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Effects of nursery environmental cycles on larval red drum (*Sciaenops ocellatus*) growth and survival

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SUMMARY: Red drum early larval stages migrate through coastal inlets and settle into shallow seagrass meadows within estuaries. This study describes environmental rhythms (ER) in red drum nursery habitats and evaluates their role in larval growth. Well-defined diel ER were observed in temperature (amplitude: 2 to 4.5ºC) and dissolved oxygen (DO) (range: 2.9-7.5 mg O_2 L^{-1}), and sporadic cooling caused by cold fronts. We exposed groups of settlement sized larvae (4.9 mm standard length) to two oscillating temperature treatments (amplitudes: 3 and 6ºC; daily mean 27ºC), an oscillating DO treatment (range: 2.4-6.1 mg O_2 L^{-1}; daily mean 4.2 mg O_2 L^{-1}) and a control (no cycles; daily mean 27ºC, 6.4 mg O_2 L^{-1}). Relative to controls, growth was significantly reduced in the DO treatment but not in the temperature treatments. Survival was similar in all treatments. Fish previously exposed to temperature cycles maintained faster growth rates and higher food intake than control fish when exposed to a simulated cold front. These results suggest that (1) ER may impart a physiological advantage to fish, (2) acclimation to oscillating DO environments is unlikely, and (3) field estimates of environmental characteristics based upon averaged daily point samples are inadequate for predicting fish growth.

***KEY WORDS:* red drum, settlement, recruitment, temperature, dissolved oxygen, diel rhythms**

INTRODUCTION

Fish recruitment is a central issue for understanding fish population dynamics. Fish nursery areas are thought to play a critical role in determining adult population size by influencing year class recruitment.[1,2] Red drum is a valuable resource along the Gulf and East coast of North America. From late August through October, red drum produce numerous planktonic larvae in offshore waters near estuarine inlets. After two to three weeks in the plankton, the larvae settle in seagrass beds within estuaries.[3,4] Seagrass beds serve as settlement and primary nursery habitat for young red drum. Rapid larval growth during this extremely vulnerable period greatly increases the probability of survival of larvae,[5] and therefore recruitment.[6]

Seagrass beds are structurally complex and highly productive habitats which provide shelter for larval red drum as well as abundant food to fuel their rapid growth. However, these shallow estuarine habitats experience substantial fluctuations in environmental characteristics to which settled larvae will be exposed.[7] Environmental parameters may fluctuate widely in estuaries as a result of diel and tidal cycles, and stochastic events (storms and cold fronts). Diel temperature cycles of 3 to 5ºC have been reported in shallow estuarine environments.[8] Similarly, water cooling associated with frontal systems is common during the settlement season. Dissolved oxygen (DO) oscillations may be large in shallow subtropical seagrasses due to photosynthesis-respiration rhythms of benthic communities.[8] Temperature and DO fluctuations in seagrass beds are perhaps the most important abiotic factors controlling growth during the larval period and hence recruitment to adult stocks.

Although the effects of temperature and DO on growth and survival have been studied intensively in numerous species, very few studies have addressed the effect of fluctuating environmental conditions (diel and tidal rhythms) and short-term atmospheric events (storms, cold fronts) on fish growth. The aim of the present study was two fold: 1) describe naturally occurring environmental rhythms (range and patterns of variation) within prospective red drum nursery habitats during the settlement period, and 2) determine the effects of temperature and DO cycles on larval growth and survival in laboratory studies.

MATERIALS AND METHODS

Identification of cyclical environmental patterns in red drum nursery habitats (seagrass beds):

Environmental data surveys were compiled from three locations in the Aransas-Corpus Christi estuary system during the fall of 2000. Two stations were located in shallow seagrass beds (SG1 and SG2) within the estuary where red drum larvae have been found previously.[3)] A third station (INLET) was located in the Aransas Pass Ship Channel linking the estuary to the Gulf of Mexico.

Temperature, dissolved oxygen (DO), pH, conductivity, turbidity and water height in the seagrass stations were recorded at 30 min intervals for six weeks by YSI multiparameter water quality data sondes placed within the seagrass canopy. The sondes were checked and data downloaded weekly to ensure proper working conditions and to prevent data loss. Environmental data from the INLET was obtained from the automated monitoring program established at the University of Texas Marine Science Institute Pier Laboratory. The study was coincident with the peak period of larval red drum settlement to the seagrass beds.

Effects of diel temperature and DO fluctuation on the growth and survival of settlement sized red drum:

Red drum larvae were initially raised in 300 L circular tanks. Larvae of approximately 5-6 mm SL (19-22 d) were randomly assigned to experimental tanks at a density of 5-10 larvae L^{-1}. Two groups of three replicate tanks (150 L) were used in all experiments. Tanks from each treatment were connected to a 150 L reservoir for water conditioning. Water was recirculated through each system 1.2 times $hour^{-1}$ to ensure a homogeneous environment between the three replicate tanks within treatments. Temperature, DO, pH and salinity were recorded in at least one tank from each treatment at 15 min intervals by YSI multiparameter water quality data sondes. Preliminary tests have shown that due to the high recirculation rate used, there are no differences in water quality among replicate tanks. To estimate treatment effects on fish growth a total of 20-25 fish from each tank were sampled at regular intervals throughout the experiment and the standard length (SL) measured to the closest 0.1 mm.

Diel temperature cycles. Settlement sized red drum larvae (4.9 mm standard length; SL) were exposed to two oscillating temperature treatments (OSC T_{Lo} and OSC T_{Hi}) (amplitudes: 3 and 6ºC; daily mean 27ºC) and their growth and survival compared to larvae held at constant temperature (CONTROL) (no cycles; daily mean 27ºC). Temperature cycles were simulated using timer-controlled heaters (total 1500 watts) and a water chiller unit connected to the reservoir. The experiment was repeated twice; once to test the high fluctuation and the other the low fluctuation regimen. The experiments lasted for 20-22 days.

Diel DO cycles. Settlement sized red drum larvae (5.2 mm standard length; SL) were exposed to an oscillating dissolved oxygen treatment (OSC DO) (range 2.4 to 6.1 mg O_2 L^{-1}) and growth and survival compared to larvae held in constantly well-oxygenated water (CONTROL) (6.4 mg O_2 L^{-1}). The experiments lasted for 22 days. An oxygen depletion column was placed between the reservoir and the experimental tanks to generate the desired fluctuating DO conditions. DO levels were controlled by the flow of nitrogen injected into the column. All tanks were kept at constant 27ºC.

Effects of storm related cooling on the growth and survival of red drum grown in stable and oscillating temperature:

Fish previously exposed to temperature cycles (OSC T) and fish grown at constant temperature (CONTROL) were subjected to a simulated cold front. Water temperature was dropped in all tanks from 27ºC to 17ºC over a 36 hour period. The temperature was kept at 17ºC for 48 hours (day 2 and 3) and then raised back to 27ºC on day 4. The experiment lasted for six days. Water parameters were monitored at 15 min intervals as described previously. Samples were obtained five days before the beginning of the experiment (from the conditioning tanks) and on days 0, 3 and 6. Groups of 25-30 fish from each tank were measured on each sampling date. Food level was adjusted daily ensuring that fish ate to satiation. Every morning the tanks were carefully siphoned and the unconsumed food collected and dried at 60ºC for 36 h. Food consumption was then estimated by subtracting the food recovered (corrected for leaching) from the total food provided during the day.

RESULTS

Identification of cyclical environmental patterns in red drum nursery habitats (seagrass beds):

Well-defined diel environmental rhythms were observed in temperature (amplitude: 2 to 4.5ºC) and dissolved oxygen (DO) (range: 2.9-7.5 mg O_2 L^{-1}) in seagrass beds (Fig. 1). DO levels were high during daytime and decreased during the night to low levels (2-4 mg/L). Sporadic cooling episodes with temperature drops greater than 10ºC in two to three days were recorded during the passage of cold fronts. Much less variability was observed in the others parameters in the survey (data not shown). Relative to seagrass beds, diel patterns and overall variability were greatly reduced in the INLET. Diel temperature fluctuation was only 1 to 1.5ºC. Diel DO cycles were absent in the inlet with DO levels remaining near to saturation levels at all times (Fig. 1). All other parameters remained nearly constant during the study (data not shown).

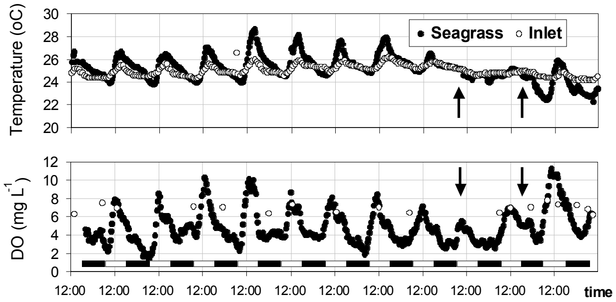

Fig. 1 Temperature and DO levels in the INLET and SG1. The arrows indicate the passage of cold fronts. Clear rectangles indicate daytime.

Effects of diel temperature and DO fluctuation on the growth and survival of settlement sized red drum:

Since the fish were exposed to different thermal treatments a cumulative degree index (15 min interval) was used. Relative to controls, growth was significantly reduced ($p<0.01$) in the DO treatment (Fig. 2) but no differences in growth relative to control fish were observed in either of the two temperature cycles used (Fig. 3). Survival was similar in all treatments.

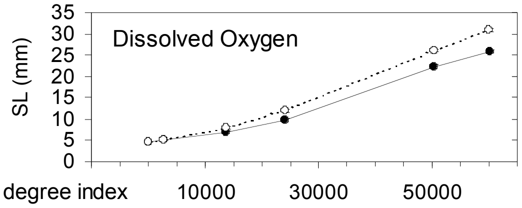

Fig.2 Growth of red drum under cyclic DO conditions (OSC DO; close circles) and stable conditions (CONTROL; open circles). Means ± SE (n=3).

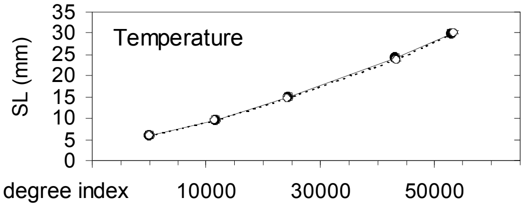

Fig.3 Growth of red drum under cyclic temperature conditions (OSC T_{Hi}; close circles) and stable constant (CONTROL; open circles). Means ± SE (n=3).

Effects of storm related cooling on the growth and survival of red drum grown in stable and oscillating temperature:

Fish previously exposed to temperature cycles maintained faster growth rates during the cooling phase (days 0-3) of the cold front ($p<0.05$). The difference in growth was no longer apparent by day six (Fig. 4). Food consumption was on average higher for fish previously grown under cycling conditions than control fish during the simulated cold front ($p<0.01$) (Fig. 5). No fish died during the 6-day experiment.

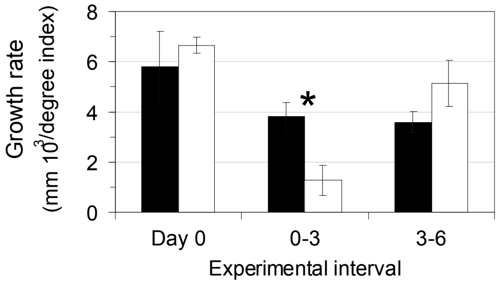

Fig.4 Growth rate of juvenile red drum during the simulated cold front experiment. Black columns represent fish previously exposed to temperature cycles. White columns represent CONTROL fish. Means ± SE (n=3). The asterisk indicates significant difference between groups ($p<0.05$).

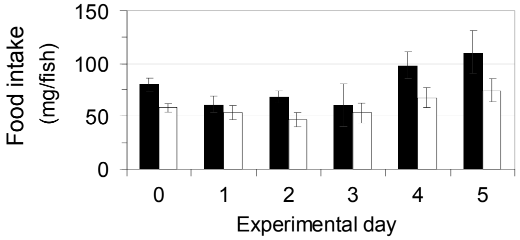

Fig.5 Food consumption during the simulated cold front experiment. Black columns represent fish previously exposed to temperature cycles. White columns represent CONTROL fish. Means ± SE (n=3).

DISCUSSION

Naturally occurring environmental cycles are linked to different patterns of energetic input within the relatively small nursery habitat. Circadian rhythms arise from day-night and tidal cycles while stochastic fluctuation are linked to meteorological disturbances. Diel temperature and DO cycles weaken or completely disappear on cloudy days. Both cycles were clearly related to irradiation. In shallow, productive seagrass beds there is an extensive primary productivity (photosynthesis) [9] and respiration confined to a small volume of water, resulting in large diel DO changes.

Red drum larvae are very tolerant of temperature fluctuations. Diel temperature fluctuation in excess of that found in our environmental surveys did not impair growth in the laboratory. Nevertheless the simulated cold front experiment seems to suggest that exposure to diel temperature rhythms may impart a physiological memory to the fish that allows for faster growth compared to CONTROLS during rapid cooling events. Food consumption during that experiment was on average higher in fish previously exposed to diel temperature fluctuation. However, no significant differences were detected at any particular day. Herzka [10] found that the isotopic composition of settlement sized red drum changed significantly faster in larvae stocked in the field than siblings held in laboratory and concluded that metabolic turnover (changes in isotopic composition not explained by growth) was accelerated in the caged fish. It can be inferred that the cost of growth (i.e. energy used per unit weight gain) was higher in the natural environment. Since no predation and unrestricted food access was assumed in both caged and laboratory fish, it seems possible to hypothesize that environmental fluctuations may drive these physiological differences in growth.

Fish in the OSC DO grew significantly less than CONTROL fish, while survival was not affected. Taylor and Miller[11] reported growth reduction in southern flounder (*Paralichthys lethostigma*) cyclically exposed to nocturnal hypoxia (2.8 mg O_2 L^{-1}). Although the lowest DO concentration used in the experiment (2.4 mg O_2 L^{-1}) was similar to the lowest observed values in the seagrass, these levels were reached only occasionally in the seagrass beds. The levels administered in the laboratory were well into the range where oxygen acts as a limiting factor resulting in retarded growth. A reduced growth potential is predicted in estuarine areas where strong diel DO cycles are present even when daytime DO levels are high. These experiments also indicate that the use of field estimates of environmental characteristics based solely upon averaged daily samples is inadequate for predicting fish growth in the pristine seagrass beds studied.

The benefit of evolving an estuarine dependent lifestyle strongly argues for an overall increased growth potential in these fluctuating environments and the possibility for specific adaptations to meet environmental challenges of the nursery habitat. Larval growth and survival in fluctuating environments of estuaries is a crucial aspect for understanding recruitment variability/mechanism and ultimately fish population dynamics in estuarine dependent species like red drum.

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REFERENCES

1. Underwood A.J. and Fairweather P.G. Supply-side ecology and benthic assemblages. Trends in Ecology and Evolution. 1989; **4**(1): 16-20
2. Sale P.F. Recruitment of marine species: Is the bandwagon rolling in the right direction? Trends in Ecology and Evolution. 1990; **5**(1): 25-27
3. Rooker J.R. and Holt S.A. Utilization of subtropical sea-grass meadows by newly settled red drum (*Sciaenops ocellatus*), patterns of distribution and growth. Marine Ecology Progress Series. 1997; **158**: 139-149
4. Rooker J.R., Holt S.A., Holt G.J. and Fuiman L.A. Spatial and temporal variability in growth, mortality, and recruitment potential of post-settlement red drum (*Sciaenops ocellatus*) in a subtropical estuary. Fisheries Bulletin. 1999; **97**: 581-590
5. Fuiman L.A. and Magurran A.E., 1994. Development of predator defenses in fishes. Rev. Fish Biol Fish **4**: 145-183
6. Houde E.D. Comparative growth, mortality, and energetics of marine fish larvae: temperature and implied latitudinal effects. Fisheries Bulletin. 1989; **87**(3): 471-495
7. Robbins B.D. and Bell S.S. Dynamics of a subtidal seagrass landscape: Seasonal and annual change in relation to water depth. Ecology 2000; **81**(15): 1193-1205
8. Beck N.G. and Bruland K.W. Diel biogeochemical cycling in a hyperventilating shallow estuarine environment. Estuaries 2000; **23**(2): 177-187
9. Moncreiff C.A., Sullivan M.J. and Daehnick A.E. Primary production dynamics in seagrass beds of Mississippi Sound: the contributions of seagrass, epiphytic algae, sand microflora, and phytoplankton. Marine Ecology Progress Series. 1992; **87**: 161-172
10. Herzka S.Z. and G.J. Holt. Changes in isotopic composition of red drum (*Sciaenops ocellatus*) larvae in response to dietary shifts: potential applications to settlement studies. Can. J. Fish Aquat. Sci. 2000; **57**: 137-147
11. Taylor J.C. and Miller J.M. Physiological performance of juvenile southern flounder, *Paralichthys lethostigma* (Jordan and Gilbert, 1884), in chronic and episodic hypoxia. Journal of Experimental Marine Biology and Ecology. 2001; **258**: 195-214