1991

Environmental Factors and Production Characteristics Affecting the Culture of Red Drum, Sciaenops Ocellatus.

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Order Number 9200095

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The Louisiana State University and Agricultural and Mechanical Col., 1991

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ENVIRONMENTAL FACTORS AND PRODUCTION CHARACTERISTICS AFFECTING THE CULTURE OF RED DRUM, *Sciaenops ocellatus*

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry, Wildlife, and Fisheries

by
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May 1991

ACKNOWLEDGEMENTS

I would like to thank the faculty who served on my graduate committee, Drs. Charles A. Wilson, Robert P. Romaire, James W. Avault Jr., Mark K. Johnson, and Jerrold T. Haldiman for their guidance and assistance. Special gratitude is extended to my major professor, Dr. William R. Wolters, who provided advice and support throughout my work at Louisiana State University. I'm indebted to the researchers who provided assistance, friendship, and exchange of ideas; especially Joe Craig, Mike Pursley, Cindy Chritton-Meeker, Simon Ellis, Eileen Peppard Ellis, Richard DeMay, Deb Kelly, Dave Edmonson, Ralph Laprarie, and Mark Schexnayder.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

LIST OF TABLES

Number Page

STUDY I

STUDY II

STUDY III

LIST OF TABLES (cont.)

LIST OF FIGURES

ABSTRACT

Experiments with red drum, Sciaenops ocellatus, were conducted to assess environmental requirements and culture characteristics. Pond trials were used to evaluate the effects of salinity, chloride source, predator control, acclimation procedure, stocking density, and size at stocking on production. Survival in individual ponds ranged from 0-92%; average daily weight gain from 0.46-2.22g; and feed conversion ratio from 2.30-4.90. Survival, growth, and feed conversion ratio did not differ significantly between equivalent treatments in saltwater and freshwater ponds. The minimum chloride concentration necessary for acceptable production of red drum in freshwater ponds (250-300 mg/l) was at least 100% higher than the concentrations reported to support high survival and growth in some laboratory experiments. Mortality in ponds could be attributed to hypoxia, handling and stocking stresses, and vertebrate predators. A laboratory experiment was designed to determine the dissolved oxygen tolerance of juvenile red drum in relation to temperature and salinity. Fingerling red drum acclimated to combinations of 0.5 and 5 ppt salinity and 25 and 30 C survived to low dissolved oxygen concentration (0.34 mg/l) when concentration was reduced over several hours, as might occur in culture ponds. No difference due to temperature or salinity was detected in resistance to hypoxia. Red drum survived to significantly lower mean dissolved oxygen concentration when rate of deoxygenation was reduced. Results of these experiments indicate that red drum can be successfully cultured if water quality, predation, and handling stesses are controlled.

INTRODUCTION

Red drum (<u>Sciaenops ocellatus</u>, family Sciaenidae) is a popular game and food fish along the Gulf of Mexico and South Atlantic coasts, with high consumer demand throughout the United States because of the popularity of South Louisiana cuisine. Commercial landings of red drum increased dramatically during the 1980's; 1.3 million kg were reported nationwide in 1983 (Mercer 1984) and 3.6 million kg were harvested in Louisiana waters alone in 1986 (U.S. Department of Commerce 1986). Recreational catch historically exceeded commercial landings, but this trend has reversed in the last 5 years. The National Marine Fisheries Service estimated the 1985 inshore Louisiana sportfishing catch (1.28 million kg) decreased 40% since 1980 (U.S. Department of Commerce 1986).

Conflict between commercial and recreational harvests of red drum has become an issue in the depletion of stocks in Gulf states. The Scientific and Statistical Committee of the Gulf of Mexico Fisheries Management Council recently concluded that overfishing was threatening recruitment of spawning age red drum to offshore habitats. The Committee estimated that only 3-4% of Louisiana's red drum were surviving to sexual maturity and approximately 20% escapement is needed to maintain reproductive rates necessary for continued maximum sustained yield (Condrey 1986). Size limits, seasons, and catch restrictions have been enacted in all Gulf Coast states to regulate commercial and recreational catches of red drum. Legislation in Louisiana, Florida, Mississippi, and Texas now restricts the commercial sale of red drum, and the National Marine Fisheries Service has prohibited commercial exploitation of offshore stocks (in the zone between 4.8 and 321.8 km from the coast).

In 1986 the Louisiana legislature imposed two laws to limit the catch of red drum: (1) a possession limit of two fish over 76.2 cm;

and (2) a ban on possession of red drum on boats carrying a purse seine. When the quota for commercial catch was reached in 1987, both commercial and recreational harvests of red drum were suspended for 6 months. In 1988 the Louisiana legislature imposed a moratorium on the commercial harvest and sale of wild stocks of red drum. Strict size and creel limits were also imposed on recreational fishermen. However, mariculture of red drum is still permitted under separate legislation, and inland aquaculture is permitted under fish farming regulations.

Legislative restriction on commercial capture of red drum will necessitate that red drum sold in fish markets and restaurants be imported or commercially cultivated. The need for sources of cultured red drum, promising early results from aquaculture studies, and relatively high market value have created considerable interest in commercial aquaculture ventures. Dock-side prices for red drum in Louisiana doubled between 1977 and 1981, and then tripled between 1981 and 1987. Small numbers of cultured red drum were marketed in 1989 in Louisiana for $5.0/kg whole-fish.[1]

Successes with large-scale spawning and fingerling production at stock-enhancement hatcheries in Florida and Texas have provided a fundamental knowledge base on the husbandry of red drum and have enhanced the potential for pond culture (Colura et al. 1976, Arnold et al. 1977, Roberts et al. 1978, Crocker et al. 1981, Hysmith et al. 1983). However, information on production of marketable fish in earthen ponds or recirculating systems is limited, and further information is necessary before commercial culture is feasible. Investigations into red drum culture began in South Carolina in 1947 (Lunz 1951,1956). Growth of red drum and other marine fish were

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[1] Danny Dupree, Purchasing Agent, Cajun Bayou Seafood Distributors, Baton Rouge, Louisiana, January 1991, personal communication.

monitored in extensive saltwater ponds. The only source of feed was from natural forage and yield was low (52 kg/ha/yr), but red drum attained marketable sizes of over 1.0 kg in one year. In later work in these ponds red drum survived water temperatures as low as 1 C (Bearden 1967).

Replicated pond studies utilizing formulated diets were conducted in Alabama in the mid-1970's in brackishwater ponds. Diverse stocking densities, stocking dates, growout periods, and fingerling sizes were investigated, and red drum were reared to marketable sizes on formulated diets. However, yields and survival were variable, growth was reduced by pathogens, and feed prices limited economic feasibility (Trimble 1979).

A recent grow-out experiment with red drum was conducted in plastic-lined saltwater ponds in South Carolina (Sandifer et al. 1988). Relatively high rates of water exchange (15%/day) and essentially continuous aeration with paddlewheel aerators were used to produce 7,251 - 15,011 kg/ha in 18 months. Infestation by the parasitic dinoflagellate Amyloodinium and oxygen depletion caused mortalitys in some ponds, but survival of 94.6% was attained in one pond.

In the late 1970's, research was conducted on spawning techniques and fingerling production, and food habits (Colura et al. 1976, Arnold et al. 1977, Roberts et al. 1978, Holt et al. 1981, Hysmith et al. 1982, Overstreet 1983, Lee et al. 1984, Reagan 1985). Red drum broodstock collected from natural sources were acclimated in indoor tanks equipped with biological filters, and temperature and photoperiod control. Condensing annual cycles of temperature and photoperiod to 150 days induced spawning twice per year.

Researchers have also investigated nutritional requirements, environmental requirements, and problems associated with transportation of fingerlings (Campbell 1982, Davis and Stickney 1986,

Robinson et al. 1988). Advances in these areas have further enhanced the potential for red drum culture in ponds. Although red drum are euryhaline, little comparative information exists on pond culture in different salinities. Crocker et al. (1981) found significantly greater growth for fingerling red drum in saltwater (35 ppt) than in freshwater (unspecified ion content) in flow-through raceways. Davis and Stickney (1986) reported growth and survival of fingerling red drum in freshwater channel catfish ponds was reduced when compared to fingerlings held in low salinity (4 ppt) raceways. Laboratory experiments by Wurts and Stickney (1989) indicated that adequate environmental calcium ion concentration is critical to survival of fingerling red drum, and minimum levels differ between fresh (25 mg/l) and saltwater (340 mg/l). However, because of physiochemical fluctuations common to pond environments, satisfactory conditions for red drum culture in ponds may be expected to differ from environmental minima defined in the laboratory.

Controlled studies utilizing different stocking densities, stocking sizes, or salinities have been inconclusive. The narrow scope of previous studies limits the conclusions that can be drawn regarding economic feasibility of red drum culture. Other factors such as the effects of low dissolved oxygen on red drum growth and survival are not known. Dissolved oxygen is a critical factor limiting fish production in ponds (Swingle 1969), and low dissolved oxygen levels commonly cause mortality in intensive fish culture ponds when feeding rates and water temperatures are high (Stickney 1986). The lower lethal dissolved oxygen concentration for red drum has not been established. Commercial producers need to know those concentrations that are critical to the well-being of red drum to know when to aerate ponds.

Sufficient information exists to indicate that culture of red drum is feasible in the Gulf coast region in saltwater and some

freshwater areas. However, additional research is clearly needed and results from this study will provide information about optimal stocking rates, stocking sizes, and environmental requirements necessary for commercial culture.

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PRELIMINARY INVESTIGATIONS INTO RED DRUM CULTURE IN LOUISIANA

INTRODUCTION

Red drum, Sciaenops ocellatus, commonly known as redfish, is popular among Louisiana recreational and commercial fishermen and has recently attracted culinary acclaim throughout the United States. Popularity of Cajun cuisine, particularly blackened redfish, has led to a substantial increase in red drum demand and value. Retail prices for fresh red drum fillets of more than $5 per pound are common in Louisiana. Dockside whole-fish prices have more than tripled in the last ten years, and commercial fishermen currently receive wholesale prices of $.80 to $1.50 per pound.

In 1983, 2.8 million pounds of red drum were commercially captured, and the recreational catch might have exceeded this amount. Many experts feel this yield cannot be sustained, and several states bordering the Gulf of Mexico have begun to regulate or ban the catch and sale of red drum. In light of these trends, there has been a renewed emphasis on the commercial culture of red drum to market size. Pond culture studies have shown red drum to be hardy, fast-growing, able to tolerate a wide range of salinities, and readily trainable to accept formulated fish feeds. Recent experiments in Texas, Mississippi, and South Carolina have been aimed at providing information on dietary and environmental requirements, transport of larvae and juveniles, and systems for pond production of marketable fish.

Preliminary investigations into red drum culture by the Louisiana Agricultural Experiment Station in cooperation with the

Louisiana Department of Wildlife and Fisheries and the Gulf Coast Conservation Association have focused on growth rate, survival, and feed conversion at different stocking densities in saltwater and freshwater ponds.

METHODS

Six 0.33-acre freshwater ponds at the Louisiana Agricultural Experiment Station's Ben Hur Research Farm at Baton Rouge and eight 0.25-acre saltwater ponds at the Louisiana Department of Wildlife and Fisheries' Lyle S. St. Amant Marine Laboratory near Grand Isle were stocked with 0.25 gram red drum fingerlings obtained from the Gulf Coast Conservation Association and Texas Parks and Wildlife Department. Six freshwater ponds were stocked with red drum fingerlings on 14 June 1986 (3 ponds at 2,000 per acre, 3 ponds at 4,000 per acre), and eight saltwater ponds were stocked on 29 May 1986 (4 ponds at 2,000 per acre, 4 ponds at 4,000).

Fish were fed five days per week starting with a finely ground salmon ration (49% protein) at 5 pounds/acre/day and terminating with satiation feeding of pelleted floating catfish chow (32% protein). Maximum feeding rates were 30 pounds/acre/day. Morning dissolved oxygen, temperature, and salinities were recorded daily. Emergency aeration with centrifugal pumps or paddlewheels was required when dissolved oxygen levels declined below 2.0 mg/liter, and an automatic pumping system was installed to deliver ambient Barataria Bay water daily into saltwater ponds to control water levels from pond seepage and increase dissolved oxygen levels.

Fish were harvested after 188 days. Thirty fish from each pond were weighed and measured for calculation of length-weight relationships (Table 1). A one-way analysis of variance was performed to determine if significant differences existed in harvest weight due to stocking density.

RESULTS AND DISCUSSION

Complete mortality of red drum occurred in four out of six freshwater ponds from oxygen depletion, and survival in the two remaining ponds ranged from 5 to 10%. Dissolved oxygen levels were as low as 1.0 mg/liter during early morning hours on many occasions. Other factors that may have contributed to low survival were low salinity or chloride levels, and small fish size at stocking. Chloride levels in freshwater ponds in this study were 160 mg/liter, and well above the minimum level for successful stocking of red drum at 125 mg/liter. Due to the low survival of fish (5-10%) in the freshwater ponds, no data analysis was performed.

Survival in saltwater ponds was much higher and averaged 62% (Table 2). Low dissolved oxygen levels (0.2 to 1.0 mg/liter) were also encountered in saltwater ponds during early morning hours, and complete fish mortality from oxygen depletion occurred in two out of eight ponds. Salinity during the study ranged from 16 to 28 ppt, and temperature ranged from 11.0 to 34.5 C.

No significant difference in growth due to density was observed at harvest (Table 2 and 3). Standing crops or yields from all ponds at harvest were low due to small size at stocking and low stocking rates. Feed conversion ratios were high probably the result of feed wastage during the early part of the study when fish were small. Higher yields and lower feed conversion ratios common to commercial culture with other species such as catfish might be expected with larger fingerlings, better feeding practices, and higher feeding rates during the peak of the growing season.

CONCLUSIONS

Encouraging results of this study are the rapid acceptance to pelleted feeds, acceptable pond survival in saltwater ponds, tolerance of pond conditions in saltwater ponds, and lack of

noticeable disease or parasite problems. Although growth rates were relatively rapid in this study (approximately 1.0 mm/day), it is unlikely that red drum can be raised to marketable sizes in less than one year.

Spring-spawned fingerlings used in this study averaged approximately 150 grams at harvest, well below the marketable size of 1.5-4.0 pounds. These fish would have to be overwintered and cultured for an additional growing season in order to reach market size. Successful red drum culture would then be analogous to channel catfish production with first year fingerling growth in nursery ponds followed by second year growout at lower densities in production ponds. Stocking fall spawned fingerlings would be an alternative to spring spawning. However, these fish would also have to be overwintered and may be of such a small size that considerable mortality could occur during the winter months.

Overwintering of fingerlings or submarketable fish could result in problems with mortality associated with low temperature tolerance. Although red drum have been reported to survive 2-4 C, high mortality has been reported during abrupt temperature drops associated with passages of winter cold fronts. A research study conducted by the Texas Parks and Wildlife Department determined that red drum held in freshwater (150 ppm chlorides) ceased feeding at 5-9C, and that considerable mortality is likely below 4 C in freshwater.

More research is needed before conclusions regarding the feasibility of red drum culture can be made. Additional information is needed on stocking rates, feeding rates, and the length of time required to raise red drum to marketable sizes. Although red drum can withstand a wide range of environmental conditions, efforts to culture red drum in suboptimal areas (low winter temperature, dissolved oxygen, and salinity) will undoubtedly decrease

performance, survival, and economic viability. It seems likely that red drum culture will be most feasible in brackish water southern Louisiana.

ACKNOWLEDGEMENTS

Funds for this study were obtained through the Louisiana Agricultural Experiment Station and a private grant from J. Wayne Plaisance, Inc., Galliano, LA.

Table 1.1. Length-weight relationship[1] for 0.25 gram red drum fingerlings raised in saltwater ponds for 188 days, 1986

LENGTH (mm)	LENGTH (inches)	WEIGHT (g)	LBS/1,000	#FISH/LB
25	1.0	0.15	0.33	3,015
51	2.0	1.31	2.89	346
76	3.0	4.40	9.70	103
102	4.0	10.74	23.68	42
152	6.0	36.06	79.5	13
203	8.0	86.79	191.34	5
254	10.0	171.38	377.82	3
305	12.0	298.67	658.44	2
356	14.0	477.58	1,052.87	1

[1]Log(weight) = -11.7 + 3.04(log length); r^2 = 0.99

Table 1.2. Mean (± SD)survival, growth, feed conversion, and pond yields of 0.25 gram red drum fingerlings grown for 188 days in 0.1 hectare saltwater ponds, 1986

DENSITY (#/ha)	PERCENT SURVIVAL	HARVEST WEIGHT(g)	LENGTH (mm)	FEED CONV.	YIELD (kg/ha)
5,000	63	109±43	224±29	4.9	344
5,000	66	159±131	254±39	3.1	525
5,000	48	193±98	273±43	4.1	462
5,000	70	132±71	232±40	4.1	463
10,000	71	86±43	215±29	3.5	613
10,000	53	123±72	225±36	3.3	648

Table 1.3. Mean (± SD) survival, length, weight, and yield for 0.25 gram red drum fingerlings grown for 188 days in saltwater ponds, 1986

DENSITY (#/ha)	PERCENT SURVIVAL	LENGTH (mm)	HARVEST WEIGHT(g)	YIELD (kg/acre)
5,000	62±10	246±42	148±36	449±75
10,000	62±13	221±33	104±25	630±25

Factors Affecting the Survival of Fingerling Red Drum, *Sciaenops ocellatus*, in Freshwater Ponds

ABSTRACT

Interest in red drum, *Sciaenops ocellatus*, aquaculture in inland leveed ponds has increased because of restrictions on the commercial fishery. However, survival and yield of fingerling red drum in freshwater ponds has been erratic. Acclimation rate, chloride level, salt or chloride source, and predator controls were evaluated as factors expected to affect survival of fingerling red drum stocked in freshwater ponds.

Two 30-day trials were conducted in 0.04-ha ponds stocked at 2,500 fish/ha. Twelve ponds were used in trial 1 to assess affects of two chloride levels (150 ppm and 300 ppm) and two acclimation rates (2 hours and 6 hours). Survival was poor at all treatment combinations (1.2% overall). No fish survived at 150 ppm chlorides, and only 2.3% survived at 300 ppm. Acclimation rate did not significantly affect survival. Eighteen ponds were used in trial 2 to evaluate two higher chloride levels (250 ppm and 400 ppm), two salt or chloride sources (sodium chloride and calcium chloride), and predator control treatments (insecticide treatment and net enclosures). Survival was signficantly higher at 400 ppm than at 250 ppm chlorides (49.3% vs 15.0 %) and with sodium chloride rather than calcium chloride (76.0% vs 28.7%). Predator control treatments did not signficantly affect survival. Results indicate survival as high as 90% can be obtained in inland freshwater ponds with the proper water quality parameters.

INTRODUCTION

Interest in red drum culture has increased in recent years. Market popularity has contributed to overexploitation of natural populations and subsequent restrictions on commercial red drum fisheries. Hatchery produced fingerlings have been used in several states along the Gulf of Mexico to enhance coastal populations or establish fisheries in natural freshwater systems (Lasswell et al. 1977; Dolman 1983). Interest in culture of red drum in inland low-salinity or freshwater ponds has increased because of possible legal constraints on pond construction in coastal zones. Aquifers underlying the Gulf Coast Salt Basin yield water with suitable ionic concentrations for red drum culture (Lefond 1969) in inland areas. Addition of bulk-grade salt to raise chloride levels in freshwater ponds has also been proposed as a method to provide suitable water quality for red drum culture.

Initial research on survival of red drum fingerlings in freshwater has focused on minimum ion requirements and acclimation rates. Survival of fingerling red drum in laboratory studies has been 80-85% at chloride levels of 125-130 ppm and survival did not differ between 2, 4, or 8 hours of acclimation (Dolman 1983; Miranda and Sonski 1985). Reduced fingerling survival has been demonstrated at low levels of water hardness (Davis and Stickney 1986; Wurts and Stickney 1989). In spite of adequate survival in laboratory studies, survival rates in waters of similar chemistry in freshwater and brackishwater ponds has been inconsistent (Lasswell et al. 1977; Trimble 1979).

Our preliminary studies also indicated survival rates obtained from laboratory studies were often different from pond trials. Two pond trials were conducted to evaluate effects of water quality variables such as chloride level and source, acclimation rate, and predator control on fingerling survival in freshwater ponds.

Evaluation of these effects in replicated ponds will be critical to successful culture of red drum in inland ponds.

METHODS

Two 30-day pond trials were conducted to evaluate how factors such as chloride level, acclimation rate, salt or chloride source, and predator controls affected the survival of red drum fingerlings in freshwater ponds.

Trial 1

The first 30-day trial evaluated effects of two chloride levels, two acclimation rates, and their interaction in a 2 x 2 factorial with three replicate 0.04-ha ponds for each treatment combination. Two chloride levels, 175 and 300 ppm, were obtained through additions of coarse rock salt to freshwater ponds that had been filled with wellwater at 20 ppm chlorides. Two acclimation rates, fast and slow, were used to lower the salinity from approximately 22.2 ppt in transport water to the same chloride level as the ponds. The rapid acclimation rate involved exchanging transport water with pond water to reduce salinity from 22.2 to 5.0 ppt in 1 hour followed by 1.0 ppt decreases every 10 minutes down to the pond levels. The slow acclimation differed in that each 1.0 ppt salinity decrease below 5.0 ppt was followed by a 1-hour stabilization interval.

Red drum fingerlings (mean weight = 6.0 g) were reared in laboratory conditions and held in fiberglass tanks equipped with biological filtration prior to stocking into outdoor ponds. Fish were fed a 45% protein salmon diet (Rangen Inc.) to satiation daily and transported to ponds in fiberglass tanks at 22.2 ppt salinity and 24.1 C.

Replicate ponds were stocked at 2,500 fish/ha. Fish were fed 5.6 kg/ha/day of 45% protein salmon diet daily. Chloride levels and

total hardness were measured at the beginning and end of the pond trial by mercuric nitrate titrations for chlorides and EDTA titrations for hardness (APHA 1980). Temperature, conductivity, and dissolved oxygen were measured each morning before dawn with electronic meters (Yellow Springs Instruments).

Ponds were drained after 30 days and survival rates calculated. A two-way analysis of variance was used to determine significant differences in survival at different treatment combinations. A square-root transformation was used to correct for skewness produced by low survival values in comparison of means by analysis of variance (Steel and Torrie 1980).

Trial 2

The second 30-day trial evaluated effects of two higher chloride levels, 250 and 400 ppm, in 0.04-ha earthen ponds with three replicate ponds at each chloride level. Chloride levels were adjusted to desired levels as described in trial 1. A different series of twelve ponds was used to compare effects of chloride source (sodium or calcium chloride) and predator control methods (insecticide or net enclosure) on survival in a 2 x 2 factorial with three replicate ponds for each treatment combination. Six ponds were adjusted to 300 ppm chlorides with either sodium chloride or calcium chloride. Six ponds were treated with fenthion at 0.25 ppm to control aquatic insects prior to stocking fingerling red drum. Net enclosures (1 m x 2 m x 1 m deep) with 0.5- mm nylon mesh were placed in three sodium chloride ponds not treated with insecticide.

Fingerlings (mean weight = 8.5 grams) were from the same source as in trial 1 and acclimated at the slow rate to pond conditions prior to stocking. Ponds were stocked at 2,500/ha and each net enclosure was stocked with 20 additional fish. Water quality measurements were taken as described in trial 1. Fish in ponds were

fed 5.6 kg/ha on alternate days and those in nets 0.1kg/net on alternate days. Ponds were drained after 30 days and survival rates were calculated. One-way analyses of variance were used to test for significant differences in survival between 250 and 400 ppm chlorides and between net enclosures and open ponds. A two-way analysis of variance was used to test for differences in survival between chloride sources (sodium and calcium chloride), insecticide pretreatment, and their interaction.

RESULTS

Trial 1

Water temperature at stocking was 24.1 C and morning temperatures ranged from 18.5 to 29.0 C during trial 1. Morning dissolved oxygen levels ranged from 2.6 to 12.4 ppm. Emergency aeration with centrifugal pumps was used on two occasions when the dissolved oxygen level fell below 3.0 ppm. Chloride levels were within 15% of target levels (175 and 300 ppm) during the 30-day trial. Actual mean chloride levels for the two treatment levels determined from titrations were 177.5 ppm and 284.2 ppm, respectively. Total hardness for the two chloride levels were 151.6 and 183.3 ppm.

No significant differences in survival were found between treatment combinations (Table 1). Overall survival was poor in all treatment combinations. No fish survived at 175 ppm chlorides and only 2.3% survived at 300 ppm chlorides. Fish subjected to rapid acclimation had 1.0% survival while slow acclimation yielded 1.3% survival.

Trial 2

Water temperature at stocking was 22.0 C and morning temperatures ranged from 10.5 to 20.0 C. Morning dissolved oxygen levels remained above 5.8 ppm during the entire 30-day trial.

Because of leakage, one of the ponds had to be deleted from the analysis.

Chloride levels determined from titrations were within 6% of target values (250 and 400 ppm). Actual mean values were 242.7 and 425.6 ppm, respectively. Significant differences in survival were found between the two chloride levels (Table 2). Mean survival was 9.0% at 250 ppm and 49.3% at 400 ppm.

A significant difference in survival was found for chloride source, but not for insecticide pretreatment (Table 3). The mean chloride level for both sources was 296.5 ppm and was within 1% of the target value (300 ppm). Mean fingerling survival in ponds adjusted with sodium chloride was 76.0%, whereas survival in ponds adjusted with calcium chloride was 28.7%. Ponds adjusted with calcium chloride had significantly higher hardness levels than those adjusted with sodium chloride: 622.5 and 329.3 ppm, respectively.

Survival in ponds pretreated with insecticide (40.0%) was not signficantly different than in nontreated ponds (55.0%). Stocking of fingerlings into net enclosures had no signficant effect on survival. Survival in net enclosures was $66.7 \pm 23.6\%$ while survival in the open ponds in which nets were placed was $82.7 \pm 8.3\%$.

DISCUSSION

Overall survival among treatments and ponds varied considerably and was similar to previous studies (Lasswell et al. 1977; Trimble 1979). Although laboratory studies have shown high survival (80-85%) of red drum fingerlings at 125-130 ppm chlorides (Dolman 1983; Miranda and Sonski 1985), survival of fingerlings at similar levels in outdoor ponds in this study was unacceptable for successful aquaculture production.

Results of these trials more closely follow recent laboratory

trials by Pursley and Wolters (1989) in which significant variations in growth, survival, and feed conversion of 3- to 6-gram red drum was found among 100, 200, and 400 ppm total hardness and 125, 150, 250, and 500 ppm chlorides. Higher chloride levels had a greater effect on survival, growth, and feed conversion than higher hardness levels. Minimum chloride concentration for acceptable and consistent freshwater pond culture is probably 250-300 ppm based on the results of the laboratory study by Pursley and Wolters (1989) and these pond trials. Stocking into freshwater ponds below 250 ppm chloride has yielded inconsistent and low survival. Factors such as the fluctuations in oxygen, temperature, pH, and handling stress may contribute to the higher minimum chloride concentration required for pond culture.

Fewer red drum fingerlings survived in ponds supplemented with calcium chloride than in ponds supplemented with sodium chloride. Both treatments had the same chloride levels, but the calcium chloride ponds had higher water hardness (622.5 vs. 329.3 ppm) and might have been expected to yield higher survival. Lower survival rates in calcium chloride supplemented ponds may be due to relatively low sodium levels (approximately 22 ppm). Though environmental calcium has been shown to inhibit the sodium efflux rate in seawater acclimated fishes transferred to freshwater (Pickford et al. 1966; Potts and Fleming 1971; Carrier and Evans 1976; Pic and Maetz 1981), there may be a minimum sodium requirement for marine fish in freshwater. Hulet et al. (1967) showed several species of marine fish to thrive in markedly hypo-osmotic solution to which calcium had been added, but freshwater used in the study contained sodium concentrations of at least 150 ppm. Wurtz and Stickney (1989) experimented with juvenile red drum at several calcium levels, unreported chloride levels, and at least 170 ppm sodium. They suggested an optimum calcium:sodium ratio of 0.038:1 at 59 ppm

calcium and 1,526 ppm sodium. Although minimum concentrations of sodium ions have not been established, water containing low sodium concentrations are probably not suitable for red drum culture. Minimum sodium requirements need to be established for rearing red drum in freshwater of varied ionic content.

Predaceous insects were evidently not a source of mortality for fingerling red drum (6.0-8.5 g; 76-102 mm) used in this study. Since insect larvae are often found in the stomachs of fingerling red drum raised in earthen ponds, insecticide treatment may actually reduce a desirable food source. Holding fingerling red drum in net enclosures after stocking also did not improve fish survival. Fingerlings used in this study were probably large enough to avoid invertebrate predators common to pond systems.

Results of this study indicate that acceptable pond survival can be obtained in inland freshwater ponds with the proper ion content. Use of inland leveed ponds filled with groundwater containing suitable chloride, water hardness, and sodium levels would minimize concern over ecological impacts from pond construction in coastal regions.

ACKNOWLEDGEMENTS

Partial funding for this project was obtained from the Louisiana Board of Regents through the Louisiana Education Quality Support Fund (Contract Number LEQSF(1986-1989)-RD-B-07.

Table 2.1. Survival (%) of red drum fingerlings stocked into earthen ponds at two chloride levels (ppm) and acclimated at two rates (h) in trial 1.

Pond	Acclimation Rate	Chloride Level	Measured Chloride	Survival	Treatment Mean Survival
23	2	175	192.6	0.0	0.0±0.0
24	2	175	165.0	0.0	
27	2	175	176.7	0.0	
20	2	300	264.6	6.0	2.0±3.1
25	2	300	310.9	0.0	
30	2	300	266.3	0.0	
19	6	175	166.7	0.0	0.0±0.0
26	6	175	181.6	0.0	
28	6	175	182.4	0.0	
21	6	300	275.6	4.0	2.7±1.2
22	6	300	296.7	2.0	
29	6	300	291.3	2.0	

Table 2.2. Survival (%) of red drum fingerlings stocked into earthen ponds at two chloride levels (ppm) in trial 2.

Pond	Chloride Level	Measured Chloride	Survival	Treatment Mean Surv.
2	250	264.2	6.0	9.0±4.2
3	250	221.1	12.0	
4	400	455.5	56.0	49.3±6.1
5	400	385.3	48.0	
6	400	435.9	44.0	

Table 2.3. Survival (%) of red drum fingerlings stocked into earthen ponds supplemented with two salt sources and treated with insecticide in trial 2.

Pond	Salt Source	Insecticide	Measured Chloride	Hardness	Survival	Treatment Mean Surv.
20	NaCl	No	351.2	311.2	92.0	82.7±8.3
25	NaCl	No	334.1	296.7	80.0	
28	NaCl	No	268.8	355.4	76.0	
23	NaCl	Yes	269.9	322.3	74.0	69.3±5.0
26	NaCl	Yes	253.4	322.2	70.0	
29	NaCl	Yes	405.6	355.9	64.0	
21	$CaCl_2$	No	246.7	541.4	44.0	27.3±16.0
24	$CaCl_2$	No	237.6	588.2	12.0	
27	$CaCl_2$	No	292.0	630.9	26.0	
19	$CaCl_2$	Yes	316.6	695.3	40.0	30.0±11.1
22	$CaCl_2$	Yes	306.3	674.4	32.0	
30	$CaCl_2$	Yes	275.5	602.9	18.0	

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FIRST-YEAR GROWTH OF RED DRUM, *Sciaenops ocellatus*, IN FRESHWATER AND SALTWATER PONDS

ABSTRACT

Fingerling red drum of two sizes (7 and 27 g) were stocked at two densities (4,075 and 8,150/ha) into replicate freshwater ponds adjusted to 400 mg/l chlorides. For comparison, a concurrent trial was conducted with 27 g fish at 4,075/ha in saltwater ponds. After 150 days, average daily weight gain of small fingerlings was 0.73 g, and of large fingerlings 2.00 g (freshwater) and 2.22 g (saltwater). Mean specific growth rate was higher for small fingerlings. No significant differences ($P > 0.95$) in survival (33.3-43.1%) or feed conversion ratio (2.99-4.11) were found between stocking rates or stocking sizes in freshwater. Survival (55.5%), individual final weight (360.4 g), pond yield (706.3 kg/ha) and feed conversion (2.16) were not significantly different in red drum grown in saltwater ponds from those in the comparable freshwater treatment. Problems were encountered with post-stocking mortality and predation. Indications are that large-scale freshwater culture of red drum is technically feasible with proper water quality, predation control, and minimal handling of fish.

INTRODUCTION

As the harvest of wild populations of red drum, Sciaenops ocellatus, has declined, interest in the culture of the species has increased. Red drum are euryhaline, tolerating salinities of less than one part per thousand (ppt) (Crocker et al. 1981, Miranda and Sonski 1985, Pursley and Wolters 1989) to more than 45 ppt (Simmons 1957). Most investigations into pond culture of red drum have been conducted with water of appreciable salinity: 3-19 ppt (Trimble 1979), 20-34 ppt (Hopkins et al. 1986), 26-32 ppt (Sandifer et al. 1988). In order evaluate the potential for pond culture of red drum in non-coastal areas, we previously looked at short term (30 day) survival of juvenile red drum in freshwater ponds having chloride concentrations of 100-400 mg/l (Thomas and Wolters, in review). The current study evaluates longer term (150 day) performance of two fingerling sizes stocked at two densities into freshwater ponds adjusted to chloride levels at the upper range of the previous trials. Additionally, we conducted a concurrent trial in saltwater ponds in which one stocking treatment combination was repeated, for comparison of freshwater and saltwater production.

METHODS

Freshwater Ponds

Twelve replicate 0.04-ha ponds were filled with wellwater having 40 mg/l chloride. Each was adjusted to 400 mg/l chloride with coarse rock salt and fertilized with 1.5 kg superphosphate. One week later, ponds were stocked at night with pond-reared red drum fingerlings which were produced from captive broodstock. Three ponds were stocked with each combination of two treatments: fingerling size (6.7 g or 27.4 g mean individual weight) and stocking rate (4,075 or

8,150 fish/ha). Fingerlings were transported at 27 C and 10 ppt salinity with 10 mg/l nitrofurazone added to hauling water. Acclimation to pond conditions was accomplished by water exchange, reducing salinity to 5 ppt in the first hour with continued reduction of 1 ppt at hourly intervals. Large fingerlings (27.4 g) were fed floating pellets of 35% protein red drum diet (Table 1) to satiation daily. Small fingerlings (6.7 g) were fed a mixture of sinking and floating pellets of 35% protein red drum diet at 7% initial weight per day until surface feeding became apparent, after which floating pellets were fed to satiation. All ponds were equipped with 0.33 hp electric aerators which operated automatically for 6 hours each night.

Dissolved oxygen and water temperature were measured daily before dawn with an electronic meter (Yellow Springs Instuments Model 51B). Additional aeration with a tractor-powered paddlewheel was provided when when dissolved oxygen concentration dropped to less than 3.0 mg/l. Additional water quality parameters were measured every 10 days. Conductivity and pH were measured with electronic meters (Yellow Springs Instruments Model 33 and Orion Research Model 701 A). Total hardness and chloride measurements were by EDTA and mercuric nitrate titrations (APHA 1980). Total ammonia determination was made with an electronic colorimeter (Hach Model DR200). Alkalinity and nitrite concentrations were measured with Hach (Model FF1-A) titrations, and chlorophyll-a concentrations were determined with a Turner Model 112 fluorometer.

Ponds were drained and fish harvested after 150 days. Mean specific growth rates (G) were calculated according to Brown (1957): $G = (\log_e W_t - \log_e W_0)\ 100\ /\ t$. Treatment effects on survival, specific growth rates, and feed conversion were analyzed with ANOVA using 2 x 2 factorial arrangements. Duncan's New Multiple Range test was used to determine if water quality parameters differed

between treatments. Regression of principal components was used to evaluate the relative contributions of water quality parameters to survival, specific growth rate, and feed conversion.

Saltwater Ponds

A concurrent 150-day trial was conducted in three 0.1-ha saltwater ponds at the Louisiana Wildlife and Fisheries Lyle St. Amant Marine Laboratory on Grande Terre Island. Ponds were stocked with 27.4 g red drum fingerlings at 4,075/ha. Fish were fed to satiation four or five days per week with the same diet used in the freshwater trial. To maintain water quality, ponds were overflowed with bay water at 90 l/min/pond for eight hours each night. Fish were harvested after 150 days. One-way analyses of variance were used to compare survival, yield, mean individual weights with the equivalent freshwater treatment.

RESULTS

Freshwater Ponds

Changing levels of rainfall, evaporation, and pond seepage, along with the need to add water and salt separately caused wide variation in chloride concentration (201-612 mg/l) and conductivity (1,100-2,300 micromhos). However, mean values did not differ significantly ($P > 0.95$), Duncans New Multiple Range Test, Table 2) between treatments for conductivity, chloride concentration, total hardness, alkalinity, pH, total ammonia, or dissolved oxygen. Only one non-zero nitrite value was recorded during the study; 0.165 mg/l nitrite was present in the pond having highest fish biomass on the final date tested. Mean chlorophyll *a* concentration (2.63 μ/l) was

significantly higher in the large fingerling/low density ponds than in other treatments, and was significantly lower in the small fingerling/low density treatment (0.00068 mg/l). Water temperatures in ponds stocked with large fingerlings were significantly warmer than temperatures of small fingerling ponds.

Principal component analysis produced three main factors which together explained 84.2% of total variance in water quality parameters (Table 3). Factor 1 showed a tendency for high values of conductivity, chloride, total hardness, alkalinity, chlorophyll a, dissolved oxygen, and temperature to occur together. Factor 2 indicated that low pH values occurred with high values of alkalinity and hardness, and in factor 3 lower temperatures were related to higher total ammonia concentrations. Regression of these factors on survival, feed conversion ratio, and specific growth rate (Table 3) demonstrated significant ($P > 0.95$) relationships for the models:

SURVIVAL = FACTOR1 + FACTOR2 + FACTOR3
SURVIVAL = FACTOR1
FEED CONVERSION RATIO = FACTOR1

Survival in freshwater ponds ranged from 7.9% in one large fingerling/low density pond, to 63.6% in another pond stocked with the same treatment combination (Table 5). Overall mean survival was 38.4% in freshwater; differences due to stocking size, stocking rate, or size/rate interaction were not significant (Table 6).

Small fingerlings averaged 116.8 g after 150 days; large fingerlings grew to a significantly larger average weight (342.5 g). Final mean individual weight did not differ between fingerlings of the same size stocked at 4,075 or 8,150 fish/ha. Mean specific growth rate was higher for fingerlings stocked at 6.7 g (mean 2.85; Table 4) than for those stocked at 27.4 g (mean = 2.52). Feed conversion did not differ significantly due to stocking size or stocking rate.

Saltwater Ponds

Salinity ranged from 19-24 ppt during the trial. Survival in saltwater ponds was 26.4%, 66.3%, and 73.9%. Comparison of the performance of red drum at equivalent treatments in freshwater and saltwater ponds by one-way analyses of variance showed no significant differences in survival, final weight, yield, or feed conversion ratio (Table 7).

DISCUSSION

In freshwater ponds maximum and minimum values of temperature (11.8-30.5 C), chloride concentration (201-612 mg/l), ammonia concentration (0.0016-0.0205 mg/l as unionized ammonia), and total hardness (161-361 mg/l) remained within what are generally believed to be acceptable levels for red drum (Neill 1987). Alkalinity (151-325 mg/l) was adequate to prevent excessive pH fluctuation (Stickney 1979).

On six occasions in freshwater ponds morning dissolved oxygen concentrations of individual ponds were below 3.0 mg/l, and additional aeration was provided. The lowest recorded dissolved oxygen concentration was 1.2 mg/l, which is above the acute lethal level for juvenile red drum at similar temperature and salinity (Thomas and Wolters 1990, publ. abstract).

Temperature differences between freshwater ponds stocked with small and large fingerlings may have been due in part to increased absorption of solar radiation from increased turbidity in the ponds stocked with large fingerlings. Non-biological turbidity was probably higher in ponds with higher fish biomass due to suspension of sediments by fish activity. Light extinction by suspended sediments would also be expected to reduce algal growth, and could

have caused the reduced chlorophyll a concentrations seen in the large fingerling/high density ponds.

Principal component analysis of mean water quality parameters produced three factors which were each responsible for explaining more than 10% of the total variance. The reasons for particular factor patterns can be varied. Factor 1 showed that high values of conductivity, chloride, total hardness, alkalinity, chlorophyll a, dissolved oxygen, and temperature were correlated. Varying inputs of salt and wellwater, and normal physiochemical variation between ponds (affecting especially conductivity, chloride, total hardness, and alkalinity) contribute to biological cycles (influencing chlorophyll a/dissolved oxygen/temperature cycles) which in turn affect water chemistry. The buffering effects of higher alkalinity and hardness would be expected to prevent rises in pH (factor 2), and nitrification rates could be slowed with lower temperatures (factor 3).

The regression models which demonstrated the most significant relationship of water quality parameters to survival rate and feed conversion ratio included only factor 1 (Table 3). Higher survival and lower feed conversion ratios were found to be related most significantly to higher levels of conductivity, chloride, total hardness, alkalinity, chlorophyll a, dissolved oxygen, and temperature.

Specific or instantaneous growth rate has been used to compare growth of a species at different ages (Brown 1957) or during different seasons (Brett 1944). Specific growth rate is greatest for the young of many fish species, and declines with age therafter (Ricker 1975), and may decline to zero after the onset of sexual maturity in some species (Brown 1957). The difference in mean specific growth rate between fish of two size groups in the present study follows this trend.

Absolute growth rates (expressed as average daily weight gain or mean individual weight gain per day) are commonly reported for red drum cultured in ponds. These rates are typically lower for smaller fish: Clark and Linton (1986) found 0.6-0.7 g/day growth for fingerlings stocked at 0.4 g and cultured for 149 days, while Trimble (1979) reported 1.1 g/day growth for 11.5 g fish over 290 days. Hopkins et al. (1986) found 1.1 g/day growth for 0.3 g fish over 270 days, but 2.2 g/day gain for these fish (beginning at 304 g) for days 270-630. The absolute growth rate for 6.7 g fish in the current trial (0.73 g/day for 150 days) is between the rates reported by Clark and Linton (1986) and Trimble (1979) for smaller and larger fingerlings. Growth of 2.00 g/day (freshwater) and 2.22 g/day (saltwater) for red drum stocked at 27.4 g in our study is better than might be expected from the reports from previous research using appreciable fish densities and formulated diets. Clark and Linton (1986) reported 2.8 g/day growth over 290 days for fingerlings <1 g stocked into a freshwater pond containing hybrid tilapia for forage.

No differences in final mean individual weight were seen between stocking rates of 4,075 or 8,150 fish/ha for fish stocked at either 7 g or 27 g. This indicates that higher stocking rates should be feasible without growth inhibition. Sandifer et al. (1988) found similar mean fish weights (0.9-1.3 kg) at harvest for red drum stocked at 7,500, 15,000, and 22,500 per hectare. These fish were stocked into saltwater ponds at 1.7-3.0 g and fed for about 540 days. Fish in high and medium density ponds died from Amyloodinium infestation and oxygen depletion. These high stocking densities for red drum did not appear to inhibit growth, but may have increased risk of mortality due to poor water quality and parasitism.

Predation by birds was a cause of mortality of red drum in the freshwater ponds. During the latter part of the trial, red drum were often seen schooling in shoreline areas. Ospreys (Pandion haliaetus)

and especially great blue herons (Ardea herodias) were seen preying on the fish. While only a few fish bearing wounds were found during the study, harvest revealed fish carcasses in most ponds, and many of the red drum from some ponds had fresh or healed wounds. Saltwater ponds had walled sides which effectively excluded wading birds. In addition to reducing survival in the freshwater trial, predation increased feed conversion ratios. The fact that fish were lost late in the study after considerable feed consumption and growth produced higher calculated conversion ratios than were expected for surviving fish. Still, conversion ratios ranged from 2.30 to 5.32 (mean=2.99) in freshwater ponds and 1.57 to 2.52 (mean=2.16) in saltwater; these data compare favorably with others reported for first-year red drum held in ponds: 4.6 (Trimble 1979), and 5.2 (Hopkins et al. 1986). In the current study, care was taken to feed only the amount consumed readily at each feeding. Higher survival rates would produce more accurate, and probably lower, feed conversion ratios. Feed conversion ratios for red drum can also be expected to improve as ongoing research in red drum nutrition provides the information required for optimal diet formulations.

First-year pond grow-out of red drum has in the past produced reports of survival of 68% (Clark and Linton 1986) to 98.2% (Hopkins et al. 1986). Lower survival in the current study (38.4% overall in freshwater ponds and 55.5% in saltwater) may have been due to handling and transport as well as to predation. All fish were individually counted for stocking, and fish stocked in saltwater ponds underwent both road and boat transport with the necessary transfer handling between tanks. Relatively high rates of observed mortality (4.2-39.1%) occurred in freshwater ponds during three days post-stocking. Crocker et al. (1981) reported that nearly half of all mortality experienced during growth trials of red drum in raceways occurred during or immediately following hauling and

handling. Improved post-stocking survival of red drum can probably be accomplished by minimizing net handling of fish; Flagg and Harrell (1990) found that water-to-water transfer of salmon smolts produced higher survival (85%) than did dip-net handling (48%).

The results of these trials indicate that use of freshwater ponds of suitable ionic profile can be an option for the culture of red drum. However, techniques which minimize both handling stress and opportunities for predation will be necessary if expanded efforts at pond culture of red drum are to be profitable.

Table 3.1. Formulation of red drum diet (LSU Red Drum 35) used in freshwater and saltwater growth trials.

INGREDIENT	Percent[a]	%CP[b]	%EE[c]	%NFE[d]
Soybean meal (45% CP)	55.0	24.64	0.66	16.99
Corn grain, ground	20.0	1.92	0.76	14.16
Menhaden meal	10.0	6.11	0.96	0.08
Wheat middlings	5.5	0.90	0.24	3.11
Crab meal	5.0	1.61	0.10	0.37
Dicalcium phosphate	2.0			
Menhaden oil	0.8		0.80	
Vitamin mix	0.1			
Mineral mix	0.1			
Menhaden oil (top spray)	1.5		1.50	
	100.0	35.18	5.02	34.71

[a] Percent as fed, dry weight

[b] Percent crude protein

[c] Percent ether extract

[d] Percent nitrogen-free extract

Table 3.2. Mean (± standard deviation) of water quality variables for treatment combinations of stocking size (SM=6.7 g, LG=27.4 g) and stocking density (LOW=4,075/ha, HIGH=8,150/ha) of red drum in freshwater ponds. Units are: micromhos (conductivity); mg/l (chlorides, total hardness, alkalinity, total ammonia, dissolved oxygen); μg/l (chlorophyll a); degrees C (temperature). Values of water quality parameters followed by the same letter do not differ significantly between treatments.[a]

	TREATMENT			
	SM/LOW	SM/HIGH	LG/LOW	LG/HIGH
Conductivity	1677±263 A	1722±269 A	1788±238 A	1671±171 A
Chloride	412±87 A	426±78 A	447±92 A	396±85 A
Total Hardness	257±53 A	275±49 A	276±43 A	263±31 A
Total Alkalinity	217±51 A	237±43 A	240±37 A	225±57 A
pH	8.4±0.3 A	8.4±0.3 A	8.4±0.3 A	8.3±0.3 A
Total Ammonia	0.33±0.26 A	0.46±0.40 A	0.41±0.31 A	0.47±0.55 A
Chlorophyll a	0.68±1.01 A	1.84±1.45 A B	2.63±1.92 B	1.54±1.10 A B
Dissolved Oxygen	5.8±1.7 A	6.0±1.1 A	6.1±1.1 A	5.8±1.3 A
Water Temperature	25.4±3.7 A	25.5±3.7 A	26.0±3.4 B	25.9±3.4 B

[a] Horizontal treatment comparisons

Table 3.3. Principal component loadings extracted from 9 environmental variables from freshwater red drum culture ponds: proportion of total variance explained by each of three main factors, and factor pattern values > ±0.45.

	FACTOR 1	FACTOR 2	FACTOR 3
PROPORTION OF VARIANCE	0.487	0.245	0.110
FACTOR PATTERN			
Conductivity	0.923		
Chloride	0.874		
Total Hardness	0.686	0.500	
Total Alkalinity	0.508	0.718	
pH		-0.929	
Total Ammonia			0.768
Chlorophyll<u>a</u>	0.881		
Dissolved Oxygen	0.848		
Water Temperature	0.584		-0.492

Table 3.4. Results of regression of factors of principal components (Factors 1-3) on survival (SURV), feed conversion ratio (FCR), and specific growth rate (SGR) of juvenile red drum cultured in freshwater ponds.

MODEL	PR>F	R^2	T/H_0: PARAMETER=0
SURV=F1+F2+F3	0.045	0.615	F1=3.40 F2=0.64 F3=0.35
SURV=F1	0.005	0.557	F1=3.54
FCR=F1+F2+F3	0.213	0.412	F1=-2.14 F2=-0.88 F3=-0.51
FCR=F1	0.048	0.336	F1=-2.25
SGR=F1+F2+F3	0.592	0.202	F1=-0.12 F2=-0.04 F3=1.42

Table 3.5. Mean values (± standard deviations) for percent survival, individual weight, specific growth rate, and feed conversion ratio for red drum stocked into freshwater ponds at two sizes (SM=6.7 g, LG=27.4 g) and two densities (LOW=4,075/ha, HIGH=8,150/ha).

	TREATMENT			
	SM/LOW	SM/HIGH	LG/LOW	LG/HIGH
SURVIVAL	35.1±5.7	43.1±16.2	42.0±29.9	33.3±14.5
WEIGHT	118.7±14.1	114.8±24.2	327.8±65.6	357.1±14.1
SGR	2.87±0.12	2.83±0.20	2.47±0.21	2.57±0.04
FCR	4.11±0.53	3.39±1.67	2.99±0.21	3.20±0.04

Table 3.6. Statistical results (PR>F) of two-way analyses of variance testing differences in percent survival, mean final individual weight, specific growth rate, and feed conversion ratio of red drum stocked into freshwater ponds at 6.7 or 27.4 g and 4,075 or 8,150/ha over 150 days.

	SIZE	DENSITY	SIZE*DENSITY
SURVIVAL	0.8987	0.9749	0.4628
WEIGHT	0.0001	0.5620	0.4510
SGR	0.0072	0.7659	0.4619
FCR	0.3142	0.6857	0.4703

Table 3.7. Mean values, standard deviations, and statistical results (PR>F) of one-way analyses of variance of percent survival, individual weight (g), yield (kg/ha), and feed conversion ratio for 27.4 g red drum stocked at 4,075/ha into fresh and saltwater ponds.

	FRESHWATER	SALTWATER	PR>F
SURVIVAL	42.0±29.9	55.5±25.5	0.5829
WEIGHT	327.8±65.6	360.4±118.8	0.6984
YIELD	532.1±402.6	706.3±193.8	0.5365
FCR	2.99±0.21	2.16±0.42	0.0609

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Dissolved Oxygen Tolerance of Juvenile Red Drum, *Sciaenops ocellatus*, in Relation to Temperature and Salinity.

ABSTRACT

The lower lethal dissolved oxygen concentration for juvenile red drum, (*Sciaenops ocellatus*), was determined in a recirculating vacuum degassing system. Red drum (mean weight 16.65 g) were acclimated for 10 days at treatment combinations of 25 and 30 C and 0.5 and 5.0 ppt salinity. Fish were placed in four sealed 24 l tanks and water at acclimation temperature and salinity was recirculated through each tank at 4 l/min. Dissolved oxygen content was reduced from 8.0 mg/l by increasing the vacuum in the degasser at 1/2-hour intervals. The lethal dissolved oxygen concentration was recorded for each fish with four replicates at each temperature/salinity combination. Four additonal trials were conducted by increasing the vacuum rate at 1-hour intervals to assess the effect of rate of oxygen decrease on lethal concentration. Overall mean lethal dissolved oxygen level was 0.355 mg/l when the vacuum rate was reduced at 1/2-hour intervals, and juveniles survived to lower dissolved oxygen levels (0.289 mg/l) by increasing vacuum level at 1-hour instead of 1/2-hour intervals ($P>T=0.002$). There were no significant effects of of temperature or salinity ($P>F>0.05$) on lethal dissolved oxygen concentration, but interaction between these factors was significant ($PR>F= 0.0001$).

INTRODUCTION

The red drum (Sciaenops ocellatus) is a euryhaline marine sciaenid common to the Gulf of Mexico and the Mid- and South Atlantic coasts of the United States. Due to recent high demand, and the resultant heavy pressure on natural stocks, capture fisheries have been limited or curtailed in many areas, and interest in culture of the species has expanded. Low salinity inland sites may have advantages over coastal locations for the culture of red drum. There are extensive areas in states bordering the Gulf of Mexico which have saline groundwaters (Lefond 1969) suitable for red drum culture. Use of inland locations avoids the wetland-use problems associated with coastal sites.

One of the most critical environmental factors in fish culture is dissolved oxygen concentration (Stickney 1979). Typically, dissolved oxygen (DO) levels in ponds are highest in the afternoon, after maximum algal photosynthesis. During the night, respiration of pond organisms consumes dissolved oxygen reserves, sometimes at high rates and to the point of complete anoxia. An understanding of the ability of a cultured species to tolerate this phenomenon will help to evaluate its general culture potential, and to outline its need for supplemental aeration.

In order to evaluate the response of juvenile red drum to hypoxia in brackish water conditions, laboratory experiments were conducted at combinations of 0.5 and 5 ppt salinity and 25 and 30 C. The specific objective was to approximate the conditions of oxygen depletion as they might occur in a culture pond during the warmer months, when oxygen depletions occur most often.

METHODS

A vacuum degassing device was constructed based on the design described by Mount (1961, 1964). A vacuum chamber was constructed of 30.5 cm diameter schedule 80 PVC pipe, 213 cm in length (Figure 1). Vacuum was provided with a 1/3 horsepower vacuum pump capable of 1 x 10^{-4} Torr ultimate vacuum (Precision Scientific, Model D-75). Vacuum level was controlled with a mechanical regulator (Squire-Cogswell Model VR3600). Water was recirculated through the vacuum chamber, through heating and cooling units, and through four sealed 24-l tanks with a 3/4 hp magnetic-drive pump (Tecumseh Products Model TE-7-MD-HC). Flow meters (Blue-White Industries) were adjusted to provide 4 l/min exchange through each tank. Water temperature was maintained by heating to experimental level during set-up, when thermostatic control of the cooling unit would prevent further rise in temperature. Dissolved oxygen was continuously monitored with an electronic meter (YSI Model 58) equipped with a probe stirrer and connected to a graph recorder.

Red drum fingerlings (mean weight 16.65 g) were placed in four 300 l acclimation tanks equipped with biological filters and maintained at either 25 or 30 C and 0.5 or 5.0 ppt salinity for at least 10 days. Fish were fed to satiation once daily with 40% protein salmon feed (Rangen, Inc.). Food was withheld for 24 hours prior to each experimental trial.

In each trial, two fish were placed into each of the four experimental tanks at the conditions to which they were acclimated. Initial water pH and ammonia were recorded (Sargent Welch Model PH8000 and Hach Colorimeter Model DR100, respectively). Tanks were sealed with tops of clear acrylic seated on gaskets below the water surface to eliminate uptake of atmospheric gasses and allow observation of test animals. Dissolved oxygen concentration was

reduced from an initial level of 8.0 mg/l by increasing the vacuum level by 12.7 cm Hg vacuum at 30-min intervals; from 25.4 cm Hg to 76.2 cm Hg. Elapsed time and dissolved oxygen concentration was recorded at the death of each fish (defined for this experiment as the point when opercular movement ceased). When all fish were dead, each was weighed and the pH and ammonia concentration of system water were measured.

Four trials were conducted at each of the four combinations of temperature and salinity. Four trials were also conducted at 25 C and 5.0 ppt with 1-hour intervals between successive increases in vacuum level to evaluate the effect of reduced deoxygenation rate. Order of the trials at each condition of temperature, salinity, and oxygen depletion rate was random. Testing for differences in mean lethal dissolved oxygen level was with ANOVA using a 2 x 2 factorial arrangement of treatments. Effect of rate of oxygen reduction on lethal concentration at 25 C and 5.0 ppt was tested by t-test.

RESULTS

Graphs of deoxygenation curves showed little variation between trials at the different temperatures and salinities. Consistent rates of deoxygenation were achieved by careful maintenance of vacuum level and water flow rate. Temperature varied no more than ± 0.2 C during deoxygenation trials.

As dissolved oxygen concentration was reduced, fish typically went from resting or slow swimming to what appeared to be searching behavior at about 3 mg/l dissolved oxygen (Fig. 2). At between 3 and 2 mg/l, fish moved up in the water column and swam throughout the tank. At 1.5 mg/l, searching behavior became much more rapid. Between 1 mg/l and 0.5 mg/l, most fish would attempt to pipe, or

orient vertically in the water column to accesss the water surface. Loss of equilibrium followed, with cessation of buccal/opercular ventilation occurring at between 1.5 and 0.2 mg/l. Overall mean lethal concentration was 0.34 mg/l. Increasing vacuum levels by 12.7 cm Hg/30 min produced mean lethal dissolved oxygen concentration (0.379 mg/l) in 166 minutes, while vacuum increases of 12.7 cm Hg/h produced lethal dissolved oxygen concentration (0.289 mg/l) in 291 minutes. The mean lethal concentration for standard and reduced rates differed significantly (PR> T = 0.002).

Water quality parameters remained acceptable through the trials. Initial pH ranged from 8.32 to 8.61 (Table 1), with maximum pH shift over the course of a trial of 0.05 units. Mean un-ionized ammonia concentration rose by 0.04 mg/l during each trial.

Red drum subjected to the standard deoxygenation rate survived to a mean dissolved oxygen concentration of 0.36 mg/l. Mean lethal concentration for treatment combinations ranged from 0.28 mg/l at 25 C and 0.5 ppt, to 0.44 mg/l at 30 C and 0.5 ppt (Table 2). Analysis of variance indicated that interaction of main effects contributed significant variance (Table 3), masking the contributions of temperature and salinity. Significant variation between trials at each treatment combination was apparent (P = 0.0007). No differences were seen between responses in the four tanks in the degassing apparatus (PR>F = 0.77). Regression of fish weight (range 6-34 g) on lethal DO concentration demonstrated low correlation (r = 0.14).

Orthogonal contrasts were calculated to identify differences within main effect comparisons (Table 4). Fish resisted hypoxia longer at 25 C than at 30 C when salinity was 0.5 ppt, but no temperature effect was detected at 5.0 ppt. The effect of salinity on resistance to reduced DO was different at the two temperatures: fish survived to a lower level at 0.5 ppt when temperature was 25 C, and to a lower level at 5.0 ppt when temperature was 30 C.

DISCUSSION

Two types of regimes may be used for the determination of dissolved oxygen tolerance limits; continuous decline or constant level. Specific methods used in continuous decline testing have included nitrogen stripping, mixing with boiled water, mixing with naturally anoxic water, and sealed vessel assay. Each method produces a different set of experimental difficulties. For example, in sealed vessel assays, free CO_2 can reach levels at which blood oxygen affinity is reduced. Another problem with sealed vessel testing is that the rate of deoxygenation is not controllable. While these problems were avoided with a recirculating vacuum degassing apparatus, the limitation of each trial to include only a single temperature/salinity combination and limited numbers of experimental animals probably contributed to variance due to trial, and the inability to differentiate between main effects.

In a survey of oxygen tolerance studies, Doudoroff and Shumway (1970) reported that methodology unquestionably affects findings, with "threshold" levels reported by some researchers several times those reported by others, using the same species. Disturbing the seal of tank covers at low dissolved oxygen levels caused an immediate rise in dissolved oxygen concentration within the tanks in the apparatus used in the present study. Previous experiments in which dissolved oxygen could not be monitored without physical access to experimental vessels may have produced reports of higher DO levels than fish actually experienced. This phenomenon may be a factor in the lower lethal DO level (0.35 mg/l) found for red drum in the current study than was reported for other warmwater species in continuous decline testing: largemouth bass, 0.79 mg/l (sealed vessel assay, Carmichael, et al 1988); largemouth bass, 0.9-1.4 mg/l, bluegill, 0.7-1.2 mg/l, and channel catfish, 1.08 mg/l (nitrogen

stripping, average 24-hr minimum tolerance, Moss and Scott 1961).

Red drum in our trials resisted hypoxia longer when rate of deoxygenation was reduced. Work with other species (Moss and Scott 1961; Downing and Merkens 1957) also showed that tolerance of low dissolved oxygen concentrations was improved when rate of decline was reduced.

Generally, larger individuals of a species are more resistant to oxygen deficiency than are smaller animals (Eccles 1985; Beamish 1964). However, we saw no significant size effect in red drum ranging from 6-34 g which had been reared together. Moss and Scott (1961) reported decreasing per-gram oxygen consumption for largemouth bass and bluegill up to 15 g, but no further variation beyond this size, and no differences due to size in 20-105 g channel catfish.

Doudoroff and Shumway (1970) summarized that temperature effects on lower limits have been found to be extremely variable, but lethal level often rises with temperature (Moss and Scott, 1961). This was the case for juvenile red drum acclimated and tested at 0.5 ppt and 25 and 30 C, but not for those at 5.0 ppt.

The effect of salinity on resistance to hypoxia in red drum differed between treatments of 25 C and 30 C. At 0.5 ppt, fish died at the lowest DO concentration of any treatment (0.28 mg/l) at 25 C, and at the highest concentration at 30 C (0.44 mg/l). In markedly hypo-osmotic water, the physiological optimum temperature for young red drum may be closer to 25 C than 30 C. Standard deviation (0.249) was particularly high at the combination of 0.5 ppt and 30 C, indicating some degree of difference in the responses of individual fish. It is possible that an unkown factor of pathology or condition may have affected fish held in separate acclimation tanks. Larger-scale experimentation at wider ranges of temperature and salinity might detail the effects of these parameters.

The lack of trends in the differences in DO tolerance at 25 and

30 C and 0.5 and 5.0 ppt seems to indicate that no combination of these factors induced significant metabolic stress in red drum acclimated to each combination. Young red drum were resistant to hypoxia at conditions which are likely to occur in low-salinity culture in the Southeast.

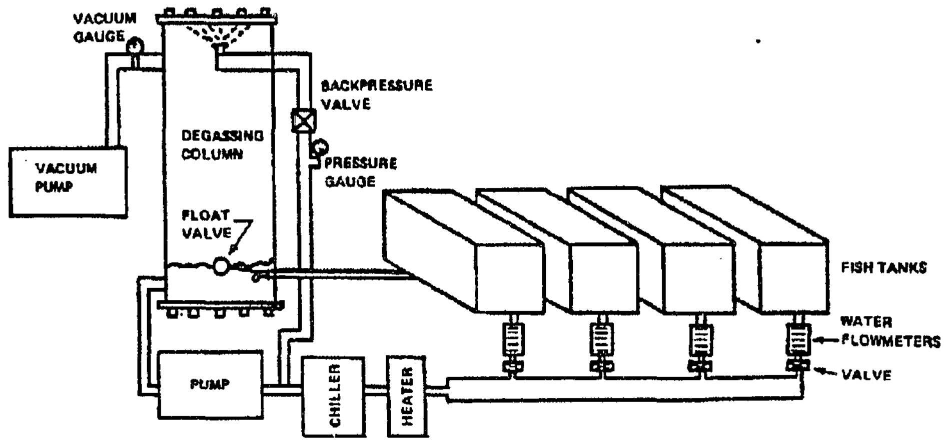

Figure 4.1. Diagram of vacuum degassing system used in dissolved oxygen tolerance testing of juvenile red drum.

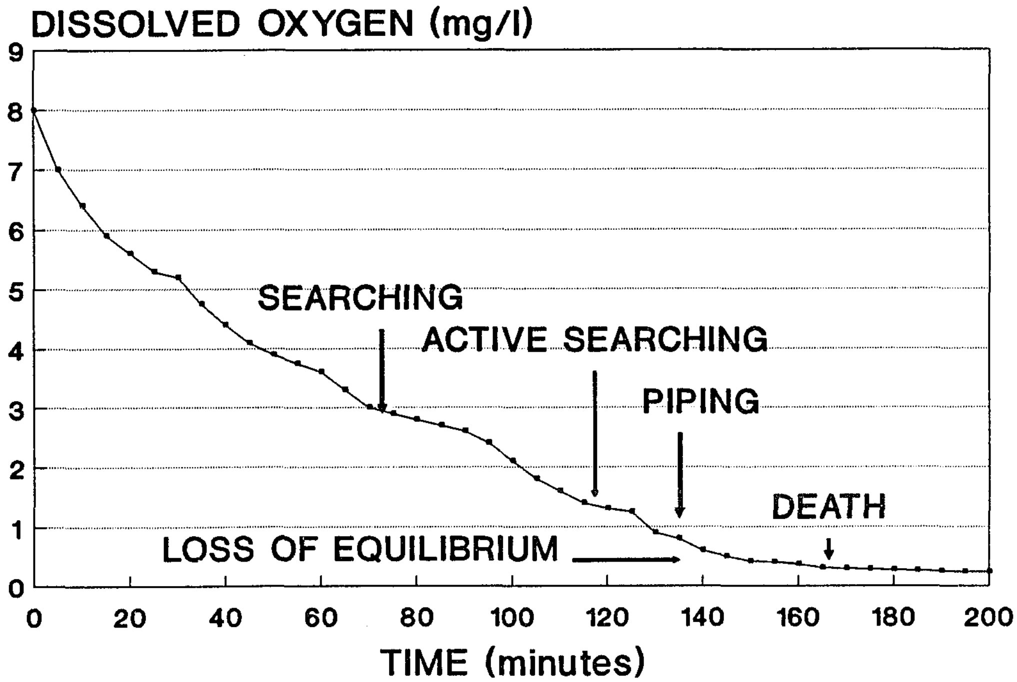

Figure 4.2. Representative deoxygenation curve following vacuum increases of 12.7 cm/30 min, with typical responses of juvenile red drum.

Table 4.1. Mean (± SD) pH, un-ionized ammonia concentration (mg/l), and temperature (C) variation during dissolved oxygen tolerance trials with juvenile red drum.

	INITIAL	FINAL
pH	8.47±0.08	8.50±0.08
Un-ionized Ammonia	0.00	0.04±0.12
Water Temperature	25.0±0.2 30.0±0.2	25.0±0.2 30.0±0.2

Table 4.2. Mean lethal dissoved oxygen concentration (± SD) for juvenile red drum at combinations of 25 and 30 C and 0.5 and 5.0 ppt (N=32).

TEMPERATURE	SALINITY	MEAN LETHAL CONCENTRATION
25	0.5	0.28±0.08
25	5.0	0.38±0.15
30	0.5	0.44±0.25
30	5.0	0.32±0.11

Table 4.3. Two-way analysis of variance of lethal dissolved oxygen concentration for juvenile red drum at combinations of 25 and 30 C and 0.5 and 5.0 ppt salinity.

SOURCE	F-VALUE	PR>F
Trial	6.12	0.0007
Temperature	3.90	0.0506
Salinity	0.08	0.7835
Temperature * Salinity	16.78	0.0001

Table 4.4. Orthogonal contrasts of mean lethal dissolved oxygen concentration for juvenile red drum at combinations of 25 and 30 C and 0.5 and 5.0 ppt.

CONTRAST		MEAN LETHAL CONCENTRATION	PR>F
0.5 PPT	25 C	0.28	0.0001
	30 C	0.44	
5.0 PPT	25 C	0.38	0.1596
	30 C	0.32	
25 C	0.5 PPT	0.28	0.0120
	5.0 PPT	0.38	
30 C	0.5 PPT	0.44	0.0042
	5.0 PPT	0.32	

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SUMMARY

Summary Methods

Two series of short term trials (30 d) were conducted in freshwater ponds to assess factors expected to effect post-stocking survival of juvenile red drum (mean wt. 6.0 g). Treatments tested were acclimation rate (2 h vs. 6 h), chloride concentration (175, 250, 300, and 400 ppm), chloride source (sodium chloride vs. calcium chloride) and predator controls (insecticide pretreatment of ponds and stocking into net enclosures). Longer term studies of the growth of red drum in freshwater and saltwater ponds involved stocking of 0.25-27.4 g fingerlings at densities of 4,075-9,880/ha. Fish were fed formulated diets for 150-188 days. Rates of survival, absolute and specific growth, and feed conversion ratios were compared between treatments of salinity, stocking density, and size at stocking.

A laboratory experiment defined the dissolved oxygen tolerance of juvenile red drum at combinations of two temperatures (25 & 30 C) and two salinities (0.5 & 5.0 ppt). To simulate the hypoxic conditions which can occur in pond systems, a high-vacuum degassing device was employed to deoxygenate circulating water at a controlled rate. The effects of salinity, temperature, and deoxygenation rate were evaluated by determination of mean lethal dissolved oxygen concentration for red drum at combinations of these treatment conditions.

Summary Results

In the first 30-day pond trial, no red drum fingerlings survived in freshwater adjusted to 175 mg/l chloride, and only 2.3% survived in water adjusted to 300 mg/l. No difference in survival was found between two and six hour acclimation regimes. Survival in trial 2 was

significantly higher at 400 mg/l chloride (49.3%) than at 250 mg/l (9.0%). Survival was not significantly different between groups of fish stocked into ponds treated with insecticide prior to stocking and those stocked into untreated ponds. Stocking into net enclosures also did not significantly affect survival. Survival was greater in ponds in which the chloride source was sodium chloride (76.0%) than in ponds containing calcium chloride (28.7%).

During the first series of growout trials, mortality from oxygen depletion in freshwater ponds prevented comparison with results from saltwater ponds. Two of eight saltwater ponds were also lost to hypoxia, but survival at 188 days averaged 62% in the remaining six ponds. No significant differences (PR>0.95) were seen in survival, mean individual weight (148 vs 104 g), or feed conversion ratio (4.05 vs 3.40) for 0.25 g red drum stocked into saltwater ponds at 5,000 or 10,000/ha. Growth data provided the calculated length-weight regression:

$$\log_e(\text{weight}) = -11.7 + 3.04(\log_e \text{length});\ r^2 = 0.99$$

Improved aeration techniques used during the second series of growout trials prevented losses due to oxygen depletion. Red drum stocked at 27.4 g and 4,075/ha grew to mean individual weight of 327.8 g (freshwater) and 360.4 g (saltwater) in 150 days. While no measurements of performance in freshwater and saltwater differed at the 0.05 significance level with ANOVA, fish grown in saltwater performed relatively well in terms of survival (55.5% vs 42.0% in freshwater), feed conversion ratio (2.16 vs 2.99), and mean yield (706.3 vs 532.1 kg/ha).

Overall mean lethal dissolved oxygen concentration for juvenile red drum was 0.34 mg/l. Mean lethal concentration for standard and reduced rates differed significantly (PR> T = 0.002). Increasing vacuum levels by 12.7 cm Hg/30 min produced mean lethal dissolved oxygen concentration (0.38 mg/l) in 166 minutes, while vacuum increases of 12.7

cm Hg/h produced lethal dissolved oxygen concentration (0.29 mg/l) in 291 minutes.

Mean lethal concentration for treatment combinations ranged from 0.28 mg/l at 25 C and 0.5 ppt, to 0.44 mg/l at 30 C and 0.5 ppt. Interaction of main effects contributed significant variance, masking the contributions of temperature and salinity.

Orthogonal contrasts demonstrated inconstant trends within main effects. Fish resisted hypoxia longer at 25 C than at 30 C when salinity was 0.5 ppt, but no temperature effect was detected at 5.0 ppt. The effect of salinity on resistance to reduced DO differed with temperature: fish survived to lower DO concentrations at 0.5 ppt when temperature was 25 C, but at 5.0 ppt lived longest when temperature was 30 C.

Summary Discussion and Conclusions

While some laboratory studies have shown high survival (80-85%) of red drum at 125-130 mg/l chloride (Dolman 1983; Miranda and Sonski 1985), survival at similar levels in outdoor ponds in these studies was unacceptable for successful aquaculture production. Minimum chloride concentration for acceptable and consistent freshwater pond culture is probably 250-300 mg/l based on the results of the laboratory study by Pursley and Wolters (1989) and these pond trials. Factors such as the fluctuations in oxygen, temperature, pH, and handling stress may contribute to the higher minimum chloride concentration required for pond culture.

Survival of red drum in freshwater ponds supplemented with calcium chloride alone was significantly less than in ponds with sodium chloride supplementation, though both treatments produced essentially the same chloride levels. Apparently higher water hardness (622.5 vs 329.3 mg/l) and the resulting inhibition of sodium

efflux will not support high survival rates in red drum transferred to freshwater with very low sodium concentration (22 mg/l). Minimum sodium requirements need to be established for the culture of red drum in freshwater of varied ionic content.

Insecticide pretreatment of ponds used for fingerling red drum culture is probably unnecessary. Predaceous insects were evidently not a source of mortality for fingerling red drum (6.0-8.5 g; 76-102 mm) used in this study. Since insect larvae are often found in the stomachs of fingerling red drum raised in earthen ponds, insecticide treatment may actually reduce a desirable food source. Holding fingerling red drum in net enclosures after stocking also did not improve fish survival. Predation was not a likely source of mortality of red drum fingerlings in the first month after stocking.

Low dissolved oxygen concentrations in culture ponds during the first grow-out trials caused reduced survival and growth, and increased feed conversion ratios. Complete mortality occurred in some ponds due to anoxia, and partial losses occurred in others. Red drum fed poorly or not at all on days in which pre-dawn d.o. concentrations fell below 1.5 mg/l. Improved d.o. management during the last grow-out trial produced survival and growth rates which reflect more favorably on the potential for large-scale culture of red drum.

The absolute growth rate for 6.7 g fish seen in the final growth trial (0.73 g/day for 150 days) is similar to growth reported by other researchers for similar-sized fingerlings raised in ponds. Growth of 2.00 g/day (freshwater) and 2.22 g/day (saltwater) for red drum stocked at 27.4g in our study is better than might be expected from the reports from previous research using appreciable fish densities and formulated diets.

Bird depredation was a cause of mortality of red drum in freshwater ponds during the last grow-out trial. During the latter

part of the trial, red drum schooled in shoreline areas. Ospreys (Pandion haliaetus) and especially great blue herons (Ardea herodias) were seen preying on the schooled fish. At harvest fish carcasses were found in most ponds, and up to one quarter of the red drum from some ponds had fresh or healed wounds. Saltwater ponds had walled sides which effectively excluded wading birds. In addition to reducing survival in the freshwater trial, predation increased apparent feed conversion ratios. Still, calculated conversion ratios ranged from 2.30 to 5.32 (mean=2.99) in freshwater ponds and 1.57 to 2.52 (mean=2.16) in saltwater; these data compare favorably with others reported for first-year red drum held in ponds: 4.6 (Trimble 1979), and 5.2 (Hopkins et al. 1986). Optimizing formulations of red drum diets should help improve feed conversion ratios in the future.

Growth of red drum did not differ significantly due to any of the stocking densities tested (4,075 - 10,000/ha). Higher stocking rates should be feasible without growth inhibition.

Mortality in the final growth study (61.6% overall in freshwater ponds and 44.5% in saltwater) may have been due to extensive handling and transport as well as to predation. Relatively high rates of observed mortality (4.2-39.1%) occurred in freshwater ponds during three days post-stocking. Hauling and handling probably contributed to mortality in previous pond trials as well.

In laboratory tests, red drum resisted hypoxia longer at a reduced deoxygenation rate. There was no significant size effect on tolerance of hypoxia for sibling red drum ranging from 6-34 g which had been reared together. Effects of temperature (25 vs 30 C) and salinity (0.5 vs 5.0 ppt) on dissolved oxygen tolerance were not clear due to significant interaction of effects. The lack of trends in the differences in DO tolerance at 25 and 30 C and 0.5 and 5.0 ppt seems to indicate that no combination of these factors induced

significant metabolic stress in red drum acclimated to each combination. Young red drum were resistant to hypoxia at conditions which are likely to occur in low-salinity culture in the Southeast, especially when deoxygenation rate could be mitigated.

The results of these experiments indicate that red drum culture merits continued investigation. Culture in freshwater ponds should be a viable option, with production similar to that in saltwater ponds, but probably with fewer siting problems. However, careful water quality management, optimization of feed formulations, and use of techniques which minimize both handling stress and opportunities for predation will be necessary if expanded efforts at pond culture of red drum are to be profitable.

VITA

Rowland Glenn Thomas was born on July 3, 1954, in Kinston, North Carolina. He received his B.S. degree in Biology from Augusta College, Georgia, in 1979, and M.S. in Wildlife and Fisheries Science from the University of Tennessee in Knoxville in 1983. He was employed as a fisheries researcher at Southeastern Louisiana University before becoming a PhD candidate in the School of Forestry, Wildlife, and Fisheries at Louisiana State University, Baton Rouge.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Rowland Glenn Thomas

Major Field: Wildlife and Fisheries Science

Title of Dissertation: Environmental Factors and Production Characteristics Affecting the Culture of Red Drum, Sciaenops ocellatus

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

14 March 1991