976) obtained similar results with eels. It has been noted that F. kansae (Pickford et al., 1966) and the brown trout (Oduleye, 1976) require a minimum ambient calcium concentration for freshwater survival following hypophysectomy.

Environmental calcium is necessary either as an absolute requirement or for improved survival when hatching or rearing the eggs and larvae of certain euryhaline or marine teleosts (Brown and Lynam, 1981; Lee and Hu, 1983; Lee and Krishnan, 1985). Crocker et al. (1983) observed that red drum fry transferred from salt water to fresh water exhibited a drop in blood osmolality. This decline was reduced by the addition of calcium. Miranda and Sonski (1985) indicated the importance of an optimum chloride level (above 130 mg/1) for good red drum survival in fresh water. However, they noted that some additional, unidentified ion appeared to be critical in this respect. All of these observations are consistent with the successful survival and growth of red drum in hard fresh water.

Hard water can result from the presence of calcium and/or magnesium. However, these elements form insoluble compounds with carbonate at or above a pH of 8.3 (Boyd, 1979). Most waters, both salt and fresh, range below a pH of 8.3. Hardness is a method of indirectly reporting divalent ion levels as calcium carbonate (CaCO₃) but does not indicate actual ionic composition with respect to calcium and/or magnesium. Apparently, it is the presence of one of these ions in natural waters which improves the survival of red drum. There are a number of inland saltwater wells or impoundments which have atypical ionic profiles and ratios
relative to sea water. These waters might also be made available for red drum culture in the future.

Red drum fit the profile of an excellent aquaculture candidate: hatchery technology is well established; fry readily accept commercial trout/salmon diets; growth rates are rapid in marine and fresh waters. However, additional information is needed to successfully culture red drum commercially: optimum ionic profile for fresh water versus a minimum osmotic need with respect to total dissolved solids; red drum performance on commercially available feed in terms of growth rate and food conversion efficiency; freshwater survival and growth; crowding tolerance; and size requirements for stock-out. The purpose of this research was to evaluate specific ionic and growth parameters affecting the feasibility of commercially producing red drum. This was accomplished through a series of experiments.

DISCUSSION (for excerpts from the discussion section click here)

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VERTEBRATE & FISH EVOLUTION: WHY CAN SOME FISH LIVE IN FRESH WATER, SOME IN SALT WATER, AND SOME IN BOTH? (view also as PDF) World Aquaculture, 29(1): 65.
Also as: Why do some fish normally live in freshwater and others in saltwater? How can some fish adapt to both?

USING SALT TO REDUCE HANDLING STRESS IN CHANNEL CATFISH (view also as PDF) World Aquaculture, 26(3): 80-81.


RESPONSES OF RED DRUM (Sciaenops ocellatus) TO CALCIUM AND MAGNESIUM CONCENTRATIONS IN FRESH AND SALT WATER 1989. Aquaculture, 76: 21-35.


POLYCULTURE OF RED DRUM WITH BLUE TILAPIA AND RED SWAMP CRAWFISH In: An evaluation of specific ionic and growth parameters affecting the feasibility of commercially producing red drum (Sciaenops ocellatus). Doctoral dissertation. Texas A&M University, College Station, TX. 1987.
EFFECTS OF BICARBONATE ALKALINITY AND CALCIUM ON THE ACUTE TOXICITY OF COPPER TO JUVENILE CHANNEL CATFISH (Ictalurus punctatus)

EFFECTS OF CALCIUM AND MAGNESIUM HARDNESS ON ACUTE COPPER TOXICITY TO JUVENILE CHANNEL CATFISH (Ictalurus punctatus)

UNDERSTANDING WATER HARDNESS

INTERACTIONS OF PH, CARBON DIOXIDE, ALKALINITY AND HARDNESS IN FISH PONDS
Southern Regional Aquaculture Center, Publication No. 464.

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