

RELATIVE ABUNDANCE, GROWTH, AND MORTALITY OF FIVE ESTUARINE AGE-0
FISH IN RELATION TO DISCHARGE OF THE SUWANNEE RIVER, FLORIDA

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2007

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To my family and son “Hunter”

ACKNOWLEDGMENTS

Gratitude is expressed to the many people who helped me carry out this project. Special thanks are given to Dr. Mike Allen who took me on as a student and helped initiate my project. I also thank Jered Jackson, Bill Pine, and Tom Frazer for their reviews and advice. Data for this study was collected over nine years by FWCC Fish and Wildlife Research Institute personnel at the Senator George G. Kirkpatrick Marine Laboratory in Cedar Key, Florida. I thank all those who participated in field work, data collection, data entry, and data proofing during that time. I also thank the USGS and SRWMD for flow and precipitation data that they have made available in public domain. Support for this study was provided in part by funds from Florida Recreational Saltwater Fishing License sales and the Department of Interior, U.S. Fish and Wildlife Service, Federal Aid for Sport Fish Restoration, Project number F-43.

TABLE OF CONTENTS

	<u>page</u>
ACKNOWLEDGMENTS	4
LIST OF TABLES	6
LIST OF FIGURES	7
ABSTRACT	8
CHAPTER	
1 INTRODUCTION	10
2 METHODS	14
Study Location	14
Data Collection	14
Analyses	16
Seasonal River Discharge	16
Age-0 Fish Relative Abundance and Seasonal River Discharge	16
Growth	17
Mortality	18
Growth and Mortality Validation	19
3 RESULTS	20
Age-0 Fish Relative Abundance and Seasonal River Discharge	20
Growth and Mortality	21
Growth and Mortality Validation	22
4 DISCUSSION	31
LIST OF REFERENCES	38
BIOGRAPHICAL SKETCH	43

LIST OF TABLES

<u>Table</u>		<u>page</u>
3-1	Summary of species, period fish were recruiting into the estuary and vulnerable to the gear (Recruitment window), and SL (standard length) cut-off for fish used in calculation of relative abundance of fish considered to be within age-0 classification.....	23
3-2	Significant multiple regression equations predicting age-0 fish relative abundance within zones (1997 – 2005) from seasonal mean Suwannee River discharge rates between years.....	24
3-3	Summary table of species and their mean relative growth rates reported as millimeters per day ($\text{mm}\cdot\text{d}^{-1}$), standard error (SE), and minimum and maximum relative growth rates for fish captured from 1997-2005.	25

LIST OF FIGURES

<u>Figure</u>		<u>page</u>
1-1	Map of the sampling area around the Suwannee River estuary, Florida.	13
3-2	Relationship between log transformed age-0 fish relative abundance (fish·100 m ⁻²) and seasonal mean Suwannee River discharge between years... ..	26
3-3	Relationship between yearly instantaneous daily growth estimates (G) and mean Suwannee River discharge.....	27
3-4	Relationship between yearly instantaneous mortality rate estimates (Z) and mean Suwannee River discharge.....	28
3-5	Observed (bars) length frequency of fast (A) and slow (B) growing pinfish with the predicted length frequency (solid line) overlaid, after calculated growth and mortality were applied to observed catches.....	29
3-6	Observed (bars) length frequency of fast growing red drum with the predicted length frequency (solid line) overlaid, after calculated growth and mortality were applied to observed catches.	30

Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
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December 2007

Chair: Micheal Allen

Major: Fisheries and Aquatic Sciences

Understanding relationships between river discharge and recruitment of estuarine fishes is important due to hydrology alterations from anthropogenic water withdrawals. Variation in river discharge alters salinity, turbidity, nutrient and detrital concentrations which influence all estuarine biota. The Suwannee River system is one of the few remaining large river systems in the United States that has no major impoundments. I assessed the relationship between seasonal river discharge and age-0 fish relative abundance, growth, and mortality for five estuarine-dependent species in the Suwannee River estuary. Analyses included nine years of data (1997-2005) collected as part of a long-term fisheries-independent monitoring program. I found a positive relationship between age-0 fish relative abundance and seasonal mean river discharge for spotted seatrout *Cynoscion nebulosus*, sand seatrout *Cynoscion arenarius*, and red drum *Sciaenops ocellatus*. Pinfish *Lagodon rhomboides* was the only species for which relative abundance was negatively related to river discharge, and spot *Leiostomus xanthurus* relative abundance was not significantly related to changes in river discharge. Instantaneous daily growth estimates were positively related to river discharge for all species except spotted seatrout, for which a negative correlation was found. Instantaneous daily mortality estimates were positively correlated with river discharge for sand seatrout, pinfish, and red drum. Changes in

fresh water discharge clearly affected the abundance, growth, and survival of these juvenile fish, stressing the importance of water allocation decisions to estuarine fishes and the fisheries they support.

CHAPTER 1 INTRODUCTION

River discharge affects many abiotic and biotic characteristics of estuaries. River discharge influences salinity and turbidity as well as nutrient and detrital concentrations, and these changes can strongly influence estuarine biota (Wilber 1994; Garcia et al. 2003; North and Houde 2003; Binett et al. 1995; Crivelli et al. 1995; Livingston 1991; Livingston 1997; Winemiller and Leslie 1992). Freshwater input provides nutrients for primary production in estuaries (Strydom et al. 2002; Wooldridge and Bailey 1982; Baird and Heymans 1996) and quality habitat for many estuary-dependent larval and juvenile fishes recruiting into estuarine nursery areas (Whitfield 1994). Global-scale atmospheric circulation anomalies and patterns such as El Niño and La Niña events have caused unusual precipitation and drought, leading to variation in river discharge in many areas of the world (Molles and Dahm 1990; Gillanders and Kingsford 2002). Modified reductions in freshwater discharge into estuarine ecosystems are of particular concern as potable water withdrawals are increased to meet the demands of growing human populations (Browder 1991). Conversely, land use changes can actually increase freshwater discharge and disrupt the natural timing of water delivery to an estuary (Drinkwater and Frank 1994; Gillanders and Kingsford 2002). Changes in the timing and magnitude of freshwater discharge have the potential to impact recruitment, growth, and mortality of age-0 fishes that use estuarine nursery habitat during their first year of life. Annual changes in age-0 fish abundance, growth, and mortality may subsequently impact year-class strength of fish that support important fisheries.

Several hypotheses have been published concerning how river discharge influences fish recruitment in estuaries. The short-food hypothesis states that recruitment would be enhanced in the vicinity of river plumes because fish larvae experience superior feeding conditions, resulting

in faster growth and lower mortality (Govoni et al. 1989; Finucane et al. 1990; Grimes and Finucane 1991). The total-larval-production hypothesis postulates that nutrients associated with river discharge support high total production of fish larvae and that specific dynamics of growth and mortality are not relevant (Grimes and Finucane 1991). The third hypothesis contends that plumes facilitate retention of more fish larvae within a limited area, and it is the physical retention rather than production that explains the effects of discharge on fish recruitment (Sinclair 1988; Grimes and Kingsford 1996). In all of these cases, variation in river discharge may lead to changes in relative abundance and potentially growth and mortality of age-0 fishes.

Interactions among river discharge, estuarine productivity, and fisheries has been reported in many regions of the world (Caddy and Bakun 1995; Deegan et al. 1986; Martins et al. 2001). Major fisheries have been negatively impacted as a result of altering river discharge. For example, totoaba, *Totoaba macdonaldi*, once supported important commercial and recreational fisheries in the northern Gulf of California. Totoaba was placed on the endangered species list in 1976 after diversion of the Colorado River altered spawning and nursery areas (Barrera-Guevara 1990). Similarly, the Aswan Dam, Egypt, decreased river discharge by 40 km³ year⁻¹, with a concomitant decline in primary fisheries production in estuarine waters and adjacent Mediterranean Sea (Bebars and Lasserre 1983; Bishara 1984). Anthropogenic alteration of river discharge regimes has been detrimental to fisheries (Baird and Heymans 1996; Grange et al. 2000; Strydom and Whitfield 2000). However, fisheries have also been shown to flourish in estuaries that received increased freshwater discharge. In the Kariega estuary, South Africa, Strydom et al. (2002) found a positive correlation between catches of juvenile fish and river discharge. In Australia a positive correlation was reported to exist between barramundi *Lates calcarifer* year class strength and river discharge (Staunton-Smith et al. 2004).

I examined fish responses to river discharge in the Suwannee River estuary, Florida. This watershed is one of the few remaining large river systems in the United States with no major impoundments constructed within its drainage system (Mattson and Rowan 1989). The headwaters originate in the Okefenokee Swamp of Georgia and the river flows 426 km to the Gulf of Mexico in Florida (Figure 1). The bulk of human water consumption and river baseflow is supplied by groundwater, which is intricately connected to the surface water via abundant springs. The biological communities within the Suwannee River estuary could be impacted by impending increases in water withdrawal from the Suwannee River system (Tsou and Matheson 2002).

I utilized an existing long term fishery-independent monitoring database to evaluate whether relative abundance, growth, and mortality of age-0 fish was related to river discharge at the Suwannee River estuary. My objectives were to 1) determine if relative abundance of age-0 fish varied with seasonal river discharge among years, and 2) assess potential mechanisms that might underline any relations with river discharge by evaluating growth and mortality of each species. An evaluation of these relationships may have implications for setting water withdrawal policy for rivers and estuaries.

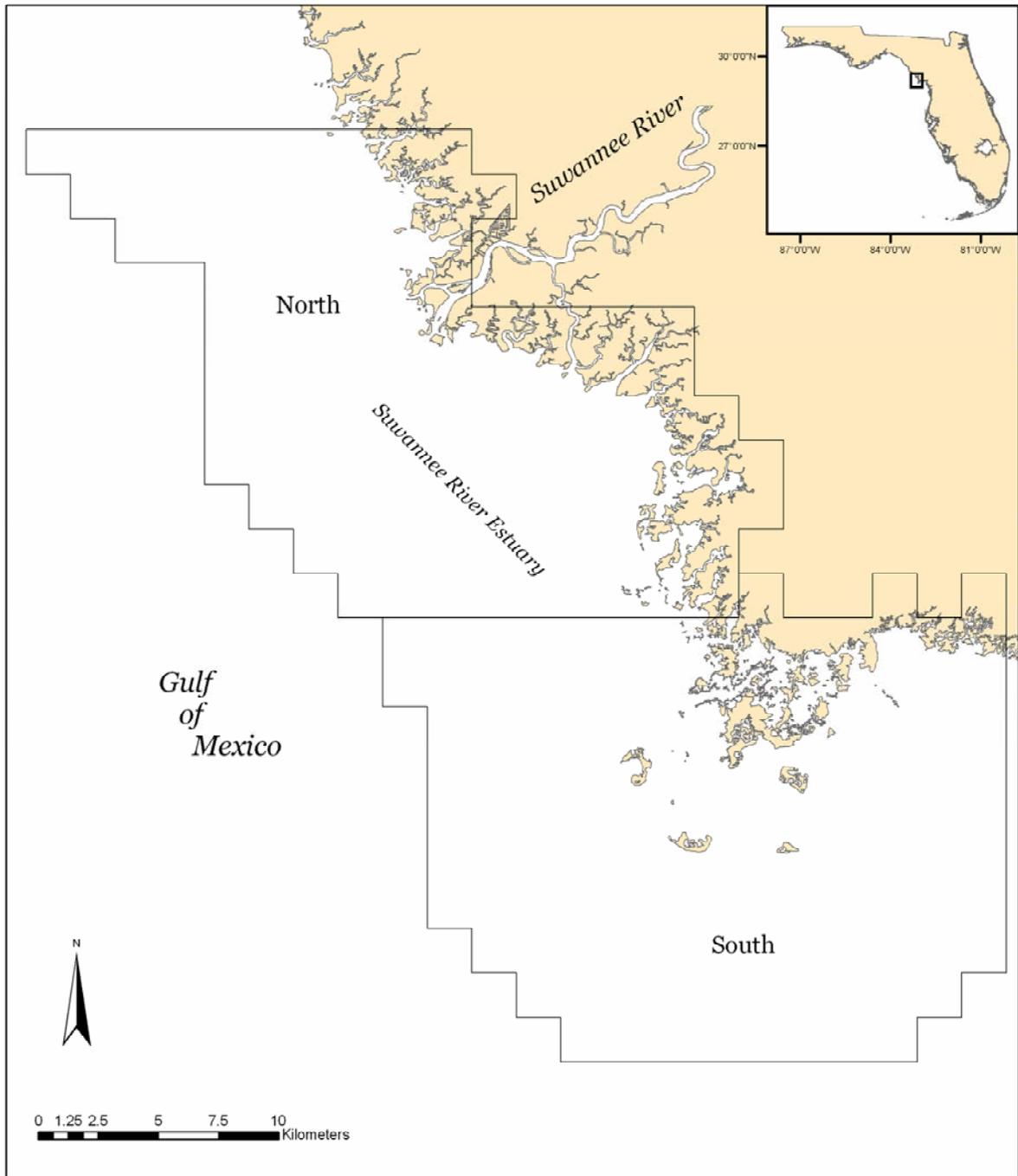


Figure 1-1. Map of the sampling area around the Suwannee River estuary, Florida.

CHAPTER 2 METHODS

Study Location

The Suwannee River estuary is a relatively pristine estuary with mostly undeveloped shorelines and is located in the Big Bend region of Florida's west coast. Unlike most estuaries, the Suwannee River estuary is an open system, lacking a barrier island (Figure 1). The shorelines are dominated by salt marshes and the bottom substrate is primarily mud, sand, and oyster reef. The Suwannee River has the second largest discharge in Florida with an average discharge rate near the mouth of the river of $125 \text{ m}^3 \text{ s}^{-1}$ (USGS 2006). In general, there are two peaks of freshwater discharge to the estuary: a relatively large peak between February and April and a somewhat smaller peak between August and October (Mattson and Rowan 1989; Tsou and Matheson 2002). However, seasonal discharge of the Suwannee River is highly variable across years.

Data Collection

Spotted seatrout *Cynoscion nebulosus*, sand seatrout *Cynoscion arenarius*, red drum *Sciaenops ocellatus*, spot *Leiostomus xanthurus* (family: Sciaenidae), and pinfish *Lagodon rhomboides*, (family: Sparidae) were collected in the Suwannee River estuary during monthly stratified-random sampling efforts from January 1997 through December 2005. These fish species were selected due to their recreational or commercial importance and also because of their dependence upon estuary habitats during the juvenile life stage. The estuary was divided into two zones (North and South) (Figure 1). Water chemistry in the north zone was directly influenced by discharge from the Suwannee River and surrounding tidal creeks. Water chemistry in the south zone was minimally affected by changes in river discharge with the exception of extremely high flow events. Fish were collected during daylight hours and during

all tidal stages using a center bag seine that measured 21.3-m x 1.8-m with a 3.2-mm #35 knotless nylon Delta mesh, deployed in water depths ranging from 0.3 - 1.8 m. Three deployment techniques were used to set the bag seine to ensure that predominate habitat types were effectively sampled. Shoreline deployments sampled shorelines with emergent vegetation, mangrove fringes, seawalls, and beaches. Offshore deployments sampled shallow waters at least 5 m away from a shoreline and sampled vegetated and unvegetated flats. River deployments sampled the shorelines of tidal creeks and the lower Suwannee River. All collections were standardized with regard to amount of area covered in each haul. The area sampled with shoreline and offshore deployments was 140 m² and for river deployments was 68 m². Effort among the three deployment techniques was roughly proportional to the available habitat within the sampling universe.

All fish collected were counted and up to 40 individuals per species and sample were measured to the nearest millimeter standard length (mm SL). Length measurements were then extrapolated to the unmeasured portion of the sample by species. Collections containing more than 1,000 fish by species were subsampled with a modified Motoda box splitter and the total number of individuals was estimated by fractional expansion of the subsampled portion (Winner and McMichael 1997). Length-frequency histograms were developed by month and year for each species to identify the timing of recruitment into the estuary and to identify cohort length modes. For quality control, the first three individuals of each species identified in the field, and up to ten individuals of species that were unidentifiable in the field were retained and later identified at the lab using dichotomous keys. At each sample site, salinity (psu), water temperature (°C), and dissolved oxygen (mg·L⁻¹) were measured 0.2-m and every 1.0-m bellow

the water surface, down to 0.2-m from the bottom. Water depth (m), and location (degrees, minutes, seconds) were measured and recorded at all sample sites.

Suwannee River discharge ($\text{m}^3 \cdot \text{s}^{-1}$) was provided by the U.S. Geological Survey (USGS) and was based upon measurements at Wilcox, Florida, approximately 51 kilometers from the river mouth. Monthly precipitation data (cm) was provided by the Suwannee River Water Management District (SRWMD) and was based upon measurements at Manatee Springs, Florida

Analyses

Seasonal River Discharge

Seasons were determined by evaluating environmental variables using Principal Component Analysis (PCA). Within each month of each year (1997-2005), environmental parameters included average monthly water temperature, salinity, dissolved oxygen, river discharge, and precipitation. To reduce variability during PCA analyses, monthly river discharge and precipitation values were calculated as monthly proportions of the entire annual values for each variable. To determine if principal component scores differed for each month, general linear models (GLM; $\alpha=0.05$) were used. Months were then grouped into each of four seasons based primarily upon Student Newman Keuls (SNK) tests (SAS Institute Inc. 1989). Within each year and season, monthly discharge data were then averaged, establishing seasonal mean river discharge.

Age-0 Fish Relative Abundance and Seasonal River Discharge

Age-0 fish relative abundance (i.e., $\text{fish} \cdot 100 \text{ m}^{-2}$) was estimated for each species within species-specific recruitment windows in both north and south zones, across years. Recruitment window was defined as the months when newly-recruited fish settled out into the estuary and remained vulnerable to the sampling gear. Length-frequency histograms were developed by month for each species to identify timing of recruitment into the estuary and to determine size

ranges that were vulnerable to capture for each species. Fish that were considered vulnerable to the gear were confirmed to be age-0 based upon size ranges found in literature reviews for each species. Relative abundance of age-0 fish was calculated separately for north and south zones in to detect response differences based on distance from the river mouth (i.e. river plume).

Relationships between age-0 fish relative abundance and seasonal river discharge across years were assessed using multiple linear regression. To determine lagged effects of river discharge on relative abundance, seasonal river discharge used in regression models included seasons that occurred up to one year prior to and during recruitment windows for individual species. In instances when a season occurred during and beyond a recruitment window, a partial season which only included the months occurring during the recruitment window was used in the model.

Relative abundance and seasonal river discharge data were \log_{10} -transformed prior to analyses to normalize the data. A Shapiro-Wilk test was used to test for normality (Zar 1996). Stepwise elimination and Akaike's information criteria (AIC) were used for model selection. Multicollinearity was assessed by evaluating the variance inflation factor (VIF) (Meyers 1990). Residuals were inspected to assure the appropriateness of the linear models. All statistical analyses were conducted using Statistical Analysis System (SAS Institute Inc. 1989). Statistical tests were considered significant when $P < 0.10$. A p-value of 0.10 was chosen to reduce Type-II error (Peterman 1990).

Growth

Instantaneous daily growth rates were estimated for age-0 fish of each species. For increased sample size, length-frequency data from north and south zones were combined to track cohort modes and by using the following model:

$$G = \frac{\ln(L_2 - L_1)}{T_2 - T_1} \quad (2-1)$$

where G = the instantaneous daily growth rate;

L = cohort mode length (mm SL); and

T = time in days.

When cohort modes were absent or not evident, growth rate estimates were not calculated for that particular year and species. Due to bi-modal spawning of spotted seatrout and sand seatrout during single recruitment windows, separate calculations for growth were estimated for “early” and “late” recruiting fish. Early-recruitment fish were those that settled into the estuary at the beginning of the recruitment window while late-recruitment fish were those that were spawned in the middle of the recruitment window and later settled into the estuary. Growth calculations began with the first month in which recruiting fish length frequencies were not truncated and a clear shift in cohort modes could be detected. First and last months included in growth calculations never varied by more than one month from year to year. Length-frequency histograms were developed by month for each species to determine at which minimum and maximum SL each species were vulnerable to the gear. To minimize bias associated with gear escapement, only cohort modes that fell within the gear vulnerability range were used for growth estimates. Instantaneous daily growth rate estimates for year classes of each species were related to mean river discharge using linear regression. Only river discharge that occurred during months from which growth was calculated was included in the model.

Mortality

Instantaneous daily mortality rates were estimated for age-0 fish of each species. For increased sample size, length-frequency and abundance data from both north and south zones were combined to track cohort modes and using the following equation:

$$N_t = N_0 e^{-Zt} \tag{2-2}$$

where N_t = abundance (fish·100 m⁻²) of fish at time t ;

N_0 = initial abundance; and

Z = daily instantaneous mortality

t = time interval between N_0 and N_t .

Initial abundance of fish (N_0) applied to the earliest month at which specific species were considered to be fully recruited to the sampling gear. To reduce bias associated with smaller fish still recruiting into the gear and larger fish avoiding the gear, I only included fish that were captured within ± 5 -mm SL around the cohort mode when calculating relative abundance. When cohort modes were absent or not clear, mortality estimates were not calculated for that particular year and species. Instantaneous daily mortality estimates for each recruitment-class of each species were correlated with mean river discharge using linear regression. Only river discharge that occurred during months from which mortality was calculated was included in the model.

Growth and Mortality Validation

To further investigate the possibility of bias associated with gear vulnerability on growth and mortality estimates, I applied growth and mortality estimates to observed length-frequencies of pinfish and red drum. Predicted length frequencies were overlaid on top of observed length frequencies to evaluate the potential for fish to grow into or out of the gear at a different rate than was predicted from equations 2-1 and 2-2. Fast growth and slow growth pinfish and fast growth red drum were used as examples.

CHAPTER 3 RESULTS

Age-0 Fish Relative Abundance and Seasonal River Discharge

Principal Component Analysis indicated that water temperature and dissolved oxygen combined accounted for the highest monthly environmental variation followed by salinity and river discharge combined. General linear models revealed a significant difference between PCA scores for each month. Subsequent SNK tests performed on monthly PCA scores resulted in the assignment of four seasons. Winter was defined as December – February; Spring as March – May; Summer as June – September; and Autumn as October and November.

Multiple regression models revealed significant relationships between age-0 fish (summary of age-0 fish defined in Table 1) relative abundance and changes in seasonal mean Suwannee River discharge between years ($P < 0.10$) for all species except spot during the period 1997 through 2005 (Table 2). In general, relative abundance of age-0 spotted seatrout, sand seatrout, and red drum were positively related to seasonal river discharge occurring prior to juvenile fish recruiting into the estuary and during recruitment (Table 2 and Figure 2). Relative abundance of sand seatrout and red drum captured in the north zone, directly influenced by the Suwannee River discharge, was positively related to seasonal river discharge. No significant relationship could be found for these species in the south zone. Spotted seatrout was the only species that exhibited a positive relationship between river discharge and age-0 fish relative abundance in the south zone. Red drum in the north zone had the best-fitting multiple regression equation, indicating that age-0 fish relative abundance was positively related to pre-spawn summer and winter river discharge (Table 2). Relative abundance of age-0 pinfish was negatively related to seasonal river discharge in both north and south zones (Table 2 and Figure 2). Spring river discharge was negatively related to relative abundance of pinfish captured in the north zone,

whereas winter discharge was negatively related to abundance in the south zone. No significant relationship between relative abundance and seasonal mean river discharge was found for spot in either the north or south zones. None of the species analyzed displayed an opposite relationship to river discharge between north and south zones. Variation explained by significant regression models (r^2) ranged from 0.37 to 0.88 (Table 2).

Growth and Mortality

Linear regression models for red drum, pinfish, spot, and early-recruitment sand seatrout indicated a significant increase in instantaneous daily growth rates with higher river discharge ($P < 0.05$; Figure 3). Early-recruitment spotted seatrout was the only species that demonstrated a decrease in growth with higher river discharge (Figure 3). I detected no relationship between growth and river discharge for late-recruitment spotted seatrout or sand seatrout. Variation explained by significant regression models (r^2) ranged from 0.48 to 0.96 (Figure 3). Relative daily growth for all five species ranged from 0.083 to 0.833 $\text{mm}\cdot\text{d}^{-1}$ (Table 3). Red drum, pinfish, spot, and early recruiting sand seatrout all had similar average growth rates which ranged from 0.359 to 0.387 $\text{mm}\cdot\text{d}^{-1}$. Late recruitment spotted seatrout (0.181 $\text{mm}\cdot\text{d}^{-1}$) and early recruitment spotted seatrout (0.233 $\text{mm}\cdot\text{d}^{-1}$) exhibited slower growth (Table 3).

Linear regression models for pinfish, red drum, and early-recruitment sand seatrout indicated a significant increase in instantaneous daily mortality rates with river discharge rate ($P \leq 0.05$; Figure 4). River discharge was not \log_{10} transformed for the early-recruitment sand seatrout model. No significant relationship was detected between mortality and river discharge for spot and late-recruitment sand seatrout. Early-recruitment sand seatrout had the lowest and highest instantaneous daily mortality across all species, ranging from 0.002 to 0.124. Mortality rates were not determined for spotted seatrout due to limited data. Variation explained by significant regression models (r^2) ranged from 0.46 to 0.81 (Figure 4).

Growth and Mortality Validation

Comparisons of predicted length frequencies to the observed catches suggested no gear selectivity issues for the size of fish that I used in this analysis (Figures 3-5 and 3-6). Fish did not appear to be avoiding the gear or moving out of the sample able areas at larger sizes, suggesting that the growth and mortality rates I estimated were not biased by gear selectivity. In general predicted length frequency modes closely resembled the observed modes (Figures 3-5 and 3-6).

Table 3-1. Summary of species, period fish were recruiting into the estuary and vulnerable to the gear (Recruitment window), and SL (standard length) cut-off for fish used in calculation of relative abundance of fish considered to be within age-0 classification.

Age-0 Fish Relative Abundance			
Species	Recruitment Window	Age-0 length (SL)	Reference
spotted seatrout	June - October	≤ 100 mm	McMichael and Peters 1989
sand seatrout	May - October	≤ 100 mm	Nemeth et. al. 2006
red drum	September - January	≤ 100 mm	Peters and McMichael 1987
pinfish	January - June	≤ 80 mm	Hanson 1969
spot	January - April	≤ 75 mm	Livingston 1984

Table 3-2. Significant multiple regression equations predicting age-0 fish relative abundance within zones (1997 – 2005) from seasonal mean Suwannee River discharge rates between years.

Model	R²	P-value
Spotted seatrout fish ·100m ² (south zone) = -0.4999 + 0.1644 x Log spring	0.37	0.08
Sand seatrout fish ·100m ² (north zone) = -1.4082 + 0.5683 x Log summer	0.77	< 0.01
Red drum fish ·100m ² (north zone) = -3.8543 + 0.5109 x Log winter + 0.6135 x Log pre-spawn summer	0.88	0.02
Pinfish fish ·100m ² (north zone) = 5.4088 - 1.0951 x Log spring	0.61	0.01
Pinfish fish ·100m ² (south zone) = 4.3659 - 0.9065 x Log winter	0.56	0.02

Table 3-3. Summary table of species and their mean relative growth rates reported as millimeters per day ($\text{mm}\cdot\text{d}^{-1}$), standard error (SE), and minimum and maximum relative growth rates for fish captured from 1997-2005. Months from which growth rates were calculated from are listed. Maximum length was the maximum size the cohort mode reached during growth calculations within any year. All fish captured within the maximum length were considered to be within selectivity of the gear. Fish captured in north and south zones were combined for growth calculations. Spotted seatrout and sand seatrout were separated into early and late recruitment due to bi-modal spawning.

Species	Months	Max Length (SL)	Mean Growth $\text{mm}\cdot\text{d}^{-1}$	SE	Min Growth $\text{mm}\cdot\text{d}^{-1}$	Max Growth $\text{mm}\cdot\text{d}^{-1}$
spotted seatrout						
early recruitment	June - July	≤ 35 mm	0.233	0.0717	0.083	0.500
late recruitment	August - September	≤ 35 mm	0.181	0.033	0.083	0.333
sand seatrout						
early recruitment	May - July	≤ 55 mm	0.359	0.078	0.167	0.833
late recruitment	August - October	≤ 40 mm	0.255	0.070	0.083	0.750
red drum	October - January	≤ 55 mm	0.368	0.079	0.125	0.667
pinfish	March - July	≤ 60 mm	0.387	0.017	0.321	0.444
spot	February - April	≤ 60 mm	0.368	0.079	0.125	0.667

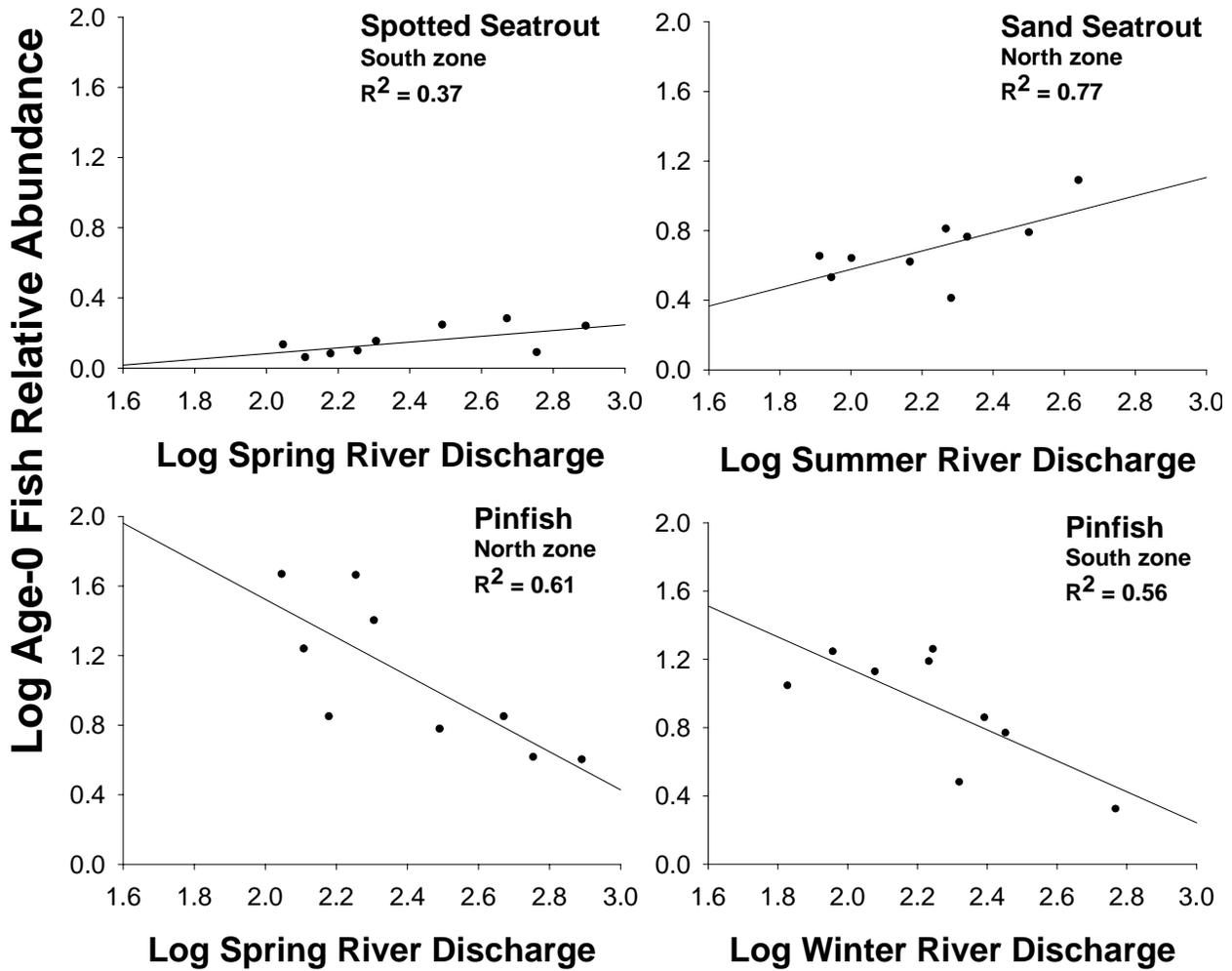


Figure 3-2. Relationship between \log_{10} -transformed age-0 fish relative abundance (fish·100 m⁻²) and seasonal mean Suwannee River discharge between years. River discharge is in \log_{10} transformed cubic meters per second (m³ s⁻¹).

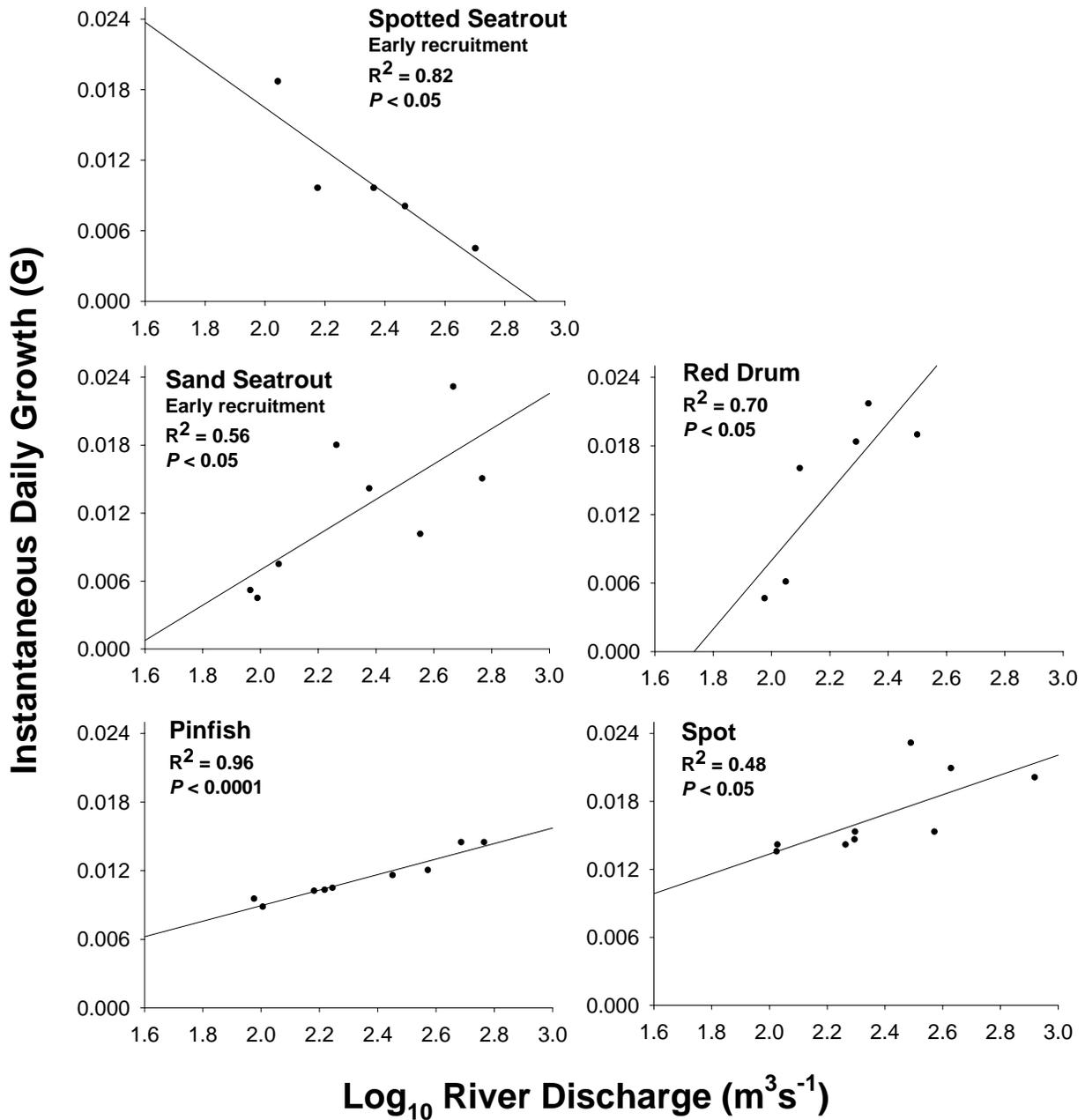


Figure 3-3. Relationship between yearly instantaneous daily growth estimates (G) and mean Suwannee River discharge during months in which growth was calculated by year.

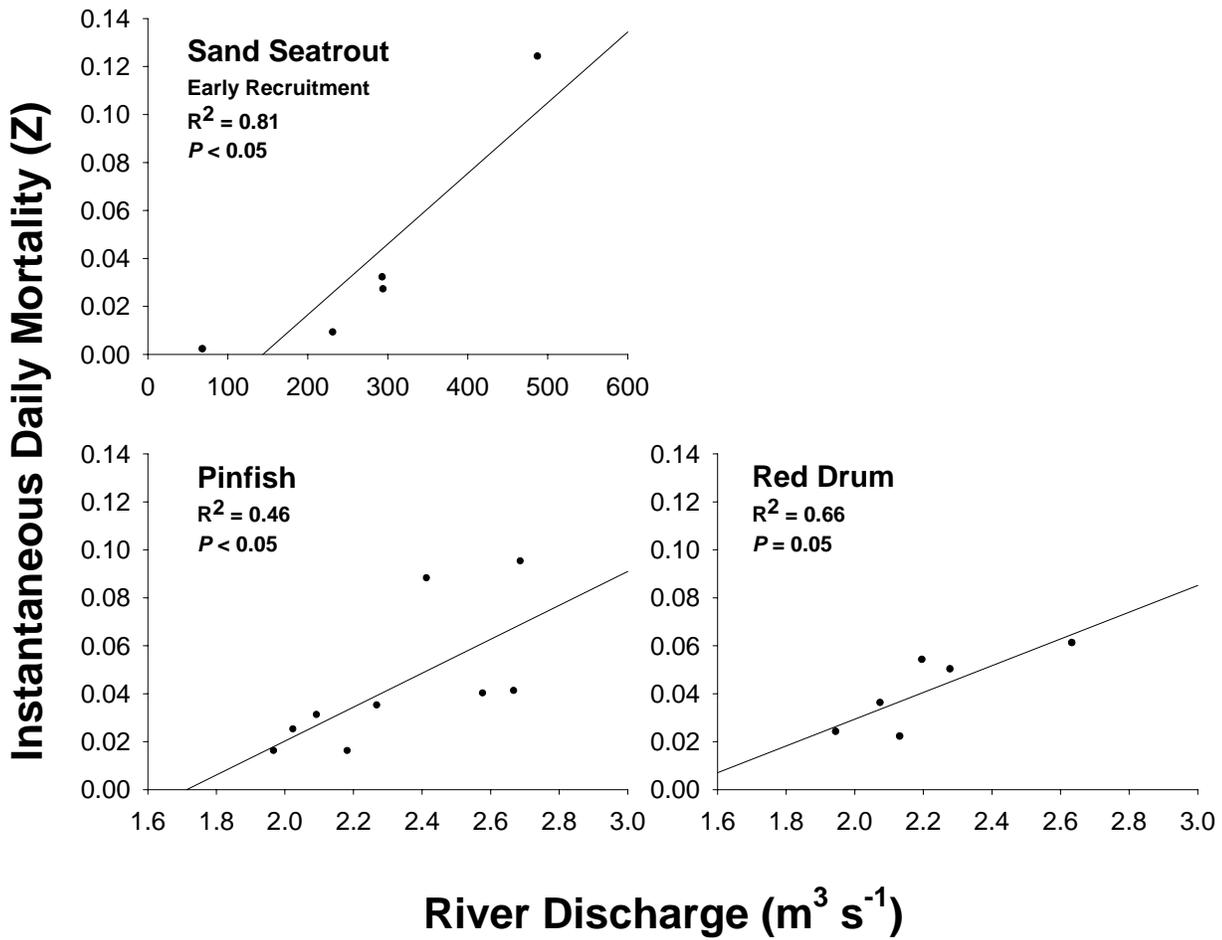


Figure3-4. Relationship between yearly instantaneous mortality rate estimates (Z) and mean Suwannee River discharge during months in which mortality was calculated by year. River discharge is in \log_{10} -transformed cubic meters per second ($\text{m}^3 \text{s}^{-1}$) for pinfish and red drum only.

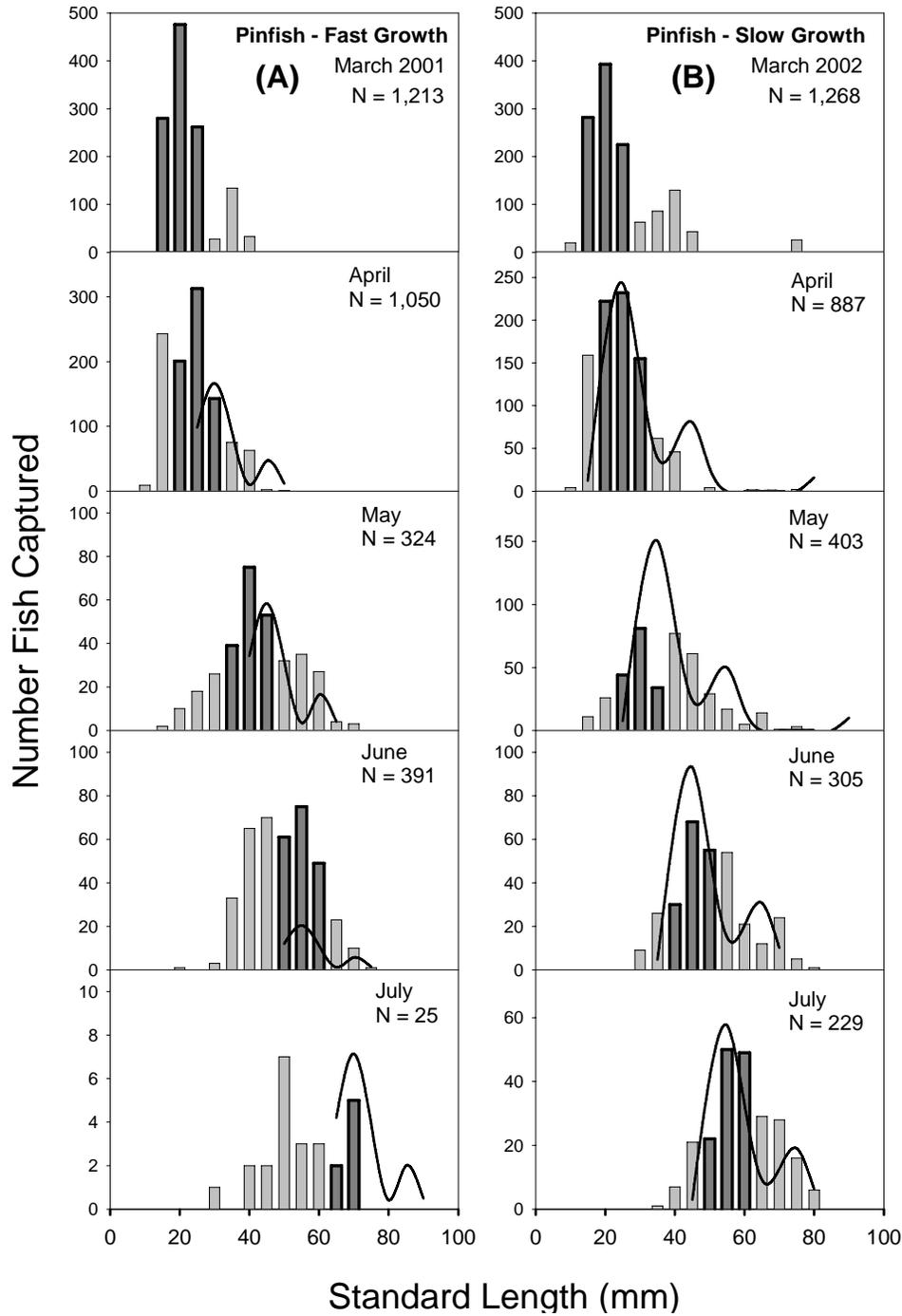


Figure 3-5. Observed (bars) length-frequency of fast (A) and slow (B) growing pinfish with the predicted length-frequency (solid line) overlaid, after calculated growth and mortality were applied to observed catches. Dark bars represent + 5-mm increments around the cohort mode, used in calculating mortality estimates.

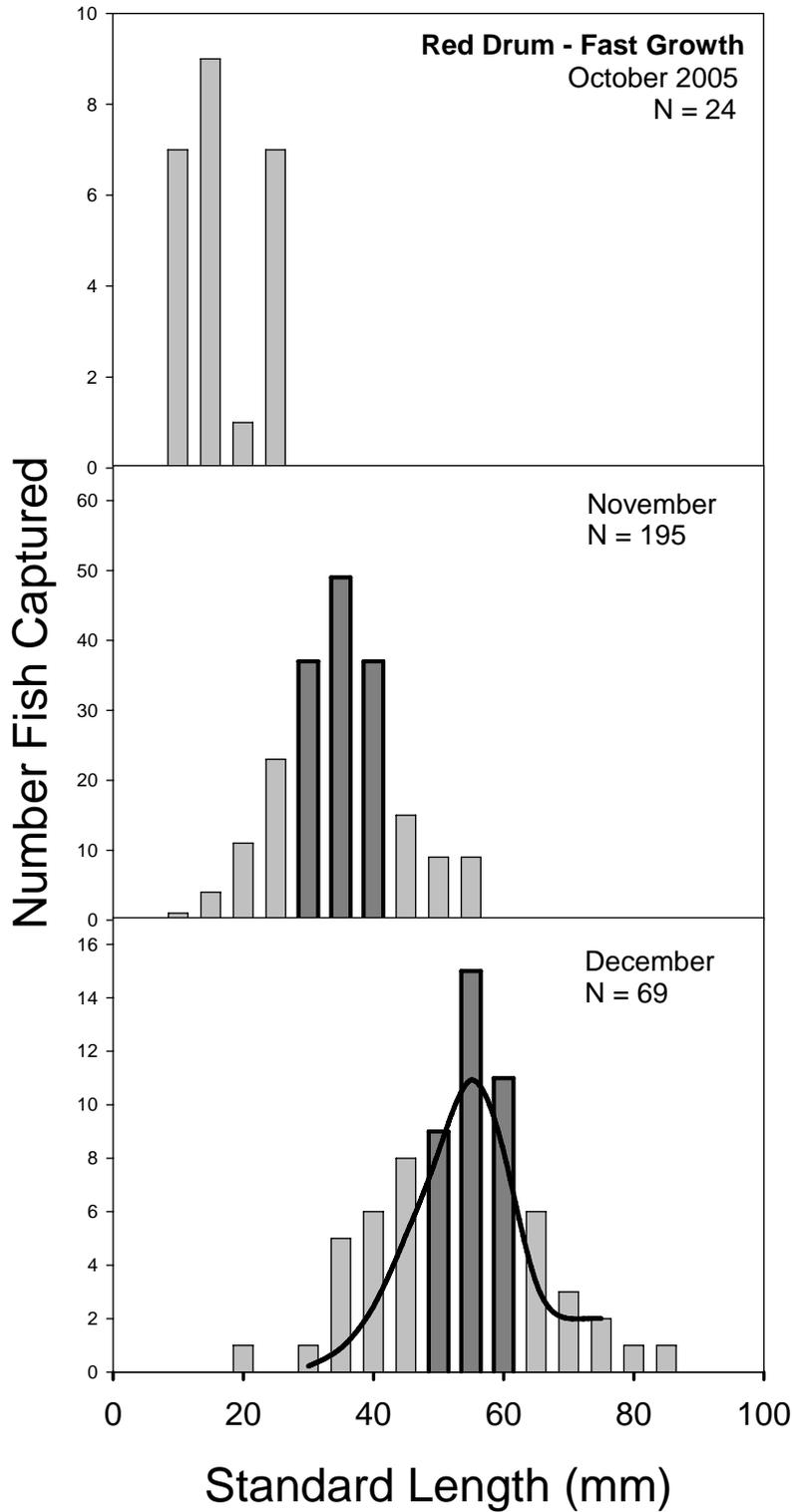


Figure 3-6. Observed (bars) length-frequency of fast growing red drum with the predicted length-frequency (solid line) overlaid, after calculated growth and mortality were applied to observed catches. Dark bars represent + 5-mm increments around the cohort mode, used in calculating mortality estimates.

CHAPTER 4 DISCUSSION

Previous work has evaluated the effects of river discharge on fish larvae retention, growth, and survival (Grimes and Kingsford 1996; Grimes and Finucane 1991; Govoni et al. 1989), but few have evaluated the effects that changes in river plumes may have on fish once they reach a juvenile stage within an estuary and compare these effects to hypotheses associated with larvae fish. The short-food hypothesis stated higher recruitment in the vicinity of river plumes due to enhanced feeding conditions, promoting fast growth and lower mortality of fish larvae (Govoni et al. 1989; Finucane et al. 1990; Grimes and Finucane 1991). The size and shape of river plumes and their associated fronts is variable, and depends primarily upon the nature of ocean currents, topography, dimensions and shape of the estuary and adjacent shelf area, and the rate of freshwater discharge. Rivers with high discharge rates typically produce large plumes (Gillanders and Kingsford 2002). I found that relative abundance and growth of age-0 sand seatrout and red drum increased with river discharge across years. However, these species also suffered higher mortality rates during increased river discharge which lends some credence to the total-larval-production hypothesis which states that superior trophic conditions found during high river discharge support such high total production of fish larvae that specific dynamics of growth and mortality are not relevant (Grimes and Finucane 1991).

Although both the short-food and total-larval-production hypotheses apply to larval fish, these concepts may also be applicable to juvenile fish recruiting into an estuary. The physical mechanisms associated with intensity of river plumes may affect juvenile fish relative abundance and the relationship between growth and mortality. Changes in mortality may have a much larger effect on survival (ultimately recruitment success) than incremental changes in growth (Grimes 2001). Effects of these mechanisms on juvenile fishes may vary depending on species.

Therefore, analysis for juvenile fish should be conducted on an individual species basis. In my study, pinfish suffered lower relative abundance and higher mortality rates with increased river discharge, despite higher growth with high discharge. Whereas previously mentioned, red drum and sand seatrout exhibited higher relative abundance, higher growth and higher mortality with increased river discharge. The third hypothesis stated that it is the physical retention of river plumes rather than production that explains the variation in recruitment (Sinclair 1988; Grimes and Kingsford 1996). Loneragan and Bunn (1999) suggested that changes in turbidity and salinity as a result of changing river discharge may restrict distribution of fish or stimulate their movements into areas more likely to be caught thus leading to higher densities rather than an actual increase in fish production. I was not able to evaluate this hypothesis due to the inability to isolate the relative contribution of nutrients and intensity of the retention mechanism because both vary with river discharge and mixing with ocean currents (Grimes and Kingsford 1996).

My study found relative abundance of age-0 spotted seatrout from the south zone, and sand seatrout and red drum from the north zone to be positively related to increases in seasonal river discharge. None of the five species abundances displayed an opposite relationship to river discharge between north and south zones which would have indicated a river-induced change in spawning location or settling location of new recruits transported from offshore waters. Both spotted seatrout and sand seatrout are nearshore or estuarine spawners and both spawn from spring through summer months (Walters 2005). The positive relationship found between relative abundance of spotted seatrout and sand seatrout to spring and summer river discharge respectively, may be attributed to the higher input of nutrients into the estuary leading to enhanced primary and secondary production during summer months as opposed to other seasons (Whitfield 1994; Loneragan and Bunn 1999). Spotted seatrout was the only species which

displayed an increase in relative abundance in the south zone during increased river discharge. This may have been a result of spotted seatrout avoiding lower salinity areas in order to reduce osmoregulatory stress, commonly found in marine species (Whitfield and Harrison 2003).

Red drum and spot are two of three estuarine-dependent species I analyzed that spawn offshore (Rooker et al. 1998; Weinstein 1983) and depend upon ocean currents to transport larvae back into the estuary. Red drum begin spawning during late summer when Suwannee River discharge rates are normally relatively low. Many species of marine fishes use changes in freshwater discharge as physical and chemical stimuli to initiate migration offshore for spawning and for passive transport of larvae towards estuaries (Champalbert et al. 1989; Champalbert and Koutsikopoulos 1995). As a result, high recruitment levels should be expected for high river discharge occurring during optimal periods (Costa et al. 2007). North and Houde (2003) found similar results in the Chesapeake Bay estuary where juvenile white perch and striped bass abundances were positively correlated to Susquehanna River discharge during spring. Juvenile *Gilchristella aestuaria* abundances were positively correlated with river discharge in the Kariega Estuary along the coast of South Africa (Strydom et al. 2002). This may explain the strong positive association I found between relative abundance of age-0 red drum and river discharge during pre-spawn summer seasons and winter seasons. No significant relationship was found between discharge and relative abundance of age-0 spot. Spot spawn during winter and spring months when Suwannee River discharge is generally at its highest. Although increased river discharge can be important for nutrient input, extreme high freshwater discharge may actually flush out nutrients and even create a physical barrier to recruitment of fish (Gillanders and Kingsford 2002; Costa et al. 2007).

In contrast, other studies of juvenile fishes have shown negative relationships between abundance and river discharge. Juvenile gulf menhaden *Brevoortia patronus* abundance has been found to be negatively associated with Mississippi River discharge (Govoni 1997), and age-0 Japanese seaperch *Lateolabrax japonicus* abundance exhibited an inverse correlation to the Chikugo River discharge (Shoji and Tanaka 2006). In this study, pinfish was the only species in which age-0 fish abundance was negatively related to river discharge. Pinfish are the third of three species I analyzed that spawn offshore (Hansen 1969) and depend upon ocean currents to transport larvae back into the estuary. Pinfish spawn during late winter and early spring when the Suwannee River discharge rates generally are highest. High discharge, may restrict the shoreward transport of pinfish larvae.

Food supply is perhaps the most important biological factor influenced by changes in river discharge (Grimes and Finucane 1991). My results showed sand seatrout, red drum, pinfish, and spot experienced higher growth during years with elevated river discharge, supporting the argument of enhanced feeding opportunities during increased river discharge. Spotted seatrout was the only species that displayed slower growth during years with increased river discharge. Deegan (1990) found a similar relationship with growth of juvenile gulf menhaden declining with increased discharge from the Mississippi River. Spotted seatrout in my study may have suffered from prolonged freshwater conditions (lower salinity) during increased river discharge which can lead to osmoregulatory stress in some marine species (Whitfield and Harrison 2003), thus leading to slower growth.

My results, however, do not support the contention that higher growth rates of juvenile fish leads to better survival as is often found with larvae fish (North and Houde 2001; Grimes and Kingsford 1996). In my study, red drum, sand seatrout, and pinfish mortality increased with

river discharge, despite these species exhibiting faster growth under the same physical conditions. There is some evidence in the literature supporting a relationship of high mortality rates with high growth rates in juvenile estuarine-dependent species. Walters and Martell's (2004) foraging arena theory suggests juvenile fish respond to changes in food concentrations to maintain constant growth. This theory assumes most predation occurs while fish are foraging and this attempt to maintain constant growth likely results in linear increase in mortality with increasing juvenile density. Prey such as juvenile finfish can hide from predators unless the prey density is so high that it forces that prey to spend more time foraging outside of their preferred habitat, resulting in higher mortality. Munch and Conover (2003) also found fast growing Atlantic silversides *Menidia menidia* suffered higher mortality from predation despite being 40% larger than the slow-growing population (Munch and Conover 2003). Consumption of larger meals by fast growth fish may be detrimental to swimming ability and predator evasion (Billerbeck et al. 2001). Furthermore, the same physical and biological dynamics that lead to accumulated larval fish and prey may also accumulate their predators (Fernández-Delgado et al. 2007; Govoni et al. 1989) although the number of prey eaten may not depend on the number of predators (Walters and Martell 2004; Munch and Conover 2003). Cannibalism associated with high abundance is another major source of mortality common in early life stages that should be considered (Grimes and Finucane 1991). Thus, my results indicate that faster growth associated with high river discharge might result in higher mortality for juvenile fishes.

Benefits of increased production associated with river plumes (Gillanders and Kingsford 2002; Grimes and Finucane 1991) may or may not out weigh the disadvantage of increased mortality. For example, Grimes and Kingsford (1996) showed higher instantaneous natural mortality rates in the vicinity of the Mississippi river plume than away from the plume for larval

Spanish mackerel *Scomberomorus maculatus* and king mackerel *Scomberomorus cavalla*, despite enhanced growth. Similar results for striped anchovy *Anchoa hepsetus* suggest that natural mortality in the plume front and within the river plume was higher than that experienced in shelf waters (Day 1993). Connel (1998) reported a positive relationship between juvenile reef fish abundance and mortality rates due to predation. If conditions in the vicinity of river plumes support higher growth or fish abundances, but also aggregate predators and increase mortality rate, enhanced recruitment into the fishery may not occur. In my study, red drum, sand seatrout, and pinfish all suffered from higher mortality despite either rapid growth or higher relative abundance during high-discharge years.

Differences in mortality rates based on changes in relative abundance with fish size should be interpreted with caution because the method assumes that fish have equal vulnerability to capture by the sampling gear. Faster growth rates may lead to biased mortality estimates, because large fish become less vulnerable to capture and would be under-represented, thus leading to inflated mortality rates. However, any inherent biases in the mortality estimates would be present during all years. Moreover, the data used in calculating instantaneous mortality rates was within the bounds of gear selectivity of each species analyzed. Fish captured during initial recruitment months in which they appeared to be partially vulnerable to the gear, as well as later months when larger fish would be expected to either leave the area or avoid the gear were not included in mortality estimates. By only including fish captured ± 5 -mm around the cohort mode when calculating cohort abundance, I further reduced the chance of gear selectivity biasing mortality estimates. This approach appeared to be valid based on the observed and predicted changes in the length frequency distributions through time.

Results of this study could assist managers in the development and implementation of strategies to compensate for poor year-class production as a result of changes in river discharge. In areas where water control devices (i.e., dams and levies) currently exist along major tributaries, managers could work with water controlling authorities to manage water levels for better fish production. This study has broad implications for assessing how river discharge influences recruitment of ecologically and recreationally important estuarine-dependent species in an estuary.

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BIOGRAPHICAL SKETCH

Caleb Hunter Purtlebaugh was born February 20, 1975 in Winchester, Virginia, the son of Michael and Sun Purtlebaugh. He graduated from James Wood High School, Virginia in 1993. He received his Bachelor of Science degree in Wildlife and Fisheries Resources from West Virginia University. He became interested in the outdoors while hunting and fishing with his father. He would often canoe and camp along the Shenandoah River located in the western part of Virginia. After graduating from college with his Bachelor of Science degree, he briefly attended graduate school at Frostburg State University, however eventually moved and started a job working for the Delaware Division of Fish and Wildlife for a couple of years. It was there that he became interested in marine science. During his time in Delaware, he continued graduate school at Delaware State University while also working for the Delaware Division of Fish and Wildlife. It soon became apparent to him that he wanted to broaden his experience in marine science. In 2000, he accepted a job as a marine fisheries research scientist with the Florida Fish and Wildlife Research Institute, located in Cedar Key, Florida. After gaining extensive experience in the marine science field and after the birth of his son "Hunter", he decided to finally finish what he had started. He contacted the University of Florida and Dr. Mike Allen took him on as a graduate student in the fall 2005. After his enrollment into graduate school he continued to work full-time. After his graduation in December 2007, he plans to continue his successful career in marine fisheries research.