1989

Age and Growth of Red Drum, Sciaenops Ocellatus, and Black Drum, Pogonias Cromis, in the Northern Gulf of Mexico.

Daniel William Beckman

Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses

Recommended Citation


https://digitalcommons.lsu.edu/gradschool_disstheses/4699

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.
INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book. These are also available as one exposure on a standard 35mm slide or as a 17” x 23” black and white photographic print for an additional charge.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6” x 9” black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI
University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313/761-4700     800/521-0600
Age and growth of red drum, *Sciaenops ocellatus*, and black drum, *Pogonias cromis*, in the northern Gulf of Mexico

Beckman, Daniel William, Ph.D.
The Louisiana State University and Agricultural and Mechanical Col., 1989
AGE AND GROWTH OF
RED DRUM, SCIAENOPS OCELLATUS, AND BLACK DRUM, POGONIAS CROMIS,
IN THE NORTHERN GULF OF MEXICO

A Dissertation

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

in

The Department of Marine Sciences

by

Daniel William Beckman

B.A., University of North Alabama, 1979
M.S., University of South Carolina, 1983

May, 1989
ACKNOWLEDGEMENTS

This dissertation was accomplished with help and support from many individuals. The research was carried out as a part of several studies which required the cooperation of numerous scientists, fishermen, and seafood handlers, some of which are acknowledged in individual chapters.

First, I thank Chuck Wilson for his support as major professor. He went out of his way to provide the support that brought me into age and growth work at L.S.U., and the encouragement that convinced me to take that final step and pursue a Ph.D. Throughout my studies, he gave me the independence I wanted, but was there for the assistance I needed. His critical review of manuscripts was extremely helpful in getting them to publishable quality. I thank the other members of my committee for their contributions and assistance: James Geaghan and Gary Shaffer for the statistical counselling and critical reviews; John Fleeger and Larry Rouse for the thorough review and suggestions that made a real difference in the final product; Rick Shaw and Gene Turner for thorough reviews and for convincing me to take that last step, which resulted in Chapter 5 and a significantly improved dissertation.

I thank Gary Fitzhugh for his conviction that we could initiate and carry out the black drum studies, and for his help in accomplishing that task; Dave Nieland and Robby Parker for the reproductive work and for developing friendships with the fishermen and getting valuable samples at dock and at sea; Jeff Render for assisting with sampling and being a dedicated otolith reader; Dave Stanley for sampling at tournaments, for computer help, and for listening to and improving upon my speculations; Louise Stanley for being so organized and conscientious
in handling data and running the lab, and for being unsurpassed at otolith reading; Bruce Thompson for sharing his lab when space was tight, for the 'oldest-but-not-biggest' black drum and other rodeo samples, and for getting excited with me about otoliths. I thank Stewart Ancon, Benny Barns, Dean Blanchart, Tony Gaspard, and Karen Texada for numerous hours sawing otoliths.

I thank Dave Burdick, Jim Cowan, Scott Dinnel, Jim Lee, and Gary Shaffer for their undying friendship and unerring advice. Thanks to Gary Shaffer for his knowledge and camaraderie, and helping me over hurdles along the way; to Jim Cowan for his advice on larval fish biology; to Scott Dinnel for setting me onto the river discharge data; and to Gerry Newman for help in fighting through all the red tape.

I thank the National Marine Fisheries Service and Louisiana Department of Wildlife and Fisheries biologists who provided samples. Thanks to Jay Grymes, Louisiana Office of State Climatology, for providing temperature data on a moments notice. Many people involved with fisheries in Louisiana and Mississippi, to numerous to name here, provided samples I could not have obtained on my own. I sincerely thank them for better-than-could-be-expected cooperation. Special thanks to Ricky Cheramie who went out of his way to help with my impoundment studies. Support for my dissertation studies was provided through the Louisiana Sea Grant Program, Louisiana Board of Regents, U.S. Department of commerce MARFIN program, and the L.S.U. Coastal Fisheries Institute and Department of Marine Sciences.

I thank Donny Simbeck for initiating my excitement about biology as a potential career and suggesting marine biology as a 'field of the future'. I thank Bob Shipp, and John Dean for their contributions to my
education and leading me in the right directions. I thank Bill Herke for getting me into Louisiana and Eric Knudsen for going out of his way to get me to Baton Rouge.

I am especially grateful to my parents, William and Anna Beckman. Their financial help enabled me to develop an interest in marine science, but more than this they encouraged independence to choose my own directions, and provided love and examples without which I could not have accomplished what I have. My deepest thanks go to my wife, Michiko, for her extreme patience and love through it all; and to my son, Christopher, for always being there with a hug and a laugh when I needed it most.
FORWARD

For Michiko & Christopher

the true loves

of my life
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>FORWARD</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>xiv</td>
</tr>
<tr>
<td>GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Life History</td>
<td>1</td>
</tr>
<tr>
<td>Fisheries Management</td>
<td>2</td>
</tr>
<tr>
<td>Age Estimation</td>
<td>5</td>
</tr>
<tr>
<td>Growth Models</td>
<td>8</td>
</tr>
<tr>
<td>Year-Class Analysis</td>
<td>10</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>14</td>
</tr>
<tr>
<td>Chapter 1. GROWTH RATES AND VALIDATION OF AGE ESTIMATES OF RED DRUM, SCIAENOPS OCELLATUS, IN A LOUISIANA SALT MARSH IMPOUNDMENT</td>
<td>25</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>26</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>27</td>
</tr>
<tr>
<td>MATERIALS AND METHODS</td>
<td>28</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>29</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>32</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>33</td>
</tr>
<tr>
<td>Chapter 2. AGE AND GROWTH OF RED DRUM, SCIAENOPS OCELLATUS, FROM OFFSHORE WATERS OF THE NORTHERN GULF OF MEXICO</td>
<td>39</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>40</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>41</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATERIALS AND METHODS</td>
<td>42</td>
</tr>
<tr>
<td>RESULTS</td>
<td>44</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>47</td>
</tr>
<tr>
<td>Sampling</td>
<td>47</td>
</tr>
<tr>
<td>Validation</td>
<td>48</td>
</tr>
<tr>
<td>Growth</td>
<td>49</td>
</tr>
<tr>
<td>Age Structure</td>
<td>50</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>51</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>53</td>
</tr>
<tr>
<td>Chapter 3. <strong>AGE AND GROWTH OF BLACK DRUM IN LOUISIANA GULF OF MEXICO WATERS</strong></td>
<td>66</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>67</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>68</td>
</tr>
<tr>
<td>METHODS</td>
<td>70</td>
</tr>
<tr>
<td>RESULTS</td>
<td>72</td>
</tr>
<tr>
<td>Otolith Microstructure</td>
<td>72</td>
</tr>
<tr>
<td>Validation</td>
<td>72</td>
</tr>
<tr>
<td>Reader Variability</td>
<td>73</td>
</tr>
<tr>
<td>Growth</td>
<td>73</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>75</td>
</tr>
<tr>
<td>Otolith Growth</td>
<td>75</td>
</tr>
<tr>
<td>Annulus Formation</td>
<td>76</td>
</tr>
<tr>
<td>Reader Variability</td>
<td>77</td>
</tr>
<tr>
<td>Age Estimates</td>
<td>77</td>
</tr>
<tr>
<td>Growth Rates</td>
<td>78</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Chapter 4.</th>
<th>YEAR-CLASS STRUCTURE OF BLACK DRUM FROM LOUISIANA GULF OF MEXICO WATERS.</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td></td>
<td>79</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>91</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
<td>92</td>
</tr>
<tr>
<td>METHODS</td>
<td></td>
<td>93</td>
</tr>
<tr>
<td>RESULTS</td>
<td></td>
<td>94</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 5.</th>
<th>CORRELATION OF RED DRUM AND BLACK DRUM RELATIVE YEAR-CLASS ABUNDANCE WITH ENVIRONMENTAL VARIABILITY IN THE NORTHERN GULF OF MEXICO.</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
<td>111</td>
</tr>
<tr>
<td>METHODS</td>
<td></td>
<td>112</td>
</tr>
<tr>
<td>RESULTS</td>
<td></td>
<td>114</td>
</tr>
<tr>
<td>Red Drum</td>
<td></td>
<td>117</td>
</tr>
<tr>
<td>Black Drum</td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>Red Drum</td>
<td></td>
<td>119</td>
</tr>
<tr>
<td>Black Drum</td>
<td></td>
<td>126</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td></td>
<td>127</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
<td>129</td>
</tr>
<tr>
<td>SYNOPSIS AND CONCLUSIONS</td>
<td></td>
<td>146</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS (Continued)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Future Work</td>
<td>149</td>
</tr>
<tr>
<td>Implications for Fisheries</td>
<td>151</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>154</td>
</tr>
<tr>
<td>VITAE</td>
<td>158</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Distributions of black drum samples by capture gear and area</td>
<td>103</td>
</tr>
<tr>
<td>5.1</td>
<td>Name and description of environmental variables which were compared with relative year-class abundance of adult red drum</td>
<td>137</td>
</tr>
<tr>
<td>5.2</td>
<td>Correlation coefficients for comparisons among mean yearly environmental variables</td>
<td>138</td>
</tr>
<tr>
<td>5.3</td>
<td>Correlation coefficients for annual mean of environmental variables with back-calculated year-class abundance of red drum</td>
<td>139</td>
</tr>
<tr>
<td>5.4</td>
<td>Correlation coefficients for monthly environmental variables with red drum back-calculated relative year-class abundances (assuming total instantaneous mortality (Z) = 0.1)</td>
<td>140</td>
</tr>
<tr>
<td>5.5</td>
<td>Predictive linear models of back-calculated relative year-class abundance (assuming Z=0.1) from environmental variables</td>
<td>141</td>
</tr>
<tr>
<td>6.1</td>
<td>Summary of age and growth information for red drum and black drum from the northern Gulf of Mexico</td>
<td>157</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1.1</td>
<td>Growth of tagged-recaptured red drum from date-of-release to date-of-recapture</td>
<td>36</td>
</tr>
<tr>
<td>1.2A</td>
<td>Photomicrograph under bright field light of a transverse section from a sagitta of a red drum injected with tetracycline August 28, 1985 and recaptured March 7, 1987.</td>
<td>37</td>
</tr>
<tr>
<td>1.2B</td>
<td>Enlarged photomicrograph of same sagitta section as A, under bright field plus fluorescent light.</td>
<td>38</td>
</tr>
<tr>
<td>2.1</td>
<td>Red drum purse seine sampling locations in the northern Gulf of Mexico.</td>
<td>57</td>
</tr>
<tr>
<td>2.2</td>
<td>Length-frequency distribution for red drum captured by purse seine from offshore Gulf of Mexico waters.</td>
<td>58</td>
</tr>
<tr>
<td>2.3</td>
<td>Photomicrograph of a transverse section of a red drum otolith (sagitta) sampled in May, 1986.</td>
<td>59</td>
</tr>
<tr>
<td>2.4A</td>
<td>Plot of percent occurrence of otoliths (sagittae) with opaque margins vs. month of capture for red drum by sample month and year.</td>
<td>60</td>
</tr>
<tr>
<td>2.4B</td>
<td>Plot of percent occurrence of otoliths (sagittae) with opaque margins vs. month of capture for red drum grouped by annulus counts, sample years combined.</td>
<td>61</td>
</tr>
<tr>
<td>2.5</td>
<td>Age-frequency distributions for red drum captured by purse seine from offshore northern Gulf of Mexico waters.</td>
<td>62</td>
</tr>
<tr>
<td>2.6</td>
<td>Year-of-birth frequency distributions for red drum captured by purse seine from offshore northern Gulf of Mexico waters.</td>
<td>63</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.7A</td>
<td>Growth models by length for male and female red drum captured in offshore northern Gulf of Mexico waters</td>
<td>64</td>
</tr>
<tr>
<td>2.7B</td>
<td>Growth models by weight for male and female red drum captured in offshore northern Gulf of Mexico waters</td>
<td>65</td>
</tr>
<tr>
<td>3.1</td>
<td>Photomicrograph of a transverse section of a black drum otolith (sagitta)</td>
<td>85</td>
</tr>
<tr>
<td>3.2A</td>
<td>Plot of percent occurrence of opaque margins in otoliths (sagittae) of black drum vs. month of capture</td>
<td>86</td>
</tr>
<tr>
<td>3.2B</td>
<td>Plot of percent occurrence of opaque margins in otoliths (sagittae) of black drum vs. month of capture; by age groups, years combined</td>
<td>87</td>
</tr>
<tr>
<td>3.3A</td>
<td>Von Bertalanffy growth models by fork length for black drum captured in Louisiana Gulf of Mexico waters</td>
<td>88</td>
</tr>
<tr>
<td>3.3B</td>
<td>Von Bertalanffy growth models by weight for black drum captured in Louisiana Gulf of Mexico waters</td>
<td>89</td>
</tr>
<tr>
<td>4.1</td>
<td>Sampling areas for black drum captured off Louisiana from January 1986 through July 1988</td>
<td>104</td>
</tr>
<tr>
<td>4.2</td>
<td>Length percent frequency distributions for black drum randomly sampled from commercial fisheries catches off Louisiana</td>
<td>105</td>
</tr>
<tr>
<td>4.3</td>
<td>Age percent frequency distributions for black drum randomly sampled from inshore fisheries catches off Louisiana</td>
<td>106</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>4.4</td>
<td>Age percent frequency distributions for black drum randomly sampled from offshore fisheries catches off Louisiana</td>
<td>107</td>
</tr>
<tr>
<td>4.5</td>
<td>Year-of-birth percent frequency distributions for black drum randomly sampled from fisheries catches off Louisiana; by gear and area</td>
<td>108</td>
</tr>
<tr>
<td>4.6</td>
<td>Year-of-birth percent frequency distributions for black drum randomly sampled from fisheries catches</td>
<td>109</td>
</tr>
<tr>
<td>5.1</td>
<td>Plots of relative year-class abundance for offshore adult red drum, back-calculated to age 5 years using mortality estimates indicated</td>
<td>142</td>
</tr>
<tr>
<td>5.2</td>
<td>Plots of mean values for environmental variables by year (September-August)</td>
<td>143</td>
</tr>
<tr>
<td>5.3</td>
<td>Plot of correlation coefficients for best environmental groupings with relative year-class abundance, back-calculated assuming different levels of constant mortality</td>
<td>144</td>
</tr>
<tr>
<td>5.4</td>
<td>Plots of regression models obtained using best monthly environmental groupings</td>
<td>145</td>
</tr>
</tbody>
</table>
ABSTRACT

The objectives of this study were to obtain age estimates and describe growth for two sciaenid fish species, red drum *Sciaenops ocellatus* and black drum *Pogonias cromis*, in the northern Gulf of Mexico. Age estimates were made using annulus counts in transverse sections of otoliths (inner ear bones). Aging techniques were validated for juvenile red drum by imparting oxytetracycline into otoliths as a time marker. Recaptures validated that annuli were deposited in otoliths yearly up to 2.5 years age, with the first annulus formed in the second winter at 1-1.5 years age. Age estimates for remaining age classes of red drum and all age classes of black drum were validated by marginal increment analysis, following the progression of annulus formation throughout the year. Analyses indicated that annuli were formed yearly during winter-spring months for red drum and black drum at all ages. There was low variability in age estimates made independently by two or three readers for each fish. Age estimates ranged from one to thirty-seven years for red drum, and one to forty-three years for black drum. Both species grew rapidly until approximate age at maturity, followed by a significant decrease in growth rates. Red drum adult females exhibited faster growth and attained larger sizes than males, while differences in black drum growth between sexes were not apparent.

The majority of red drum and black drum from schools of primarily mature fish were greater than nine to ten years old. Relative year-class strengths were determined based on year-of-birth distributions back-calculated from age estimates. Dominant year classes for red drum were born 1971-1974, and the 1975-1977 year classes were relatively reduced in abundance. There was a significant negative correlation of
red drum year-class strength with summer air temperature during juvenile stages, and a possible positive correlation with fall-winter sea levels. Great variability was observed in strengths of adjacent black drum year classes. Several strong year classes were each separated by three to four relatively weak year classes, and no correlation was observed with environmental variables.
GENERAL INTRODUCTION

Life History

Red drum *Sciaenops ocellatus* and black drum *Pogonias cromis*, family Sciaenidae, are common fishes in the northern Gulf of Mexico. Both species occur in coastal waters from the northeast U.S. to Mexico. The black drum's range extends to Argentina waters. These species attain the largest size of any sciaenids in the Gulf of Mexico, and they exhibit similar life history patterns.

Both species spawn in coastal waters of the U.S. Gulf of Mexico. Black drum spawning occurs in the offshore waters of the northern Gulf (Osburn and Matlock 1984, Pearson 1929), although there is some evidence for spawning in the estuaries (Simmons and Breuer 1962). Red drum spawning is documented in offshore waters (Mercer 1984), but adults are not commonly seen in inshore estuarine waters (Pearson 1929, Simmons and Hoese 1959).

Spawning seasonality differs for these species. Black drum spawn during the winter-spring months, with a peak generally from February through May (Pearson 1929, Simmons and Breuer 1962). Red drum spawn between August and November (Simmons and Breuer 1962; D. Nieland, L.S.U., unpublished data). Black drum and red drum young resulting from these spawns apparently migrate into nearshore and estuarine waters (Pearson 1929, Mercer 1984).

As they near maturity, red drum are reported to move from the estuaries to offshore waters, where they have been observed to form large schools (Overstreet 1983). However, biological information on the composition and dynamics of these schools is incomplete. Black drum also form large schools offshore, suggesting a general offshore movement.
with maturity. Movement of large, mature black drum offshore may not be permanent because they are found inshore as well (Simmons and Breuer 1962). The extent of inshore-offshore movements is not well documented for either species.

General feeding habits of these large sciaenids are known through analyses of gut contents. Crabs, shrimp, and fish are commonly fed upon by adult red drum (Simmons and Breuer 1962), while crabs, shrimp, other invertebrates, and fish are prey for black drum (Pearson 1929). Their feeding preferences appear to differ from each other in that black drum have a higher dietary incidence of mollusks and other bottom organisms than red drum (Simmons and Breuer 1962). Black drum have strong pharyngeal teeth enabling them to crush mollusks.

Attempts to determine growth rates and estimate the ages of red drum and black drum are lacking. Age estimates are available for juvenile and young adult red drum and black drum (see Introduction of Chapters 1,2,3 for literature review). Validated age estimates and growth rate determinations are not available for large mature individuals. The age at maturity is reported to be four or five years for red drum (Mercer 1984) and as young as two years for black drum (Simmons and Breuer 1962).

Fisheries Management

Stocks of red drum and black drum in the northern Gulf of Mexico have undergone increased fishing pressure from both commercial and recreational sectors in recent years. All U.S. Gulf coastal states have substantial restrictions on red drum harvest in state-controlled waters. Concomitant federal regulations restricted red drum landings in offshore
waters beginning in 1986. These restrictions coincide with an increase in reported black drum landings (U.S. Department of Commerce, National Marine Fisheries Service, 1970-1984). Currently, there are no federal restrictions on black drum harvest and few restrictions by U.S. Gulf of Mexico coastal states.

There is a severe lack of information concerning the life history of red drum and black drum, despite the recent levels of harvest of these species. A critical component of the life history which must be documented to properly manage any fish species is age and growth. Age and growth information is utilized in fisheries management in a number of ways, for example:

1. Growth parameters obtained from von Bertalanffy growth models are utilized in fishery population dynamics models. The yield model of Beverton and Holt (1957) has been the most widely accepted of these models, and is used to determine the optimum combination of fishing mortality (F) and age of recruitment to fishable stocks \( t_r \), such that maximum yield can be maintained from the fishery. Legal size and catch limits are determined based on this model. By using von Bertalanffy (1938, 1957) model, parameters needed to fit the Beverton-Holt model are obtained, including \( W \) (the ultimate asymptotic weight), \( k \) (growth coefficient), and \( t_0 \) (the theoretical age at which fish would have zero length). The age at recruitment must be estimated for management purposes using length at age data, and mortality (M) is often estimated using relative abundance of age-classes. Despite the constraining assumptions of the Beverton-Holt model (e.g. steady state of the population (Pitcher and Hart 1982), it is used when more extensive data that would allow the use of more complex approaches are unavailable.
2. Length-at-age data, in conjunction with reproductive maturity data, are directly used in determination of size restrictions for fishery catches. For example, if fish are allowed to reach maturity before exploitation, their harvest may be less deleterious to population stability, because even with extreme levels of harvest of older post-maturity fish, some level of spawning stock can be maintained. In contrast, overharvest of smaller fish at ages before maturity could result in an irreversible decrease in population abundance through removal of the future spawning stocks.

3. The age distribution and longevity of a species provide data enabling development of potential management strategies. For example, short-lived species with a young age at maturity (e.g. less than 2 years) would recover more quickly from overfishing of spawning stocks if adequate juvenile stocks remained available. For a long-lived species, with late age at maturity (e.g. greater than 4 years), overfishing of spawning stocks becomes more critical, since populations recover slowly due to greater time needed for fish to reach maturity. A long-lived species, however, would not be as vulnerable as a short-lived species to overfishing of a few year classes, due to the buffering effect provided by multiple age classes. These implications are important in management decisions, e.g. the determination of size limits and exploitation levels.

4. The population age structure can be used as an indicator to determine the status and predict the future of the fishery. If a year class is recruited into the populations at lower (higher) abundances than other year classes, this indicates poor (strong) recruitment years.
If anomalous year classes can be correlated to changes in fishing pressure or environmental parameters, models can be obtained to predict the level of recruitment of future year-classes into the fishery and allow for adjustment of catch levels accordingly.

Age Estimation

A variety of procedures have been used to obtain age and growth estimates of fish. Fish of known age can provide direct measurement of growth rates. However, such samples are usually from cultured stocks and growth may differ from that observed in the wild. For wild stocks, tag-recapture methods can provide direct measurement of age and growth. However, due to cost and practicality, indirect methods are more commonly utilized, specifically length-frequency analysis and analysis of growth patterns in calcified tissues. Although age estimation has become common-place using these techniques, methods once considered routine have recently come under question and are being re-evaluated. Many of the historical age and growth estimates have not been validated, and in some cases age estimates proved to be severely erroneous, resulting in mismanagement of fisheries (Beamish and McFarlane 1983).

Length-frequency analysis, in which modal progressions of cohorts are followed, has provided valid age estimates of rapid growth stanzas of species with discrete spawning periods. However, for species which are long-lived or have protracted spawning periods, the overlap of lengths between cohorts makes age and growth determination by length-frequency analysis difficult or impossible. The movements of individuals within and between populations may also affect analyses.
Length-frequency analysis may not be feasible beyond early life stages for red drum and black drum if a slowing of growth occurs in adults.

The calcified tissues utilized in fish age and growth determination include scales (van Oosten 1929, Carlander 1987), otoliths (Hederstrom 1959, Williams and Bedford 1974, Brothers 1987), fin rays (Cass and Beamish 1983), spines (Beamish and McFarlane 1985), vertebrae (Cailliet et al. 1986), clithera (Harrison and Hadley 1979), opercula (LeCren 1947), illicia (Dupouy et al. 1984), pterigiophores (Love et al. 1987), and other bones (Menon 1950). Scale analysis has traditionally been the preferred method of age estimation, because of the ability to obtain scales without sacrificing the fish and the ease in preparing scales for counting. However, age is often underestimated using scale analysis, especially in long-lived fish, due to regeneration, resorption, or discontinuation of growth of scales (Beamish and McFarlane 1987). Ages could only be estimated up to five years or less in past studies using the scale method for red drum (Pearson 1929, Simmons and Breuer 1962, Wakeman and Ramsey 1985). Black drum could only be aged up to ten years by Richards (1973) using scales, although much greater ages were postulated.

Otoliths are calcium carbonate accretions located in the semicircular canals of the inner ear of all teleost fish, and function in balance and sound perception (Popper and Coombs 1980). Otoliths were first used to estimate fish ages by Hederstorm over 200 years ago, in 1759 (Hederstorm 1959). They have recently been shown to provide valid age estimates for many long-lived species (Beamish and McFarlane 1987), due to the continued growth of the otolith with time, even though the growth in length and weight slowed or stopped (Casselman 1987).
The sagitta, the largest of the three pairs of otoliths in sciaenids (Chao 1986), has been used to provide valid age estimates for other sciaenid species, *Pseudotolithus senegalensis* and *Pseudotolithus typus* off West Africa (Poinsard and Troadec 1966) and Atlantic croaker *Micropogonias undulatus* in the northern Gulf of Mexico (Barger 1985). Theiling and Loyacano (1976) observed distinct annuli in red drum otolith sections, and my preliminary observations indicated a similar pattern of otolith growth for black drum. An enumeration of these annuli provided a potential means of obtaining age estimates for both red drum and black drum.

The periodicity of deposition of growth increments (bipartite structures which indicate a unit passage of time (Wilson et al. 1987)) must be validated before age estimation (Beamish and McFarlane 1983). A direct validation of the increment can be made if known-age individuals are available. Unfortunately this is rarely possible for wild stocks. Mark-recapture techniques provide the most direct alternative. Using this technique, the otoliths of fish are chemically marked and the fish are tagged, released, and recaptured at a later date. The growth increments deposited from the time of release to recapture can be compared to the time-at-large to validate the periodicity of annulus formation. Chemicals such as tetracycline (Holden and Vince 1973, Wild and Foreman 1980, Smith 1984), and calcein (Wilson, Beckman, and Dean 1987; Beckman, Wilson, Lorica, and Dean in press) have been used to impart a fluorescent mark as a time marker in otoliths and other calcified tissue. In Chapter 1, tag-recapture techniques with tetracycline marking of the otolith are used to test the hypothesis that annuli (growth increments) are deposited at the rate of one per year in
the otoliths of juvenile red drum during inshore residence.

Less direct means of validation must be performed when known-aged or marked-recaptured fish are not available over the entire range of the population's ages. These other methods include marginal increment analysis. In marginal increment analysis, the width of the marginal increment (annulus), or the percent of individuals with annuli at the growing edge, is followed throughout the year for the population (Casselman 1987). Marginal increment analysis is based on the premise that, if annuli are being formed at the same general time of the year for all individuals in a population, then individuals sampled at this time will have a partial annulus at the growing edge of the otolith. Individuals sampled during other times of the year will have no annulus at the growing edge.

Previously, validation of annulus formation has not been completed to support otolith based age estimates of red drum and black drum. In Chapter 2, marginal increment analysis is used to test the hypothesis that schooling red drum from offshore coastal waters of the northern Gulf of Mexico form one annulus per year in their otoliths. In Chapter 3, marginal increment analysis is used to test the hypothesis that annuli are deposited yearly in the otoliths of black drum at all ages in inshore and offshore waters of the northern Gulf of Mexico.

Growth Models

Precise validated age estimates provide data enabling synthesis of accurate growth models. There are several traditional models which have been used to describe fish growth. The Gompertz (Silliman 1967) and logistic (Kaufman 1981) curves are S-shaped, asymptotic, three parameter
models. The logistic curve, most commonly applied to population growth (Wilson and Bossert 1971), is symmetrical about an inflection point at half the distance up the curve. The Gompertz curve is best used to describe weight at age (Ricker 1987) and has an inflection point at an age less than half the distance up the curve. The von Bertalanffy (1938, 1957) curve is a flexible, asymptotic, three parameter model.

The von Bertalanffy growth model is by far the most commonly used model in describing fish growth, because of its flexibility and the use of its parameters in population dynamics models. The von Bertalanffy curve is used to model growth in length; however, growth in weight can be described by converting weight to a multiple of length (Allen 1967). A disadvantage of this model is that the parameters have limited biological meaning and its overuse has been argued (Roff 1980). The growth curve of Richards (1959) is a four parameter model and is usually avoided if a three parameter model fits the data adequately. However, this model can be used to determine which of the three parameter models best fits the data or is most appropriate.

The fit of these growth models was traditionally a complex process. However, with the use of nonlinear regression techniques and modern computer technology (e.g. Statistical Analysis System, Inc. 1985) the adequacy of the fit to the data can be readily discerned for all models. The appropriateness of the available models in describing growth should be determined primarily by the fit of the curve to the data, and the distribution of the residual error. However, these basic criteria have apparently not been followed in many cases, since von Bertalanffy models are commonly fit to all length-at-age data with no mention of the adequacy of the fit. Statistical assumptions of
regression analysis (Sokal and Rohlf 1981) are often ignored or not mentioned in studies, and often the data from which the fit was obtained are not presented.

In Chapter 2, red drum growth is modelled using the von Bertalanffy curve, to test the hypothesis that red drum growth follows the pattern described by this model. Growth is compared between males and females to obtain the best fit, and to test the hypothesis that growth differs between sexes. In Chapter 3, these same hypotheses are tested for black drum. In addition, other previously-mentioned growth curves are fit to determine the best curve to model black drum growth. Residuals from the curves are analyzed to test the assumptions of regression analysis.

Year-Class Analysis

Besides their use in fitting of growth models, accurate, validated age estimates can be used to determine population age structure and indicate relative year-class strengths. Fisheries landing data have traditionally been compared to environmental variables in attempt to determine factors controlling survival and recruitment to fishery populations (Cushing 1982). The disadvantage of this type of approach is that fishery landings are influenced by such factors as consumer demand for the species and gear efficiency, and may not be indicative of abundance. Also, most fisheries target more than one year-class, which hinders the correlation of a given year's landings with a given year's environmental data. Despite these problems, certain environmental variables have been successfully correlated with fisheries landings, suggesting controls of the population. These variables include past
fishing pressure (e.g. Sutcliffe et al. 1977), sea temperature (e.g. Favorite and McClean 1973), salinity (e.g. Johansen 1926), freshwater runoff (e.g. Sutcliffe 1972, 1973, Gibson and Meyers 1988), meteorological patterns and winds (e.g. Koslow et al. 1987), long-term tidal cycles (e.g. Cabilio et al. 1987), El Nino events (e.g. Mysak 1986), and sunspot cycles (Southward et al. 1975).

The relative abundance of age classes can be determined, and specific year classes followed from year-to-year by obtaining random samples from a population and precise age estimates of individuals sampled. Year-class strengths can be compared directly to environmental and fisheries factors potentially affecting survival, in order to explore which factors may be controlling relative success of a given year class. Because of the lack of valid age estimates, accurate year-class abundance information is available for relatively few populations of long-lived marine fish species. Extreme variability in year-class strengths has been suggested for populations of tilefish *Lopholatilus chamaeleonticeps* to 35 years age (Turner et al. 1983), the snapper *Chrysophrys auratus* to 30 years age (Horn 1986), and the gadid *Micromesistius australis* to 23 years age (Barrero-Oro and Tomo 1988). However, the possible reasons for this variability were not given. Lower year-class strength variability was observed for populations of scamp *Mycteroperca phenax* to 21 years age (Matheson et al. 1986), and speckled hind *Epinephelus drummondhayi* and snowy grouper *E. niveatus* to 15 and 17 years age, respectively (Matheson and Huntsman 1984). To my knowledge such data are available only for relatively deep-water, open-ocean species such as these. Environmental variability may not be as important in controlling year-class success for these species as in
coastal/estuarine species including red drum and black drum.

In Chapter 2, age-frequency distributions are developed for offshore schooling populations from the northern Gulf of Mexico, allowing determination of variability in strength of year-classes within the population. Comparisons are made between year-class distributions for separate years and sample areas. In Chapter 4, age-frequency distributions are developed for populations of large, schooling black drum. Comparisons of age distributions are made between inshore and offshore samples and among capture locations along the Louisiana coast, to test the hypothesis that black drum are schooling by size/age within separate areas in the Louisiana northern Gulf of Mexico. In Chapter 5, year-class data for red drum and black drum are compared with river discharge, cold front frequencies, sea level, air temperature, and precipitation to test the hypothesis that year-class variability is correlated with environmental variability in the area of spawning and residence.

The following chapters provide descriptions of age and growth of two closely related species occupying similar habitats and exhibiting similar life history patterns. This provides data for comparisons of several aspects of their life histories and factors controlling the observed patterns. Management of the fisheries for each of these species must take into account population dynamics information for both species.

The chapters included in this dissertation were written as manuscripts for publication in peer reviewed journals. Therefore each chapter contains a separate Abstract, Introduction, Materials and Methods, Results, Discussion, Acknowledgements, and References section.
Chapter 1 is to be published in *Contributions in Marine Science* (Beckman, Fitzhugh, and Wilson. in press. Vol. 30). Chapter 2 is to be published in *Fishery Bulletin* (Beckman, Wilson, and Stanley. in press). Chapter 3 has been submitted to *Transactions of the American Fishery Society* (Beckman, Stanley, Render, and Wilson. in review). Chapters 4 and 5 are being prepared for submission to appropriate journals.
REFERENCES


Johansen, A. C. 1926. On the remarkable quantities of haddock in the Belt Sea during the winter of 1925-26 and causes leading to the same. Journal du Conseil International pour l'Exploration de la Mer 1:140-156.


Chapter 1.

GROWTH RATES AND VALIDATION OF AGE ESTIMATES OF
RED DRUM, *SCIAENOPS OCELLATUS*,
IN A LOUISIANA SALT MARSH IMPOUNDMENT
ABSTRACT

One hundred and eighty six yearling red drum were captured, tagged, and released into a coastal Louisiana impoundment after injecting individuals with varying concentrations of oxytetracycline to incorporate a fluorescent marker into their otoliths. Thirty individuals were recaptured over the next 20 months. Nineteen were returned for analysis and for the remaining 11 only tags were returned. A low growth rate was observed for initial recaptures, however mean growth rate of red drum at large for more than 200 days was 0.58 mm/d and 4.2 g/d.

Transverse sections of otoliths (sagittae) from tetracycline injected returns exhibited a fluorescent mark under ultraviolet light corresponding to the date of release. Subsequent annuli were laid down in sagittae at the rate of one per year, opaque and translucent zones corresponding to winter-spring and summer-fall growth, respectively. Thus yearly age estimates based on annuli counts were validated up to approximately 2.5 years in age.
INTRODUCTION

Estimates of growth rates of juvenile red drum *Sciaenops ocellatus* have been primarily indirect, based on changes in modal or mean lengths (Pearson 1929, Roessler 1970, Bass and Avault 1975, Theiling and Loyacano 1976, Wakeman and Ramsey 1985). Such estimates are imprecise as they are confounded by recruitment, movements, mortality, sampling bias, and variation in individual growth rates. A direct measure of growth can be obtained through mark-recapture studies. Knowledge of growth rates of juvenile red drum is essential for aquaculture feasibility studies. Simons and Breuer (1962) obtained growth rates of immature tagged-recaptured red drum in Texas coastal waters, otherwise no direct growth rate determinations are available.

Ages of red drum have been estimated by following modes in length-frequency distributions and counting scale annuli (Pearson 1929, Wakeman and Ramsey 1985). Age estimates based on changes in length-frequency distributions are confounded by overlapping year classes due to extended spawning seasons and variable growth. Age estimates from scales have not been validated as is necessary for understanding the temporal meaning of the annuli (Beamish and McFarlane 1983). Theiling and Loyacano (1976) utilized counts of otolith annuli for age estimations, however they did not provide complete validation.

Direct validation of age estimations requires fish of known age or mark-recapture studies in which a time marker is incorporated into the hardpart used for age estimates. Tetracycline has been injected into fish to impart a fluorescent mark on hardparts such as spines (Tucker 1985), vertebrae (Holden and Vince 1973), and otoliths (Wild...
and Foreman 1980, Beamish et al. 1983) to validate age estimates. The objectives of this study were to directly measure growth rates for immature red drum released into a salt marsh impoundment, determine the time of first annulus formation in otoliths (sagittae), and directly validate age estimation techniques.

MATERIALS AND METHODS

One hundred and eighty six red drum were captured by hook-and-line in a southeast Louisiana salt marsh on August 28, 1985, and immediately placed into holding pens. Following weighing and measurement (total length) three groups of red drum were tagged with the following: 1) Floy FT-4 cinch-up tag (N = 63), 2) Floy FT-68 anchor tag (N = 62), and 3) Floy belly tag with 8 mm diameter laminated disk (N = 61). Within each experimental tag group, three tetracycline dosage levels were administered interperitoneally by syringe to subgroups of approximately 20 fish at 0 (sham injected control), 50, and 100 mg/kg body weight using Liquamycin LA-200 with 200 mg/l oxytetracycline base. Fish were released into a 1,000 hectare salt marsh impoundment. Total time from capture to release was less than one hour.

Recaptures within the impoundment were fortuitous, by hook-and-line or gill net. Recaptures from outside the impoundment were returns from recreational fishermen. For recaptured fish, date of capture, fork length and weight were recorded as available. Sagittae were removed and embedded in an epoxy resin medium (Spurr 1969). Transverse sections (0.7 mm thick) were made through the core of the left sagitta using a Buehler Isomet low-speed saw and observed under a
compound microscope with incident ultraviolet (UV) light for detection of fluorescent marks. Observations of annuli formed after incorporation of the fluorescent tetracycline mark were made under transmitted light at 40X magnification and compared to the time at large. Annuli (opaque zones) were counted medial to the core of the sagitta, the region of the most regular growth.

RESULTS AND DISCUSSION

High waters as a result of Hurricane Juan in October, 1985 resulted in the release of some of the tagged red drum from the impoundment. Eighteen individuals were recaptured inside the impoundment after being at large from 16 to 610 days. Twelve recaptures were reported from outside the impoundment, however, only one individual, at large for 140 days, was returned.

Fish returned from inside the impoundment were divided into two groups: 1) Growth of four individuals at large for 16 to 76 days ranged from 0.0 to 0.41 mm/d ($\bar{x} = 0.17$, SD = 0.20), and -1.4 to 1.2 g/d ($\bar{x} = 0.03$, SD = 1.28). 2) Growth rate of individuals at large for 348 to 610 days (N = 14) ranged from 0.40 to 0.72 mm/d ($\bar{x} = 0.57$, SD = 0.11), and from 3.0 to 5.5 g/d ($\bar{x} = 4.2$, SD = 0.87, N = 8 weights). Growth rate of the return from outside the impoundment was 0.48 mm/d (weight not available). The growth of each red drum recaptured is shown in Figure 1.1.

Growth rates may have been reduced in the early (Group 1) returns due to initial stress due to handling and injection. If this were true then all growth rates would be reduced from that expected for
unmarked fish. The tetracycline did not appear to affect growth of fish in Group 2, as the mean growth of returns from the 0, 50, and 100 mg/kg injection groups were 0.57 mm/d (SD = 0.16, N = 4), 0.56 mm/d (SD = 0.10, N = 6), and 0.59 mm/d (SD = 0.04, N = 3) respectively. Though fewer returns were received from the higher injection dosage (There were 11, 11, and 6 returns for the 0, 50, and 100 mg/kg dosage levels respectively), the significance of these differences could not be ascertained. A larger number of returns would be necessary to determine the effect of tagging and injection.

Growth rates reported in this study were generally greater than those reported by Wakeman and Ramsey (1985) (0.45 mm/d) calculated from changes in length distribution modes for one year old red drum in Louisiana. Our data compared closely to Pearson's (1929) calculation of 0.54 mm/d from changes in average length of red drum from one to 1.5 years age in Texas, and Simmons and Breuer's (1962) reported 0.59 mm/d for one year olds from mark-recaptures in Texas. This suggests that the red drum in our study exhibited natural growth rates regardless of injection, tagging, and retention in the impoundment.

All recaptured red drum which had been injected with tetracycline exhibited a fluorescent mark in the sagittae under UV light (Figure 1.2). The amount of growth in the sagitta subsequent to the mark increased with time at large. Uninjected fish did not exhibit a fluorescent mark.

Annulli were not observed in sagittae of individuals recaptured from September through November, 1985. All tetracycline injected red drum recaptured between January and November, 1986 had one opaque zone
(annulus) between the fluorescent mark and the edge of the sagitta.

Sagittae from individuals recaptured from January through April 1987 had two annuli following the fluorescent mark. Sagittae from control group returns (not injected with tetracycline) exhibited identical patterns of annulus formation as returns from injection groups (Figure 1.1). There was 100% agreement among three readers for all annulus counts, made without knowledge of the sample source. These data show that annuli were formed once per year, with an apparent winter-spring opaque zone and a summer-fall translucent zone. Further studies are necessary to determine the exact timing of opaque and translucent zone formation in red drum sagittae (Chapter 2).

Red drum spawning is concentrated from August to October in the northern Gulf of Mexico, with peak spawning around September-October (Simmons and Breuer 1962), and individuals grow to a total length of approximately 300-350 mm during their first year (Pearson 1929, Peters and McMichael 1987). Therefore red drum in this study were approximately 11 months old when released in August, assuming birth around the first of October the year prior to release. Based on this information, ages were determined from counts of annuli in the sagittae (Figure 1.1). Formation of the first annulus began at approximately 15 months assuming fish were spawned in October, and was followed by formation of a second annulus 12 months later.

In summary, average growth of one and two year old red drum in a Louisiana salt marsh impoundment was 0.57 mm/d and was similar to growth rates reported in other studies for unimpounded red drum.
Counts of annuli in transverse sections of sagittae can be used to estimate ages of red drum for at least the first 2.5 years.

ACKNOWLEDGEMENTS

Sea Farms, Inc. granted permission for the use of their impoundment for this study and provided all tag returns from within the impoundment. This study was funded by Louisiana Sea Grant College Program maintained by the National Oceanic and Atmospheric Administration. This is CFI Publication # LSU-CFI-87-15.
REFERENCES


the red drum, *Sciaenops ocellatus* (Pisces: Sciaenidae), in Tampa

ROESSLER, M. A. 1970. Checklist of fishes in Buttonwood Canal,
Everglades National Park, Florida, and observations on the
seasonal occurrence and life histories of selected species.

SIMMONS, E. G., and J. P. BREUER. 1962. A study of redfish, *Sciaenops*
ocellata Linnaeus and black drum, *Pogonias cromis* Linnaeus.
*Contributions in Marine Science*. 8:184-211.

SPURR, A. R. 1969. A low-viscosity epoxy resin embedding medium for

drum from a saltwater marsh impoundment in South Carolina.
*Transactions of the Americans Fisheries Society*. 105:41-44.

TUCKER, R. 1985. Age validation studies on the spines of the spurdog
(*Squalus acanthias*) using tetracycline. *Journal of the Marine

Figure 1.1. Growth of tagged-recaptured red drum. Lines depict the change in length of individual fish from date of release (0 days-at-large) to date of recapture. Numbers adjacent to lines indicate the number of annuli in sagittae at the time of recapture. Numbers in parentheses correspond to fish which were not injected with tetracycline.
Figure 1.2A. Photomicrograph under brightfield light of a transverse section from a sagitta of a red drum injected with 100 mg tetracycline per kg body weight August 28, 1985, and recaptured March 7, 1987 (556 days-at-large). Numbers indicate center of opaque zones (annuli). Brackets indicate area enlarged in Figure 1.2B. Bar = 1 mm.
Figure 1.2B. Photomicrograph under bright field plus ultraviolet light of the area of the sagitta indicated by brackets in Figure 1.2A. Fluorescent tetracycline mark is indicated (T). Numbers indicate annuli.
Chapter 2.

AGE AND GROWTH OF RED DRUM, *SCIAENOPS OCELLATUS*, FROM OFFSHORE WATERS OF THE NORTHERN GULF OF MEXICO
ABSTRACT

Otolith (sagitta) sections are used to accurately age red drum, *Sciaenops ocellatus*, from the offshore northern Gulf of Mexico. Marginal increment analysis indicated that annuli were formed during winter and spring months.

Ages of offshore schooling red drum ranged from one to 37 years. Age distributions indicated variability in relative abundances of year-classes, with the majority of fish sampled being over 10 years of age. Male and female age distributions did not differ significantly.

Growth differed significantly between males and females. The von Bertalanffy growth equation for males was $L_t = 909(1-e^{-0.137(t+7.74)})$, and for females was $L_t = 1013(1-e^{-0.088(t+11.29)})$, where $t$ is age (years) and $L_t$ is fork length (mm).
INTRODUCTION

The red drum, *Sciaenops ocellatus*, is a large sciaenid fish that inhabits temperate and subtropical nearshore and estuarine waters from Massachusetts to northern Mexico. Juveniles are most abundant in estuarine waters and move from estuarine to nearshore waters as they near maturity (Pearson 1929). The primary spawning stock in the Gulf of Mexico is thought to spawn in nearshore open waters (Overstreet 1983).

Red drum is one of the most popular recreational and commercial fish species in the northern Gulf of Mexico. Recent increase in demand for red drum has escalated the controversy concerning its management; however, little has been reported concerning its growth and population structure.

Age and growth-rate estimates of red drum have only used immature fish from inshore estuarine waters. Pearson (1929) and Wakeman and Ramsey (1985) identified modes in length-frequency distributions and performed scale analysis to determine age estimates. However, Wakeman and Ramsey (1985) reported that scale annuli were unsatisfactory for accurately estimating the age of red drum. Theiling and Loyacano (1976) reported age estimates of red drum from a South Carolina salt marsh impoundment based on otolith examination. Growth rates of juveniles were reported by Roessler (1970), Bass and Avault (1975), and Simmons and Breuer (1962).

No age or growth rate estimates have been published for adult red drum from offshore waters. Accurate information on the age and growth of adult red drum is necessary for determining population dynamics and monitoring the population's response to fishing pressure.
Age estimation by cohort analysis is not feasible due to the reduction in growth rate in larger individuals, which leads to size overlap between age classes and possible variability in seasonal migration patterns with size. Otolith sections have provided valid age estimates for many large, long-lived fish species (Beamish and McFarlane 1987).

The purposes of this study were to determine if otoliths (sagittae) could be used to obtain valid age estimates for red drum, and estimate growth rates and determine the age structure of the oceanic schooling population of red drum.

MATERIALS AND METHODS

Red drum (1726 fish) were collected in Texas, Louisiana, Mississippi, and Alabama offshore coastal waters of the northern Gulf of Mexico from September 1985 through October 1987 by purse seine (N = 1428 from 67 sets) (Fig. 2.1), gill net (N = 134 from 9 sets), and hook and line (N = 164 from 12 dates). Samples captured by unknown gear from February 1985 through June 1987 (N = 96) were included for marginal increment analysis only.

After fish were randomly sampled from landings, they were measured (fork length), weighed, and their sex determined. Sex identifications were unavailable for 182 individuals. Sagittae were removed, cleaned, and stored dry for later processing.

Length-weight regressions were fit to the data using the model: weight = a FL^b, where weight = body weight (g) and FL = fork length (mm). Regressions for male and female red drum were compared using analysis of covariance (Ott 1977). A Komolgorov-Smirnov two-sample
test (Tate and Clelland 1957), was used to detect possible sampling bias by comparison of length-frequency distributions of fish caught by different sampling gears.

Otoliths were processed for age analysis by embedding them in an epoxy resin (Spurr 1969), and sectioning transversely (0.7 mm thick) through the core of the left sagitta (or the right when the left sagitta was not available) using a Buehler Isomet low-speed saw. Sections were mounted on glass slides with thermoplastic cement (Crystalbond 509 adhesive), sanded on 600 grit wet sandpaper to remove saw marks, polished with alumina micropolish (0.3 um), and then examined with a compound microscope (transmitted light at 40 x magnification). Opaque zones (annuli) were counted in sections from the core to the margin in the medial direction. Appearance of the margin was recorded as either opaque or translucent. If the left sagitta was unreadable, the right sagitta, if available, was prepared and examined. Validation of age estimates was accomplished and the timing of annulus formation determined by plotting percent occurrence of otoliths with opaque margins by month.

Each otolith was aged by two readers, and the resulting age estimates were compared. The coefficient of variation was calculated for age estimates in order to test the reproducibility of age estimates independent of magnitude (Sokal and Rohlf 1981, Chang 1982). If readers' initial age estimates for an otolith did not agree, the section was reread. If the resulting age estimates did not agree, the fish's other sagitta was prepared and read. If the otolith readers did not agree on an age or sections from both otoliths were unreadable, the data for that fish were not used in analyses. All
aging was done without knowledge of the sample source or any previous age estimates.

Year-of-birth was back calculated from age estimates by subtracting estimated age from the year of capture and assuming that the first annulus formed in winter of year two (Beckman et al. in press). Age frequency distributions were compared using a Komolgorov-Smirnov two-sample test (Tate and Clelland 1957).

Von Bertalanffy (1938, 1957) growth curves were fit separately for males and females by nonlinear regression. The growth equation for length was: \[ L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right] \] and for weight: \[ W_t = W_\infty \left[1 - e^{-K(t-t_0)}\right]^3 \] where \( L_t \) and \( W_t \) are the estimated length and weight, \( L_\infty \) and \( W_\infty \) are the asymptotic length and weight, \( K \) is the growth coefficient, \( t \) is the age (years), and \( t_0 \) is the hypothetical age when length or weight would be zero. A full model, in which separate parameters were fit for males and females was compared to a reduced model in which sex was not considered. An F-test (Ott 1977) was used to test for differences in the models.

RESULTS

Length-weight regressions for males and females were not significantly different (\( p = 0.842 \) for intercepts, \( p = 0.605 \) for slopes). The combined length-weight regression was:

\[ \text{Weight} = 2.9 \times 10^{-6} FL^{3.22}; \quad r^2 = 0.91; \quad N = 1626. \]

The length frequency distributions of red drum collected by purse seine (Fig. 2.2) were significantly different from those obtained by gill net (\( p < 0.01 \)) and hook-and-line (\( p < 0.01 \)). Therefore, to avoid gear selectivity bias, only purse seine samples were assumed
to represent the age frequency distribution of the offshore spawning population.

Because the sagittae were extremely thick and opaque, they needed to be sectioned before they could be aged. Distinct opaque and translucent growth zones were observed in transverse sections. Annuli were most distinct and the most consistent growth patterns were observed in the region from the core to the proximal surface of the sagitta along the ventral margin of the sulcus acoustaticus. All counts were made in this region (Fig. 2.3).

The percentage of sagittae with opaque margins is plotted by month to determine the timing of annulus formation. Opaque zones were deposited in the sagittae during winter and spring months in three successive years of sampling (Fig. 2.4A). As a consistent pattern of annulus formation was exhibited each year, data were combined for all years in order to compare annulus formation between size groups (Fig. 2.4B). Data were grouped according to maturity (Overstreet, 1983) and growth patterns. Groupings were chosen to include an adequate sample size within each group for analyses as follows: 0-4 annuli -- immature and early maturity, rapid growth; 5-9 annuli -- mature, rapid growth; 10-19 annuli -- mature, reduced growth; and 20-36 annuli -- maximum ages, reduced growth. A single peak per year in all plots indicates that one annulus was formed each year in all groups. Age in years for red drum was equal to the number of annuli observed in sections of sagittae. Age estimates were obtained by assuming a birth date of early October (Simons and Breuer 1962, Ditty 1986) and annulus formation beginning the winter of the second year.
Of the 1726 fish processed, only 94 (5.4%) otoliths were judged unreadable by at least one reader. Of the 58 companion otoliths available from the unreadable fish only one was judged unreadable. No data were obtained from 36 fish with the first otolith unreadable because their second otoliths were not available. Age estimates agreed exactly between readers in 95.9% of the samples, were within one year for 99.8%, and within two years for 100%. The coefficient of variation for age estimates (V) was 0.0058. Exact agreement was improved to 99.5% by recounting sections for which agreement was not initially reached. Readers differed by one year for the remaining 0.5% of samples, and these differences were resolved for all but one sample (not included in analyses) by counting a section of the other sagitta.

The oldest female red drum was 36 years (995 mm FL, 11.96 kg) and the oldest male was 37 years (940 mm FL, 10.49 kg), both captured by hook and line. Ages of offshore schooling red drum captured by purse seine ranged from one to 34 years for females and two to 34 years for males.

There were no significant differences between male and female age distributions in samples taken by purse seine (p > 0.20). Age distributions were grouped by year of capture (October through September for 1985-1986 and 1986-1987) and compared (Fig. 2.5). Sufficient samples were not available for 1984-85 for comparisons. The 11 to 14 year age classes dominated the 1985-86 samples and 12-15 year old fish dominated in 1986-87. There was an apparent coherence between the age frequency distributions for the two sample years. Anomalies in the age distribution for 1985-86 lagged one year behind
corresponding anomalies for 1986-87. Age distributions differed significantly between the two sample years (p < 0.01); however, there were no significant differences between year of birth distributions between sample years (p > 0.20). Therefore, samples were combined for all years to obtain year-of-birth distributions (Fig. 2.6). Variability in year-class success is suggested by differences in relative numbers of individuals between year classes.

The separation of sexes in growth models resulted in a significantly better fit by weight (p < 0.001) and length (p < 0.001) when compared to models in which sexes were combined. Separate von Bertalanffy growth curves best described changes in length (Fig. 2.7A) and weight (Fig. 2.7B) of red drum. Equations by length in millimeters, were:

\[
\begin{align*}
\text{males: } L_t &= 909(1-e^{-0.137(t+7.74)}) \\
\text{females: } L_t &= 1013(1-e^{-0.088(t+11.29)})
\end{align*}
\]

and by weight, in grams:

\[
\begin{align*}
\text{males: } W_t &= 10548(1-e^{-0.117(t+8.69)})^3 \\
\text{females: } W_t &= 15207(1-e^{-0.079(t+11.57)})^3
\end{align*}
\]

DISCUSSION

Sampling

Comparison of length-frequency distribution between gear types demonstrated that gill net and hook and line were different from purse seine collections. Therefore, to provide a basis for documenting and comparing age structure in the offshore schooling population only purse seine collections were used. We assumed that purse seine
samples would result in the smallest size selection bias (Nielson and Johnson 1983). We assumed that temporal and spatial bias was minimized because sets were made throughout the year and across the coastline of the north-central Gulf of Mexico.

Validation

Periodicity of formation of aging structures must be confirmed over all year classes to validate the use of that hardpart for aging (Beamish and McFarlane 1983). Beckman et al. (in press, Chapter 1) validated that the first two annuli were formed yearly in sagittae of immature red drum from estuarine waters. The use of marginal increment analysis in this study validated that annuli continued to be deposited in red drum sagittae once per year in fish up to 37 years old. There was no significant variability in timing of annulus formation with stage of maturity or with change in growth rates with age.

Precise, reproducible age estimates were obtained for red drum using transverse sections of sagittae. Almost 100% agreement between two readers was achieved by recounting otoliths or counting the fish's other sagitta when age estimates disagreed. Initial disagreements were usually resolved by recounting the otolith, suggesting initial miscounts or errors were due to recording and transcription. Unreadable otoliths were primarily those with inadequate sample preparation. Discarding difficult-to-age otoliths, which are often from older fish, could bias age distributions as well as von Bertalanffy growth parameters (Hirschhorn 1974). Recounting otoliths for which age estimates did not initially agree and utilizing both sagittae to
obtain a readable sample allowed us to minimize the number of unused sections.

The same seasonal pattern of annulus formation reported in this study was observed in sagittae of red drum in inshore estuaries (Beckman et al. in press). This pattern is also similar to that observed in another sciaenid, the Atlantic croaker (Barger 1985). The formation of an opaque zone in red drum sagittae in winter and spring months may correspond to reduced growth rate during this period (Doerzbacher, et al. 1988). In West African sciaenids an opaque zone was formed apparently in response to cold temperatures (Poinsard and Troadec 1966).

Growth

The von Bertalanffy growth coefficients for other sciaenids (e.g., Barger 1985, Wakeman and Ramsey 1985, cited by Pauly 1980) were generally greater than those obtained for red drum in this study. Growth parameters reported herein differ from those obtained by Wakeman and Ramsey (1985) for red drum; however, their model was based only on young fish from inshore waters that have higher growth rates (Beckman et al. in press, Chapter 1). The growth models reported in this study were derived primarily from mature slower growing fish. The negative values of $t_0$ predicted suggests that our models do not adequately describe growth of young fish unrepresented in our data. Separate models may be necessary to describe growth of
immature red drum from inshore waters (Richard Condrey\textsuperscript{1}). The large variation in size at age beyond year 5 makes it impossible to precisely predict age of red drum using length or weight.

Our estimates of maximum red drum age are greater than those previously suggested. Pearson (1929), Simmons and Breuer (1962), and Wakeman and Ramsey (1985) used the scale method and reported a maximum age of 5, 3, and 4 years, respectively. The use of validated aging techniques for red drum from otoliths more accurately estimates their ages and provides much improved management data bases.

Female red drum attained significantly larger sizes than did males, with growth curves diverging with increasing age and maturity. Larger size in females has been postulated as a life history strategy in fish for increasing reproductive potential through increased egg production capability (Roff 1983). The similarities in age class compositions between sexes indicated that the increased female size was attained through somewhat higher growth rates and not greater longevity.

**Age Structure**

Examination of the age composition of the offshore population revealed that red drum begin to appear in the offshore population as early as year two. Their appearance offshore coincides with their absence inshore by four or five years age (Pearson 1929, Simmons and Breuer 1962, Wakeman and Ramsey 1985). The 1973 year class was the

\textsuperscript{1}Dr. Richard Condrey. Coastal Fisheries Institute, Louisiana State University, Baton Rouge, LA 70803. Personal communication, January 1988.
most abundant, and earlier year classes demonstrated a decay pattern indicative of natural mortality. The year classes since 1973 were variable and could be interpreted variously to indicate several poor year classes, high mortality, or incomplete recruitment to offshore schooling populations, or selection in size by purse-seines. Inadequate data are available to determine which are primary factors affecting age distributions.

Comparison of age distributions between years provided two estimates of the population age-class structure, varying in time and areas sampled. The similarities in year-of-birth distributions in 1985-86 and 1986-87 suggest that the same population was sampled in both years, and that distributions may reflect the true offshore schooling population of red drum, assuming no sampling selectivity. Recruitment into the population from one year to the next was evident only in the youngest age classes, possibly due to migration from inshore nursery areas. The relatively low numbers of individuals in age classes of less than 10 or 11 years suggests a possible delay or reduction in recruitment into the schooling population sampled. Other possible factors affecting abundance of younger age classes offshore are fishing pressure on inshore red drum, size specific fishing offshore, or other factors affecting survival.

Acknowledgements

Sampling efforts were supported by the Louisiana Sea Grant College Program; the U.S. Department of Commerce, NOAA, Marine Fisheries Initiative Program (MARFIN); the Louisiana State University, Coastal Fisheries Institute; the Louisiana Department of Wildlife and
Fisheries; and the National Marine Fisheries Service. Sampling involved the cooperation of many recreational and commercial fishermen. Thanks to Gary Fitzhugh, Dr. Bruce Thompson, David Nieland, Robby Parker, David Stanley, and Tony Gaspard for their assistance in data collection and analysis, and Dr. James Geaghan for statistical assistance. This is publication #88-06 of the Coastal Fisheries Institute.
References


Figure 2.1. Purse seine sampling locations in the northern Gulf of Mexico. Points represent individual purse seine sets. N's refer to the total numbers of red drum sampled from sets indicated. Precise locations were not available for 6 sets (N = 161).
Figure 2.2. Length-frequency distribution for red drum captured by purse seine from offshore northern Gulf of Mexico waters. "Unknowns" are individuals for which sex identifications were not available.
Figure 2.3. Photomicrograph of a transverse section of a red drum otolith (sagitta) sampled in May, 1986. Ventral is to the left and proximal is to the top in this figure. "C" indicates the core of the otolith. Numbers indicate annuli in the region where counts were made. There are 18 annuli and an opaque edge. Bar = 1 mm.
Figure 2.4A. Plot of percent occurrence of otoliths (sagittae) with opaque margins vs. month of capture for red drum, by sample month and year.
Figure 2.4B. Plot of percent occurrence of otoliths (sagittae) with opaque margins vs. month of capture for red drum, grouped by annulus counts, sample years combined. Sample size is indicated next to points.
Figure 2.5. Age-frequency distributions for red drum captured October 1985-September 1986 and October 1986-September 1987 by purse seine from offshore northern Gulf of Mexico waters.
Figure 2.6. Year-of-birth frequency distributions for red drum captured by purse seine from offshore northern Gulf of Mexico waters September 1985-October 1987.
Figure 2.7A. Growth models by length for male (M) and female (F) red drum captured in offshore northern Gulf of Mexico waters.
Figure 2.7B. Growth models by weight for male (M) and female (F) red drum captured in offshore northern Gulf of Mexico waters.
Chapter 3.

AGE AND GROWTH OF BLACK DRUM
IN LOUISIANA GULF OF MEXICO WATERS
Abstract.-Morphometric measurements and otoliths (sagittae) were collected from black drum *Pogonias cromis* from estuarine and coastal waters off Louisiana in the Northern Gulf of Mexico. Otoliths formed distinct annuli which were validated for accurate age estimation. One annulus was formed per year during winter and spring months in all age classes during each of four years of sampling. There was low variability in age estimates made independently by three readers. Maximum age observed was 43 years. Separate von Bertalanffy growth curves for early (generally immature) and late (generally mature) life stages provided the best model of black drum growth. The transition to slower growth rates was observed at approximately four to five years of age. Growth equations by length were:

**Early Growth:** \[ L_t = 1745\left[1 - e^{-0.0884(t + 1.140)}\right] \];

**Late Growth:** \[ L_t = 1745\left[1 - e^{-0.0110(t + 36.68)}\right] \].
INTRODUCTION

Fishing pressure on black drum *Pogonias cromis* has increased significantly recently in the northern Gulf of Mexico, with landings increasing from 1,931,000 kg in 1982 to 4,792,000 kg in 1987 (U.S. Department of Commerce, National Marine Fisheries Service 1983, 1988). A reduction in red drum *Sciaenops ocellatus* landings due to recent regulations has possibly contributed to increased demand for black drum and a resulting increase in pressure on the fishery. Restrictions on catch of other Gulf of Mexico species will be likely to further increase pressure on black drum stocks, yet there is little population dynamics data available on black drum including age and growth information.

Accurate age information is necessary for understanding the life history of and developing management plans for such exploited species. Such information is used to derive growth models and to determine variations in year class strengths as affected by the environment and the fishery.

Growth models are available for black drum from inshore populations through tag recapture (Doerzbacher et al. 1988). Otherwise studies using length-frequency distributions and scales for aging black drum have encountered difficulties. Only the first two year-classes could be discerned using length-frequency analysis due to overlap of older year classes ( Pearson 1929, Simmons and Breuer 1962). Pearson (1929) and Richards (1973) found scales unreadable for large size classes of black drum, and did not validate age estimates, which is a prerequisite for any age and growth study (Beamish and McFarlane 1983).
Otoliths have provided accurate, valid age estimates for many long-lived fish species (Beamish and McFarlane 1987). Use of the largest of three pairs of otoliths, the sagitta, has been validated for age determination of Gulf of Mexico sciaenids, Atlantic croaker *Micropogonias undulatus* (Barger 1985) and red drum *Sciaenops ocellatus* (Beckman et al. in press, Chapter 1,2).

The purposes of this study were: to validate age estimates of black drum by following the progression of annulus formation in sagittae throughout the year; determine the precision of age estimates by comparing independent estimates made by three readers; and to derive growth models from these age estimates.
METHODS

Black drum (N = 2259) were sampled from commercial and recreational landings from Louisiana estuarine and coastal waters from July 1984 to November 1987. Data analyzed includes that obtained through Louisiana Board of Regents funded studies in 1986-87 as well as through MARFIN funding in 1987-88. Samples were obtained using gill net, haul seine, purse seine, otter trawl, or hook and line. Fork length (mm), weight (g), and sex (when possible) were recorded and otoliths (sagittae) were removed.

Otoliths were embedded in an epoxy resin medium (Spurr 1969) and sectioned (approximately 0.7 mm thick) through the core using a Buehler Isomet low speed saw. Sections were mounted to a glass slide with a thermoplastic cement, sanded, and polished with alumina micropolish to obtain a smooth surface. Examinations of otolith sections were made with a dissecting microscope using transmitted light at 15 to 40 x magnification.

To determine reader variability and derive age estimates three readers independently aged 1080 otolith sections. The remaining otoliths (N = 1179) were read by two readers. All age estimates were made without knowledge of the date of capture or sample source. Age estimation included enumeration of opaque zones from the core to the outer edge of the otolith and recording appearance of the margins as either opaque or translucent. Timing of annulus formation was determined by marginal increment analysis which tracks the progression of annulus formation throughout the year. Ages were assigned to approximately the nearest month by assuming a biologically realistic January 1 date of birth, based
on occurrence of larvae (Ditty 1986) and timing of spawning (R. Parker, LSU, unpublished data). (Ditty 1986; G. Fitzhugh, North Carolina State University, personal communication).

Reproducibility of age estimates between readers was determined using the coefficient of variation (Sokal and Rohlf 1969; Chang 1982) and the index of precision, D (Chang 1982). Ages assigned were those upon which at least two readers agreed on initial annulus counts, by recounting sections when initial counts disagreed, or by counting sections of the fish's other sagitta when recounts disagreed. When agreement was not reached on age estimates, fish were excluded from analyses.

Fork length (FL, mm) - weight (g) regressions were fit to the data using the model: Weight = a FL \(^b\). Regressions for males and females were compared using Analysis of Covariance (Ott 1977).

Growth curves were fit by nonlinear regression. The growth equation for length (von Bertalanffy 1938, 1957) was of the form:

\[ L_t = L_\infty \left[ 1 - e^{-K(t-t_0)} \right], \]

where \( L_t \) and \( W_t \) are the estimated length and weight, \( L_\infty \) and \( W_\infty \) are the asymptotic length and weight, \( K \) is the growth coefficient, \( t \) is the age (years), and \( t_0 \) is the hypothetical age when length or weight would be zero.

Plots of residuals from growth curves were made to check the assumptions of normality and equality of variances for model residuals (Sokal and Rohlf 1981). To test for differences in growth by sex a full model, in which sexes were modeled separately, was compared to a reduced
model, in which sex was not considered. An F test (Ott 1977) was used to test for differences in the models.

RESULTS

Otolith Microstructure

Due to the large size and opaqueness of black drum otoliths, it was not possible to discern internal structures useful for age estimation from observations of whole otoliths. Thin sections exposed distinct opaque and translucent zones which alternated from the core out to the growing edge (Figure 3.1). All annuli were not observed uniformly around the entire section. The most consistent, distinct annuli were found in the region proximal to the core of the otolith, ventral to the sulcus acousticus (Figure 3.1). Therefore, it is this region in which analyses were made.

Validation

The results of marginal increment analysis are presented in Figure 3.2A. The single peak per year in plots indicates the formation of one annulus per year. Since the timing of annulus formation was the same for each sample year, samples were combined for all years to compare annulus formation among age class groupings. Groupings were chosen to enable comparison of different growth and maturity stages. Plots for each annulus grouping (Figure 3.2B) have a single peak indicating the yearly formation of annuli, composed of winter-spring opaque zones and summer-fall translucent zones.
Reader Variability

Only five of the otoliths aged by three readers were excluded from analyses, because of lack of agreement among readers and unavailability of the matching otolith. At least two readers agreed on ages for all other fish through initial annulus counts (N = 1059), recounts (N = 2), or counts from sections of the other sagitta (N = 14). Agreement among all three readers was reached on 91.7% of age estimates (990 of 1080 otoliths). Pairwise comparisons between two readers indicated 5.6% of counts differed by 1 year, 0.2% by 2 years, and 0.03% by 3 years. The mean coefficient of variation (V) was 0.0051. The mean index of precision (D) was 0.0030, which indicates an average aging error of only 0.3 annuli per 100 counts.

Age estimates agreed for 99.0% (1167 of 1179) of the fish aged by only two readers. When age estimates did not agree (N = 12), recounts or counts of the matching otolith resulted in agreement on age for all but one fish for which the matching otolith was unavailable. Maximum age estimates were 43 years for females and 42 years for males.

Growth

Length-weight regressions for males and females were not significantly different (p = 0.897 for intercepts, p = 0.248 for slopes), the length-weight regression for combined sexes was:

\[ \text{Weight} = 1.14 \times 10^{-5} \times FL^{3.05}; \quad r^2 = 0.97. \]

Based on plots of residuals, the use of a single von Bertalanffy curve to model growth resulted in an inadequate fit to the data. Inadequate fits were also obtained using Gompertz (Silliman 1967),
logistic (Kaufman 1981) and Richards (1959) growth models. The best fit was obtained, and assumptions of regression analysis were satisfied, when separate von Bertalanffy curves were fit for younger (primarily immature) and older (primarily mature) individuals. A single $L_\infty$ was fit for both curves.

The inclusion of sex in von Bertalanffy growth models resulted in a significantly better fit by length ($p < 0.001$) and weight ($p < 0.001$). However, obvious differences in size at age occurred only at ages greater than 30 years (Figure 3.3), and separate growth curves by sex differed little over the range of our data. Therefore, growth curves in which sexes were combined were considered adequate to model black drum growth, and allowed for the inclusion of individuals of unknown sex.

Growth curves are presented in Figure 3.3. The transition point to reduced growth rates by length was at 3.9 years age (at approximately 630 mm FL). Equations fit by length in millimeters were:

Less than 3.9 years: $L_t = 1745[1-e^{-0.0884(t+1.140)}],$

Greater than 3.9 years: $L_t = 1745[1-e^{-0.0110(t+36.68)}].$

For growth models by weight the transition point was 4.7 years age. (at approximately 4.3 kg). Equations fit by weight in grams were:

Less than 4.7 years: $W_t = 86903[1-e^{-0.0625(t+2.586)}]^3,$

Greater than 4.7 years: $W_t = 86903[1-e^{-0.0114(t+35.30)}]^3.$
DISCUSSION

Otolith Growth

Due to the relatively large size and opaqueness of black drum otoliths (sagittae), sectioning is required in order to observe internal structures for age estimation. Through observations of whole otoliths ages of older fish would be greatly underestimated.

Growth (calcification) of black drum sagittae does not occur uniformly in all directions throughout the life of the fish. Calcification apparently slows or is discontinued in some axes, while annuli continue to be deposited on the inner surface, thus all annuli do not form uniformly throughout the section. The most consistent formation of annuli, observed in transverse sections, was from the core to the proximal edge of the otolith primarily in the region around the sulcus acousticus (Figure 3.1). Counts in other regions could result in underestimation of age, as all annuli may not be discernible. The growth patterns observed in black drum sagittae are very similar to those described for red drum sagittae (Beckman et al. in press, Chapter 2). A similar pattern of growth has also been observed in otoliths of other species (Blacker 1974, Boehlert and Yoklavich 1984, Kenchington and Augustine 1987), suggesting that for at least some long-lived species, counts in this region may be necessary to discern all annuli and provide accurate age estimates. It is important that when utilizing an aging method, the methodology of preparation and observation is consistent with that validated.
Confusion in the description of annulus formation in otoliths has occurred in past studies, in particular with regard to timing of opaque and translucent zone formation (Pannella 1974, Casselman 1982). Though this has partially been due to utilization of ambiguous terminology (Casselman 1982), another possible source of discrepancies could be inconsistent formation of annuli throughout the otolith. We observed that opaque zone formation in one region of sections was concurrent with formation of a translucent zone in other regions. Observations of different sections or preparations may not be comparable, thus validation studies should include precise descriptions of preparation methods, structures utilized, and areas and methods of observation.

Annulus Formation

Annuli in transverse sections of black drum sagittae are validated as age estimators. One annulus per year was consistently deposited in fish collected during each of the four years of sampling. Due to the regularity of timing of annulus formation, age estimates were determined which were precise within a fraction of one year for black drum from zero to over 40 years age.

The timing of annulus formation in adult black drum otoliths coincided with reported time of spawning, in winter and spring months in the northern Gulf of Mexico (G. Fitzhugh, North Carolina State University, personal communication). However, if this were a spawning related annulus, it should not have been present in younger year classes prior to maturity as observed. Sagittae of other sciaenids, the Atlantic croaker (Barger 1985) and red drum (Beckman, et al. in press, Chapter 2) exhibited the same seasonal pattern of annulus formation as black drum,
though spawning seasons differ (September through March for Atlantic croaker (White and Chittenden 1977), and August through November for red drum (Simmons and Breuer 1962). Coincident timing of annulus formation in these three species in the Gulf of Mexico suggests a response to some exogenous factor experienced by all individuals, possibly a seasonal change in temperature. This is supported by the observation of Doerzbacher et al. (1988) of reduction or interruption of growth of black drum and red drum during coldest days of the year.

Reader Variability

At least two readers agreed on all age estimates when both otoliths were available, thus avoiding the discarding of difficult-to-read samples that could bias growth models and age distribution analyses (Hirschhorn 1974). Although precision increased with an increased number of readers, due to the low variability of age estimates among readers, accurate age estimates of black drum could be obtained by a single reading with negligible bias to growth models and aging analyses.

Age Estimates

The maximum ages estimated by Pearson (1929) and Richards (1973) using scales were only five and seven years, respectively, although greater ages were postulated. The scale method has not been validated for black drum and has resulted in significant underestimation of age for other fish species (Beamish and McFarlane 1987). Such longevity as that observed in this study (43 years) is not unreasonable, as greater ages have been determined for other fish species using otolith analyses.
(Beamish and McFarlane 1987). Red drum were documented to 36 years ages (Beckman et al. in press, Chapter 2).

Growth Rates

The von Bertalanffy growth coefficients (K) obtained for growth in length in this study (0.0884 at less than 630 mm FL, 0.0110 at greater than 630 mm FL) differ from that reported by Richards (1973) for black drum in Virginia (0.158), with his model suggesting more rapid growth. This may indicate a faster growth rate for black drum along the U.S. mid-Atlantic coast than in the Gulf of Mexico; however, it could also be a result of underestimated ages by Richards (1973). Doerzbacher et al. (1988) reported von Bertalanffy growth coefficients based primarily on black drum less than 800 mm total length (TL). Their estimate of K (0.219) was greater than mine for all black drum. This difference may be due to their exclusion of winter periods of little or no growth from growth models, which would result in a larger K.

Our estimate of $L_\infty$ (1,745 mm FL) was greater than that reported by Richards (1973) (1,474 mm TL) and Doerzbacher et al. (1988) (798 mm TL). This was probably due to the larger range of sizes for which our model was fit. The large $L_\infty$ obtained in our model, falling outside the range of samples, was due to the fact that growth was not asymptotic within the range of samples and suggests that black drum in the northern Gulf of Mexico maintain significant growth in length and weight throughout life.

The point at which growth rates decreased, according to our models, at approximately four years age and 630 mm FL corresponds to the age and size at maturity for black drum in the Gulf of Mexico (R. Parker, L.S.U., unpublished data). The decrease in growth rate with maturity may result
from a reallocation of energy from growth to reproduction. Models suggest statistically significant differences between growth of male and female black drum. However, since there were not substantial differences in growth over the majority of age classes it is not known if these differences are biologically meaningful or a possible result of anomalies in the data.

Great variability in age at a given length or weight is indicated by the scatter of points about the growth curves (Figure 3.3). Fish of a given length or weight commonly ranged in age over as much as 20 years or more; thus length or weight cannot be used to predict age of black drum with precision, especially after the first few years of growth.

ACKNOWLEDGEMENTS

Sampling efforts were supported by the Louisiana Board of Regents; the U.S. Department of Commerce, Marine Fisheries Initiative Program (MARFIN); the Louisiana State University, Coastal Fisheries Institute; the Louisiana Department of Wildlife and Fisheries; and the National Marine Fisheries Service. We thank the many fishermen, seafood dealers, and tournament organizations for their cooperation in providing samples, including Preston Battistella, Fred and Debby Black, Ralph Horn, Terry LeBlanc, Paul Morse, Harlon Pearce, Jim Reahard and Jimmy Reahard. We thank Gary Fitzhugh, David Nieland, Robby Parker, David Stanley, and Dr. Bruce Thompson for assistance in data collection; and Dr. James Geaghan and Dr. Gary Shaffer for statistical assistance. This is publication LSU-88-13 of the Coastal Fisheries Institute, Louisiana State University.
REFERENCES


Richards, C. E. 1973. Age, growth, and distribution of the black drum 
(Pogonias cromis) in Virginia. Transactions of the American 
Fisheries Society. 102:584-590.


Silliman, R. P. 1967. Analog computer models of fish populations. U.S. 
Fish and Wildlife Service Special Scientific Report in Fisheries. 
66:31-46.

Simmons, E. G., and J. P. Breuer. 1962. A study of redfish, Sciaenops 
ocellata Linnaeus and black drum, Pogonias cromis Linnaeus. 
Contributions in Marine Science. 8:184-211.

Company. San Francisco.

Spurr, A. R. 1969. A low-viscosity epoxy resin embedding medium for 

U.S. Department of Commerce, National Oceanic and Atmospheric 
Administration, National Marine Fisheries Service. 1983. Fisheries 


Figure 3.1. Photomicrograph of a transverse section of a black drum otolith (sagitta). Ventral is to the left and proximal is to the top in this figure. Numbers identify annuli in the region where counts were made. G = core. Bar = 1 mm.
Figure 3.2A. Plot of percent occurrence of opaque margins in otoliths (sagittae) of black drum vs. month of capture, by month and year. Numbers next to points indicate sample size.
Figure 3.2B. Plot of percent occurrence of opaque margins in otoliths (sagittae) of black drum vs. month of capture, by age groups, years combined. Numbers next to curves indicate age class groupings in years.
Figure 3.3A. Von Bertalanffy growth models by fork length for black drum captured in Louisiana Gulf of Mexico waters. M = male. F = female. U = sex undetermined.
Figure 3.3B. Von Bertalanffy growth models by weight for black drum captured in Louisiana Gulf of Mexico waters. M = male. F = female. U = sex undetermined.
Chapter 4.

YEAR-CLASS STRUCTURE OF BLACK DRUM
FROM LOUISIANA GULF OF MEXICO WATERS
Abstract - Year-class distributions were obtained for populations of primarily mature black drum *Pogonias cromis* from Louisiana Gulf of Mexico waters. Fish were sampled at random from fisheries catches over a 2.5 year period and aged by analyzing otoliths. Gear selectivity was evident, however, dominant sizes and year classes were similar for samples from each capture gear and in each year of sampling. There was negligible recruitment into the schools of primarily mature black drum at ages younger than four to six years, and the majority of individuals sampled were greater than eight or nine years old. Large variability in year class strengths were observed with several strong year classes dominating the population.
Introduction

The black drum *Pogonias cromis* is a large sciaenid occurring in coastal waters from the northeast U.S. to Argentina. It is the target of a substantial and growing commercial fishery in the northern Gulf of Mexico that is concentrated around the Mississippi River Delta region. Little is known concerning its population biology including year-class success and recruitment into populations targeted by the fishery.

Although the distribution patterns and movements of black drum have not been well documented, spawning probably occurs primarily offshore of the U.S. Gulf of Mexico coast (Pearson 1929, Osburn and Matlock 1984) in winter and spring months (R. Parker, LSU, unpublished data). Offspring produced apparently migrate into nearshore and estuarine waters as nursery areas. Adults move back into open Gulf of Mexico waters presumably for spawning, although this movement is not permanent. Seasonal movements occur between and within coastal waters and estuaries and during these movements black drum may form large schools (Pearson 1929, Simmons and Breuer 1962). It is these schools which are targeted by the commercial fishery. In general, gears utilized by the commercial fishery are gill nets (6-9 inch mesh), haul seines, otter trawl and purse seines; with gill net landings dominating catches in 1986 (U.S. Department of Commerce, National Marine Fisheries Service 1987).

Although age estimations have been made for black drum using length-frequency distributions (Pearson 1929, Simmons and Breuer 1962) and scales (Pearson 1929, Richards 1973), these methods have not
provided validated age estimates for large, mature black drum. Validated age estimates were made for all sizes of black drum sampled in this study using otoliths (Chapter 3). These age estimates indicate a longevity of at least 43 years.

Age estimates for black drum randomly sampled from commercial fisheries catches were used to determine the year-class structure of populations of primarily reproductively mature black drum vulnerable to fishery gears in Louisiana waters of the northern Gulf of Mexico. Comparisons are made among sampling gears, years, and geographic areas.

Methods

Black drum were sampled from Louisiana Gulf of Mexico fishery landings by gill net (6-9 inch stretch mesh), haul seine, purse seine, and otter trawl (Chapter 3). Data used in this study were only from fish sampled at random from entire unsorted catches, made from January 1986 through July 1988. Fork length (FL) measurements were made and otoliths removed and prepared for age analysis as described in Chapter 3. Samples were divided into three geographic areas based on the distribution of samples; east of the Mississippi River off Louisiana (Area A), just west of the Mississippi River (Area B), and off southwestern Louisiana (Area C) (Figure 4.1).

Age estimates were made assuming a January 1 date of birth. Integral age estimates (years) made for each fish were used to obtain year-class distributions (e.g., a 2+ age fish was included in the second year class until its assumed third birthdate). This enabled age frequency distributions to be obtained and age classes followed in
successive years of sampling. Year-of-birth was back-calculated from age estimates and frequency distributions were obtained. Percent frequency distributions were compared statistically for differences using a Komolgorov-Smirnov two sample test, $\alpha=0.05$ (Tate and Clelland 1957).

Results

Sample distributions by gear and area of capture are presented in Table 4.1. Gill net and haul seine samples were obtained from inshore and estuarine areas, primarily during spring and summer (13 of 19 sets). Purse seine and trawl samples were obtained in offshore open water areas, primarily during fall and winter (12 of 14 sets).

There were no significant differences between male and female length frequency or year-of-birth frequency distributions, therefore sexes were combined for subsequent analyses. Length frequency distributions grouped by gear type are presented in Figure 4.2. Length distribution for haul seine and gill net samples, from inshore, differed significantly. Modal sizes were similar for both gears, though haul seine samples had more individuals in size classes greater than 80 cm FL and only haul seine samples had individuals less than 60 cm FL.

Length frequencies of purse seine and trawl samples, from offshore, differed significantly. Purse seine samples had a greater modal size and more individuals in larger size classes. A similar range in sizes was evident for the majority of individuals for each of the gears sampled, with greater than 90% of individuals for each gear ranging from 60 to 100 cm FL.
Because of apparent gear selectivity, separate year-of-birth distributions were obtained for each gear. There was no significant difference in year class distributions of gill net samples between Areas A and B, the only gear with sufficient samples from these areas for comparison (Table 4.1). This allowed grouping of these samples for year-class analyses. Area B and Area C purse seine year-class distributions differed significantly, therefore areas were not combined for purse seine year-class analyses.

A wide range in ages is apparent for haul seine and gill net samples in each sample year (Figure 4.3), with the majority of fish being from 7 to 36 years age. There is large variability in year-class strengths. However certain dominant year classes can be followed through most samples, increasing one year in age for each successive sample year. The same year classes dominated haul seine and gill net samples. Fish of one, two, and three years age were present only in 1987 haul seine samples.

A pattern similar to inshore samples was observed in age distributions for trawl and purse seine samples from offshore waters (Figure 4.4). However dominant year classes offshore ranged from 4-25 years with fewer older individuals than inshore. 1988 trawl samples and 1987 Area C purse seine samples were comprised primarily of fish 4 - 15 years age, and were dominated by younger fish than all other samples. Despite these differences, similar peaks in year classes are evident for these distributions and can be followed through successive sample years. These dominant year classes match those observed from inshore samples.
Year-of-birth frequency distributions did not differ significantly between years for haul seine samples or gill net samples. Therefore samples from all years were grouped within each gear in obtaining year-of-birth frequency distributions (Figure 4.5). Catches for each gear were dominated by several year classes, the dominant year classes for each gear being born in 1966, 1970, 1974, and 1979. This suggests a four to five year cycle in strong year classes.

Purse seine year-of-birth distributions differed between areas as well as between sets within areas, however all samples were dominated by several strong year classes (Figure 4.5). Trawl samples (Figure 4.5) were dominated by strong year classes which were also observed in other samples. Year classes which dominated offshore samples were similar to dominant year classes inshore.

Because of similarities in dominant year classes, all samples were grouped to obtain a combined year-of-birth frequency distribution (Figure 4.6). Due to the uneven sampling by areas and gears and differences among gears, this distribution cannot be taken as entirely representative of the population vulnerable to this fishery. However, it does provide an indication of strong and weak year classes and the variability in year-class success. Dominant year classes appear to follow a four to five year cycle throughout the distribution.

Discussion

Based on length frequency distributions, gill nets appeared to be selective to a limited range of sizes compared to haul seines in the same area. However, the lack of small fish was probably not due to
selectivity by gill nets, as fish less than 60 cm FL have been captured in the same gears as sampled in this study. Fishery catches in which smaller fish were present were composed almost entirely of smaller size classes (S. Russell, LSU, unpublished data). These size classes are primarily immature fish and were not targeted in this study. The separation of fish by size in catches suggests a segregation of large mature black drum from juveniles.

There was no apparent reason for selectivity by otter trawl against larger individuals, therefore the narrow range in size observed may indicate the true size distribution of black drum in areas sampled. The purse seine is probably the least selective of gears sampled. The similarity in the modal size of fish captured by purse seine and other gears suggests a similarity in sizes of adult black drum in schools throughout Louisiana coastal waters. However if any size/age classes are solitary or not occurring primarily in schools vulnerable to fishery gears, they would not be adequately represented in samples.

Based on age distributions it can be seen that recruitment into this fishery does not occur until approximately four to six years age in general. This corresponds to age at maturity for black drum in the northern Gulf of Mexico at approximately four years (R. Parker, LSU, unpublished data) suggesting recruitment into the populations sampled is related to reproduction. At an age of four to five years there is also a decrease in growth rate for black drum (Chapter 3), which may occur as a result of reproductive maturity.
The majority of black drum sampled were of ages greater than eight or nine years. Reasons for this are not known, but possible reasons include delayed recruitment into these schooling populations and overfishing or other factors increasing mortality of younger year-classes in recent years. There was a similar pattern of delayed recruitment into fishery populations of red drum in offshore waters of the northern Gulf of Mexico (Beckman et al. in press, Chapter 2). Matheson et al. (1986) observed dominant year classes greater than 9 years age in the scamp Mycteroperca phenax in the South Atlantic Bight fishery, and suggested a possible delayed recruitment to the fishery or sampling biases.

Similarities in year-class distributions between gears and sample years in inshore waters provide evidence of a mixing of the population throughout the Mississippi River delta region. In addition, common modal year classes among all samples suggests common factors affecting year-class success throughout black drum populations in waters off Louisiana. The relatively narrow range of year classes in samples from each purse seine set as well as in trawl samples may indicate a schooling by age or a movement inshore by oldest fish. If this is the case more extensive sampling will be necessary to determine the true year class structure of black drum residing in offshore waters of the northern Gulf of Mexico.

Reasons for the great variability observed in year-class abundance are not known, but possible controlling factors include environmental factors during early life stages, or biological controls on the population. One or two year classes of yellowtail rockfish
*Sabastes flavidus* were observed by Carlson (1986) to dominate an artificial reef population over an 11-year period, possibly by inhibiting recruitment of younger year classes over this period. Though competition among year classes could explain the observed dominance by certain year classes in black drum populations, the types of interactions observed in yellowtail rockfish would be less likely for species such as black drum which do not reside in the restricted confines of a reef-type environment. Environmental variability has been linked to recruitment success and failure for many species (Dow 1977, Sutcliffe et al. 1977, Cushing 1982). Environmental patterns must be considered before factors controlling year class success in black drum can be determined.

Strong year classes and variable recruitment have also been observed for red drum in the northern Gulf of Mexico (Beckman et al. in press, Chapter 2) as well as for other long lived marine fish species, including tilefish *Lopholatilus chamaelonticeps* from the U.S. Atlantic (Turner et al. 1983), snapper *Chrysophrys auratus* from New Zealand waters (Horn 1986), and the gadid *Micromesistius australis* (Barrero-Oro 1988) in the South-West Atlantic. Further studies of juvenile and adult black drum are needed to monitor future year-class success, and to determine the effect of environmental variability and biological interactions on year-class success.
REFERENCES


of these data. New Zealand Journal of Marine and Freshwater Research 20:419-431.


Table 4.1. Distribution of samples by capture gear and area. Letters refer to geographic areas in Figure 1. Sets were made on separate dates and one random sample was obtained from each set.

<table>
<thead>
<tr>
<th>Gear</th>
<th>Gill net</th>
<th>Haul seine</th>
<th>Otter trawl</th>
<th>Purse Seine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>N</td>
<td>187</td>
<td>129</td>
<td>-</td>
<td>258</td>
</tr>
<tr>
<td>Sets</td>
<td>10</td>
<td>4</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 4.1. Sampling areas for black drum captured off Louisiana from January 1986 through July 1988.
Figure 4.2. Length-percent frequency distributions for black drum randomly sampled from commercial fisheries catches off Louisiana; sample years and areas combined.
Figure 4.3. Age-percent frequency distributions for black drum randomly sampled from inshore fisheries catches off Louisiana; by sample year and gear, areas combined. Lines join corresponding year classes.
Figure 4.4. Age-percent frequency distributions for black drum randomly sampled from offshore fisheries catches off Louisiana, by sample year, area, and gear. Areas refer to Figure 1. Lines join corresponding year classes.
Figure 4.5. Year-of-birth percent frequency distributions for black drum randomly sampled from fisheries catches off Louisiana; by gear and area, sample years combined. Areas refer to Figure 1.
Figure 4.6. Year-of-birth percent frequency distribution for black drum randomly sampled from fisheries catches off Louisiana January 1986-July 1988; sample years, areas, and gears combined.
Chapter 5.

CORRELATION OF RED DRUM AND BLACK DRUM
RELATIVE YEAR-CLASS ABUNDANCE
WITH ENVIRONMENTAL VARIABILITY IN THE NORTHERN GULF OF MEXICO
Abstract. Back-calculated relative year-class abundances (YCA) were determined for adult red drum and black drum at their approximate age of entry into the adult populations in the northern Gulf of Mexico. These estimated YCA were compared to variations in several environmental variables: sea level, river discharge, precipitation, cold front frequencies, and air temperature. Estimates of instantaneous rates of total mortality (Z) used in back-calculation were derived using relative abundances of year-classes for adult fish. The significance of correlations between environmental variables and YCA depended on the mortality rate used in the back-calculation of YCA. By using Z=0.1, significant correlations resulted for red drum YCA and sea level, river discharge (both positive), and cold front frequency (negative) during primarily fall-winter months of years when red drum were 0 to 3 years of age. Spring-summer air temperatures at ages 0 to 3 years were negatively correlated with red drum YCA using mortality rates ranging from 0.10-0.25. The best single linear model selected to predict red drum YCA (assuming Z=0.1) from environmental variables included October-April sea level and April-September air temperature as independent variables. For black drum, no monthly grouping of environmental variables were significantly correlated with back-calculated YCA for any of the mortality rate estimates.
INTRODUCTION

Many environmental factors have been considered important in directly or indirectly controlling the survival and recruitment of fish and invertebrate species (Cushing 1982). For example, environmental variables such as sea temperature (Favorite and McClean 1973), air temperature (Guillory et al. 1983), salinity (Johansen 1926), freshwater runoff (Sutcliffe 1972, 1973, Gibson 1988), winds (Koslow et al. 1987), tide level (Guillory et al. 1983), hurricanes (Matlock 1988), and el Nino events (Sinclair et al. 1985, Mysak 1986) have been correlated with fisheries landings and presumably fisheries abundance.

Matlock (1987) determined that hurricanes may influence year-class strength of red drum in Texas. Otherwise the effects of environmental factors on year-class survival have not been previously considered for red drum or black drum. Environmental correlations are useful for effective fisheries management in that they provide a means to predict year-class abundance of a fish population. Such relationships can be used to predict the harvest levels and to develop effective strategies for habitat management that optimize the survival and benefits of commercially and recreationally important species.

The relative abundance of given year-classes can be determined by monitoring the age structure of a population. Age-specific abundance data have advantages over fisheries landing data. Landing data are influenced by year-to-year variability due to gear efficiency and fish demand inconsistencies, and may not be indicative of the actual abundance of the species. Landings do not usually reflect the survival of a given year class, because fisheries often target more than one year class.
If realistic estimates of mortality are available, then the relative abundance can be back-calculated using year-class frequency data. A difficulty with the use of such data is that mortality affects each year-class in the population differently, and estimates of year-class abundance are very sensitive to assumed mortality rates. Realistically, mortality probably varies from year-to-year and affects each year class in the population differently (Vetter 1988). There are several accepted methods available to estimate mortality using year-class abundance data (Ricker 1987). Although certain constraining assumptions are often required in the use of these types of data (e.g., constant mortality rate from year-to-year, and constant mortality with age subsequent to recruitment into a fishery), such data have been used extensively in deriving mortality estimates (Pauly 1980).

Adequate data have been unavailable to estimate mortality rates for adult red drum (Gulf States Marine Fisheries Commission 1984) and black drum. Year-class frequency distributions presented in Chapters 2 and 4 provide the data needed to estimate mortality by cohort analysis or catch curve analysis (Ricker 1987).

In this study, a record of relative abundance of age-classes in the red drum and black drum adult populations was generated using mortality estimates derived from age-frequency data. The variability in relative abundance of given year-classes should reflect factors controlling the survival of those year-classes. Several environmental variables were considered as possible controlling factors of relative year-class abundance of red drum and black drum in the northern Gulf of Mexico.
METHODS

Relative year-class abundances for schooling red drum and black drum were determined from otolith age analysis of samples taken from northern Gulf of Mexico waters 1985-1987 (cumulative year-class distributions of Chapters 2, 4; Beckman et al. in press; Wilson et al. 1988). Year classes born after 1980 were not included in this analysis because of the apparent incomplete recruitment of younger year classes into adult populations and the uneven sampling of these year classes during each sample-year. The remaining data set used in the correlation analysis included no fish younger than five years, thus excluding immature fish (Beckman et al. 1988, Wilson et al. 1988).

The environmental data used in this analysis are listed in Table 5.1. Water temperature and local runoff were estimated from long-term NOAA weather records at New Orleans (monthly mean air temperature) and Lake Charles, Louisiana (monthly mean precipitation). River discharge estimates are for the Mississippi/Atchafalaya River, which discharges into the area of primary spawning and residence for red drum and black drum. The Continental Index of Muller and Willis (1983) provides an indication of the frequency and duration of cold front passages, which strongly influence water movement in the northern Gulf of Mexico (Dagg 1988). The monthly variation about the mean water level rise for this century at Galveston, Texas, one of the best continuous records in the northern Gulf of Mexico, provided a good indicator of sea level across the north-central Gulf (Swanson and Thurlow 1973).

Mortality was estimated for adult red drum and black drum and used to back-calculate the relative abundance of each year-class at five years of age (the approximate age at maturity and entry into the
population sampled). The total mortality rate \( Z \) for adult fish was assumed to be constant for the purpose of these analyses, and was estimated using both Catch Curve Analysis and Cohort Analysis.

1. Catch Curve Analysis (Ricker 1987): The instantaneous rate of total mortality \( Z \) (rate of survival = \(-\log Z\)) was estimated from the exponential decrease in abundance of 1952-1973 red drum year-classes and 1951-1979 black drum year classes, using cumulative year-class distributions (Chapters 2, 4). The 1974-1986 year classes for red drum and 1980-1986 year classes for black drum were not included in the calculations because they had lower abundances than older year classes, possibly due to incomplete recruitment to offshore schools during years of sampling (Chapters 2, 4).

2. Cohort Analysis (Ricker 1987): For red drum, \( Z \) was estimated as the mean logarithmic decrease in abundance of given year-classes, followed through three sampling years (1985-1988). Adequate data were not available for such calculations for black drum.

Monthly environmental variables were grouped by calendar year, and pairwise correlations made for all variables using Pearson Correlation Coefficients (Statistical Analysis Systems, 1985a). For correlations with back-calculated red drum relative year-class abundance (YCA), annual groupings of environmental variables were made for one-year periods (September-August). This grouping was chosen because it included months of peak red drum spawning (Wilson et al. 1988), young-of-the-year life stages, and consecutive winter months. For comparison with black drum YCA, variables were grouped by calendar year, since the peak spawning is January-March (Beckman et al. 1988).

The annual means of environmental variables were correlated with
back-calculated YCA using three different mortality estimates. Environmental variables were lagged one to four years in order to detect possible environmental influences on abundance during the year of birth through four years of age, which includes the period when red drum and black drum are primarily residing in estuarine-coastal regions.

The monthly values of environmental variables were correlated with the YCA for the corresponding year. By using the best mortality estimate (the mortality which resulted in back-calculated YCA which had the best fit to environmental data), monthly groupings were established for each environmental variable including only successive months with high correlations. Groupings were made based on the general criterion that months significant at the 0.05 level were preceded by or followed by months with relatively high correlations, and that adjacent months had correlations with the same sign. Correlation coefficients were then calculated, correlating these environmental groupings with YCA. Different mortality estimates were then used in back-calculation of YCA to observe effects on the resultant correlations.

Predictive linear models were produced for all significant environmental variable monthly groupings (independent variable) vs. YCA (dependent variable). Running means of successive years' values for environmental variables were used when successive year lags were significantly correlated with YCA. A stepwise regression analysis was performed (Statistical Analysis Systems 1985b) using these environmental variables to obtain the best predictive model of year-class abundance. Finally, relative year-class abundance was back-calculated by varying mortality estimates with fish age in order to improve the fit of regression models.
RESULTS

Red Drum

Data for year-classes born 1957-1964 were excluded from the cohort analysis due to the low numbers of samples. The mean instantaneous rates of total mortalities (Z) estimated by using cohort analysis and catch curve analysis were 0.22 and 0.11 (std.dev.=0.15), respectively. Because of differences in these estimates and high variability among cohort analysis estimates, I used a high (Z=0.22), intermediate (Z=0.16), and low (Z=0.10) mortality estimate to back-calculate separate YCA distributions for use in correlation and regression analyses (Figure 1). The annual means for all environmental variables (Figure 5.2) were significantly correlated with the mean adjusted sea level (Sea Level) at the 0.05 level of significance. Significant correlations were also observed for most pairwise comparisons of other environmental variables (Table 5.2).

Significant correlations between annual (September-August) environmental variables and YCA resulted only when YCA were back-calculated assuming Z=0.1 (Table 5.3). The best correlation was for YCA and Sea Level lagged one year (Sea Level when fish were one year of age) (p=0.007). The only other significant positive correlations were with YCA and Sea Level with no lag (p=0.033) and Sea Level lagged two years (p=0.027). There were no significant correlations with any of the environmental variables using back-calculated YCA, assuming Z=0.16 or Z=0.22.

I grouped months for which monthly environmental variables were highly correlated with YCA (Z=0.1) (Table 5.4). Monthly groupings resulted only for Lake Charles air temperature (Temperature), for summer
months of years 0-2, when correlated with YCA based on higher mortality estimates (0.16, 0.22). Nine variable groupings were made for use in further analyses:

- Sea Level for October-April (Oct-Apr) with no lag, lagged one year, and lagged two years;
- Temperature for April-September (Apr-Sep) with no lag (i.e. April-September as young-of-the-year, assuming an October birthdate), lagged one year, and lagged two years;
- River Discharge for October-February (Oct-Feb) with no lag, and lagged one year;
- Cold Front Index for September-February (Sep-Feb) lagged one year.

Running means were calculated for monthly groupings of each environmental variable when groupings included the same months for adjacent years (e.g., a running mean of Oct-Apr Sea Level during year 0, year 1, and year 2). Environmental variables in all but the Temperature grouping were significantly correlated with YCA only when YCA was back-calculated using the lowest mortalities, and the degree of correlation decreased with an increase in assumed mortality (Figure 5.3). There were significant correlations between Apr-Sep Temperature and YCA using mortality estimates ranging from 0.10-0.25. Only when YCA was estimated assuming Z=0.1 were there significant correlations for all chosen environmental variable groupings (Figure 5.3). Therefore, a YCA based on a Z of 0.1 was selected as the best single distribution for use in the subsequent regression analyses. A summary and plots of the predictive linear models are presented in Table 5.5 and Figure 5.4. By
using a stepwise linear regression the best model selected, at the 0.05 level of significance, included the three-year running mean of Oct-Apr Sea Level, and the three-year running mean of Apr-Sep Temperature ($R^2=0.661$). The addition of any of the other environmental variables did not significantly improve the fit of the model. In addition, varying mortality with age did not significantly improve the fit of the model. However, by assuming $Z=0.1$ at 5-25 years age and $Z=0.2$ at greater than 25 years age, correlations were slightly improved in most cases and yielded a more realistic YCA.

Black Drum

A total mortality of $Z=0.1$ was estimated for black drum using Catch Curve Analysis. I could not estimate mortality for black drum using Cohort Analysis because of the differences in year-class distributions among capture gears, years, and areas, and the high variability in relative abundance of year classes (Chapter 4). When I used mortality estimates of 0.1 and 0.2 to obtain back-calculated relative year-class abundances, I found no significant correlations with environmental variables grouped by year. Significant monthly groupings were not found and peaks in year-class abundances did not correspond with peaks in any of the environmental variables.

DISCUSSION

Red Drum

An estimate of post-recruitment mortality rate for each year class must be available to estimate past year-class strengths at the age of recruitment using age-specific abundances. Estimates of relative year-
class abundance are not valid if mortality estimates are not accurate. In order to estimate relative year-class abundances, I assumed that mortality was constant throughout the postrecruit life of the fish. Although this assumption may not be realistic for some species (Vetter 1987), it is a common assumption made for adult fish (Pauly 1980).

I used mortality estimates based on Cohort Analyses (Z=0.1) to back-calculate year-class abundances which were significantly correlated with environmental variables tested. Significant monthly groupings of environmental variables were biologically realistic, although the significance of these correlations varied with the mortality assumed. Only summer air temperatures were significantly correlated with YCA using mortality estimates based on Catch Curve Analysis, as well as other reasonable mortality estimates (Z=0.10, 0.15, 0.20, 0.25).

The survival of larval and early juvenile life stages has been proposed to be the major factor for the determination of the year class strength for fish populations (Hjort 1914, Gulland 1965). According to my analysis, environmental factors may affect the strength of red drum year classes through their influence on survival of larval, post-larval, and juvenile stages during the first three years of life. This is the primary period of estuarine recruitment and residence for larval and juvenile red drum, and a time when they should be most vulnerable to environmental fluctuations.

Although correlation coefficients provided a measure of the relationship between environmental variables and estimated year-class abundance, the cause or biological significance of such a relationship can only be speculated. Fall-winter sea level, river discharge, and cold front passages all exhibited significant positive correlations with
year-class abundance. However, these variables are all related to estuarine circulation and/or flushing and were significantly correlated with each other, although these correlations were relatively low. Due to these intercorrelations it cannot be assumed whether any single environmental variable directly affects survival or is simply serving as a surrogate of some other critical variable. However, the associations provide a framework for future work.

Sea level is the most likely controlling variable during fall-winter months, with the most significant correlations of red drum YCA with sea level from October-April. Sea level was the variable most significantly correlated with year-class abundances, and correlation groupings for sea level included all significant month and year-lag groupings selected for river discharge and cold front passages. Increased water levels could serve to increase red drum survival through increased marsh habitat, which is believed to be critical for red drum survival (Holt et al. 1983). An increase in the available marsh habitat also may result in an increase of prey items. Sea level was positively correlated with red drum year-class abundance throughout the first three years of life. This corresponds to the time period that red drum remain in estuaries.

It is also possible that high tidal levels may result in an increased transport of young-of-the-year red drum to marsh habitats. A monthly rise in sea level leads to a net movement of water into estuaries, and Shaw et al. (1985) have proposed that this may be an important transport mechanism for larvae of estuarine-dependent fish in the northern Gulf of Mexico estuaries. October-April are the months of highest correlations between YCA and sea level and include months when
post-larvae, spawned during fall months, are migrating into estuarine areas. It is not obvious why only the October-April water levels are significant at ages of one and two years. Since the lowest mean water levels occur in winter in Gulf of Mexico estuarine areas (Madden et al. 1988), this may be a critical period for red drum survival. Relatively deep waters acting as a buffer to winter temperature drops, and the increased marsh habitat availability arising with increased sea level during these months, may act as a mechanism to control red drum year-class survival.

Increased precipitation and river discharge may also result in increased water levels, or may directly increase productivity through increased input of nutrients. These nutrients may move through the food chain, resulting in an increase in food organisms and increased survival for red drum. This type of response has been suggested by Sutcliffe (1973) and Sutcliffe et al. (1983) who studied the effect of St. Lawrence River discharge variability on fish harvest. However, Sinclair et al. (1986) noted that there is little evidence that these processes controlling the variability in primary productivity affect fish production. They suggest that physical processes influenced by variability in freshwater input may have a direct impact on the survival of fish through, for example, enhanced or reduced retention of eggs and larvae in areas conducive to survival. Guillory et al. (1983) suggested that river discharge may transport larval Gulf menhaden (Brevoortia patronus) away from areas of optimum survival, since there was a negative correlation between recruitment and river discharge during larval stages. This mechanism apparently does not operate for red drum, for I observed a positive correlation for red drum survival with river
discharge. With large riverine input, an estuarine water exchange pattern is set up whereby there is an upstream movement of saltwater at the bottom (Emery and Stevenson 1957). This could provide a mechanism for transport of red drum inshore in lower water layers (Norcross and Shaw 1984).

The resultant reduction in salinity from increased freshwater input could also affect red drum survival. Holt et al. (1981) found in laboratory studies that high salinities (i.e., 25-30 ppt) were critical to hatching and first-day survival of red drum, with reduced survival at salinities below 25 ppt. However, such high salinities were not critical for survival in the first two weeks. Guillory et al. (1983) reported a positive correlation of salinity with Gulf menhaden catch. My results do not indicate a negative effect of freshwater input on survival of red drum during spawning months. Perhaps other processes may be more important in controlling survival of red drum, or river input may not influence salinities in spawning areas enough to affect red drum survival. Measurement of salinities in spawning areas may be necessary in order to determine the importance of salinity effects on red drum survival.

The index of cold front frequencies provides an indication of the percentage of time that weather patterns were dominated by winter cold front conditions. This weather pattern results in transport of water out of estuarine nursery grounds, followed by replacement with nearshore Gulf waters after the frontal passage (Smith 1977). This was proposed as an important mechanism for larval transport into estuaries (Shaw et al. 1985). However, no significant correlations between cold front passages and red drum survival as young-of-the-year were detected in
this analysis.

Cold front frequencies at the age of one year were negatively correlated with year-class-abundance. A possible effect of cold front passages is that they cause a decrease in survival due to the sudden reduction of temperatures. Although red drum can tolerate temperatures as low as 2°C when acclimated (Simmons and Breuer 1962), sudden freezes associated with cold front passages have been reported to cause significant mortalities along the Gulf of Mexico coast (Gunter 1941, Gunter and Hildebrand 1951). At least a portion of the red drum older than one year may be found in deeper offshore waters (Chapter 2, Beckman et al. in press) where the impact of a severe cold front would not be as significant. Cold front frequency was also correlated with sea level, possibly due to the effect of this weather pattern on water movements (Smith 1977). Therefore, no direct effect can be inferred for either variable.

General temperature changes could also affect larval survival and growth as suggested by the significant correlations of relative year-class abundance with mean air temperatures. Holt et al. (1981) reported significantly lower survival and growth of larval red drum at 20°C when compared with higher temperatures, and hypothesized that "red drum spawning success and subsequent year-class strength will be adversely affected by the early onset of low water temperatures." The negative correlation between survival and air temperature during peak spawning months of August and September does not support the observation of Holt et al. (1981). Measurements of water temperature in spawning areas may be necessary to establish the effect of temperature on survival.

Air temperature was the only variable correlated with red drum
relative year-class abundances during summer months. Air temperature was negatively correlated at ages 0-2 when using mortalities of 0.10, 0.16, and 0.22. All three-year running mean temperatures above 25.3°C corresponded to year-classes of reduced relative abundance. There are no reports available on temperature tolerances for red drum. However, the maximum temperature reported for the capture of juvenile red drum in Louisiana is 35°C (Perret 1971). Reduced growth was reported for plaice (Pleuronectes platessa), a nearshore marine fish species, when they were exposed to high temperature extremes. Furthermore, large plaice, winter flounders (Pseudopleuronectes americanus), and cod (Gadus morhua) apparent avoid high temperatures, possibly because of a limited physiological adaptability (Paloheimo and Dickie 1966). Hypoxia may cause reduced survival of red drum inshore during relatively hot summers. The occurrence of hypoxia in nearshore Gulf of Mexico waters is common and has been associated with hot, calm weather conditions (Turner and Allen 1982, Renaud 1986) and with concentrations of moribund fish (May 1973), local decreases in shrimp landings (Renaud 1986), and reduced abundance of demersal fishes (Gaston 1985). Miles (1950) noted fish kills including red drum in association with low oxygen. Although local hypoxic conditions or temperature extremes could be avoided by red drum during relatively hot summers, the survival of juvenile red drum in nearshore waters may be reduced through the indirect influence on survival such as a decrease in availability of food or desirable habitat.

Tropical storm frequencies and the occurrences of significant hurricanes were not correlated with year-class-abundance of red drum. This is inconsistent with Matlock’s (1987) report of a positive
correlation between young-of-the-year survival and hurricanes affecting Texas waters. Tropical storm effects may be localized in areas which receive the greatest impact of the storm, and effects may not be discernible in the overall population.

Black Drum

Numerous factors may explain a lack of significant correlations of any of the chosen environmental variables and year-class-abundances for black drum. The year-class distributions for black drum may not be as reliable as those for red drum. Significant differences were observed in black drum distributions with gear, area, and year. Therefore, the cumulative distributions may only provide an imprecise description of strong and weak year classes (Chapter 4). Differences in these distributions may be due to the complexities in acquiring representative samples of black drum, because adults commonly occupy both inshore and offshore habitats and apparently segregate by size in schools.

If one assumes that the year-class distributions for black drum are accurate, then it is possible that none of the environmental variables used in this study significantly affect black drum year-class strength during the times examined, or that shorter time frame fluctuations may be important. Other environmental factors that were not considered (e.g., current regimes, water temperature, and salinity fluctuations or extremes) may be more important.

Biological interactions may be important in controlling black drum year-class strength. For example, the four to five year cycle in year-class distributions is evidence for a hypothesis involving interspecific competition for available resources. A single year-class may dominate
inshore juvenile populations at any given time. The movement of this dominant year-class into reproductive populations offshore following maturity (at approximately five years age) would allow for another strong year-class to enter juvenile populations.

Differences in red drum and black drum life histories could result in different responses of the population to environmental or biological controls. Although the significance of such differences is not clear, they include differences in spawning seasonality (black drum spawn primarily in the winter, red drum in August-October), feeding preferences (black drum concentrate their feeding more on benthic macrofauna than red drum), habitat preferences (black drum are found inshore throughout their life, while red drum exhibit a more permanent offshore movement after maturity), and age at maturity (for black drum maturity occurs abruptly at four to five years of age, but for red drum age at maturity varies from two to five years).

CONCLUSIONS

Correlation models are presented that relate the relative abundance of red drum at recruitment into the adult populations to environmental variables. However, these models should not be used to predict the abundance of a given year-class for management purposes at this time. The models presented might be useful in predicting general "high" and "low" years for recruitment to test the models obtained. According to these results, I hypothesize that "high" red drum recruitment occurs when summer temperatures are relatively low and mean tidal levels are relatively high during larval and juvenile growth periods. Precise predictions of relative year-class abundance are not
possible because of the imprecision of mortality estimates and the high statistical variance in the data.

Future studies should concentrate on refining age-specific mortality estimates, which would allow for a more reliable back-calculation of relative year-class abundances. This could be accomplished by monitoring red drum year-class distributions through subsequent years and simultaneous monitoring of changes in specific year-class abundances over an extended period of time. Extensive tag-recapture studies could also provide mortality data. However, this type of study is expensive and may not be cost effective. Both techniques are limited in that they only provide mortality estimates during the period over which the population is monitored. Although practical limitations such as time and resources must be considered, precise estimates of mortality will require long term studies.

Further examination and comparison of environmental variables may improve the predictions of year-class strength. Extreme or threshold values for environmental variables may be more important in influencing red drum and black drum survival than general trends. Measurements of physical variables that affect red drum and black drum, such as water temperature, salinity, and current patterns, should be undertaken.
REFERENCES


129


Johansen, A. C. 1926. On the remarkable quantities of haddock in the Belt Sea during the winter of 1925-26 and causes leading to the same. Journal du Conseil International pour l'Exploration de la Mer 1:140-156.


Table 5.1. Name and description of the environmental variables which were compared with relative year-class abundances of adult red drum and black drum.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPERATURE (TEMP)</td>
<td>Monthly mean of average daily temperature for New Orleans, Moisont Airport, Louisiana (°C).</td>
</tr>
<tr>
<td>PRECIPITATION (PPT)</td>
<td>Monthly cumulative precipitation for Lake Charles, Louisiana (cm).</td>
</tr>
<tr>
<td>RIVER DISCHARGE (RIVDIS)</td>
<td>Mississippi River (at Tarbert Landing, MS) Atchafalaya River (at Simmesport, LA) mean monthly river discharge rate (m$^3$/s x 1000).</td>
</tr>
<tr>
<td>COLD FRONT INDEX (CLDFRNT)</td>
<td>Continental Index of Muller and Willis (1983). Monthly percentage of hours at New Orleans Moisont Airport for continental high or frontal overrun synoptic weather types; &quot;measure of the frequency of continental polar air masses&quot;.</td>
</tr>
<tr>
<td>SEA LEVEL (SEALEV)</td>
<td>Monthly variation about the mean water level rise for this century at Galveston, Texas (Pier 21) (cm).</td>
</tr>
</tbody>
</table>
Table 5.2. Correlation coefficients (r) (upper values) and probability levels (p) (lower values) among mean yearly environmental variables. See Table 5.1 for descriptions of the environmental variables.

<table>
<thead>
<tr>
<th>Variables</th>
<th>TEMP</th>
<th>PPT</th>
<th>RIVDIS</th>
<th>CLDFRNT</th>
<th>SEALEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPERATURE</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PRECIPITATION</td>
<td>0.220</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.178</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIVER DISCHARGE</td>
<td>0.366</td>
<td>0.488</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.028</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COLD FRONT INDEX</td>
<td>-0.625</td>
<td>-0.194</td>
<td>-0.390</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.001</td>
<td>0.333</td>
<td>0.054</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEA LEVEL</td>
<td>0.399</td>
<td>0.553</td>
<td>0.599</td>
<td>-0.511</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.024</td>
<td>0.001</td>
<td>0.0003</td>
<td>0.018</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.3. Correlation coefficients (r) (upper values) and probability levels (p) (lower values) for annual means of environmental variables with back-calculated relative year-class abundances of red drum. See Table 5.1 for descriptions of the environmental variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMP</td>
<td>-0.114</td>
<td>-0.145</td>
<td>-0.118</td>
<td>-0.209</td>
<td>-0.037</td>
</tr>
<tr>
<td></td>
<td>0.557</td>
<td>0.453</td>
<td>0.541</td>
<td>0.277</td>
<td>0.848</td>
</tr>
<tr>
<td>PPT</td>
<td>0.247</td>
<td>0.189</td>
<td>-0.014</td>
<td>0.001</td>
<td>-0.079</td>
</tr>
<tr>
<td></td>
<td>0.196</td>
<td>0.325</td>
<td>0.943</td>
<td>0.995</td>
<td>0.683</td>
</tr>
<tr>
<td>z=0.1</td>
<td>RIVDIS</td>
<td>0.213</td>
<td>0.260</td>
<td>-0.052</td>
<td>-0.028</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.267</td>
<td>0.174</td>
<td>0.789</td>
<td>0.886</td>
</tr>
<tr>
<td>CLDFRNT</td>
<td>-0.083</td>
<td>-0.256</td>
<td>-0.179</td>
<td>-0.016</td>
<td>-0.082</td>
</tr>
<tr>
<td></td>
<td>0.722</td>
<td>0.250</td>
<td>0.414</td>
<td>0.942</td>
<td>0.697</td>
</tr>
<tr>
<td>SEALEV</td>
<td>0.397</td>
<td>0.497</td>
<td>0.425</td>
<td>0.258</td>
<td>0.278</td>
</tr>
<tr>
<td></td>
<td>0.033</td>
<td>0.007</td>
<td>0.027</td>
<td>0.202</td>
<td>0.179</td>
</tr>
<tr>
<td>z=0.16</td>
<td>RIVDIS</td>
<td>0.068</td>
<td>0.137</td>
<td>-0.144</td>
<td>-0.143</td>
</tr>
<tr>
<td></td>
<td>0.725</td>
<td>0.479</td>
<td>0.457</td>
<td>0.460</td>
<td>0.691</td>
</tr>
<tr>
<td>CLDFRNT</td>
<td>0.123</td>
<td>-0.127</td>
<td>-0.071</td>
<td>0.062</td>
<td>-0.063</td>
</tr>
<tr>
<td></td>
<td>0.594</td>
<td>0.574</td>
<td>0.748</td>
<td>0.775</td>
<td>0.767</td>
</tr>
<tr>
<td>SEALEV</td>
<td>0.124</td>
<td>0.279</td>
<td>0.226</td>
<td>0.039</td>
<td>0.102</td>
</tr>
<tr>
<td></td>
<td>0.523</td>
<td>0.151</td>
<td>0.257</td>
<td>0.849</td>
<td>0.629</td>
</tr>
<tr>
<td>z=0.22</td>
<td>RIVDIS</td>
<td>-0.054</td>
<td>-0.039</td>
<td>-0.206</td>
<td>-0.219</td>
</tr>
<tr>
<td></td>
<td>0.781</td>
<td>0.839</td>
<td>0.283</td>
<td>0.254</td>
<td>0.462</td>
</tr>
<tr>
<td>CLDFRNT</td>
<td>0.240</td>
<td>-0.031</td>
<td>0.017</td>
<td>0.103</td>
<td>-0.029</td>
</tr>
<tr>
<td></td>
<td>0.296</td>
<td>0.891</td>
<td>0.938</td>
<td>0.631</td>
<td>0.891</td>
</tr>
<tr>
<td>SEALEV</td>
<td>-0.171</td>
<td>-0.042</td>
<td>-0.108</td>
<td>-0.298</td>
<td>-0.192</td>
</tr>
<tr>
<td></td>
<td>0.378</td>
<td>0.831</td>
<td>0.593</td>
<td>0.140</td>
<td>0.358</td>
</tr>
</tbody>
</table>
Table 5.4. Correlation coefficients for monthly environmental variables with red drum relative year-class abundance (assuming total instantaneous mortality = 0.10). Marked coefficients are significant at the 0.10 (+), 0.05 (x), or 0.01 (*) levels. The boxes outlined contain groupings chosen for the regression analysis. See Table 5.1 for a description of the environmental variables.

<table>
<thead>
<tr>
<th>Ocean Variable</th>
<th>SEA LEVEL</th>
<th>RIVER DISCHARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year lag</td>
<td>Year lag</td>
</tr>
<tr>
<td></td>
<td>0 1 2 3</td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>Month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>- .133</td>
<td>.064</td>
</tr>
<tr>
<td>10</td>
<td>.542</td>
<td>.295</td>
</tr>
<tr>
<td>11</td>
<td>.282</td>
<td>.214</td>
</tr>
<tr>
<td>12</td>
<td>.368</td>
<td>.463</td>
</tr>
<tr>
<td>1</td>
<td>.542</td>
<td>.539</td>
</tr>
<tr>
<td>2</td>
<td>- .047</td>
<td>.375</td>
</tr>
<tr>
<td>3</td>
<td>.264</td>
<td>.443</td>
</tr>
<tr>
<td>4</td>
<td>.475*</td>
<td>.510*</td>
</tr>
<tr>
<td>5</td>
<td>.280</td>
<td>.129</td>
</tr>
<tr>
<td>6</td>
<td>.154</td>
<td>.334</td>
</tr>
<tr>
<td>7</td>
<td>.330</td>
<td>.255</td>
</tr>
<tr>
<td>8</td>
<td>.160</td>
<td>.296</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ocean Variable</th>
<th>PRECIPITATION</th>
<th>TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year lag</td>
<td>Year lag</td>
</tr>
<tr>
<td></td>
<td>0 1 2 3</td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>Month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.445</td>
<td>.313</td>
</tr>
<tr>
<td>10</td>
<td>.159</td>
<td>.282</td>
</tr>
<tr>
<td>11</td>
<td>-.337</td>
<td>-.141</td>
</tr>
<tr>
<td>12</td>
<td>.206</td>
<td>.190</td>
</tr>
<tr>
<td>1</td>
<td>.437</td>
<td>.118</td>
</tr>
<tr>
<td>2</td>
<td>-.094</td>
<td>-.232</td>
</tr>
<tr>
<td>3</td>
<td>.097</td>
<td>.031</td>
</tr>
<tr>
<td>4</td>
<td>.020</td>
<td>.072</td>
</tr>
<tr>
<td>5</td>
<td>.271</td>
<td>.353</td>
</tr>
<tr>
<td>6</td>
<td>-.200</td>
<td>-.157</td>
</tr>
<tr>
<td>7</td>
<td>-.124</td>
<td>-.132</td>
</tr>
<tr>
<td>8</td>
<td>-.043</td>
<td>-.136</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ocean Variable</th>
<th>COLD FRONT INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year lag</td>
</tr>
<tr>
<td></td>
<td>0 1 2 3</td>
</tr>
<tr>
<td>Month</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-.075</td>
</tr>
<tr>
<td>10</td>
<td>-.091</td>
</tr>
<tr>
<td>11</td>
<td>-.357</td>
</tr>
<tr>
<td>12</td>
<td>-.200</td>
</tr>
<tr>
<td>1</td>
<td>-.417</td>
</tr>
<tr>
<td>2</td>
<td>-.106</td>
</tr>
</tbody>
</table>
Table 5.5. Predictive linear models of back-calculated relative year-class abundance (assuming Z=0.1) using the environmental variables. Sea Level and Temperature are three year running means. River Discharge is a two year running means. Cold Front is lagged one year. See Table 5.1 for a description of the environmental variables.

<table>
<thead>
<tr>
<th>Environmental variable (E)</th>
<th>Model</th>
<th>$R^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sep-Feb River Discharge (E1)</td>
<td>$Y = -0.088 + 0.040E1$</td>
<td>.208</td>
<td>.013</td>
</tr>
<tr>
<td>Sep-Feb Cold Front Index (E2)</td>
<td>$Y = 1.535 - 0.017E2$</td>
<td>.249</td>
<td>.018</td>
</tr>
<tr>
<td>Apr-Sep Temperature (E4)</td>
<td>$Y = 11.30 - 0.425E4$</td>
<td>.319</td>
<td>.0014</td>
</tr>
<tr>
<td>Oct-Apr Sea Level (E5)</td>
<td>$Y = -6.45 + 0.056E5$</td>
<td>.438</td>
<td>.0002</td>
</tr>
<tr>
<td>E4 and E5</td>
<td>$Y = 3.56 - 0.335E4 - 0.0448E5$</td>
<td>.661</td>
<td>.0001</td>
</tr>
</tbody>
</table>
Figure 5.1. Plots of relative year-class abundance for offshore adult red drum, back-calculated to age 5 years using total mortality estimates indicated.
Figure 5.2. Plots of mean values for environmental variables by year (September-August). See Table 5.1 for descriptions of environmental variables.
Figure 5.3. Plot of correlation coefficients for best environmental groupings with relative year-class abundance back-calculated assuming different levels of constant mortality. Sea Level and Temperature are 3 year running means. Discharge is a 2 year running mean. Cold Front Index is lagged 1 year. See Table 5.1 for a description of the environmental variables.
Figure 5.4. Plots of regression models obtained using best monthly environmental groupings. Points indicate back-calculated year-class abundances. Sea Level and Temperature are 3 year running means. Precipitation and River Discharge are 2 year running means. Cold Front Index is lagged 1 year. See Table 5.1 for descriptions of environmental variables. Running means are referred to by the first year for which means were calculated.
This dissertation provides data to compare and contrast age and growth patterns of two sciaenid fish species that occupy similar habitats in the northern Gulf of Mexico. A summary of the information obtained for both species is presented in Table 6.1.

The von Bertalanffy growth parameters for red drum and black drum were considerably different. The growth parameters, $K$ (growth coefficient) and $L_\infty$ (theoretical mean size for oldest individuals), are given in Table 6.1. A direct comparisons of $K$ cannot be made without consideration of the $L_\infty$ values. Although $K$ is often considered as indicative of growth rate, $K$ is actually the rate at which the actual size of the fish approaches the asymptotic size, $L_\infty$, and a larger $K$ is indicative of a smaller $L_\infty$ (Ricker 1987). Thus, $K$ is lower for black drum than for red drum, despite higher growth rates for black drum for most age classes (Table 6.1). This is because of the higher $L_\infty$ values which black drum growth is approaching. An inverse correlation of $K$ with $L_\infty$ has been reported for other fish species (Buesa 1987).

The growth rate of black drum from 1.5 to 2.5 years age is lower than for red drum (Table 5.1). However, the growth rates were determined by two different means for fish aged 1.5 to 2.5 years: 1) by change in length with age determined from the von Bertalanffy curve for black drum, and 2) as the average measured growth of recaptured red drum. The growth rates at ages greater than 2.5 years were determined for both species by using the change in length at age from von Bertalanffy models. The growth rate from 5 to 15 years was considerably slower than from one to five years and was similar for both species.
After 15 years age, red drum growth rate continued to decrease and approached an asymptote at ages around 25 years. Continued growth is evident for black drum through 42 year age, as there was little change in the growth rate for fish from 10 to 35 years of age.

An initially high growth rate, followed by an extreme slowing or apparent stoppage of growth soon after maturity, as observed for red drum, has been observed in other fish species (Buesa 1987, Brown 1962). The indeterminate growth for black drum resulted in an $L_\infty$ that is considerably greater than the observed maximum size. Although the value of $L_\infty$ fit by the model may not be biologically realistic, $L_\infty$ indicates that 1) black drum longevity is considerably greater than that observed in our samples, or 2) black drum growth is indeterminate and continues throughout the fish's life. It is unlikely that significant numbers of black drum occur in the northern Gulf of Mexico larger than those reported herein, unless they occupy habitats not vulnerable to fishery gears. Although commercial fishermen often prefer smaller fish due to their high market value, they are usually unable to discern the size of fish in a school before fishing it (Jimmy Rehard, commercial fisherman, Pascagoula, Mississippi, personal communication). Tournament samples should represent the available upper size limit since recreational fishermen competing in tournaments are attempting to catch the largest fish possible. Black drum up to 66 kg have been documented in U.S. Atlantic Ocean waters (Bigelow and Schroeder 1953).

Data collected through these studies or available in the literature do not provide definitive explanations for differences in the growth of red drum and black drum. There are some suggested differences in life history patterns which may affect growth patterns. 1) Red drum
and black drum exhibit differences in feeding habits. Black drum are known to feed more extensively on bottom organisms (Simmons and Breuer 1962) compared to red drum which lack the heavy pharyngeal teeth needed to crush bivalves such as oysters. The quality or availability of prey items may effect growth. 2) Red drum may be more sensitive to environmental fluctuations than black drum, as is suggested by environmental correlations with year-class abundances, while black drum may be more sensitive to competitive interactions (Chapter 5). 3) Some unknown or past selection pressure may have resulted in genetic differences in growth rates.

The red drum and black drum in the northern Gulf of Mexico live to at least 37 and 42 years, respectively. The actual longevities of the two species may not be significantly different because of the low numbers of individuals in older age classes. The relatively high maximum ages reported, along with high fecundities could be a mechanism for maximizing reproductive output. Producing numerous offspring each year for many years is one possible strategy to maximize the chances of a larva surviving an often unpredictable and fluctuating oceanic and coastal environment (Rothschild 1986).

Recruitment into offshore schools was earlier for red drum (2 years) than for black drum (4-5 years) (Table 6.1). The age of recruitment into the commercially-fished schools corresponds to the age at reproductive maturity for both species. The youngest age of maturity documented for red drum was two years (Wilson, Beckman, Nieland, and Stanley 1988), and for black drum was five years age (Beckman et al. 1988). Based on these observations I propose that offshore schools are being formed, in part, for reproductive purposes. The schooling
behavior of red drum and black drum throughout the year may have other roles in addition to reproduction.

Age estimates for both species were based on structurally similar annuli in sectioned sagittae. Annuli were formed synoptically for red drum and black drum (Table 6.1), which is evidence that the same factors control annulus formation in both species. Low temperature, a predominant factor affecting growth rates, probably regulates the specific timing of annulus formation as the two were correlated. This is consistent with Doerzebacher et al. (1988) who reported that winter months of coldest water temperatures were correlated with reduced growth rates for black drum and red drum. Although the onset of black drum spawning coincides with annulus formation, the months of annulus formation for both species in all years of sampling also corresponded, in general, to the months with lowest mean air temperature during those years (recorded at New Orleans, Louisiana; Louisiana Office of State Climatology, unpublished data). This is consistent with reported annulus formation in otoliths of Atlantic croaker *Micropogonias undulatus* (Barger 1985) and sheepshead *Archosargus probatocephalus* (Wilson, Render, and Beckman 1988) during similar months. It is likely that the timing of annulus formation for these Gulf of Mexico fish species is controlled by temperature changes.

Future Work

We need to improve our understanding of longevity and growth rates in black drum. Since the population dynamics estimates derived from these data are important in fisheries management they must be accurate.

I observed significant growth to maximum ages for black drum
sampled in the northern Gulf of Mexico. Continued sampling of larger fish will be required to determine if growth continues throughout the life of the fish. Samples from areas where black drum attain larger sizes (and possible greater ages) will be needed in order to extend data to maximum ages.

There was a great deal of variability in age structures of both red drum and black drum populations. Future work is needed to determine if growth varies with year-class strength. Historic year-specific growth rates may be back-calculated through measurement of widths of otolith growth increments. If the distance between annuli is proportional to growth during a given year, the increment widths can provide a relative measurement of growth for each year of a fish's life, to be compared to year-class strengths.

Growth could be reduced at all developmental stages in years of low year-class survival if the factors controlling larval/juvenile survival are also affecting general food availability or feeding efficiency. If factors affecting survival during a given year also affect the condition of survivors, growth of survivors from poor recruitment years may be reduced through competition with older, stronger year classes.

Alternatively, if food is limiting (density-dependent growth), growth could be increased in those year classes of low abundance. Density-dependent growth would be expected if the year-class does not compete directly with more abundant year-classes for food (Rothschild 1986), and is therefore more likely to occur during larval and early juvenile stages for red drum and black drum.

Growth of all age classes may be affected by environmental
variability. Year-specific growth rates can be obtained for individual fish by back-calculation using otolith annulus measurements. Yearly variability in growth can then be compared to yearly environmental variability. Further work is needed to precisely estimate mortality and refine models predicting year-class success using measurements of environmental variables. These suggestions are outlined in Chapter 5.

Implications for the Fisheries

Because both red drum and black drum live longer than 30 years, harvesting the oldest individuals will lessen the impact on populations stability. With maturity generally at five years age or less for both species, there is a lifetime potential for as many as 25 or more years of reproductive activity. It impossible to select specific age-classes beyond maturity using a range in lengths (or weights) for red drum because of individual variability in growth and the reduction of growth rate after maturity. Variability in age at maturity (Wilson, Beckman, Nieland, and Stanley 1988) also prohibits selection of only post-reproductive fish in harvests. Although fish size limits could not be placed such that only the oldest individuals are harvested, size limits could be used to manage the fishery such that limited numbers of pre-reproductive fish are harvested.

Continued growth is observed throughout the lifetime of black drum (Chapter 3). Therefore, length or weight restrictions could be applied so that, in general, a given range of ages are selected for harvest. The lack of variability in age at maturity at approximately 5 years (Beckman et al. 1988) allows size limits to be set to eliminate harvest before maturity. For example, by setting a lower size limit at 700 mm
fork length (see Figure 3.4A) almost all black drum would reach reproductive maturity before harvest. By setting a lower size limit at 750 mm, almost all black drum would be greater than 10 years age, and would have had, potentially, at least 5 reproductive seasons.

Since pre- and post-reproductive red drum and black drum appear to segregate to some degree (Chapters 2, 4), restrictions eliminating immature fish from commercial landings may be feasible. Restrictions eliminating older, post-maturity, fish would be difficult for non-selective gear fisheries (e.g. purse seines, haul seines) since substantial sorting of fish would be required and released fish may not survive capture and sorting. Size restrictions could be managed in the gill net fishery by restricting mesh size.

The preferred, most marketable, size for black drum and red drum has been the smaller 1-3 year old fish. However, the increased popularity of these species has resulted in increased harvest of the larger red drum (before recent restrictions) and black drum. Overharvesting juvenile stocks over long periods must be avoided because the recovery of the stocks would take at least several years due to the relatively late age at maturity. A limited harvest of juveniles may be feasible. The black drum population must be monitored to determine the impact of any management strategy.

Due to the variability in year-class strengths for red drum and black drum, traditional fisheries models, e.g surplus yield models (Schaefer 1954, Fox 1970), Ricker (1954) stock-recruitment model, and Beverton-Holt (1957) yield-per-recruit model, should be used with caution. These models assume a stable age structure (Jensen 1973, Pitcher and Hart 1982). Ideally, predictive models which consider
environmental variability should be utilized in the management of these fisheries, and variability in year-class strengths must be considered.

The ecological reasons for the evolution of such a life history pattern should be considered in determining management strategies for any long-lived species. The great longevity in such species may be a life history strategy to insure or maximize survival, e.g. as a protection against catastrophic events or long-term recruitment failures. This must be realized in determining harvest strategies which affect the year-class structure of the population. In general, limited harvest of long-lived species should be considered.

These implications for management of red drum and black drum fisheries in the northern Gulf of Mexico are based on the incomplete biological knowledge of these species, and may be idealistic if applied as actual management strategies. Political and sociological, as well as scientific, concerns should be considered in order to actually devise a management plan for any fisheries. All considerations need to be based on the best information available, constantly being refined.
REFERENCES


Table 6.1. Summary of age and growth information for red drum and black drum from the northern Gulf of Mexico.

<table>
<thead>
<tr>
<th>Growth parameters</th>
<th>Red drum</th>
<th>Black drum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>male</td>
<td>female</td>
</tr>
<tr>
<td>by length (mm)</td>
<td>K = 0.137</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>L = 1013</td>
<td>909</td>
</tr>
<tr>
<td>by weight (g)</td>
<td>K = 0.117</td>
<td>0.079</td>
</tr>
<tr>
<td></td>
<td>L = 10548</td>
<td>15207</td>
</tr>
<tr>
<td>Growth rate (mm/day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 - 2.5 years</td>
<td>0.465</td>
<td></td>
</tr>
<tr>
<td>5 - 10 years</td>
<td>0.044</td>
<td></td>
</tr>
<tr>
<td>10 - 15 years</td>
<td>0.024</td>
<td></td>
</tr>
<tr>
<td>15 - 20 years</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>20 - 25 years</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>25 - 30 years</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>30 - 35 years</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Maximum age sampled (years)</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>Growth differences between sexes</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Annulus formation</td>
<td>Nov. - Dec. to Apr. - May</td>
<td>Nov. - Dec. to Apr.</td>
</tr>
<tr>
<td>Age structure</td>
<td>variable, adjacent ages similar</td>
<td>variable, adjacent ages variable</td>
</tr>
<tr>
<td>Dominant year classes (in decreasing order of abundance)</td>
<td>1973,71,74,72,78</td>
<td>1970,74,79,66,75</td>
</tr>
<tr>
<td>Age at movement into large schools (years)</td>
<td>2</td>
<td>4 - 5</td>
</tr>
<tr>
<td>Maximum age in schools (years)</td>
<td>31 - 34</td>
<td>inshore 33 - 36 offshore 24 - 31</td>
</tr>
<tr>
<td>Correlation found with environmental variables</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
VITAE

Daniel William Beckman was born on May 16, 1957, in Lawrenceburg, Tennessee. I lived the first 17 years of my life in Loretto, Tennessee, where the rural setting allowed me to explore and develop an interest in nature. Throughout my elementary education I developed my interests in science, and by the time I completed high school biology courses I had decided to go into marine biology. My undergraduate biology education through the University of North Alabama was largely composed of summer courses taken at Dauphin Island Sea Lab, and it was there that I developed an interest in marine fish ecology. Undergraduate coursework in chemistry and physics prepared me for multi-disciplinary studies in marine sciences for my masters degree at the University of South Carolina. There I was introduced to otoliths and their use in fish age and growth studies. The potential of these techniques fueled my interests in fish ecology, evolution, and life history. Before finishing my masters at U.S.C., I had the opportunity to broaden my education through the study of aquaculture at the Faculty of Fisheries in Kagoshima, Japan; which also broadened my view of life through immersion in another culture (as well as introduced me to my wife-to-be). After graduation from U.S.C., work through the L.S.U. Department of Forestry, Wildlife and Fisheries in the marshes of Cameron, Louisiana provided an abundance of field experience in sampling and identifying fish. Upon moving to Baton Rouge, I eventually got back to fish age and growth work, at the Coastal Fisheries Institute (and had a son, with another child on the way). The work for this dissertation was carried out to discover more about the biology and life histories of coastal
fish in the Northern Gulf of Mexico and to provide some biological information for the fisheries managers to work with.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Daniel W. Beckman

Major Field: Marine Sciences

Title of Dissertation: AGE AND GROWTH OF RED DRUM, SCIAENOPS OCELLATUS, AND BLACK DRUM, POGONIAS CROMIS, IN THE NORTHERN GULF OF MEXICO

Approved:

[Signature]
Major Professor and Chairman

[Signature]
Dean of the Graduate School

EXAMINING COMMITTEE:

[Signature]

Date of Examination:

November 14, 1988