

Field Growth Responses of Juvenile White Trout (*Cynoscion arenarius*) to Continuous Variation in Physical Habitat Conditions

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ABSTRACT

Recruitment of early life stages of many species into shallow inshore estuarine habitats is responsible for high fisheries production. Estuarine habitats are also subject to wide fluctuations in physical conditions which can influence recruitment success through effects on the growth and survival of early life stages. In order to examine field-growth responses of juvenile white trout with respect to continuous variation in physical habitat conditions, we related modal shifts in length distributions of recruiting cohorts to continuous changes in abiotic variables. Weekly shoreline collections of juvenile white trout were made over a five week period between 12 May and 16 June, 1997 at Marsh Point in Mississippi Sound. Using a DataSonde IV®, hourly changes in water temperature, salinity, dissolved oxygen, turbidity, depth, and pH were also recorded throughout the five week recruitment period. Weekly modal shifts in length distributions of white trout reflected proportional changes in length ranging from 0.20 to 0.54; and changes in weekly growth were strongly tied to changes in weekly mean water temperature ($P = 0.013$). Other abiotic variables were unrelated to water temperature on the weekly scale. However, abiotic variables may show different interrelationships depending on the temporal scale on which they are considered, suggesting that their effects on recruitment processes need to be analyzed on the same temporal scale on which recruitment is measured. Comparison of these findings and previous work showed that within-site-temporal variability and between-site-spatial variability in growth rates can be driven by different abiotic variables. Whereas within-site variability in growth of juvenile white trout was primarily driven by water temperature, former work with juvenile mullet in the same system suggested that inter-site variability in growth was primarily determined by salinity.

KEYWORDS: Field growth, abiotic, *Cynoscion arenarius*

INTRODUCTION

Recruitment of early life stages of many species into shallow inshore estuarine habitats is responsible for high fisheries production (Weinstein 1979, Boesch and Turner 1984). Estuarine habitats are also subject to wide fluctuations in physical conditions (Kneib 1997), which may influence fish recruitment success through

effects on the growth and survival of early life stages (Currin et al. 1984, Malloy and Targett 1991, Lankford and Targett 1994). Although density dependent biotic factors can directly affect recruitment through survival rates (Myers and Cadigan 1993), many studies of transient estuarine fishes find that abiotic factors are the most important determinants of variability in their early growth rates (Rooker and Holt 1997, Baltz et al. 1998). Moreover, rapid growth may also confer enhanced survival (Peterson et al. 1999). Thus, spatio-temporal variation in abiotic variables and their effects on growth can ultimately translate into differential cohort-specific contributions to stock recruitment. Because estuarine organisms are challenged by a wide array of continuously changing abiotic variables, early growth responses are potentially dynamic and complex. Population responses are tied to underlying autecological effects of abiotic variables that regulate metabolic scope in different ways (Neill et al. 1994). The detection of such responses may become scale-dependent whenever environmental effects acting at lower levels of organization (e.g., cellular) are integrated over higher levels of organization (e.g., population).

Sciaenids represent one of the most commercially and ecologically important groups of estuarine dependent fishes that occur along the Atlantic and Gulf of Mexico coasts (Chao and Musick 1977). The genus *Cynoscion* has a center of origin in tropical coastal waters of the Western Hemisphere; and several species of *Cynoscion* occur within subtropical and temperate coastal waters of the United States. The white trout, *Cynoscion arenarius*, is one of the most common sciaenid fishes within estuaries of the northern Gulf of Mexico. In the Gulf of Mexico, adult white trout spawn offshore during winter and spring and larvae enter estuarine nursery areas after 30 - 94 d (Shaw et al. 1988). White trout larvae are transported by currents to estuaries that may be far from their offshore spawning areas, implying that their recruitment dynamics involve metapopulation processes. White trout recruitment is seasonally bimodal and accordingly, growth rates of juveniles also vary seasonally. In order to examine field-growth responses of early juvenile white trout with respect to continuous variation in physical habitat conditions, modal shifts in length frequency distributions of recruiting cohorts were related on a weekly temporal scale to changes in abiotic conditions at a site where high amplitudes of early juveniles occurred. The significance of the findings is considered with regards to the issue of recruitment variability.

MATERIALS AND METHODS

Field Collections

Between 12 May and 16 June 1997 during the peak spring recruitment period, a series of weekly collections of juvenile white trout were made at Marsh Point (30° 23' 05" N and 88° 48' 40" W) in Jackson County, Mississippi. Marsh Point is ideally situated to receive early life stages of estuarine dependent organisms that are transported across Mississippi Sound (Figure 1). Mississippi Sound represents a diurnal microtidal estuarine system with lunar tides averaging ~ 0.33 m and with

characteristically high turbidity that presumably enhances the survival of recruiting organisms. The semi-natural sandy shoreline of Marsh Point is intermittently covered with scattered marsh vegetation including *Spartina* and scrub. Each weekly collection was taken from 0.6 - 0.8 km of semi-protected shoreline habitat on both sides of the point over muddy sand and mud sediments. A 4.6 m x 3.2 mm mesh seine was used to collect fishes from 1.2 m to 0 m depth by pulling perpendicular into the shore from ~30 meters offshore. The mean depth was 0.5 m. The shoreline site was thoroughly sampled during each visit by making multiple seine hauls for between 2.75 to 3.25 hours. Other fishes commonly collected included menhaden, bay anchovy, silver perch, tidewater silverside, white and striped mullet, croaker, spot and pinfish. Another site was also sampled ~45 kilometers from the Marsh Point site at Henderson Point in Hancock County, but collections did not yield enough white trout to characterize their growth shifts. Fish were labelled and placed on ice in the field and returned to the laboratory where they were kept frozen until measured to the nearest 0.1 mm standard length (SL) using a dial calipers.

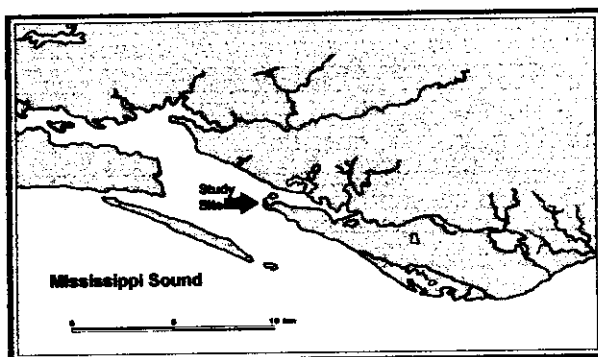


Figure 1. Map showing the study site near Marsh Point.

Abiotic Conditions

Continuous variation in abiotic conditions was monitored throughout the five week study period using a Hydrolab IV DataSonde multiparameter data logger placed at the Gulf Coast Research Laboratory dock, less than 1 km from Marsh Point. Datasondes were deployed in order to log hourly variation in salinity (ppt), water temperature ($^{\circ}\text{C}$), dissolved oxygen (DO; mg/l), turbidity (NTU), pH, and depth (m; i.e., tidal flux). Datasonde units were typically replaced weekly with recalibrated and serviced units after which recorded data were downloaded to a computer in the laboratory. An equipment failure resulted in missing salinity data for the week of 5 June.

Data Analysis

Individual lengths of juvenile white trout from weekly collections were placed

into 2 mm size classes in order to generate length-frequency distributions. Proportional length-frequency distributions were plotted to identify clear shifts in modal lengths. Differences in modal lengths between consecutive weeks were expressed as the proportion of the earlier length so that growth shifts could be examined relative to changes in abiotic conditions. Daily variability in physical parameters were derived from respective 24 hourly measurements and plotted as time series of the means \pm 2 standard errors (s.e.). Cross-correlations among the parameter series were examined on the daily temporal scale at all lags up to \pm 7 d. Missing values in the daily series for salinity were interpolated by local quadratic smoothing. Daily abiotic data were further collapsed to the weekly temporal scale in order to address coherence with weekly growth. Changes in parameter weekly profiles were visually compared. Pearson correlations among abiotic variables on the weekly scale were compared with cross-correlations on the daily scale. Weekly water temperature and salinity values were plotted against weekly growth values and the relationship between water temperature and early growth was examined using regression.

RESULTS

Growth Variation

Numbers of early juvenile white trout in collections from Marsh Point varied from 58 to 224 specimens ranging in size between 14 and 64 mm SL. Clear modes representing multiple cohorts were visible within the standardized length frequency distributions across the various collection dates. Modal shifts in length distributions of white trout reflected variation in weekly proportional growth ranging from 0.20 to 0.54 (Figure 2). Moreover, changes in the magnitude of growth did not follow a consistent temporal trend on the weekly scale, although the lowest growth rate was noted from the earliest time interval, while the highest growth rate was observed from the latest time interval.

Daily Variation in Physical Parameters

Daily means in physical parameters varied widely throughout the 35 d monitoring period: water temperature ranged between 22.9 and 31.0° C; salinity ranged between 0.4 and 11.2 ppt; turbidity ranged between 4.85 and 44.8 NTU; depth ranged between 0.3 and 1.1 m; DO ranged between 3.5 and 6.0 mg/l; and pH ranged between 6.5 and 11.5 (Figure 3). Definite fluctuations were evident on the daily temporal scale for all physical parameters. Correlations among the physical parameters were not immediately apparent on the daily scale, however, concurrent dips in multiple parameters occurred on 12 May in water temperature and depth, on 18 May in turbidity and DO, and on 1 June in salinity, pH and water temperature. Hydrographic shifts were suggested by concerted changes in several physical parameters as shown by notable bivariate cross-correlations between various pairs of abiotic variables (Table 1). For example, concurrent daily variation involving

moderate correlations occurred at a lag of +4 to +5 d between water temperature and several other parameters, including salinity, turbidity, and DO. Several other bivariate correlations also were evident at a lag of 0 d.

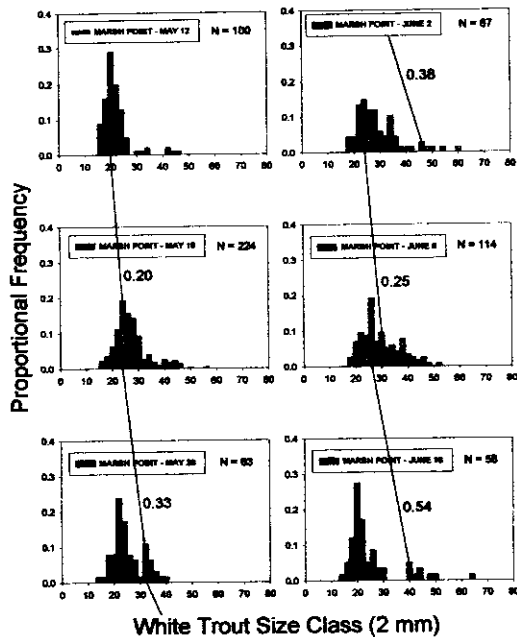


Figure 2. Proportional length-frequency distributions showing shifts in modal sizes of early juvenile white trout sampled at weekly intervals between 12 May and 16 June 1997 from the Marsh Point site. Inferred weekly growth represents the difference in consecutive modal lengths as a proportion of the earlier modal length.

Weekly Variation in Physical Parameters and Growth

Weekly temporal profiles for the physical parameters and proportional growth comprised only five data points, facilitating visual comparisons in order to identify covariation on this temporal scale (Figure 4). Profiles were apparently similar between turbidity and DO, salinity and Ph, and water temperature and proportional growth. Moreover, inverse relationships were indicated between both salinity and Ph with turbidity, depth, as well as DO (Table 1). Physical parameters and growth also fluctuated somewhat on the weekly scale. Although water temperature was apparently related to several other abiotic variables on the daily temporal scale when

lagged 4 or 5 d, it was completely unrelated to the same parameters when considered on the weekly temporal scale without any lag. Other sets of abiotic variables also varied in the strength of their association depending on the temporal scale. Thus, abiotic variables can show different interrelationships depending on the temporal scale of concern. On the weekly temporal scale, water temperature was the only physical parameter that was directly related to early fish growth, as shown by a significant linear regression between these two variables (Figure 5A). Despite its ecophysiological importance, salinity did not seem to bear any relationship with early growth on the weekly scale (Figure 5B). Relatively low weekly growth rates occurred at both ends of the observed salinity range and relatively high growth occurred at a relatively low salinity.

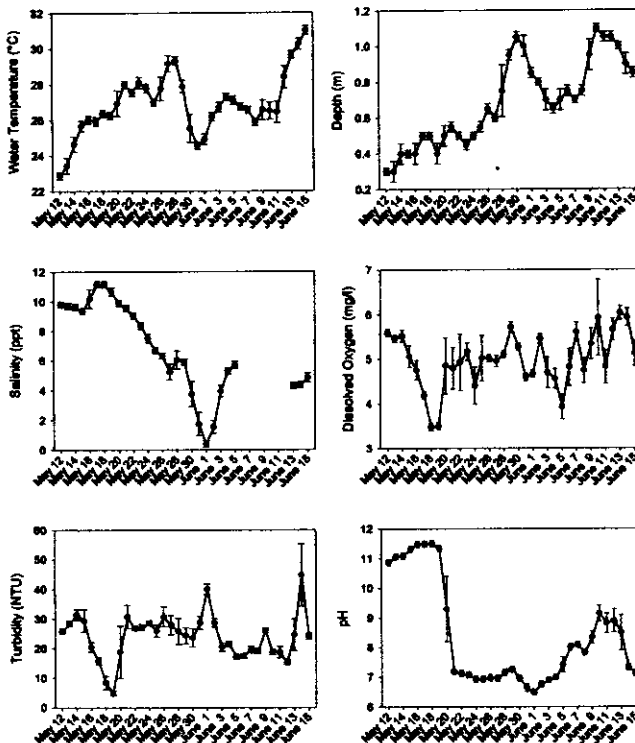


Figure 3. Daily variation in the six physical parameters across the 35 d study period. Plotted values represent means \pm 2 s.e derived from the respective 24 hourly measurements.

DISCUSSION

Based on an analysis of recruitment by several species of commercial fishes, Myers and Cardigan (1993) concluded that early life stages determine inter-annual variability in the year class strength of demersal marine fishes. The relevant spatial scale in the recruitment of marine fishes appears to be ~500 km, which supports the hypothesis that large-scale environmental variables drive marine recruitment (Myers et al. 1997). Indeed, many studies of transient estuarine fishes report that abiotic factors are the most important determinants of variability in early growth rates (Rooker and Holt 1997, Baltz et al. 1998). On a weekly scale, within-site variability in growth rates of early juvenile white trout appeared to be driven mainly by water temperature. However, our previous work within the same estuarine system suggested that inter-site variability in the field growth of juvenile mullet is primarily determined by differences in salinity (Peterson et al. 2000), indicating that within-site temporal and between-site spatial variability in growth rates can be driven by different abiotic variables. Even though the lab growth response of mullet was much more strongly linked to temperature than to salinity, a larger difference in salinity than in water temperature occurred between two field sites separated by ~45 km. This underscores the idea that causes of recruitment variability are complex and dynamic. Assuming that enhanced growth increases survival, the existence of spatio-temporal plasticity in early growth could indeed have a strong bearing on recruitment dynamics (Lankford and Targett 1994, Peterson et al. 1999). For example, based on shifts in monthly size distributions, Brusle and Cambrony (1992) documented spatial variability in growth rates of juvenile mullet they attributed to settlement by "microcohorts" within patchy Mediterranean lagoonal habitats.

Table 1. Correlations among abiotic variables and growth on daily and weekly temporal scales. Upper right diagonal displays cross-correlations and lag time in days for weekly values, main diagonal (**bold**) displays Pearson correlations with growth on the weekly scale, and lower left diagonal displays Pearson correlations among physical variables on the weekly scale. Asterisks denote conventional $P < 0.05$. Correlations are presented for illustrative purposes to show overall patterns in the interrelationships.

Growth	Temp	Salinity	Turbidity	Depth	DO	pH
Temp	+0.95*	-0.45*; +4	0.47*; +5	0.33; 0	0.40; +5	-0.47*; 0
Salinity	-0.30	-0.40	-0.35; 0	-0.82*; -1	-0.34; +1	0.74*; -1
Turbidity	+0.21	-0.89*	+0.43	0.25; -3	0.49*; 0	-0.42*; 0
Depth	+0.62	-0.93*	+0.78	+0.62	0.37; 0	-0.58*; -7
DO	+0.13	-0.86	+0.87*	+0.69	+0.29	-0.36; -5
pH	-0.45	+0.97*	-0.87*	-0.94*	-0.90*	-0.54

As a hierarchical phenomenon, recruitment can be examined at multiple scales, ranging from cellular to ecosystem levels of organization. Thus, environmental effects on recruitment should be analyzed on the same spatiotemporal scale as the process of concern and quantified at one level below that on which the process is measured. For example, the limit of temporal resolution of growth in this study was the weekly scale, but other temporal scales of growth in fishes can also be considered, including the instantaneous scale through biochemical assays (Peterson and Brown-Peterson 1992), the daily scale as inferred from otolith growth records (Comyns et al. 1989, Rakocinski et al. 2000), or the inter-annual scale (Planque and Fox 1998).

The finest temporal scale of abiotic measurement available in this study was the hourly interval which could have been collapsed with respect to the daily scale of growth in the same manner that the daily scale of measurement was consolidated in order to relate it to weekly growth. Although water temperature was apparently unrelated to other measured abiotic variables on the weekly scale, patterns of daily variation in physical parameters and growth might have revealed how other abiotic variables were also correlated with daily growth (e.g., those that correlated with water temperature at +4 or +5 d lag).

In addition, variation in the strengths of associations observed among the physical variables at the two temporal scales suggests that different abiotic variables could emerge as being important to growth variation on different temporal scales. Thus, collapsing the information on a large scale could conceal certain kinds of growth responses to environmental variables. For example, Konstantinov et al. (1990) demonstrated that fish can grow better in fluctuating temperature regimes like those experienced under field conditions than under constant laboratory conditions, because they can take advantage of intermittent cooler temperatures to increase food conversion efficiency. In the Aransas estuary, the recent growth of postlarval red drum (*Sciaenops ocellatus*) was positively correlated with water temperature, whereas there was no apparent connection between long-term growth and water temperature, suggesting other factors like prey availability were ultimately responsible for inter-cohort growth differences (Rooper and Holt 1997). On the other hand, large scale effects can also be overlooked. Estimates of consumption rates by juvenile bluefish (*Pomatomus saltatrix*) in 90 day mesocosm experiments were not accurately predicted from short-term 7 d growth experiments, leading Buckel et al. (1995) to conclude that environmental effects on growth and consumption rates should be studied over the same temporal scale on which the responses are integrated in nature.

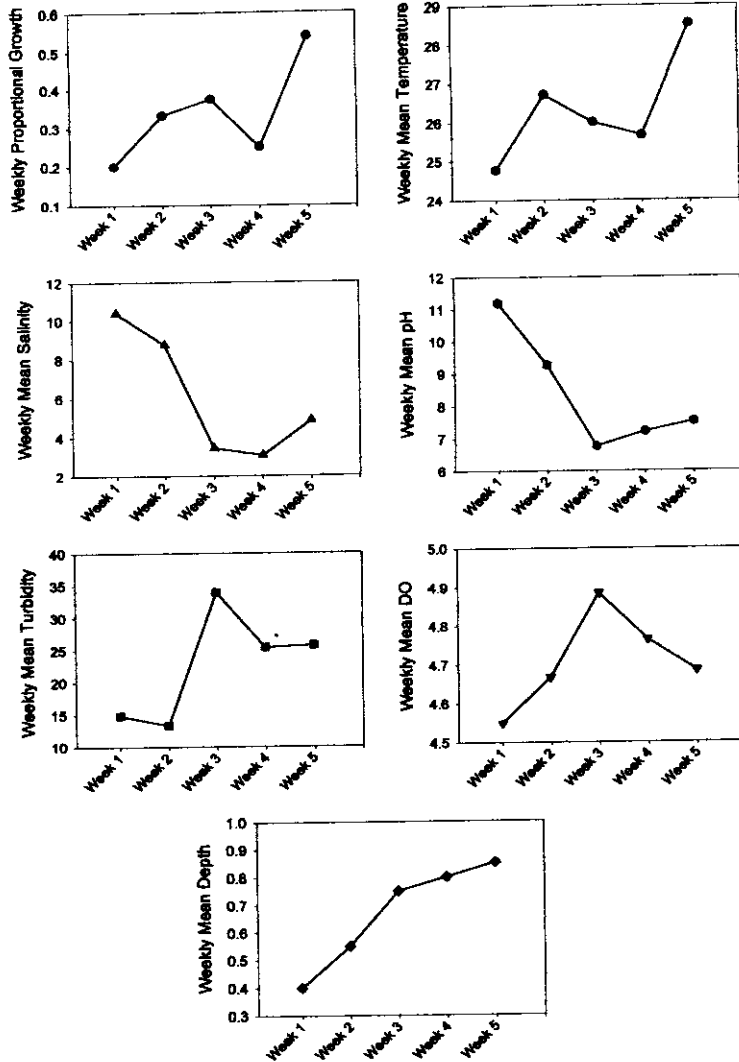


Figure 4. Weekly variation in the six physical parameters and early growth of white trout across the five week study period.

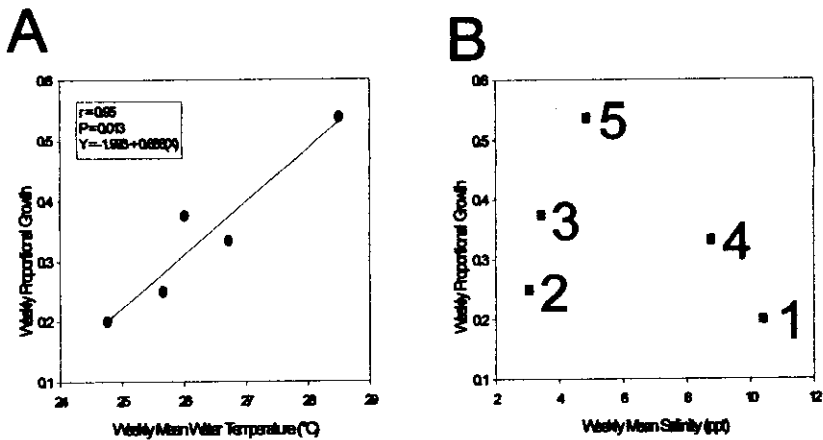


Figure 5. (A) Relationship between weekly proportional growth of white trout and weekly mean water temperature. (B) Relationship between weekly proportional growth and weekly mean salinity. Numbers on salinity plot correspond with the sequence of values from the water temperature relationship shown in 5A.

Water temperature appeared to be strongly associated with weekly growth rates of early juvenile white trout at the Marsh Point site, to the exclusion of other factors. Moreover, growth increased across the entire observed range in water temperature. Water temperature is regarded as the main controlling factor on early growth because it sets the pace of metabolism (Neill et al. 1994); and various workers have noted that temperature optima for many fishes are highest during the early life history stages (Brett 1979, Kitchell 1979, Lankford and Targett 1994). However, as a determinant of many biological rate processes, temperature also elevates the metabolic needs of organisms which must be fulfilled by sufficient food availability. A foraging constraint can severely limit the scope for growth and may lead to mass mortality of young fish (Sukhanov 1989). Juvenile Sea Bass (*Dicentrarchus labrax*) grow better in warmer British waters if food is abundant, however they grow better in cooler waters at low levels of food abundance (Russell et al. 1996). Salinity acts as a masking factor on growth through its potential metabolic demands (Neill et al. 1994). Masking and limiting factors (e.g., dissolved oxygen) can actually shift the optimum temperature away from that which maximizes metabolic activity.

Weekly growth rates of white trout in the field increased monotonically with water temperature and did not appear to be affected by observed changes in salinity at the Marsh Point site. Juveniles of the Atlantic coast cognate species to white

trout, weakfish (*Cynoscion regalis*), grew optimally at 29°C and 20‰ in the laboratory (Lankford and Targett 1994). Feeding rates increased with water temperature at all salinities, thus salinity narrowed the scope for growth by affecting growth efficiency. Very low salinities were especially costly for juvenile weakfish. In the present study, daily means in water temperature ranged between 22.9° and 31.0°C and salinity ranged between 0.4 and 11.2 ‰. These ranges exceed the temperature optimum observed for weakfish and bracket some very low salinities, yet white trout field growth was not apparently masked by the low salinities. Salinity and temperature may interact in some species to elicit growth responses. Hogchoker (*Trinectes maculatus*) grow faster and more efficiently in the laboratory with increasing salinity at cooler temperatures (15 °C), however they grow slower and less efficiently with increasing salinity at warmer temperatures (Peters and Boyd 1972). Perhaps white trout are not as sensitive to variation in salinity, or fish at this site were acclimated to lower salinities in their early life. Acclimation is another recognized factor that may shift the optimum temperature (Neill et al. 1994). Finally, the data may have been too sparse to demonstrate a salinity effect on weekly variability in field growth of early juvenile white trout.

Seasonal or climatic related variation in water temperature can potentially influence the recruitment success of estuarine dependent nekton. Spring and fall pulses of juvenile white trout grow at different rates, with fish showing markedly fast growth rates in summer (Shaw et al. 1988). In marine systems, climatic variation can elicit broad scale variability in the recruitment success of fishes (Myers et al. 1997). In the present study, rather than increasing steadily throughout the five week study period, water temperature and inferred shifts in growth fluctuated somewhat on the weekly scale, notwithstanding the gradual seasonal warming trend. Thus, the contribution of a particular cohort to recruitment would not necessarily be related to its seasonal chronology. Likewise, inter-annual variability in recruitment success may arise from climatic variation.

ACKNOWLEDGMENTS

This work is a result of research sponsored in part by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce under Grant No. NA56RG019, and the Mississippi-Alabama Sea Grant Consortium. The U.S. Government and the Mississippi-Alabama Sea Grant Consortium are authorized to produce and distribute reprints notwithstanding any copyright notation that may appear hereon. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies. Special thanks to G. Duff for his assistance in the field.

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