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Bruce Henry Comyns

Louisiana State University and Agricultural & Mechanical College

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**GROWTH AND MORTALITY OF FISH LARVAE IN THE NORTHCENTRAL
GULF OF MEXICO AND IMPLICATIONS TO RECRUITMENT**

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 Oceanography and Coastal Sciences

by

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TABLE OF CONTENTS

	Page
ACKNOWLEDGMENTS.....	ii
LIST OF TABLES.....	vii
LIST OF FIGURES.....	ix
ABSTRACT.....	xvi
INTRODUCTION.....	1
Chapter 1. Variability in the distribution and abundance of larval red drum (<i>Sciaenops ocellatus</i>), Atlantic bumper (<i>Chloroscombrus chrysurus</i>), and vermilion snapper (<i>Rhomboplites aurorubens</i>), during September in the northcentral Gulf of Mexico.....	6
INTRODUCTION.....	6
METHODS AND MATERIALS.....	8
RESULTS.....	9
DISCUSSION.....	31
Chapter 2. Variability associated with age and growth estimates of larval vermilion snapper (<i>Rhomboplites aurorubens</i>) and Atlantic bumper (<i>Chloroscombrus chrysurus</i>) in the northcentral Gulf of Mexico.....	39
INTRODUCTION.....	39
METHODS AND MATERIALS.....	41
RESULTS.....	49
DISCUSSION.....	87
Chapter 3. Estimating mortality and subsequent cumulative survival of fish larvae in the sub-tropical climate of the northcentral Gulf of Mexico.....	102
INTRODUCTION.....	102
METHODS AND MATERIALS.....	105
RESULTS.....	110
DISCUSSION.....	127
CONCLUSIONS.....	137
BIBLIOGRAPHY.....	142

APPENDICES.....	151
A Summary of collection and abundance data for <i>Sciaenops ocellatus</i> larvae taken. . .during September 1988.....	151
B Summary of collection and abundance data for <i>Sciaenops ocellatus</i> larvae taken. . .during 9-11 September 1989.....	153
C Summary of collection and abundance data for <i>Sciaenops ocellatus</i> larvae taken. . .during 16-19 September 1989.....	155
D Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i> and <i>Sciaenops ocellatus</i> taken. . .during 7-9 September 1990.....	157
E Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i> and <i>Sciaenops ocellatus</i> taken. . .during 14-16 September 1990.....	159
F Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i> and <i>Sciaenops ocellatus</i> taken. . .during 29-30 September 1990.....	161
G Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i>, <i>Rhomboplites aurorubens</i>, and <i>Sciaenops ocellatus</i> taken. . .during 14-16 September 1991.....	163
H Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i>, <i>Rhomboplites aurorubens</i>, and <i>Sciaenops ocellatus</i> taken. . .during 21-23 September 1991.....	166
I Summary of collection and abundance data for <i>Lutjanus campechanus</i> larvae taken. . .during 6-9 July 1992.....	169
J Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i>, <i>Rhomboplites aurorubens</i>, and <i>Sciaenops ocellatus</i> taken. . .during 13-20 September 1992.....	171
K Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i>, <i>Rhomboplites aurorubens</i>, and <i>Sciaenops ocellatus</i> taken. . .during 27-29 September 1992.....	174
L Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i> and <i>Sciaenops ocellatus</i> taken. . .during 9-11 September 1993.....	177

M	Summary of collection and abundance data for the larvae of <i>Chloroscombrus chrysurus</i>, <i>Sciaenops ocellatus</i>, and <i>Rhomboplites aurorubens</i> taken. . .during 19-21 September 1993.....	179
N	Summary of collection and abundance data for <i>Sciaenops ocellatus</i> larvae taken. . .during 9-11 September 1994.....	182
O	Summary of collection and abundance data for <i>Sciaenops ocellatus</i> larvae taken. . .during 20-22 September 1994.....	184
P	Summary of age/length/dry-weight data for vermilion snapper larvae collected. . .during 14-16 September 1991 cruise.....	186
Q	Summary of age/length/dry-weight data for <i>Rhomboplites aurorubens</i> larvae collected. . .during the 27-29 September 1992 cruise.....	189
R	Summary of age/length/dry-weight data for <i>Chloroscombrus chrysurus</i> larvae collected. . .during the 14-16 September 1991 cruise.....	194
VITA.....		199

LIST OF TABLES

	Page
<p>2.1 Slopes of age/length regressions and corresponding coefficients of determination (r^2) for vermilion snapper larvae collected at seven stations in the northcentral Gulf of Mexico during 14-16 September 1991. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected from same-aged larvae from the pooled data set (n=89) of all seven stations combined.....</p>	63
<p>2.2 Slopes of age/length regressions and corresponding coefficients of determination (r^2) for vermilion snapper larvae collected at ten stations in the northcentral Gulf of Mexico during 27-29 September 1992. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected from same-aged larvae from the pooled data set (n=136) of all ten stations combined.....</p>	67
<p>2.3 Pearson product-moment correlation coefficients for analyses between chlorophyll <u>a</u> concentrations, copepod densities, and macrozooplankton biomass estimates at seven stations in the northcentral Gulf of Mexico during 14-16 September 1991. Significance levels are shown below the correlation coefficients for each comparison.....</p>	77
<p>2.4 Slopes of age/length regressions and corresponding coefficients of determination (r^2) for Atlantic bumper larvae collected at nine stations in the northcentral Gulf of Mexico during 14-16 September 1991. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected from same-aged larvae from the pooled data set (n=139) of all stations combined.....</p>	85
<p>3.1 Estimates of mortality coefficients, Y-intercepts (adjusted for total # stations), and coefficients of determination for the descending limbs of red drum duration-corrected age-frequency distributions from 15 September cruises conducted from 1988 to 1994.....</p>	118

	Page
3.2 Comparison between abundance of 1.5-1.9 mm red drum larvae collected with a Tucker trawl using 333 μ m and 202 μ m mesh nets. All collections were taken in the vicinity of a subsurface current drogue during 12 September 1985. Mean abundance of larvae per tow (\bar{x}) and associated standard errors (SE) are shown for each mesh size and strata fished.....	119

LIST OF FIGURES

		Page
1.1	Numbered station locations in the northcentral Gulf of Mexico.....	10
1.2	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during a single, three-day survey in September 1988 and two, three-day surveys in September 1989.....	12
1.3	Surface water temperatures recorded in the northcentral Gulf of Mexico at National Data Buoy Center data buoy #42007 (6 km east of the northern tip of the Chandeleur Islands) during August and September of 1990, 1991, and 1992.....	14
1.4	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during three, three-day surveys conducted in September 1990.....	15
1.5	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.....	17
1.6	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during a seven-day survey, and a three-day survey, conducted in September 1992.....	18
1.7	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1993. NS means sample not sorted.....	20
1.8	Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1994. NS means sample not sorted.....	21
1.9	Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during three, three-day surveys conducted in September 1990.....	23
1.10	Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.....	25

	Page
1.11 Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during a seven-day survey, and a three-day survey, conducted in September 1992.....	26
1.12 Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1993. NS means sample not sorted.....	28
1.13 Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.....	29
1.14 Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during two surveys conducted in September 1992.....	30
1.15 Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during a three-day survey conducted in September 1993. NS means sample not sorted.....	32
2.1 Station locations in the northcentral Gulf of Mexico, September 1991 and 1992 cruises.....	42
2.2 Station locations in the northcentral Gulf of Mexico, May and August 1992 cruises.....	44
2.3 Relationship between wet weight and drying time necessary to reach a stable dry weight for eight plankton samples (each represented by a different symbol).....	45
2.4 Estimates of macrozooplankton dry-weight standing stock (g/100m ³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1991.....	50
2.5 Estimates of macrozooplankton dry-weight standing stock (g/100m ³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1992.....	52
2.6 Surface chlorophyll <i>a</i> concentrations (mg/m ³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1991.....	53

	Page
2.7 Surface chlorophyll <i>a</i> concentrations (mg/m ³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1992.....	55
2.8 Scatterplot of otolith increment widths and increment numbers for 101 vermilion snapper larvae collected during 27-29 September 1992. The increment number refers to the position of the increment in relation to the core of the otolith.....	57
2.9 Relationship between age and length for larval vermilion snapper collected in the northcentral Gulf of Mexico in May and August 1992. L = notochord or standard length in mm; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).....	58
2.10 Relationship between age and dry-weight for vermilion snapper larvae collected in the northcentral Gulf of Mexico in May and August 1992. $W = \log_e[\text{dry-weight (mg)} \times 100]$; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.01$).....	60
2.11 Relationship between age and length for vermilion snapper larvae pooled from 7 station collections in the northcentral Gulf of Mexico during 14-15 September 1991. L = notochord or standard length in mm; t = larval age in days.....	61
2.12 Age/length data for vermilion snapper larvae (n=89; same data set as summarized in Fig. 2.11) only plotted for the 7 individual stations in the northcentral Gulf of Mexico during the 14-16 September 1991 cruise. L = notochord or standard length in mm; t = larval age in days.....	62
2.13 Relationship between age and dry weight for larval vermilion snapper collected at stations 15 and 30 (see Fig. 2.1) in the northcentral Gulf of Mexico during 14-15 September 1991. W = dry weight in mg; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).....	65
2.14 Relationship between age and length for larval vermilion snapper collected at stations 13 and 17 (see Fig. 2.1) in the northcentral Gulf of Mexico during 27-29 September 1992. L = notochord or standard length in mm; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).....	68

	Page
2.15 Relationship between age and dry weight for larval vermilion snapper collected at stations 13 and 17 (see Fig. 2.1) in the northcentral Gulf of Mexico during 27-29 September 1992. W = dry weight in mg; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.01$).....	69
2.16 Relationship between age/length growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	71
2.17 Relationship between age/dry-weight growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	72
2.18 Scatterplot of age/length growth coefficients of vermilion snapper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991....	73
2.19 Scatterplot of age/dry-weight growth coefficients of vermilion snapper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991....	74
2.20 Scatterplot of age/length growth coefficients of vermilion snapper larvae and densities of copepods (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	75
2.21 Scatterplot of age/dry-weight growth coefficients of vermilion snapper larvae and densities of copepods (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	76
2.22 Scatterplot of age/length growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.....	79
2.23 Scatterplot of age/dry-weight growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³)	

	Page
at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.....	80
2.24 Scatterplot of age/length growth coefficients of vermilion snapper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992....	81
2.25 Scatterplot of age/dry-weight growth coefficients of vermilion snapper larvae and dry-weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992....	82
2.26 Age/length data for Atlantic bumper larvae (n=140) collected at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991. L = notochord or standard length in mm; t = larval age in days.....	84
2.27 Relationship between age and dry weight of Atlantic bumper larvae collected at adjacent stations 41 and 42 in the northcentral Gulf of Mexico, 15 September 1991. Slopes of linearized regression lines are significantly different ($P \leq 0.01$).....	86
2.28 Scatterplot of age/length growth coefficients of Atlantic bumper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	88
2.29 Scatterplot of age/dry-weight growth coefficients of Atlantic bumper larvae and estimates of surface chlorophyll <i>a</i> (mg/m ³) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	89
2.30 Scatterplot of age/length growth coefficients of Atlantic bumper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	90
2.31 Scatterplot of age/dry-weight growth coefficients of Atlantic bumper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991....	91

	Page
2.32 Relationship between the age/length growth coefficients of Atlantic bumper larvae and densities of copepods (retained in 333 μ m mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	92
2.33 Relationship between the age/dry-weight growth coefficients of Atlantic bumper larvae and densities of copepods (retained in 333 μ m mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.....	93
3.1 Station locations sampled during September 1988-1994 in the northcentral Gulf of Mexico.....	106
3.2 Station locations in the northcentral Gulf of Mexico during 6-9 July 1992.....	107
3.3 Size-frequency distribution of red snapper larvae (n=56) collected at 18 of 45 stations in the northcentral Gulf of Mexico during 6-9 July 1992. The index of larval abundance was obtained by pooling station abundances (# larvae under 10 m ² of sea surface).....	111
3.4 Size-frequency distributions of vermilion snapper larvae collected during four cruises conducted in the northcentral Gulf of Mexico during September 1991, 1992, and 1993. Estimates of Z, SE, and r ² refer to mortality curves produced from the duration-corrected age-frequency distributions. The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (#larvae under 10 m ² of sea surface).....	113
3.5 Size-frequency distributions of red drum larvae collected during 15 cruises in the northcentral Gulf of Mexico. Values of Z, SE, and r ² refer to mortality curves produced from the duration-corrected age-frequency distributions. The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (#larvae under 10 m ² of sea surface). Cruises are arranged in descending order of number of larvae collected.....	114
3.6 Size-frequency distribution of red drum larvae collected during seven plankton surveys conducted in the northcentral Gulf of	

	Page
<p>Mexico during September 1989-1992. The mortality coefficient (Z) is estimated from the slope of the duration-corrected age-frequency distribution. The two station numbers refer to positive/total stations sampled. The Index of larval abundance is a pooled estimate of station abundances (#larvae under 10 m² of sea surface).....</p>	117
<p>3.7 Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total # stations) for red drum larvae collected during 15, September plankton surveys, 1988-1994. For scaling purposes, values of Z were increased by a factor of 100.....</p>	121
<p>3.8 Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total # stations) for red drum larvae collected during 15, September plankton surveys, 1988-1994. For scaling purposes, values of Z were increased by a factor of 100. Smallest size class of larvae (1.5 mm) is excluded.....</p>	122
<p>3.9 Size-frequency distributions of Atlantic bumper larvae collected at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1990. These 9 stations were selected because larvae were most abundant in these collections.....</p>	124
<p>3.10 Size-frequency distributions of Atlantic bumper larvae collected during eight September cruises in the northcentral Gulf of Mexico. Values of Z, SE, and r² refer to mortality curves produced from the duration-corrected age-frequency distributions (omitting the smallest size-class). The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (#larvae under 10 m² sea surface).....</p>	125
<p>3.11 Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total # stations) for Atlantic bumper larvae collected during eight September cruises in the northcentral Gulf of Mexico, 1990-1993. For scaling purposes, values of Z were increased by a factor of 100.....</p>	126

ABSTRACT

Extensive plankton collections were taken during September for several years along the northcentral Gulf of Mexico's inner continental shelf. Significant differences in growth rates were found for both vermilion snapper and Atlantic bumper larvae collected at stations where hydrographic conditions were similar, indicating the probable existence of small-scale patchily-distributed feeding conditions. Such variability in growth rates is probably inevitable given the high variability in the observed spatial and temporal distribution of surface chlorophyll *a* levels, macrozooplankton biomass, copepod abundance, and dispersion of fish larvae.

Cruise estimates of mortality coefficients (*Z*) for larval vermilion snapper, red drum, and Atlantic bumper were derived from the descending limbs of age-frequency distributions (adjusted for stage duration). Estimates of *Z* for larval vermilion snapper (*n*=2,581, 4 cruises) and Atlantic bumper (*n*=39,247, 7 cruises) ranged from 0.18 to 0.29 and 0.20 to 0.39, respectively. Mortality coefficients for red drum larvae (*n*=13,658, 15 cruises) were highly variable (*Z*=0.17-1.62), which is most likely confounded by the aggregate, synchronous, batch-spawning behavior of red drum which would modulate the relative abundance of age classes. The overall estimate of *Z* for red drum larvae (0.31), obtained by pooling catch data, was very similar to values found for vermilion snapper and Atlantic bumper.

Projections of juvenile recruitment based on these data show that even in a sub-tropical climate, where stage durations of larvae are short, changes in

growth rates, particularly when combined with small changes in mortality rates, can cause large differences in cumulative larval survival. Even if the mortality rate is constant, twice as many vermilion snapper and Atlantic bumper larvae potentially survived to a length of 6 mm at stations with the fastest observed growth rates than at stations with the slowest observed growth rates.

Accurately predicting recruitment variability may prove to be intractable because of the massive logistical task of adequately quantifying the spatial and temporal variability of the trophic relationships and physical dynamics involved.

INTRODUCTION

Adult stocks of many marine fishes undergo large fluctuations in population size because of substantial changes in the number of individuals recruiting to the population. This variability is largely due to factors that affect mortality during early larval and postlarval stages (Cushing, 1975; Gulland, 1982; Hunter, 1982; Sissenwine, 1984; Houde, 1987; Ralston and Howard, 1995). During these early life-history stages fishes are most susceptible to the sources of mortality, i.e., predation, starvation, or their interaction.

Recruitment variability remains the single least understood problem in fishery science today (Cushing, 1994; Mertz, 1995). Many questions remain concerning the causes of recruitment variability because the many factors that affect the survivorship of larvae, postlarvae and young juvenile fishes are likely to be interrelated, and even subtle variability in these factors may have a significant effect on larval or juvenile survival. Order of magnitude differences in year class abundance can be caused by even relatively small changes in mortality or growth rates during the early life stages (Parish, 1973; Laurence, 1979; Houde 1987, 1989). Houde (1989) hypothesized that cohort survivorship is more sensitive to small changes in mortality and growth rates in high latitude systems than in tropical or sub-tropical systems because the colder temperatures cause slower growth rates which lead to longer larval stage durations (i.e., 100 days).

My research was designed to determine to what extent variable growth and mortality rates are expected to affect cohort survivorship in the sub-tropical

northern Gulf of Mexico (Gulf) when water temperatures approach 30°C and larval stage durations are typically less than 30 d. The specific objectives of this research are to: 1) describe the variability in distribution and abundance of several species of fish larvae in the northcentral Gulf of Mexico's inner continental shelf waters, and to determine; 2) whether there are significant spatial and temporal differences in the growth rates of several species of fish larvae in the northcentral Gulf; 3) whether precise field estimates of larval mortality can be made given the high variability in abundance of larvae at the station and cruise level; and 4) if observed changes in larval growth and mortality rates can also be expected to significantly affect potential recruitment success in subtropical climates.

The plankton collections used for my study were originally taken to develop annual indices of larval red drum (*Sciaenops ocellatus*) abundance in order to assess changes in spawning stock size in the northcentral Gulf. These studies were initiated in 1986 (Comyns et al. 1991), and during the past decade, 2-3, three-day cruises have been conducted during September when red drum spawning is at its peak (Wilson and Nieland, 1994). These efforts have resulted in the largest collection of plankton samples in this region of the Gulf. In addition, because of the relatively dense station coverage over a relatively small area of the Gulf and the longevity of study, these extensive data provided a unique opportunity to quantify the larval growth and mortality of several important species.

Two species were chosen for age/growth analyses; Atlantic bumper (*Chloroscombrus chrysurus*) and vermilion snapper (*Rhomboplites aurorubens*). Atlantic bumper was chosen because larvae of this species are extremely abundant in the study area, daily otolith increment formation has been validated (Leffler and Shaw, 1992), and this species is of both ecological and potential commercial importance. Vermilion snapper was included because it is of significant commercial and recreational importance and it is the most abundant species of snapper in the northern Gulf (Goodyear and Schirripa, 1991). In addition there is widespread concern that the populations of snappers have been reduced to low levels by over-fishing, and studies of the vital rates of their early lifestages promise to further our understanding of their recruitment variability. Ageing fish larvae by counting otolith growth increments is extremely labor intensive, and consequently age/growth analyses were primarily restricted to collections taken during two September cruises conducted in 1991 and 1992 when both vermilion snapper and Atlantic bumper larvae were particularly abundant. A small sample of vermilion snapper was aged from collections taken in May and August 1992 for temporal comparisons, but sample sizes were very small because of the scarcity of vermilion snapper larvae in these late Spring and Summer collections. Red drum larvae were not included in age/growth analyses because processing and reading otoliths of this species is difficult and time consuming, and red drum growth-temperature relationships had been previously developed for this area (Comyns et al., 1989).

For mortality estimates in addition to using Atlantic bumper and vermilion snapper, red drum larvae were included because length-frequency data were available from 15 September cruises conducted during 1988-1994 for the previously referenced stock assessment effort. In addition, red drum were included because estimating larval mortality rates for this species is particularly challenging. One of the underlying assumptions for estimating mortality rates from the descending limbs of age-frequency distributions is that the supply of larvae to or within the study area be relatively constant, but because of the aggregate, synchronous, batch-spawning behavior of red drum (Wilson and Nieland, 1994) this assumption is seriously tested for this species. Atlantic bumper larvae were abundant in collections and were identified from ten September cruises so that time series data could be compared with red drum. Atlantic bumper larvae were sorted from cruises beginning in 1990 when an expanded cruise track had been established, and collections were sorted through 1993 until the total sample size was considered adequate ($n=42,533$). Vermilion snapper larvae were identified from four September cruises for mortality estimates, and a fourth species, red snapper (*Lutjanus campechanus*), was briefly included in chapter 3 to show the difficulties encountered when estimating mortality rates for a species that is not abundant. Red snapper larvae, which are in general rarely found in high numbers, were primarily taken during a single cruise in July 1992 and only 59 specimens were collected.

This dissertation is organized into three chapters. The first describes the variability in the distribution and abundance of red drum, vermilion snapper, and Atlantic bumper during September in the northcentral Gulf. This chapter is included because in order to examine spatial and temporal variability in larval growth rates and mortality rates, it is important to first understand the distribution and abundance of the larvae being studied. The second chapter determines age and growth estimates and their inherent variability for larval Atlantic bumper and vermilion snapper (rationale for species selection previously discussed). The third chapter calculates mortality estimates for the three species described above by using age-frequency distributions, and discusses the implications that the high variability observed in larval growth and mortality rates has on the cumulative survival of the larvae examined.

Chapter 1. Variability in the distribution and abundance of larval red drum (*Sciaenops ocellatus*), Atlantic bumper (*Chloroscombrus chrysurus*), and vermilion snapper (*Rhomboplites aurorubens*), during September in the northcentral Gulf of Mexico.

INTRODUCTION

The geographic extent, periodicity and intensity of spawning strongly influence the abundance of larvae; therefore, when describing the distribution and abundance of larvae, it is important to know at what time during the spawning season the collections were taken. The vast majority of red drum (*Sciaenops ocellatus*, Sciaenidae) spawning occurs during September in the northern Gulf of Mexico (Comyns et al., 1989; Wilson and Nieland, 1994). To quantify spatial and temporal variation in abundance of larvae plankton sampling was restricted to September (1988-1994). Originally these collections were taken to develop an index of larval red drum abundance to estimate relative changes in adult stock size (Comyns, 1995b). The sampling station grid density and the total number of collections for this monitoring study in the northcentral Gulf are extensive (e.g., station number per cruise ranged from 30 to 60 for a geographical area that extended up to 9,000 km²). Because these samples were stored in ethanol their larvae were able to be aged and used for growth and mortality studies. In order to investigate the role that spatial and temporal variability plays in the estimation of larval growth rates and mortality rates, however, it is necessary to first understand the variability in the distribution and abundance of the larvae being studied.

In addition to red drum, an estuarine-dependent species distributed along the U.S. coast from Massachusetts to northern Mexico (Reagan, 1985;

Beckman et al., 1988; Gold et al., 1993), two other species of larvae sorted from these collections were studied: Atlantic bumper (*Chloroscombrus chrysurus*, Carangidae) and vermilion snapper (*Rhomboplites aurorubens*, Lutjanidae). Atlantic bumper is widely distributed in the western Atlantic and Gulf of Mexico (Leak, 1977). This carangid is very abundant in the northern Gulf, and is considered both ecologically important and of potential commercial importance (Leffler and Shaw, 1992). Vermilion snapper occur only in the western Atlantic from North Carolina to Rio de Janeiro, Brazil, including the Gulf of Mexico (Hilderbrand and Schroeder, 1928; Anderson, 1967; Laroche, 1977). Snappers comprise the most commercially - and recreationally - important family of reef fishes, and vermilion snapper are the most abundant representative of that family in the northern Gulf (Goodyear and Schirripa, 1991). Attention has focused on reef fishes since the early 1990's because stock sizes of many of these species are believed to have been depleted by over-fishing.

Larval stage durations of these three species in the northern Gulf are relatively short, i.e., approximately two to three weeks, because of the warm temperatures and consequent fast developmental rates during summer and fall months when spawning occurs. The end of the larval stage is defined as the time when larvae have attained the adult complement of fin rays, and for these species this occurs when larvae have attained a length of approximately 5 or 6 mm SL. At this stage of development red drum seek a demersal existence, are no longer found in plankton collections, and begin to show up in inshore

marsh-edge collections (Comyns et al. 1993). Vermilion snapper larger than approximately 6 mm are also rarely taken in plankton collections, and it is assumed that at this size these larvae begin to settle into demersal habitat offshore. Postlarval vermilion snapper remain offshore and do not move into inshore estuarine areas. Atlantic bumper postlarvae also remain offshore, but do not become demersal. These young juveniles develop a commensal relationship with the jellyfish *Aurelia aurita* (Tolley, 1987; Leffler, 1989).

Of these three species, spawning biology in the northern Gulf of Mexico is only well described for red drum (Wilson and Nieland, 1994). This species is a group, synchronous, batch spawner, and is perhaps unique in this area for the brevity of its spawning season, i.e., most spawning occurs in September. Atlantic bumper in the northern Gulf spawn primarily in nearshore coastal waters during June to October (Ditty, 1986, Leffler and Shaw, 1994), but little else is known about the spawning biology of this species. Grimes (1980) reported spawning of vermilion snapper off North Carolina to occur when surface water temperatures were between 26° and 27°C, i.e., from May to October, and plankton collections taken during the present study confirm this seasonality in the northern Gulf. Apart from some fecundity estimates (Grimes, 1980; Nelson, 1988) little else is known about the spawning biology of vermilion snapper.

MATERIALS AND METHODS

Ichthyoplankton samples were collected during September cruises in the Gulf from 1988 to 1994. Two or three cruises about 1-2 weeks apart were

conducted each year, except in 1988 when only a single survey was done. Each survey lasted two or three days and was conducted in east Louisiana (LA), Mississippi (MS), and Alabama (AL) coastal and inner-shelf waters (Figure 1.1). Collections were taken using a 1m x 1.4m Tucker trawl (fitted with a 333 μm mesh nitex net and a General Oceanics flowmeter to measure volume filtered) towed obliquely at a speed of approximately 2 knots (1.0 m/s) to within a few meters of the bottom.

Samples were stored in 95% ethanol so that otoliths could be used for age/growth analyses. In the laboratory all fish larvae were removed from either the entire sample or from a one-half aliquot derived from a Motoda plankton splitter. Only one half of a sample was sorted, if the settled volume of the plankton collection exceeded 500 ml. Lengths of larvae were measured to the nearest 0.1 mm at 12 X or 25 X using a stereomicroscope. Measurements were taken from the tip of the snout to the end of the notochord in pre-flexion larvae (notochord length) and from the tip of the snout to the end of the urostyle or hypural plate (whichever was more distal) in flexion or post-flexion larvae (standard length).

RESULTS

Red drum larvae (n=13,658) were identified from collections taken during all fifteen ichthyoplankton surveys conducted from September 1988 to September 1994. Atlantic bumper larvae (n=42,533) were identified from ten September surveys conducted from 1990 to 1993, and vermilion snapper larvae (n=2,590) were identified from five surveys conducted from 1991 to

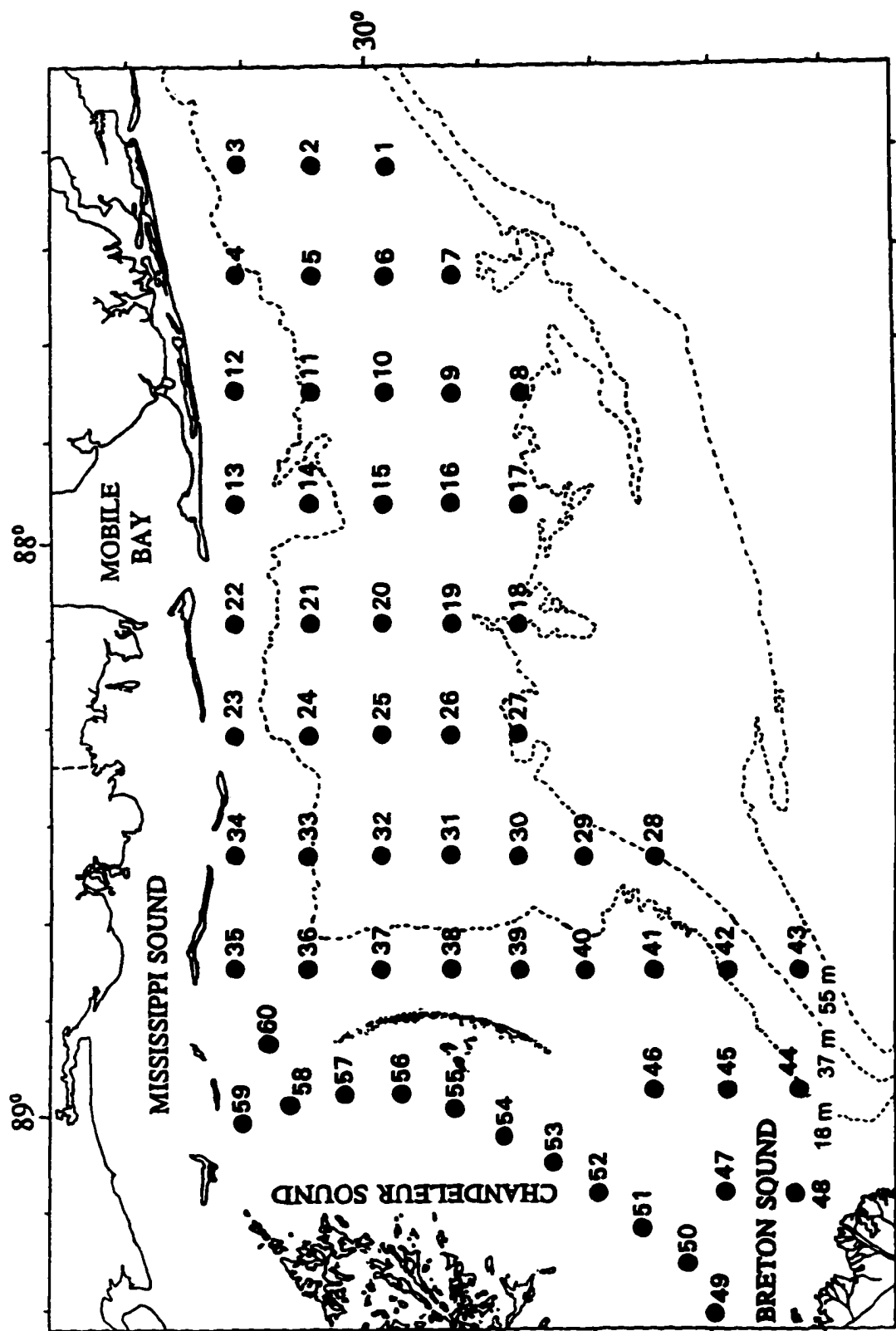


Figure 1.1. Numbered station locations in the northcentral Gulf of Mexico.

1993. Ichthyoplankton collection data for all sampling cruises are reported in Appendices A-P.

Red Drum

During the single ichthyoplankton survey conducted in 1988 (12-13 September) the abundances of red drum larvae were low and densities greater than 10 larvae under 10 m² of sea surface were found at only 5 of the 30 stations sampled (Figure 1.2). Larval abundances did not exceed 25 larvae under 10 m² of sea surface at any of the stations sampled. Red drum larvae were most abundant in the western portion of the study area and were taken at 10 of the 13 stations sampled off MS and eastern LA, whereas only 5 of the 17 collections taken off AL contained red drum. Most red drum larvae collected in 1988 were found at stations located in water shallower than 18 m; larvae were found at 12 of the 15 stations located in water shallower than 18 m, but only 3 of the 15 collections taken at depths greater than 18 m contained red drum larvae (Figure 1.2). Surface water temperatures during the September 1988 survey ranged from 25-27°C.

Red drum larvae were more abundant in collections taken during two cruises conducted in September 1989 (Figure 1.2). During the first 1989 survey conducted 9-11 September, surface water temperatures ranged from 28-30°C and larval abundances exceeded 30 larvae under 10 m² of sea surface at 5 of the 41 stations sampled with one station density as high as 99 larvae under 10 m² of sea surface. Red drum larvae were found at 34 of the 41 stations sampled (Figure 1.2), and were again generally more abundant in the

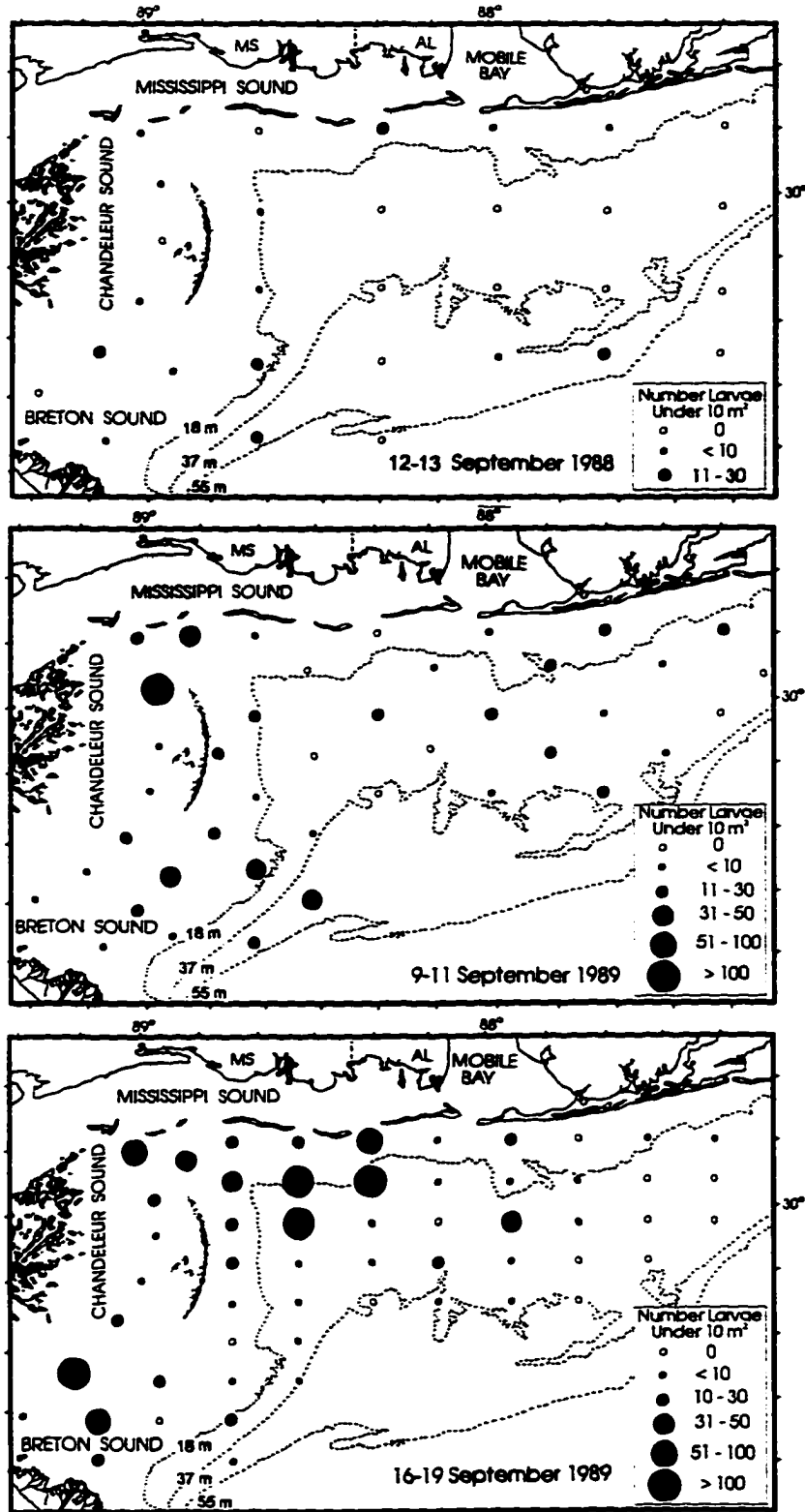


Figure 1.2. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during a single, two-day survey in September 1988 and two, three-day surveys in September 1989.

western portion of the study area in water shallower than 18 m. During the 16-19 September 1989 cruise, the number of stations sampled was increased from 41 to 55. Surface water temperatures were approximately 2°C lower than those measured during the first 1989 survey (26-28°C), and densities of red drum larvae had increased since the previous cruise. Larval densities exceeding 50 larvae under 10 m² of sea surface were found at 7 of the 55 stations sampled, and at 4 of these stations larval densities exceeded 100 larvae under 10 m² of sea surface (Figure 1.2). Highest densities of red drum larvae were found in the northeast portion of the study area off the MS coast in water shallower than 30 m. In the northcentral Gulf, surface water temperatures typically remain at 29°-30°C during the summer until September when temperatures are lowered by atmospheric cold front passages (Figure 1.3).

Three ichthyoplankton surveys were conducted in September 1990 (Figure 1.4). During the first survey conducted 7-9 September, surface water temperatures were 29-30°C and densities of red drum larvae were very low. Larvae were only found at 16 of the 53 stations sampled and only one station abundance exceeded 10 larvae under 10 m² of sea surface (Figure 1.4). The few larvae that were collected were small, i.e., all but two specimens were < 2.5 mm. A week later (September 14-16) surface water temperatures had decreased slightly (28-29°C) and red drum larvae were found at 26 of the 54 stations sampled (Figure 1.4). Larval abundances still remained low and only 3 station abundances exceeded 10 larvae under 10 m² of sea surface. By the third cruise (29-30 September 1990) surface water temperatures had

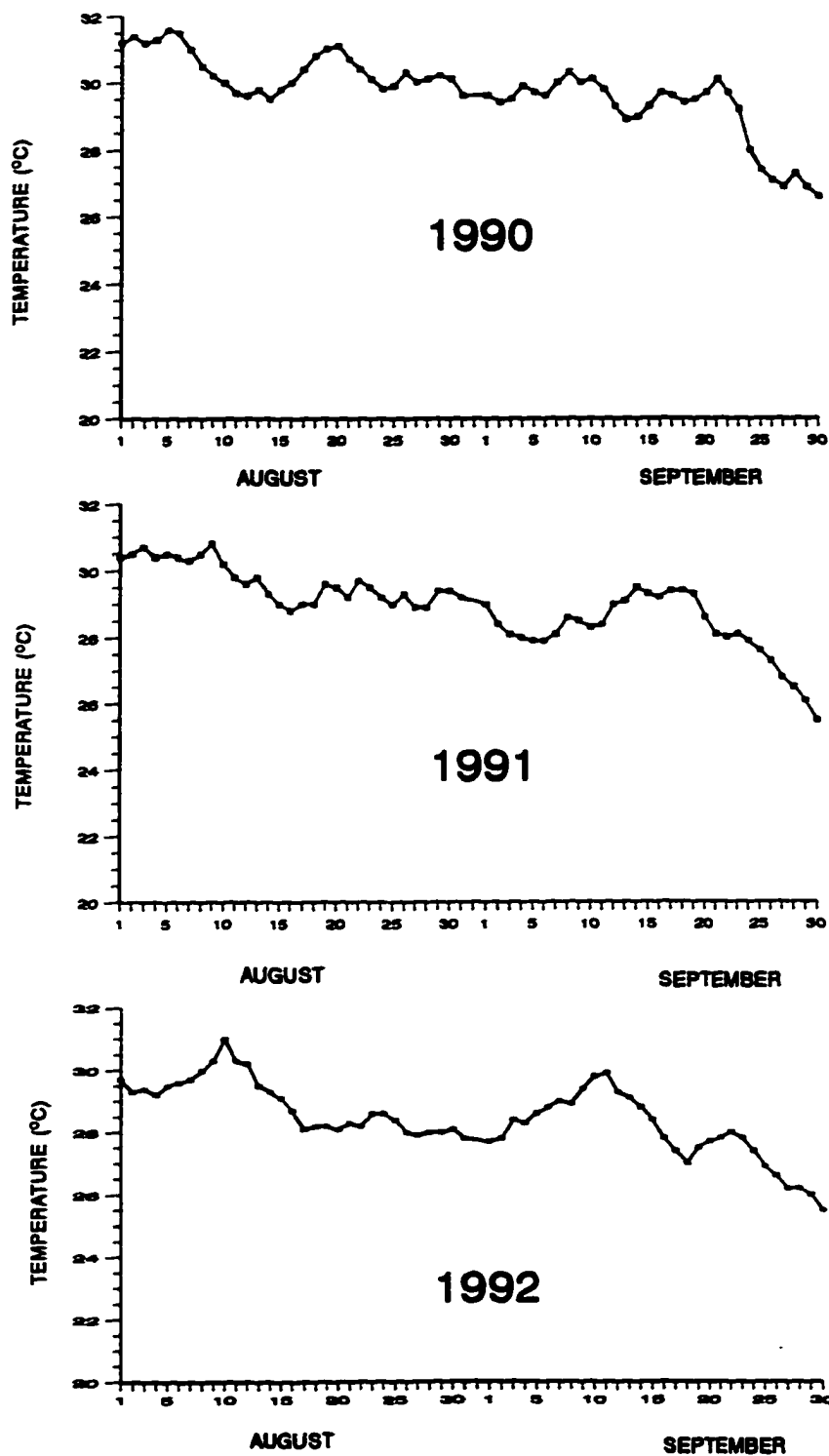


Figure 1.3 Surface water temperatures recorded in the northcentral Gulf of Mexico at National Data Buoy Center data buoy #42007 (6 km east of the northern tip of the Chandeleur Islands) during August and September of 1990, 1991, and 1992.

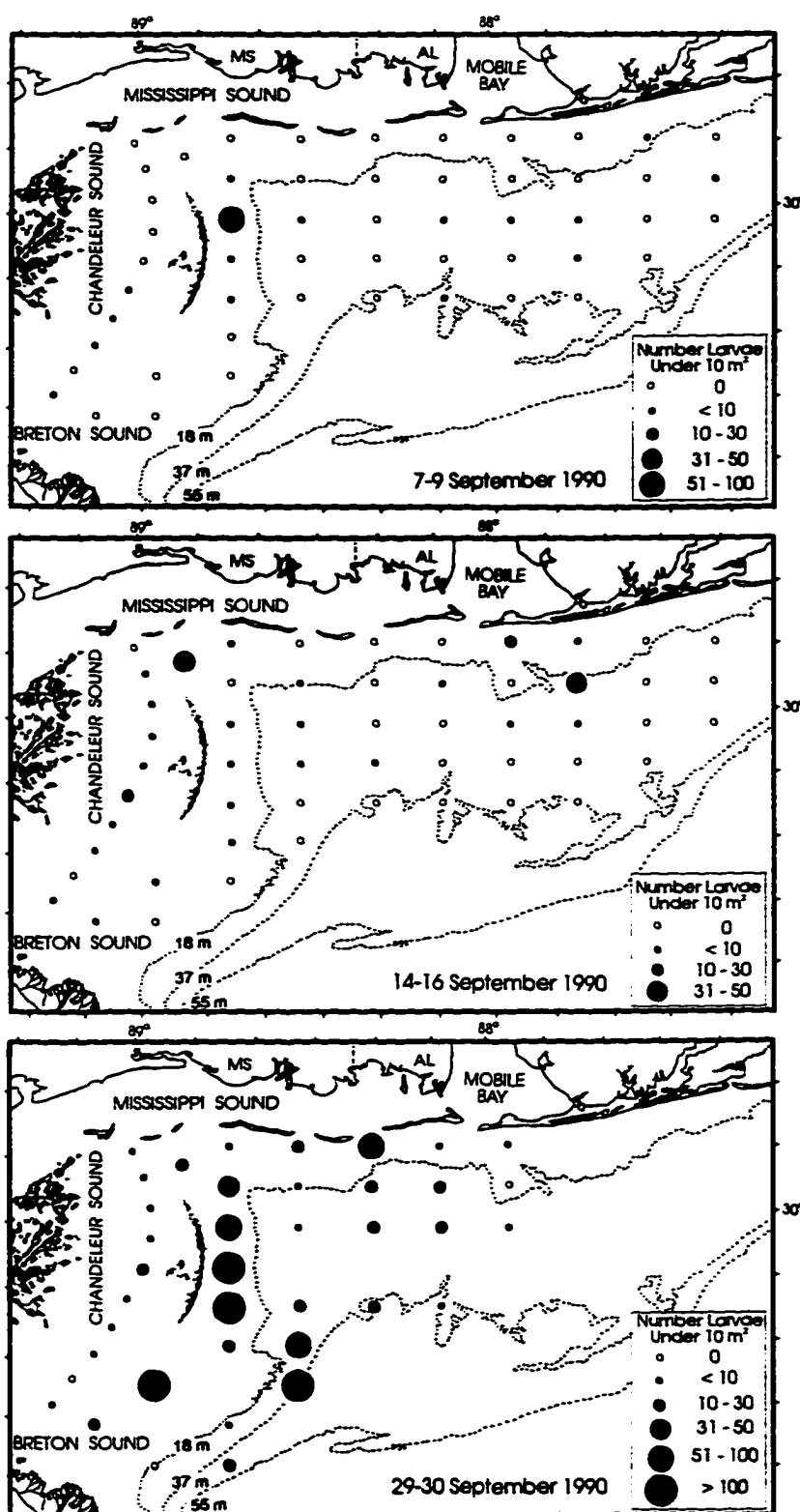


Figure 1.4. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during three, three-day surveys conducted in September 1990.

decreased to 25-26°C and red drum larval abundances had greatly increased. Thirty-five of 38 stations sampled had red drum larvae (Figure 1.4). Seven stations had abundances greater than 50 and 4 of these had abundances exceeding 100 larvae under 10 m² of sea surface.

In 1991 two ichthyoplankton surveys were conducted during the second and third weeks of September when surface water temperatures ranged from 28-30°C and 27-28°C, respectively. During the first sampling cruise red drum larvae were most abundant at stations located along a north-south transect immediately east of the Chandeleur islands in water shallower than 18 m (Figure 1.5). Densities of red drum larvae exceeded 30 larvae under 10 m² of sea surface at 6 of the 9 stations along this transect. Densities of larvae were low in Chandeleur and Breton Sounds and larvae were particularly scarce in the eastern portion of the study area off AL. During the second survey larval red drum abundances increased (Figure 1.5) with eight stations having abundances greater than 50 and four of these stations had densities exceeding 100 larvae under 10 m². Red drum larvae were most abundant in Breton Sound and the southern portion of Chandeleur Sound. Off the coast of AL larvae were again found only in low densities.

In 1992 two plankton surveys were conducted during 13-20 and 27-29 September when surface water temperatures ranged from 27-29°C and 24-27°C, respectively. During both surveys red drum larvae were most abundant in the central portion of the study area off the coast of MS and AL between the 18 m and 37 m isobaths (Figure 1.6). Sampling was not conducted in

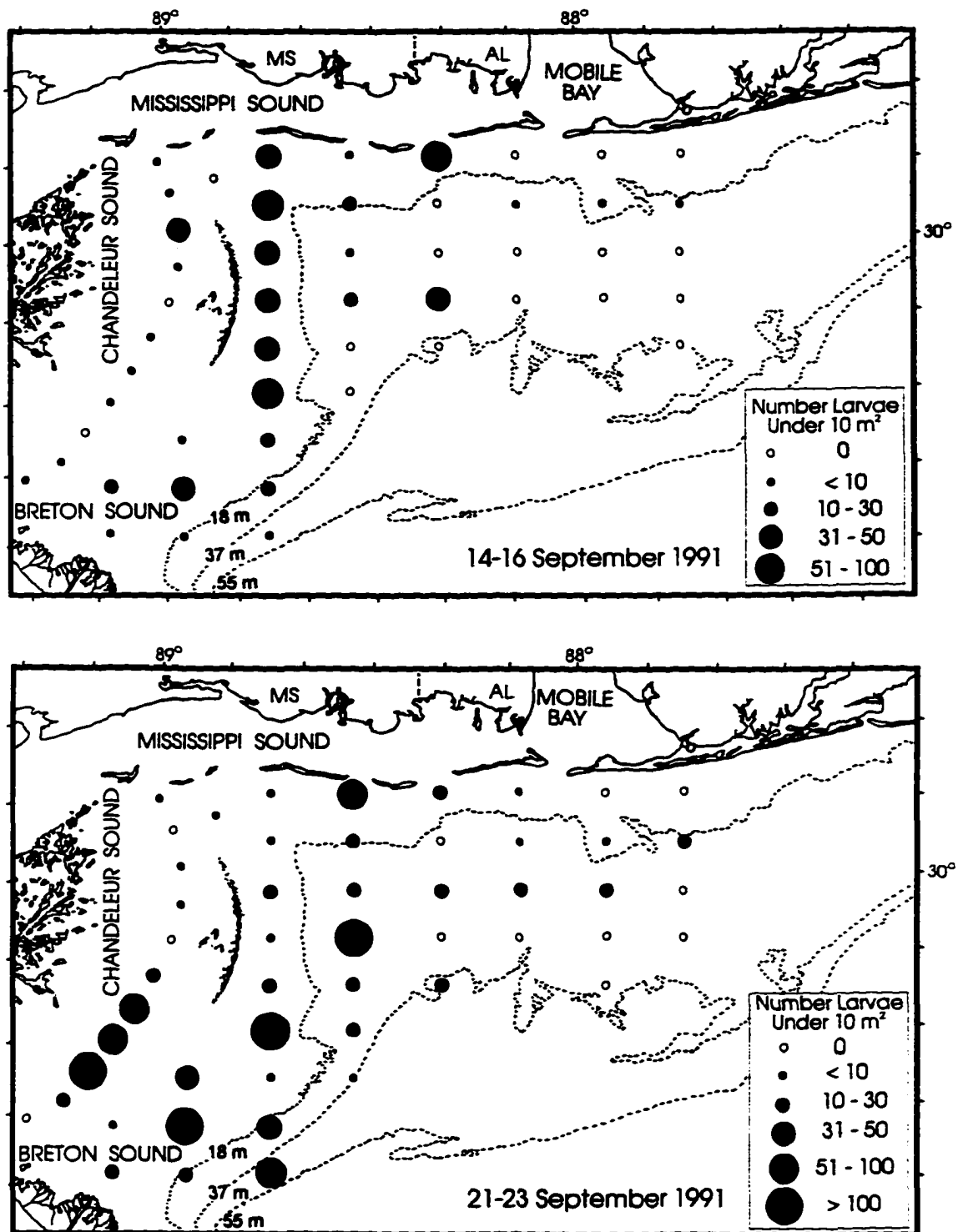


Figure 1.5. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.

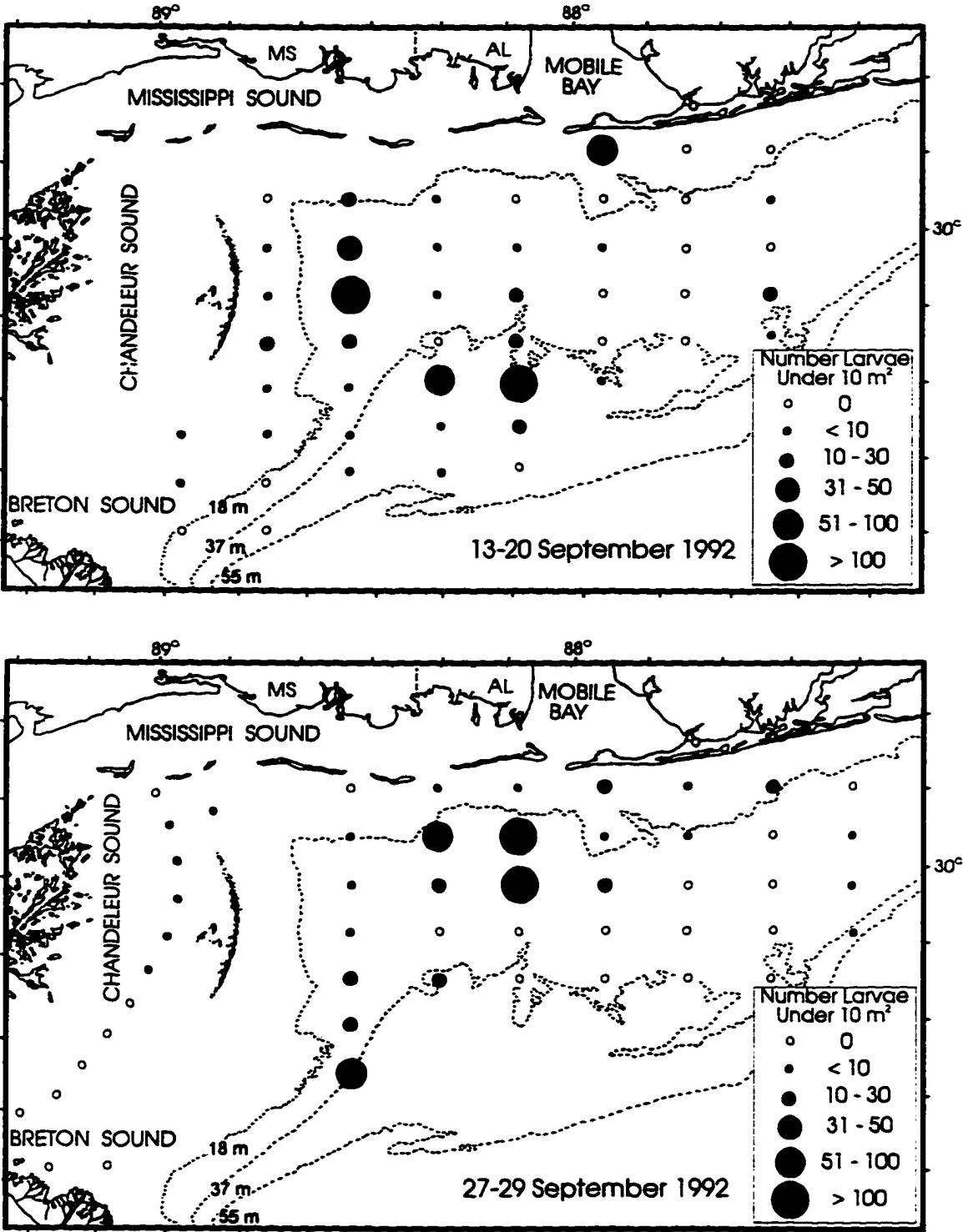


Figure 1.6. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during a seven-day survey, and a three-day survey, conducted in September 1992.

Chandeleur Sound during the first survey, and during the second sampling period very few red drum larvae were collected in this area. Of the 13 stations sampled in Chandeleur and Breton Sounds, red drum larvae were only taken at five stations, and at three of these stations only a single specimen was collected (Figure 1.6).

During two plankton surveys conducted between 9-11 and 19-21 September 1993, highest densities of red drum larvae were found in Chandeleur Sound (Figure 1.7). During the first survey red drum larvae were found at all 15 stations within Chandeleur and Breton Sounds, and at three of the stations densities of red drum larvae exceeded 100 larvae under 10 m² sea surface. These densities are particularly high given the shallow depths within Chandeleur Sound (depth range = 3.7 to 7.5 m); station depths at locations where red drum larvae were most abundant were less than 6 m. During both sampling cruises, the lowest abundances of red drum larvae were found in the eastern portion of the study area.

During the two plankton surveys conducted between 9-11 and 20-22 September 1994, red drum larvae were conspicuously scarce in Chandeleur Sound (Figure 1.8) where only one station had larval abundances exceeding 10 larvae under 10 m². Red drum larvae were most abundant during the second survey when surface water temperatures had dropped to 26°-27°C. During this second survey red drum larvae were most abundant in the central and eastern portions of the study area at stations located between the 18 m and 37 m isobaths (Figure 1.8). Abundances of red drum larvae exceeded 50 at 10 of

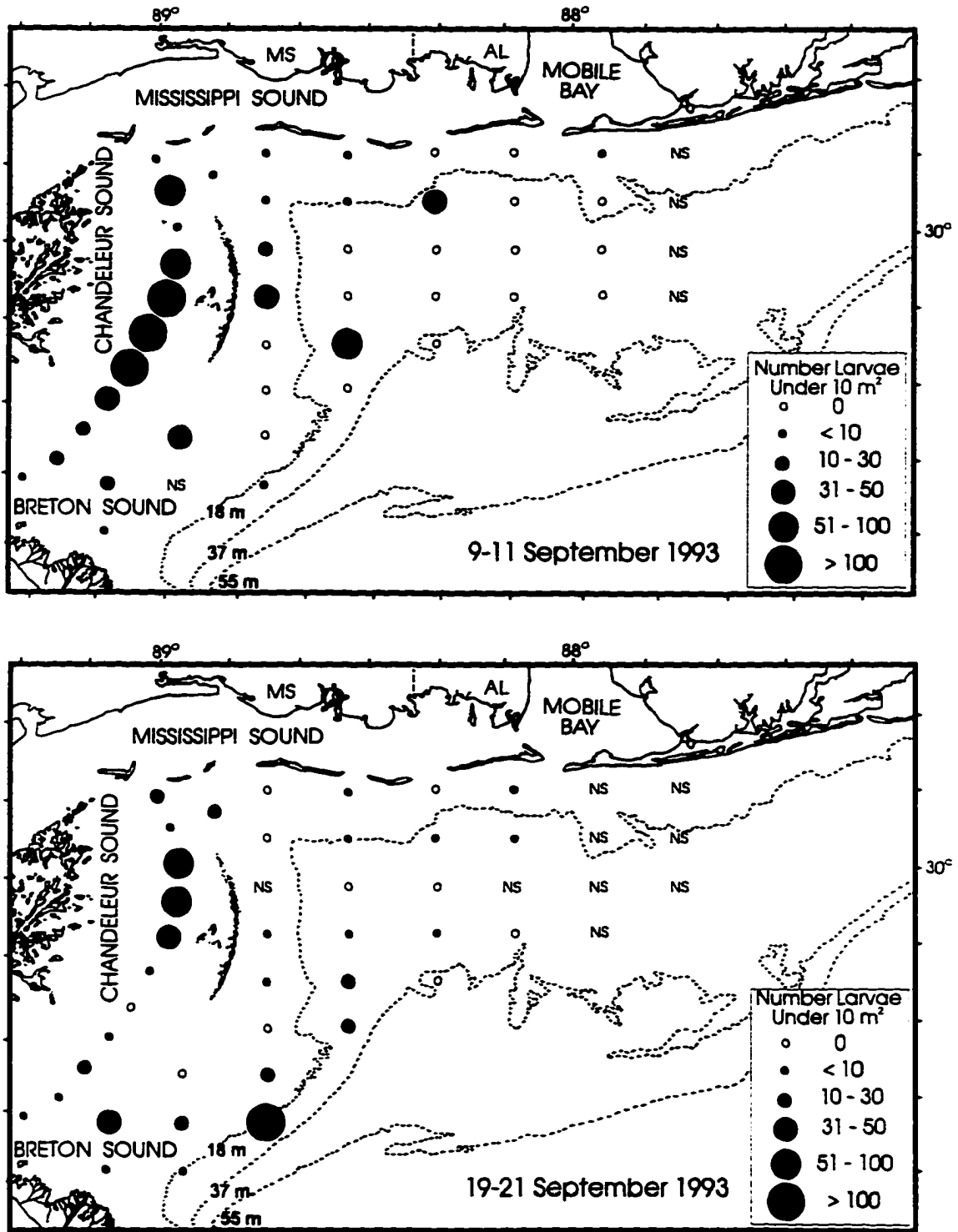


Figure 1.7. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1993. NS means sample not sorted.

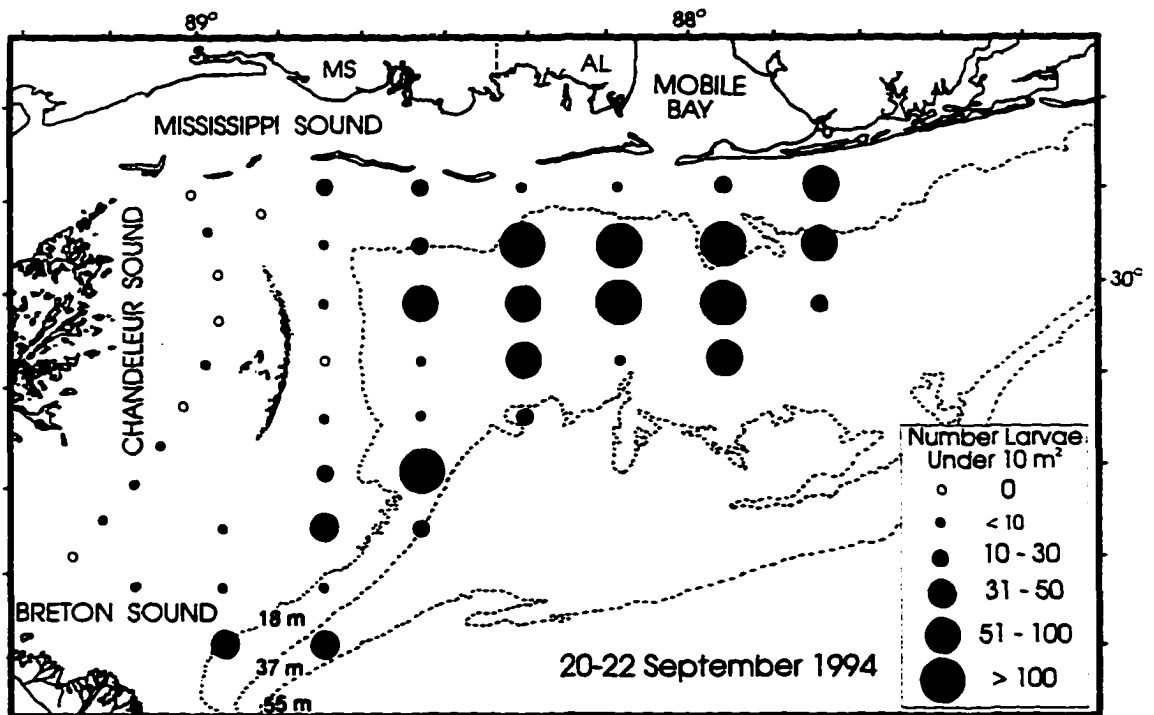
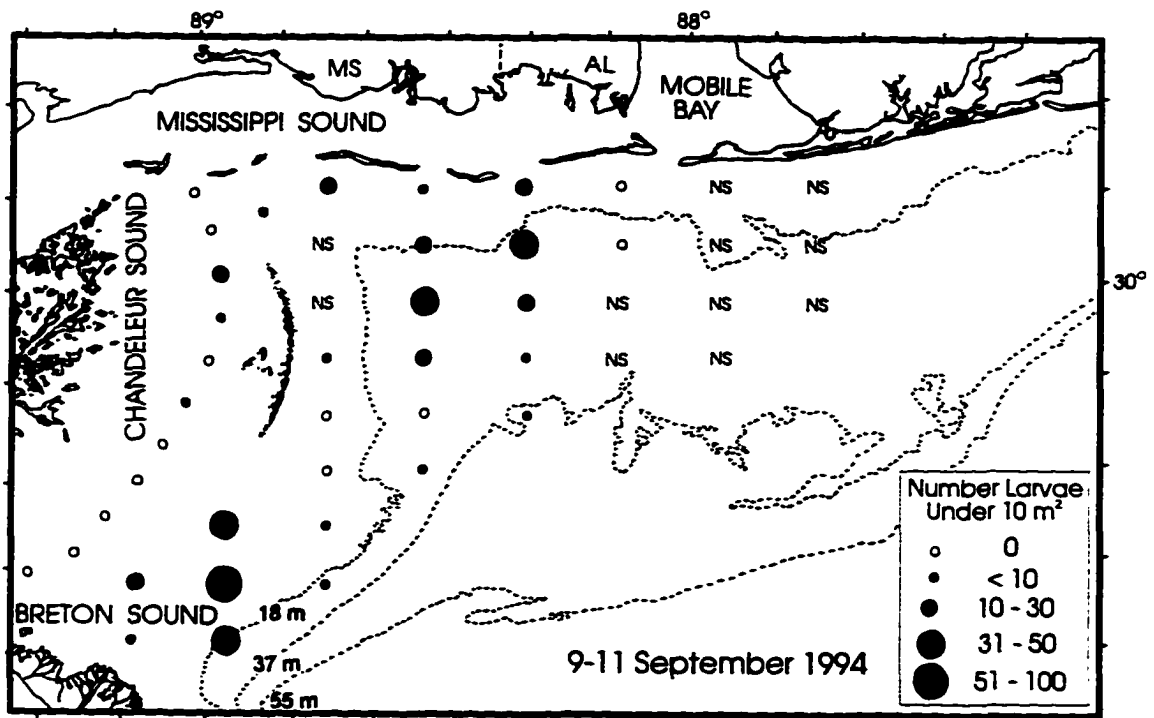


Figure 1.8. Distribution and abundance of red drum larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1994. NS means sample not sorted.

the 16 stations located off AL and 6 of these had abundances exceeding 100 larvae under 10 m².

Atlantic Bumper

In 1990 three, 2-3 day ichthyoplankton surveys were conducted during the second, third and fourth weeks of September, and Atlantic bumper larvae were abundant during all three sampling periods. Surface water temperatures during the first two cruises were $\geq 28^{\circ}\text{C}$, but during the third survey (September 29-30) surface temperatures had dropped to $25^{\circ}\text{-}26^{\circ}\text{C}$. In general Atlantic bumper larvae were found at most stations inside Chandeleur and Breton Sounds, but larvae were most abundant immediately northeast and east of Chandeleur Sound in waters shallower than 18 m (Figure 1.9). For example, larval abundances exceeding 1,250 larvae under 10 m² of sea surface were found at two stations immediately northeast of Chandeleur Sound during the second survey (Figure 1.9).

During the first survey in September 1990, Atlantic bumper larvae were also relatively abundant in waters southeast of Mobile Bay at stations located between the 18 m and 37 m isobaths. Larvae were not as abundant in the eastern portion of the study area during the second survey, but larval abundances exceeding 250 larvae under 10 m² sea surface were once again found at two stations immediately southeast of Mobile bay (Figure 1.9). Easternmost stations were not sampled during the third survey in 1990.

Three surveys were conducted in September 1991, but larval distribution data is presented only for the first two cruises because rough seas severely

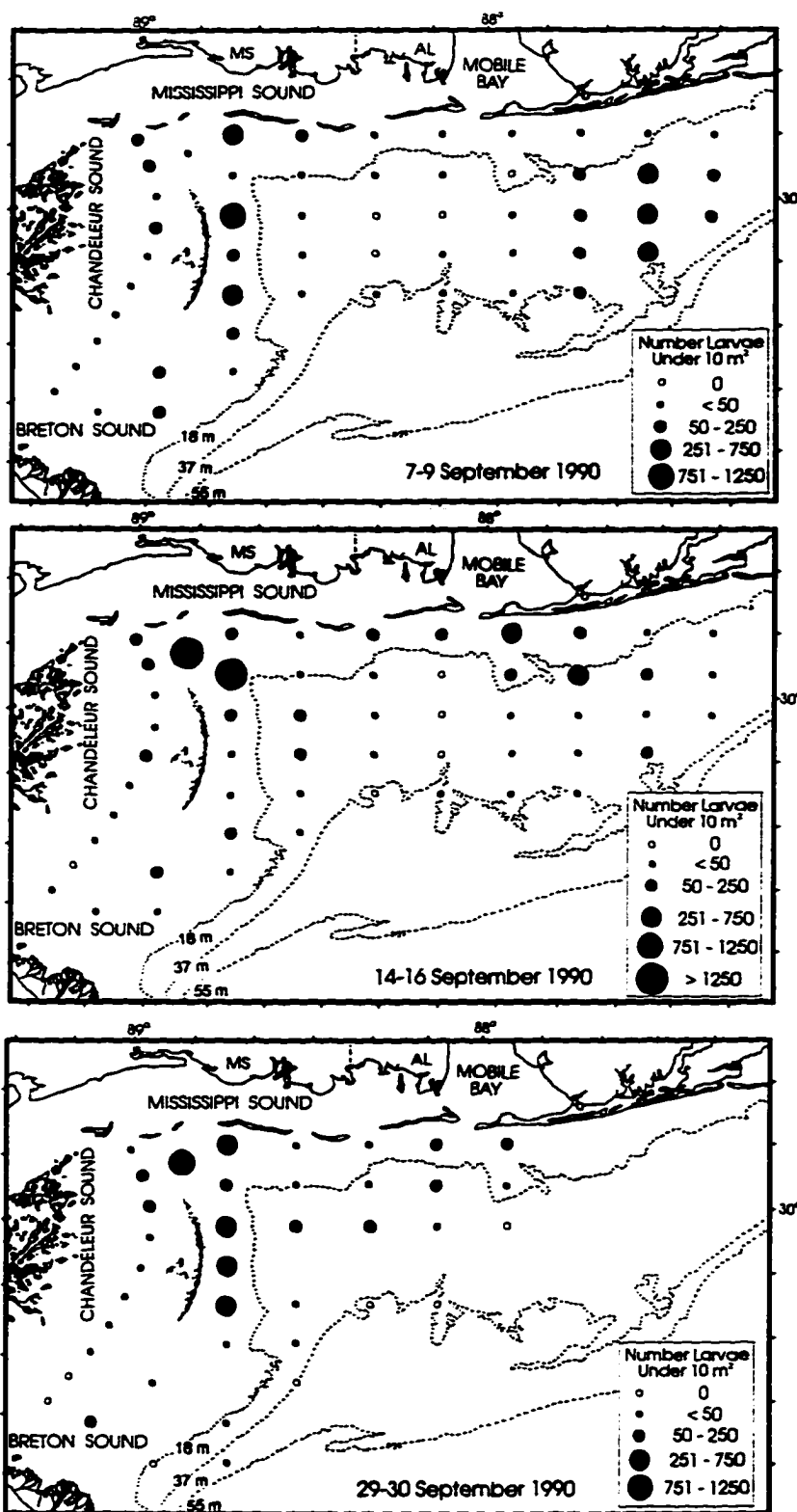


Figure 1.9. Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during three, three-day surveys conducted in September 1990.

curtailed sampling during the third cruise and collections could only be taken in Chandeleur Sound. Atlantic bumper larvae were again most abundant in the western portion of the study area in water shallower than 18 m (Figure 1.10). During the first survey (14-16 September 1991) larval abundances exceeding 50 larvae under 10 m² sea surface were found at all shallow stations (≤ 18 m) east of Candeluer Sound extending to Mobile Bay. At all stations within Chandeleur and Breton Sounds abundances were less than 50 larvae under 10 m². During the second survey (21-23 September) the pattern in areal abundance was similar, although catches were higher at several stations within Chandeleur Sound. At two of these stations larval abundances exceeded 250 larvae under 10 m² of sea surface (Figure 1.10).

In September 1992 densities of Atlantic bumper larvae were relatively low during both surveys. During the September 13-19 survey, surface water temperatures ranged from 27°-28°C, and abundances greater than 50 larvae under 10 m² were found at only one station (no stations were sampled in Chandeleur Sound). During the 27-29 September cruise, surface water temperatures had further decreased to 24°-27°C, and densities of Atlantic bumper larvae were less than 50 larvae under 10 m² at all stations sampled (Figure 1.11).

In 1993 plankton cruises were conducted between 9-11 and 19-21 September when surface water temperatures ranged from 28°-29°C, and 26°-27°C, respectively. During the first survey Atlantic bumper larvae were abundant, particularly east of Chandeleur Sound off the MS coast within the

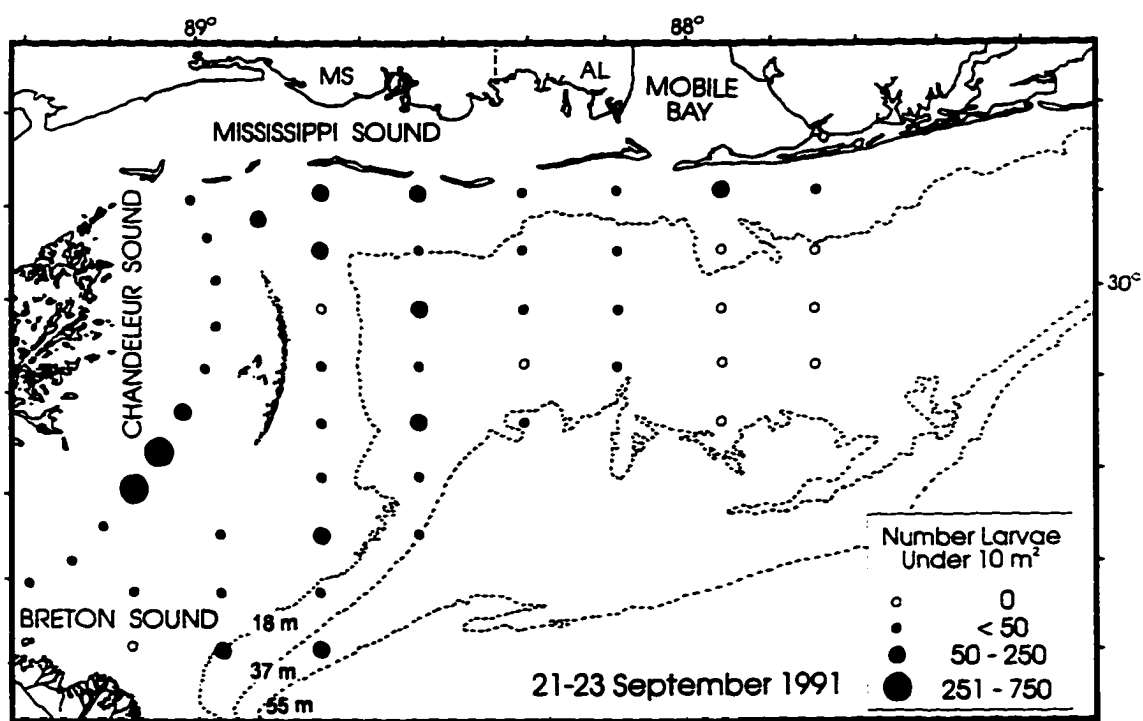
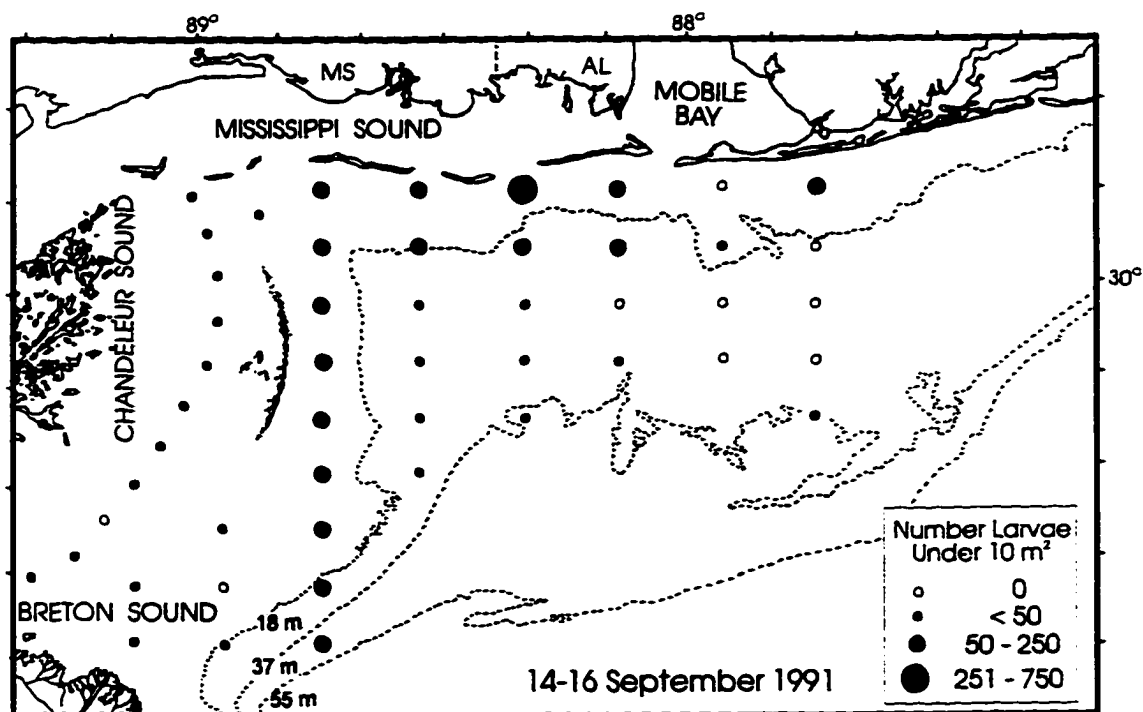


Figure 1.10. Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.

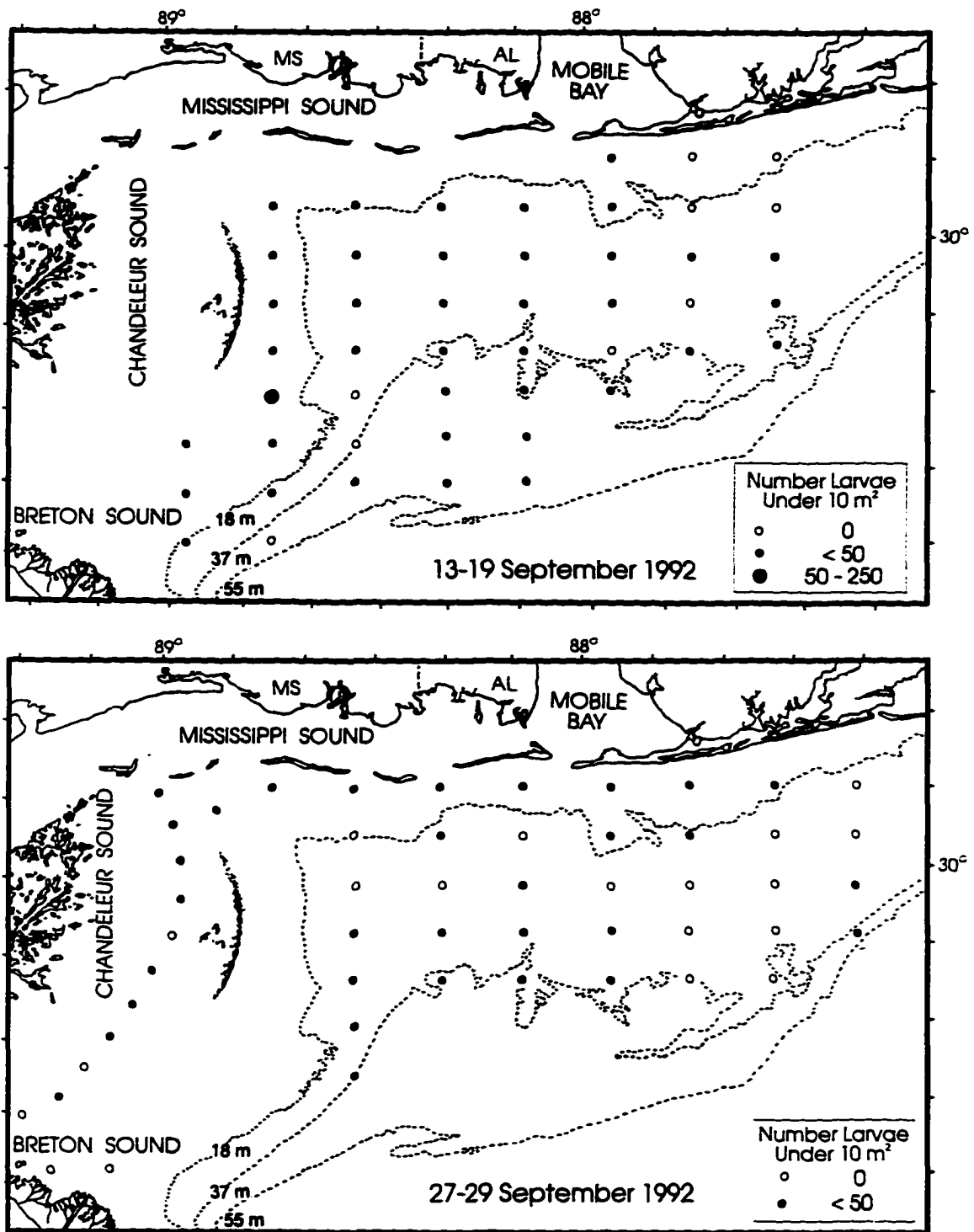


Figure 1.11. Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during a seven-day survey, and a three-day survey, conducted in September 1992.

18 m isobath (Figure 1.12). Abundances at four stations in this area exceeded 250 larvae under 10 m² sea surface. Abundances were low in the eastern portion of the study area, particularly in water deeper than 18 m. Abundances of larvae decreased during the second survey, when only five stations had abundances exceeding 50 larvae under 10 m² (Figure 1.12).

Vermilion Snapper

Vermilion snapper larvae were identified from two September plankton surveys in both 1991 and 1992, and a single survey in September 1993. In 1991 collections were taken between 14-16 and 21-23 September and distributions of vermilion snapper larvae were very similar during both surveys (Figure 1.13). Larvae were absent in Chandeleur and Breton Sounds and were most abundant off the MS and AL coast with larval abundances exceeding 50 larvae under 10 m² at numerous stations. High larval abundances were restricted exclusively to an area bounded by the 18 m and 37 m isobaths (samples were not taken in water deeper than 40 m).

During the first 1992 larval survey (13-19 September) when surface water temperatures ranged from 27°-28°C, vermilion snapper larvae were conspicuously absent throughout the study area. Larval abundances did not exceed 10 larvae under 10 m² sea surface at any of the stations sampled (Figure 1.14). Apart from a single specimen collected in shallow water at a station immediately south of Chandeleur Sound, all vermilion snapper larvae were collected in water deeper than 18 m. During the 27-29 September cruise surface water temperatures had dropped to 24°-27°C and abundances of

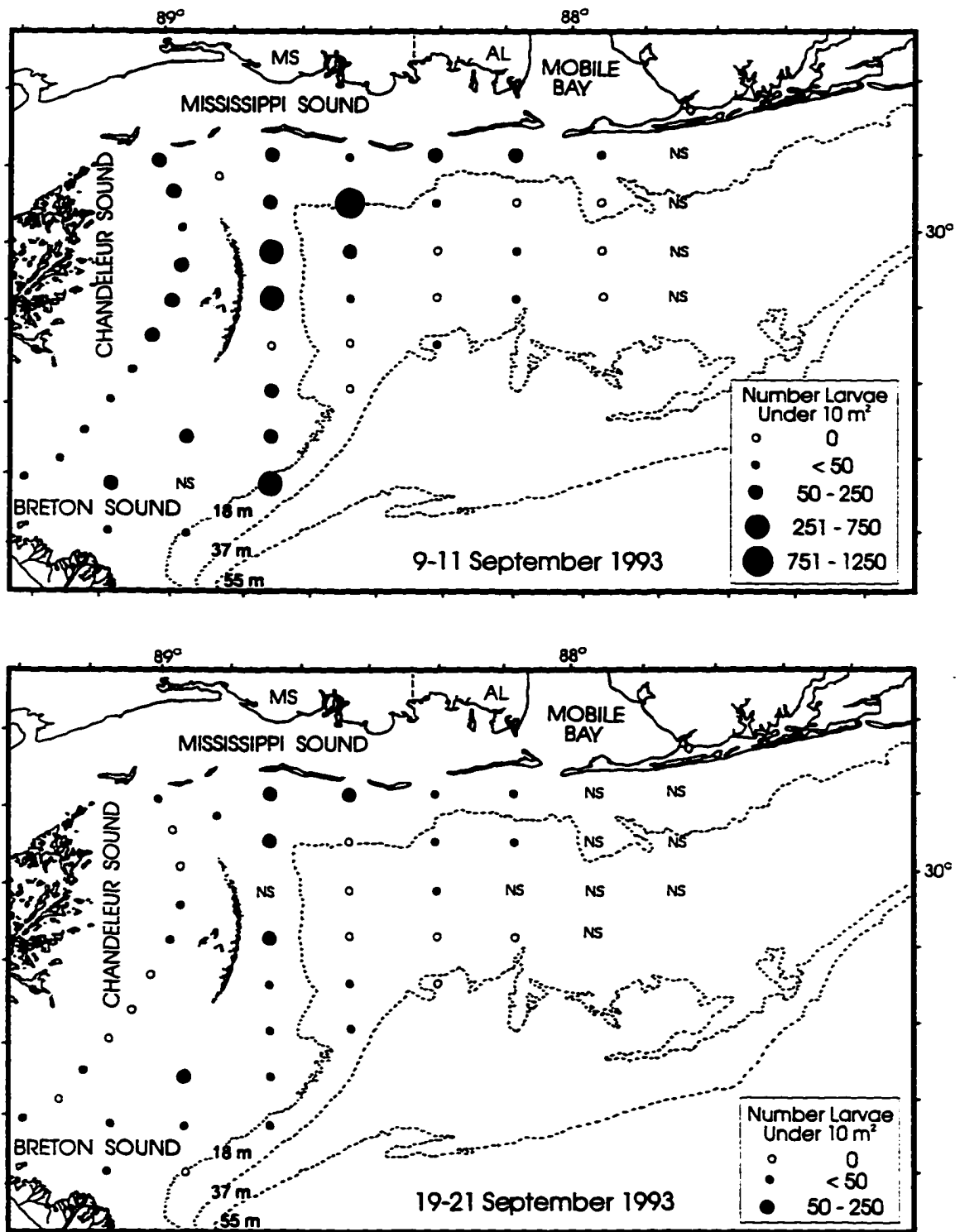


Figure 1.12. Distribution and abundance of Atlantic bumper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1993. NS means sample not sorted.

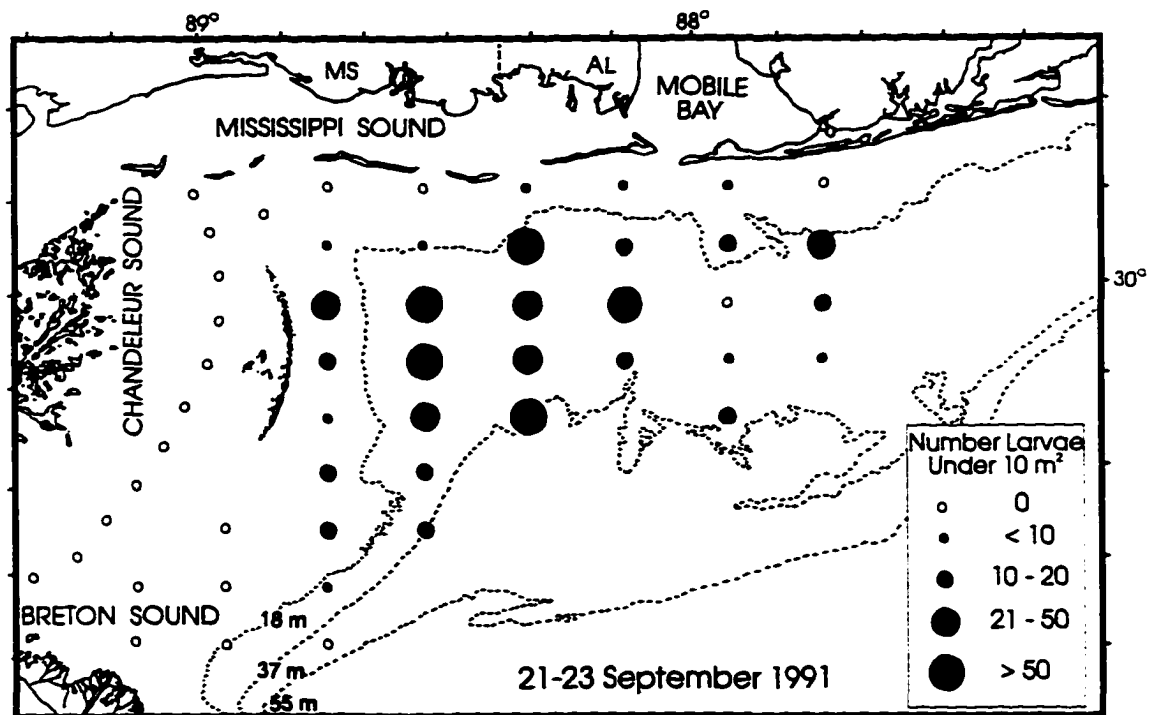
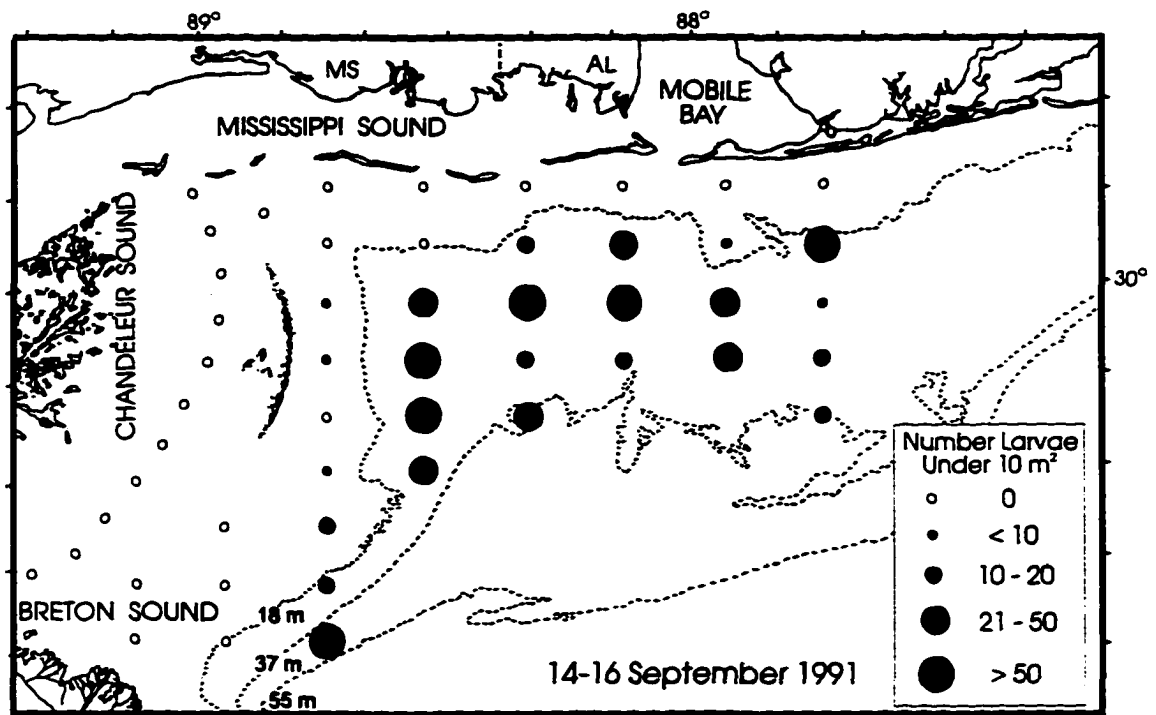


Figure 1.13. Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during two, three-day surveys conducted in September 1991.

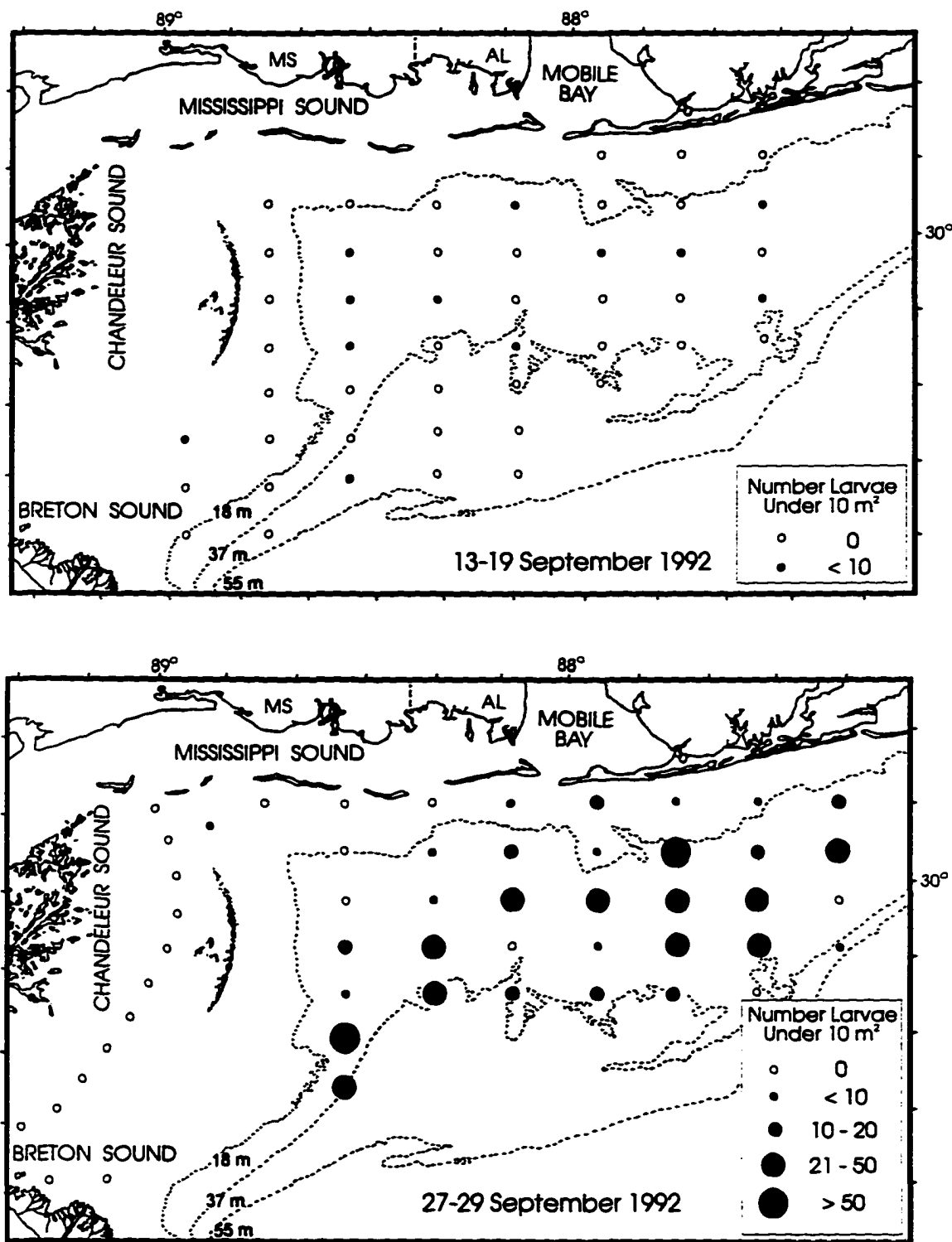


Figure 1.14. Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during two surveys conducted in September 1992.

vermilion snapper larvae had greatly increased (Figure 1.14). Larvae were again absent in Chandeleur and Breton Sounds, but abundances >20 larvae under 10 m² of sea surface were found at most stations off MS and AL in waters deeper than 18 m.

During the 19-21 September cruise in 1993 Vermilion snapper larvae were again found primarily at stations in water deeper than 18 m, and were absent in the relatively shallow sounds (Figure 1.15). The three stations where the highest abundances of larvae were found were located off the Alabama coast between the 18 m and 37 m isobaths, a region where artificial reefs have been built.

DISCUSSION

The timing of spawning for many fishes is controlled by seasonal changes in water temperature (e.g., Peter and Hontela, 1978). Collections for this study were taken during September, a month when water temperatures over the inner shelf in the northcentral Gulf typically drop 5 or 6°C from summertime (June to August) values of approximately 29-30°C. It is, therefore, understandable that spawning activity in September, with the associated decreasing water temperatures, is often very dynamic. Larval fish distributions are determined by both the distribution of spawning adults, spawning frequency and duration, and the transport of larvae by water currents. Directed movement of water over the inner-shelf in the northcentral Gulf east of the Mississippi River is limited, although a weak cyclonic gyre often forms in the northcentral Gulf east of the Mississippi River Delta (Schroeder et al., 1987; Dinnel, 1988).

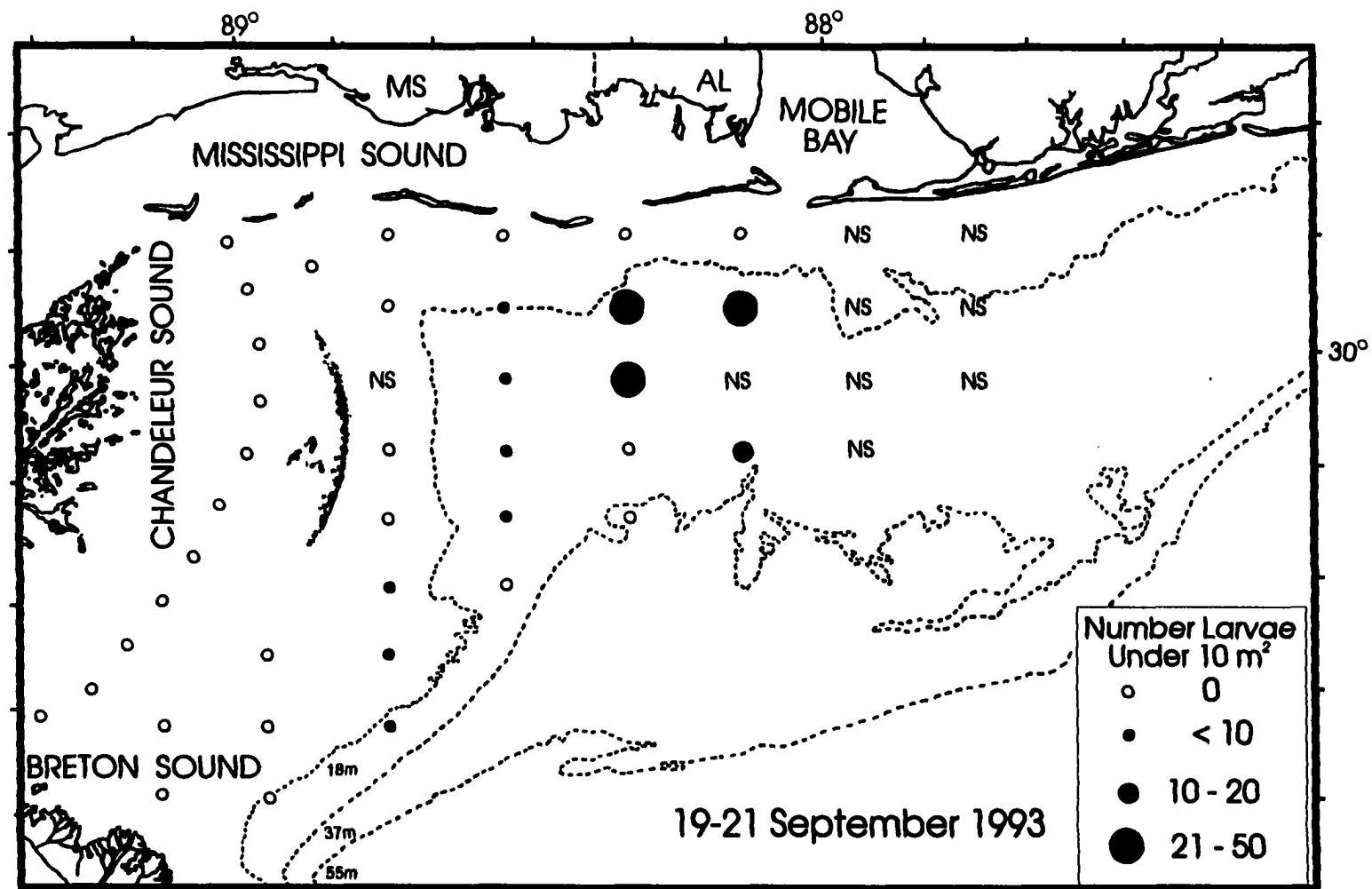


Figure 1.15. Distribution and abundance of vermilion snapper larvae collected in the northcentral Gulf of Mexico during a three-day survey conducted in September 1993. NS means sample not sorted.

Lyczkowski-Shultz et al. (1988) deployed a total of 15 drogues for periods of 1 or 2 d in my study area during the fall months from 1983 to 1985. Apart from one drogue that in 24 h drifted for ten miles in a southerly direction immediately east of the Chandeleur Islands, movement of the drogues was generally quite random and drogue tracks often reversed direction 180°. Shaw et al. (1988) deployed three drogues on six sampling dates during Fall 1986 in the study area, and these drogue trajectories were also very meandering. These drogue studies were not conducted during atmospheric cold front passages, however, because of the adverse sea conditions caused by the energetic rotation of the wind field. One of the characteristics of these cold fronts are northerly winds which have been shown to cause a westward flow immediately south of the Mississippi-Alabama barrier islands (Schroeder et al., 1985; 1987).

Red Drum

Red drum spawning in the northern Gulf usually begins in August and peaks during September when water temperatures typically decrease rapidly (Comyns et al., 1991; Wilson and Nieland, 1994) and terminates in October. During the latter part of September, water temperatures in the study area decreased by 1°C every two to three days. Even though most red drum spawning occurs during late August, September, and early October, spawning intensity within this six week period is highly variable. During the seven years of this study (1988 to 1994), with the exception of 1993, highest densities of red drum larvae were observed during the latter half of September when surface water temperatures ranged from 25°-28°C. In 1993 high densities of red drum

larvae were collected during the second week of September when surface water temperatures had decreased only to 28°C at many of the sampling locations. September is the beginning of the season for atmospheric cold front passages. These high energy events are responsible for the rapidly decreasing surface water temperatures, and turbulent mixing of the stratified water column which is set up during summer months. Once the cold front season is established, surface water temperatures become more indicative of the temperature throughout the well-mixed water column over the inner-shelf of the northern Gulf (Lyczkowski-Shultz et al., 1988).

The changing distributions of spawning red drum were often reflected by large differences in the geographical distributions of their larvae. For example during the 9-11 September survey in 1993, red drum larvae were collected at all 8 stations within Chandeleur Sound, and abundances at three of these stations exceeded 100 larvae under 10 m² of sea surface. During this same cruise red drum larvae were taken at only 4 of the 14 stations east of Chandeleur Sound between the 18 m and 37 m isobaths. During the 20-22 September 1994 cruise this larval distribution was completely reversed. During this survey red drum larvae were found in Chandeleur Sound at very low densities and were present at only 4 of the 8 stations sampled. In addition, larvae were found at all 18 stations east of Chandeleur Sound between the 18 m and 37 m isobaths, and at 5 of these stations larval abundances exceeded 100 larvae under 10 m². It is unlikely that the difference in spatial distribution of larvae during both cruises was caused by larval transport because the sizes of larvae during both

cruises were similar. These data clearly indicate that the distribution of spawning red drum in the northcentral Gulf is variable. Although this variability can occur on the scale of tens of kilometers (e.g., distance between stations = 10 km) it can influence the distribution pattern of larvae over thousands of square kilometers (e.g., study survey area approximately 9,000 km²).

In addition, a survey conducted 14-16 September 1991 found low densities of red drum larvae in Breton and southeast Chandeleur Sound, but a week later larval abundances had increased dramatically at eight of the ten sampling stations in this area. Larvae collected within the large area of the Sounds were the result of spawning by a number of red drum schools, and the increased spawning activity shows a synchronicity in spawning between schools of red drum within the same general area on a scale of days. These data support the findings of Wilson and Nieland (1994) that this species is a synchronous spawner, and indicate that there may be some synchrony in spawning on the order of days among schools of red drum within relatively large areas.

I found densities of red drum larvae to generally be most abundant in water shallower than approximately 18 m, findings that concur with Lohoefer et al. (1988) who conducted an aerial survey in September to estimate the abundance of surface-schooling adult red drum in the northcentral Gulf. Within my study area, sightings of red drum schools were made exclusively in the vicinity of the Chandeleur Islands and the barrier islands off the coast of MS and AL. However, I frequently found recently-spawned red drum

larvae (<2 mm) at stations located further offshore (18-37 m), and during several surveys highest densities of red drum larvae were found in this deeper stratum. It is likely that many of these extremely small larvae were spawned offshore, and raises the possibility that Lohoefer et al. (1988) only observed surface schools of red drum in the vicinity of the barrier islands because red drum may not surface as frequently in deeper water further offshore.

Atlantic Bumper

Atlantic bumper also spawn over the inner continental shelf in the northern Gulf (Shaw and Drullinger, 1990), but unlike red drum that increase spawning activity during September, Atlantic bumper spawning decreases during the latter part of September. Previous studies, based on the occurrence of larvae, have shown the spawning period of Atlantic bumper in the northern Gulf to extend from June to October with peaks usually occurring in July or August (Stuck and Perry, 1982; Ditty, 1986; Ditty et al., 1988; Leffler and Shaw, 1992). Even though the sampling period of this study was towards the end of the Atlantic bumper spawning season, their larvae were very abundant during most sampling cruises with over 42,000 specimens being collected during the nine surveys conducted from 1990-1993. Larval abundances exceeding 250 larvae under 10 m² of sea surface were found at several stations during six of the nine surveys, and during the second September 1990 cruise abundances of Atlantic bumper larvae at two stations exceeded 1250 larvae under 10 m².

Relatively low densities of Atlantic bumper larvae were collected only during two surveys in the latter half of September 1992 and during a survey

conducted in the third week of September 1993. These low densities were most likely caused by the decrease in spawning activity at the end of the season. Factors signalling the end of the spawning season for Atlantic bumper remain unclear: decreasing water temperatures may be partly responsible, but larvae were relatively abundant during the last two days of September 1990 when surface water temperatures had decreased to 25°-26°C. It is possible that other factors such as the shortening photoperiod in September may contribute to signals heralding the end of their spawning season.

Atlantic bumper larvae were found throughout the study area but stations with highest abundances were located near or shoreward of the 18 m isobath. Very rarely were high densities of Atlantic bumper found in water as deep as 37 m. These data support the findings of Shaw and Drulinger (1990) who noted that off Louisiana and Mississippi Atlantic bumper spawn primarily in nearshore coastal waters.

Vermilion Snapper

The distribution of vermilion snapper larvae was strikingly different from that of red drum or Atlantic bumper larvae. Larval vermilion snapper were most abundant in water deeper than 18 m and they were absent in Chandeleur and Breton Sound. Also, larval abundances were greatest in the central and eastern portion of the study area. This distribution reflects the distribution of adult vermilion snapper which are also uncommon in shallow nearshore areas (Darnell and Kleypas, 1987), probably because natural or artificial reef habitat is located in deeper water. Offshore boundaries of the larval vermilion snapper

distribution cannot be determined with my data because very few sampling stations were located in water deeper than 37 m.

Spawning of vermilion snapper in the northcentral Gulf begins in May, remains at a relatively low level during the summer months, and increases in September (Comyns and Lyczkowski-Shultz, 1993; Comyns, 1995a).

Collections taken during two surveys in September 1992 clearly showed the onset of peak spawning to occur in September, i.e., a plankton survey taken during 13-19 September 1992 yielded very few vermilion snapper larvae but by the 27-29 September cruise, vermilion snapper larvae were relatively abundant. During the first September 1992 cruise, vermilion snapper larvae were found at only 11 of the 35 stations located east of Chandeleur Sound in water deeper than 18 m, and abundances of larvae at all stations were <10 larvae under 10 m² of sea surface. Two weeks later, however, vermilion snapper larvae were found at 24 of the 28 stations sampled within this area, with larval abundances at 12 stations ranging from 20-50 larvae under 10 m².

Chapter 2. Variability associated with age and growth estimates of larval vermilion snapper (*Rhomboplites aurorubens*) and Atlantic bumper (*Chloroscombrus chrysurus*) in the northcentral Gulf of Mexico.

INTRODUCTION

The purpose of this study was to determine the spatial and temporal variability in estimated growth rates of larval vermilion snapper (*Rhomboplites aurorubens*) and Atlantic bumper (*Chloroscombrus chrysurus*) in the northcentral Gulf, and to determine whether the observed variability in larval age/length and age/weight growth coefficients could be explained by (e.g., were correlated with changes in) water temperature and estimates of potential food availability. Vermilion snapper occur only in the western Atlantic from North Carolina to Rio de Janeiro, Brazil, including the Gulf of Mexico (Hilderbrand and Schroeder, 1928; Anderson, 1967; Laroche, 1977). Snappers (Lutjanidae) comprise the most commercially - and recreationally - important family of reef fishes, and in the northcentral Gulf vermilion snapper is the most abundant of this group (Goodyear and Schirripa, 1991). Atlantic bumper are widely distributed in the western Atlantic and Gulf of Mexico (Leak, 1977), and because of their abundance this carangid is both ecologically - and potentially commercially - important (Leffler and Shaw, 1992).

Soon after the discovery of daily growth increments in the otoliths of certain adult temperate fishes (Pannella, 1971), daily otolith growth increments were used to age fish larvae (Brothers et al., 1976). The discovery of this powerful ageing tool has lead to the improved understanding of biological factors that may strongly influence subsequent recruitment to adult populations.

In addition, it has lead to more precise and accurate determinations of growth rates (i.e., change in length or weight over time), and age-specific mortality rates.

Otolith increment formation, however, has been shown on occasion to depart from daily periodicity (Campana and Neilson, 1982; Geffen, 1982; Rice et al., 1985), and it is strongly advisable to validate the periodicity of increment formation. Validation is not as essential, however, if daily periodicity has been validated in closely-related species, and if larval growth is not expected to be impacted by factors such as low food supply or low water temperatures (e.g., De Vries et al. 1990). Daily periodicity has been validated in otoliths of newly-hatched red snapper (*Lutjanus campechanus*) from the northern Gulf (Lyczkowski-Shultz and Comyns, 1992), and in otoliths of red snapper juveniles (S.T. Szedlmayer, Auburn Univ., pers. comm.). Daily periodicity has not been validated for vermilion snapper larvae, however, I assume that the otolith increments observed and counted were formed daily, since they were very similar to the daily increments found in otoliths of co-occurring red snapper larvae. The periodicity of otolith increment formation for larval Atlantic bumper has been validated (Leffler and Shaw, 1992).

Year class strength of many marine fishes undergo large fluctuations because of the large variability in larval, postlarval and juvenile survivorship (Hjort, 1914; Lasker, 1975; Cushing, 1975; Hunter, 1982; Houde, 1987; Goshorn and Epifanio, 1991; Pepin and Myers, 1991), and this variability remains one of the least understood and quantified questions in fisheries

science (Cushing, 1994; Mertz and Myers, 1995). Early mortality can be significantly influenced by changes in larval fish growth rates which can change the duration of the vulnerable larval stage and alter the length of time that larvae are exposed to the accumulative effects of the high predation rates that are frequently experienced by many small plankters (Houde, 1987; Anderson, 1988; Bailey and Houde, 1989). Pepin (1991) formalized this concept by depicting the cumulative mortality (C) of a population from stage (a) to older stage (b) as the direct function of the growth ($g[x]$) and mortality ($M[x]$) rates such that

$$C = \int_a^b \frac{M[x]}{g[x]} dx$$

where x are factors that influence the vital rates such as food availability, temperature, and abundance of potential predators. It has been hypothesized that even subtle variations in growth rates of larvae can cause order of magnitude differences in the cumulative larval/juvenile survival (Laurence, 1979; Houde, 1987). The investigation of the variability in growth and the factors that can influence growth rate, either temporally or spatially such as temperature or food availability, will always remain fundamentally important in any attempt to partition the sources of variability in recruitment to adult populations.

METHODS AND MATERIALS

Sampling Location and Shipboard Procedures

Vermilion snapper and Atlantic bumper larvae were collected in the northcentral Gulf during September 1991 and 1992 (Figure 2.1), and additional

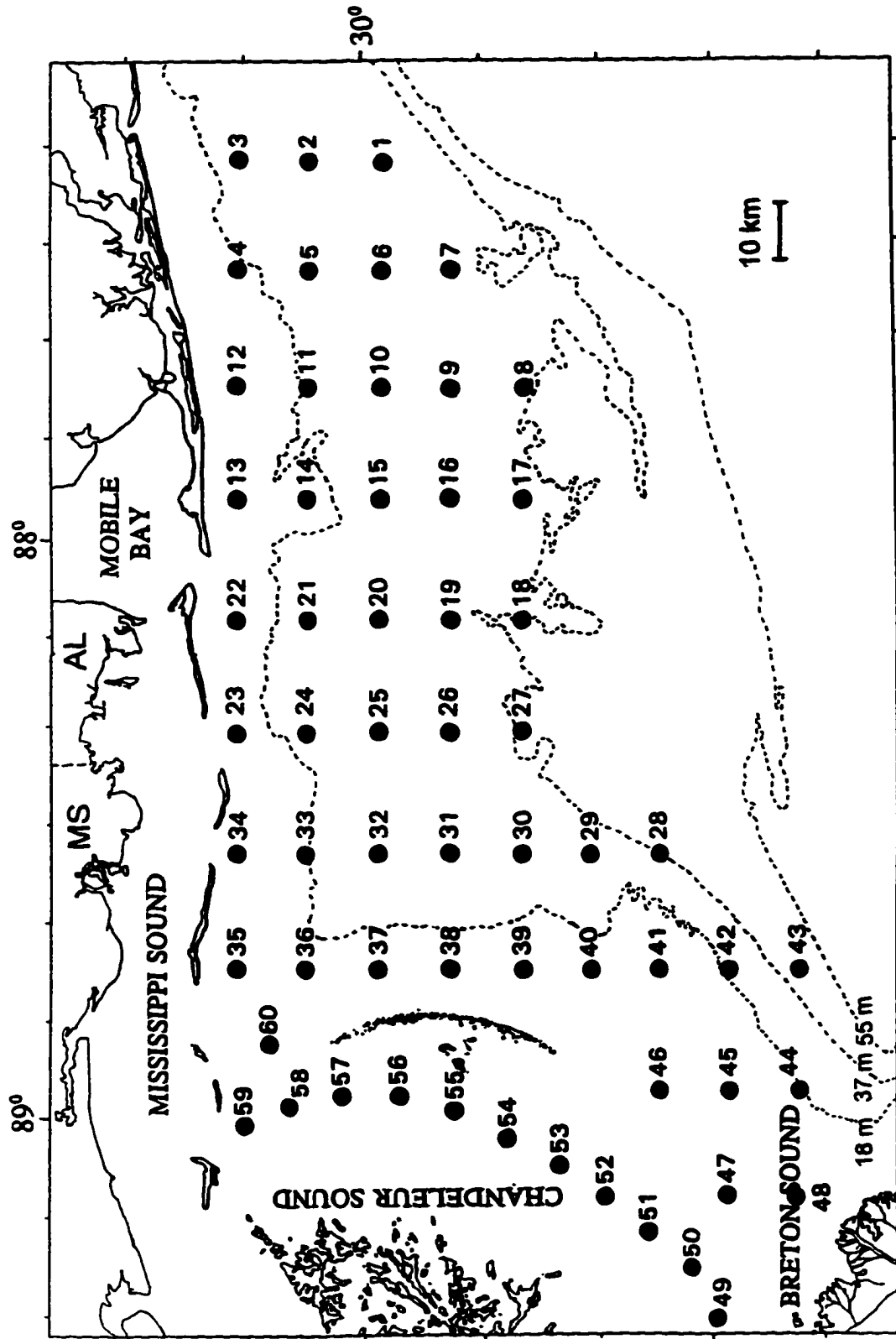


Figure 2.1. Station locations in the northcentral Gulf of Mexico , September 1991 and 1992 cruises.

samples of vermilion snapper larvae were collected in May and August 1992 (Figure 2.2). Larvae were collected with a Tucker trawl (1m x 1.4m) fitted with a 333 μm mesh nitex net and a mechanical flowmeter (General Oceanics) to measure water volume filtered. The net was fished obliquely from the surface to within a few meters above the bottom and back to the surface at a towing speed of approximately two knots (1.0 m/s). Samples were drained of seawater and stored in 95% ethanol. At each sampling location surface, midwater, and bottom water samples were obtained with water-bottle casts. Measurements of temperature and salinity were made at each depth, while water samples for chlorophyll *a* determinations were taken only at the surface.

Laboratory Procedures

Macrozooplankton dry-weights for biomass or standing stock estimates ($\text{g}/100 \text{ m}^3$) were determined by removing fish larvae and large conspicuous plankters (i.e., jellyfish fragments) from plankton collections which were then rinsed in freshwater, dried at 60°C for $>2 \text{ d}$, and weighed to the nearest milligram. It was determined that a drying time of 2 d was needed to fully dehydrate plankton collections (Figure 2.3). Adult copepods were counted from aliquots containing at least 2000 individuals. Collections were split using a Matoda plankton splitter, and the smallest fraction of a plankton collection used was a $1/32$ aliquot. Densities of adult copepods were expressed as numbers per m^3 . Copepods were the only taxa that were enumerated from plankton collections because they were by far the dominant group of zooplankters, and because copepod nauplii are a primary prey item for many fish larvae (Duka

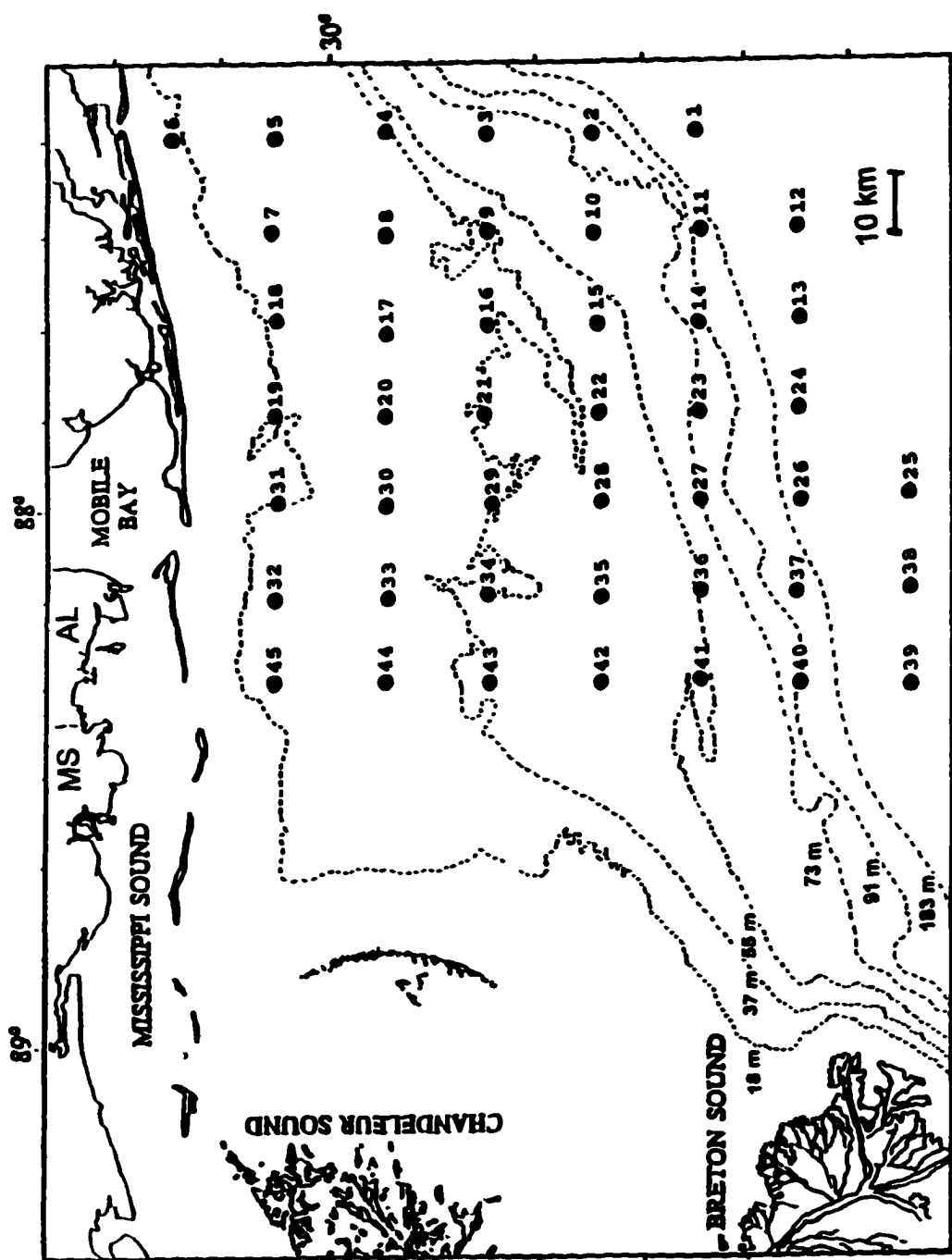


Figure 2.2. Station locations in the northcentral Gulf of Mexico, May and August 1992 cruises.

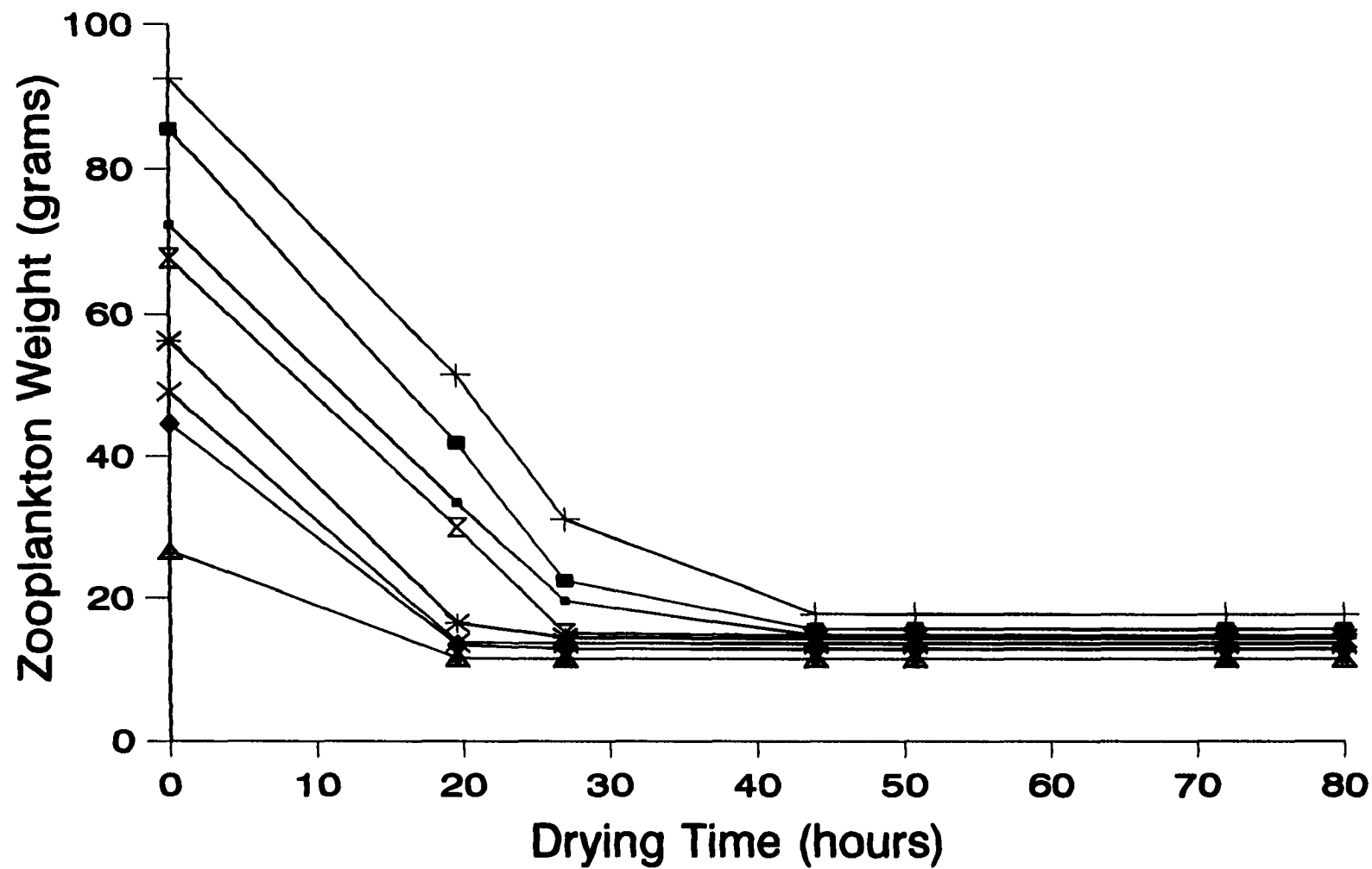


Figure 2.3. Relationship between wet weight and drying time necessary to reach a stable dry weight for eight plankton samples (each represented by a different symbol).

and Gordina, 1973). Chlorophyll *a* concentrations (mgm^{-3}) were determined in the laboratory using standard methodology involving spectrophotometric analyses (Strickland and Parsons, 1972; Jeffrey and Humphrey, 1975).

Lengths of larvae were measured to the nearest 0.1 mm using a stereomicroscope (12 X or 25 X) fitted with an ocular micrometer. Measurements were taken from the tip of the snout to the end of the notochord in pre-flexion larvae (notochord length), and from the tip of the snout to the end of the urostyle or hypural plate (whichever was more distal) in flexion or post-flexion larvae (standard length). It was not necessary to account for larval shrinkage because between-station and between-cruise comparisons of growth rates were made with larvae that were handled the same way. Station densities for larvae, expressed as numbers of larvae under 10 m^2 of sea surface, were determined by dividing the number of larvae collected at a station by the volume of water filtered, and then multiplying this number by $10 \times$ the depth fished.

To determine dry weights of larvae, specimens were rinsed with distilled water, dried for 24 h at 60°C , and weighed to the nearest $0.1\mu\text{g}$. For subsequent otolith analysis, dried larvae were soaked in water for 12 h to soften body tissues, and both sagittal otoliths were removed (using polarized light) and mounted convex side up on a glass microscope slide with a drop of Pro-Texx mounting medium and a cover slip. Otolith growth increments were observed in the sagittal plane under oil immersion (1250X).

Data Analysis

A total of 225 vermilion snapper larvae and 137 Atlantic bumper larvae were used for age and growth analyses. Specimens were selected from stations at which a wide size range of larvae were collected; for each of these stations approximately 3 to 4 larvae were selected for each size interval using the criteria that the larvae be undamaged and relatively uncoiled. Otolith growth increments were counted using the right or left sagitta that provided the most distinct incremental zones as a paired *t*-test showed no significant difference ($P \leq 0.05$) in diameters of left and right sagittae in both vermilion snapper ($n=11$) and Atlantic bumper ($n=20$). Daily increments were counted along the longest axis of the otolith from the core to the outer edge. Otoliths were read once by a single reader, and a random subsample of otoliths from vermilion snapper ($n=30$) and Atlantic bumper ($n=30$) were read a second time to examine within-reader variability. Otolith increment counts differed by one day for only two of the 30 otoliths during the second reading for both species.

Age-length and age-weight relationships were described using the exponential equation $L \text{ or } W = \exp(a + bt)$, where, in its linearized form, L = notochord or standard length in mm, W = dry weight in mg, a = Y-intercept, b = slope of regression line (instantaneous growth rate), and t = age of larvae in days. The Y-intercept of the age-length regression corresponds to the larval length at time zero, i.e., the hatching length. Because observed Y-intercepts were similar to known hatching lengths (corrected for ethanol-induced shrinkage) for both vermilion snapper and Atlantic bumper, it was not

necessary to artificially force the Y-intercepts through the point of known hatching length. Values of a and b were calculated from the linearized form of the growth equation after the length or weight data were transformed to their natural logarithms. The instantaneous growth rate (b), i.e., the slope of the log transformed age-length or age-weight relationship, is also referred to as the growth coefficient.

To maximize the probability of finding a statistically significant difference between station estimates of larval growth rates, instantaneous growth coefficients were compared between stations at which the highest and lowest growth coefficients were found with a t -test for equality of regression coefficients (Zar, 1984). Simple regression analyses and associated estimates of power (SigmaStat, 1995) were first used to examine possible correlations between the magnitude of the growth coefficients and individual values for several independent variables such as adult copepod densities, surface chlorophyll a levels, and macrozooplankton biomass. A Pearson product-moment correlation analysis was used to examine possible correlations between the independent variables and growth rate estimates but no significant correlations were found. A stepwise multiple regression was then used to reduce the errors of prediction and to account for more of the variance of the dependent variable (i.e., the growth coefficients).

The extent of spatial patchiness for surface chlorophyll a concentrations (mg/m^3), station estimates of macrozooplankton standing stock ($\text{g dry weight}/100\text{m}^3$), densities of adult copepods, and station densities of fish larvae,

were made using the following Morisita's (1962) index of dispersion (I_d):

$$I_d = \frac{\sum [x(x-1)]}{n \sum x(\sum x - 1)}$$

x = station concentration or density.
Values >1 indicate aggregation or patchiness.

Departures from randomness were judged significant ($P < 0.05$) when:

$I_d(\sum x - 1) + n - \sum x$ was outside the appropriate significance levels of χ^2 for $n-1$ degrees of freedom.

RESULTS

Macrozooplankton Biomass

Dry-weight estimates of macrozooplankton standing stock during the 14-16 September and 21-23 September 1991 cruises ranged from 0.8 to 17.1 g/100 m³. The spatial distribution of macrozooplankton biomass was quite variable during the first survey, although station estimates greater than 5g/100 m³ were generally located in waters shallower than 18 m, and estimates less than 3 g/100 m³ were commonly found at stations located between the 18 m and 37 m isobaths (Figure 2.4). The highest station estimates of macrozooplankton biomass during the second survey were found in the northern portion of Chandeleur Sound (e.g., the three most northern stations had dry-weight values exceeding 10 g/100 m³). Dry-weight estimates of macrozooplankton standing stock at stations outside Chandeleur and Breton Sounds were lower, and only 4 of the 36 stations sampled had values exceeding 3 g/100 m³. Estimates of macrozooplankton standing stock were patchily distributed for both 1991 cruises (e.g. values of I_d were 1.4 and 1.8, $P < 0.05$).

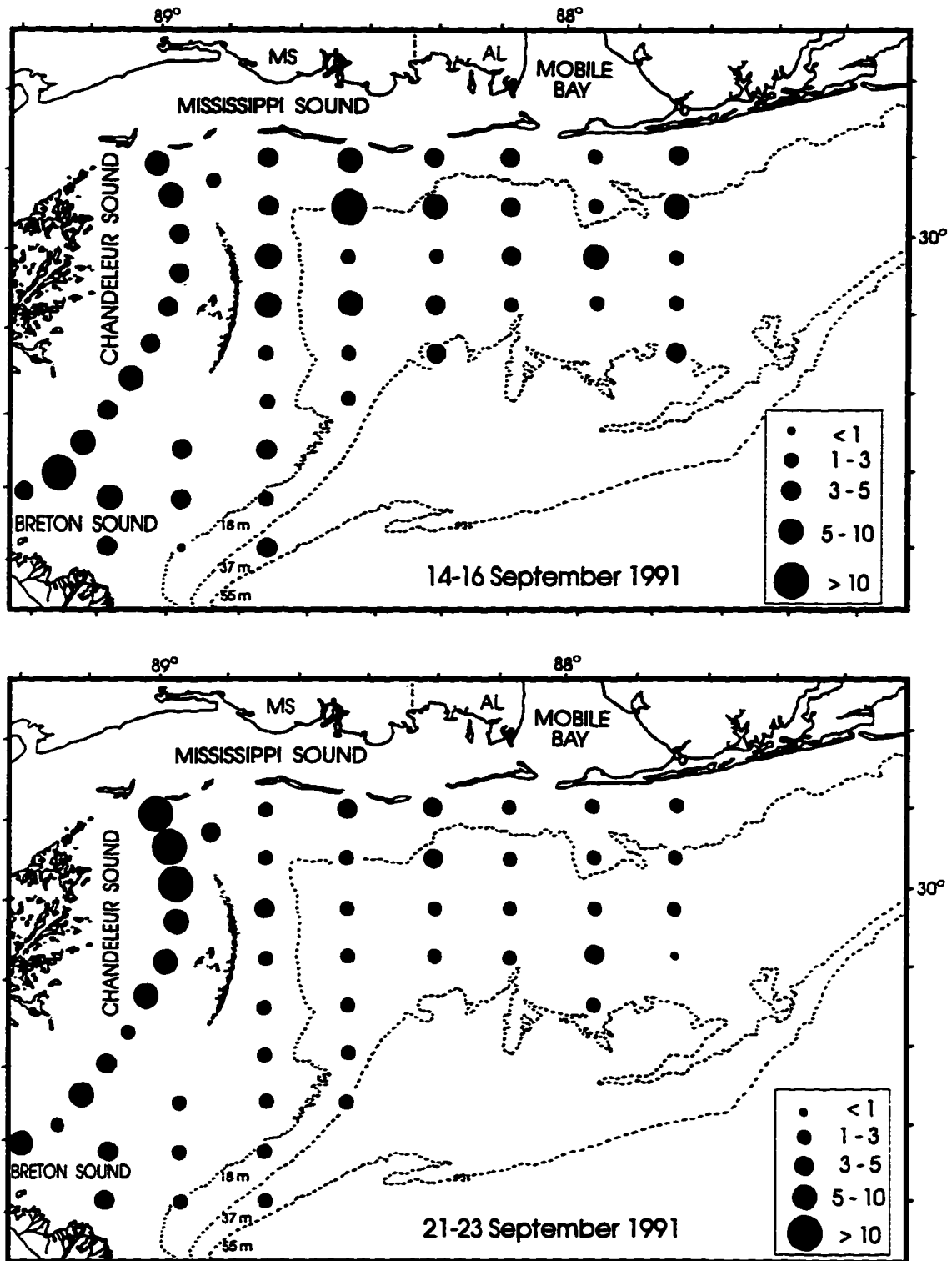


Figure 2.4. Estimates of macrozooplankton dry-weight standing stock (g/100m³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1991.

Dry-weight estimates of macrozooplankton biomass for 13-19 September 1992 were relatively low and ranged from 0.4 to 3.6 g/100 m³ (Figure 2.5). No stations were sampled within Chandeleur or Breton Sounds during this cruise. The spatial pattern of macrozooplankton biomass during the September 27-29 cruise was also low (Figure 2.5). Only 5 of 50 stations had estimates exceeding 3 g/100 m³, and these stations were located in water shallower than 18 m. Although values of I_δ were only slightly greater than one for the two 1992 cruises ($I_\delta = 1.1$ and 1.2), departures from randomness for the station estimates of macrozooplankton biomass were judged significant ($P < 0.05$).

Copepod Abundance

Abundances of adult copepods were determined for 16 station collections taken during 14-16 September, 1991. It was from these stations that intra-specific comparisons of growth rates for vermilion snapper and Atlantic bumper larvae were made. Station estimates of copepod abundance were highly variable (e.g., $I_\delta = 2.3$, $P < 0.05$), and ranged from 105 to 2906 copepod/m³.

Surface Chlorophyll a

Concentrations of surface chlorophyll *a* between 14-16 September and 21-23 September 1991, ranged from 0.12 to 10.31 mg/m³. Highest concentrations of surface chlorophyll *a* (≥ 3 mg/m³) were found at most stations within Chandeleur and Breton Sounds (Figure 2.6). Concentrations between 1-3 mg/m³ were found during both cruises at several nearshore stations off

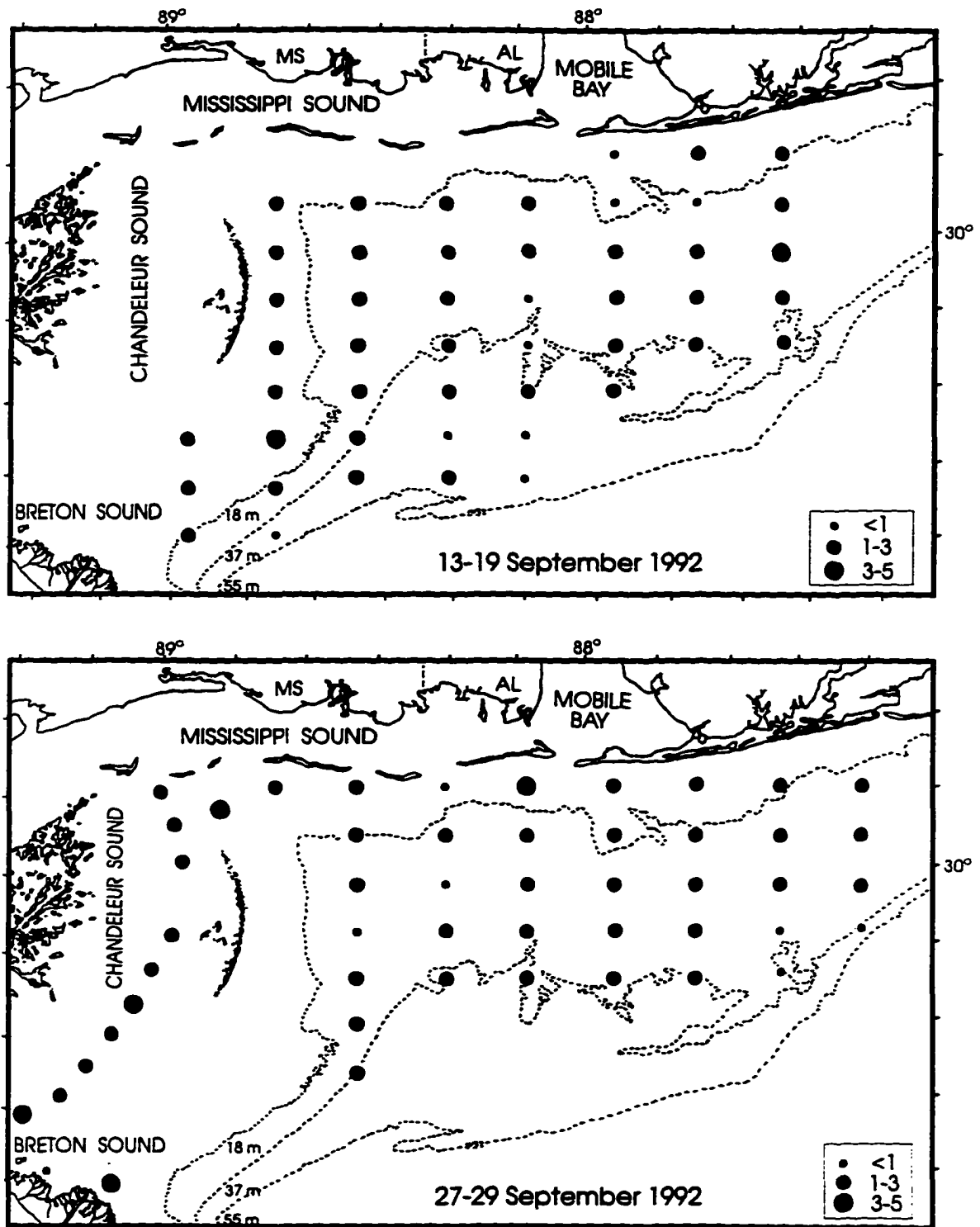


Figure 2.5. Estimates of macrozooplankton dry-weight standing stock (g/100m³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1992.

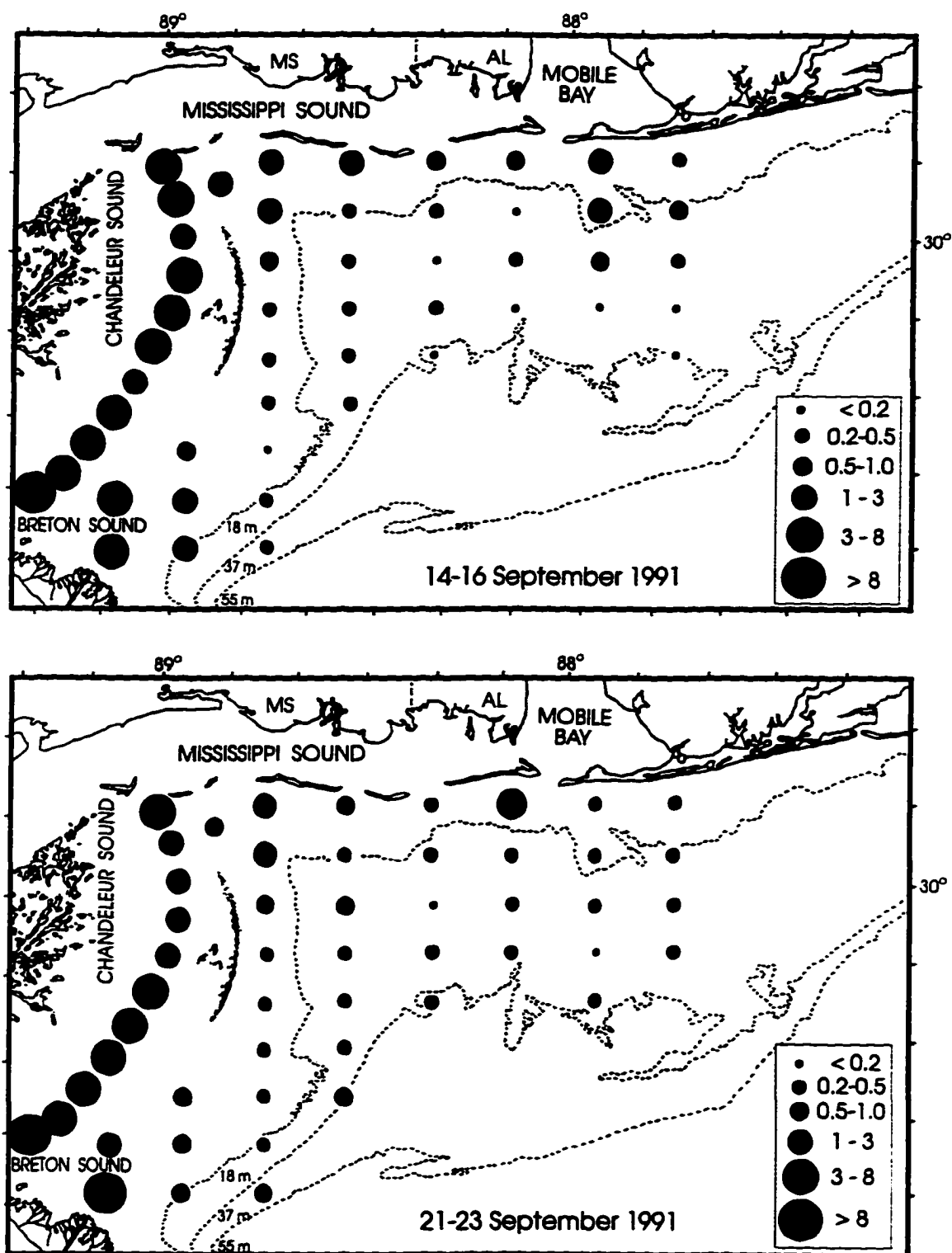


Figure 2.6. Surface chlorophyll *a* concentrations (mg/m³) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1991.

Mississippi and Alabama, and lowest concentrations were found at mid-shelf stations. Morisita's index of dispersion indicated a relatively high degree of aggregation or patchiness for surface chlorophyll *a* during both cruises ($I_d = 2.5$ and 3.5 , $P < 0.05$).

The Chlorophyll *a* concentrations found during the two September cruises of 1992 were generally higher than in 1991. During the first 1992 survey no stations were sampled within Chandeleur or Breton Sounds. The only two stations with surface chlorophyll *a* concentrations greater than 3 mg/m^3 were nearshore stations immediately south of Mobile Bay (Figure 2.7).

Chlorophyll *a* levels at most innershelf stations (18 m - 37 m isobaths) ranged from $1\text{-}3 \text{ mg/m}^3$, and the lowest levels ($< 0.2 \text{ mg/m}^3$) were found at several offshore stations (37 m - 55 m isobaths). During the second 1992 cruise, highest chlorophyll *a* concentrations were found within Chandeleur and Breton Sounds, and at nearshore stations ($\leq 18\text{m}$) just south of Mississippi and Alabama (Figure 2.7). Levels of chlorophyll *a* exceeding 3 mg/m^3 were found at 12 of the 13 stations within Chandeleur and Breton Sounds, and at two stations in Breton Sound levels exceeded 8 mg/m^3 . Levels at innershelf stations (18 m - 37 m) generally ranged from $0.2\text{-}1.0 \text{ mg/m}^3$, but at the most offshore station along the easternmost transect the chlorophyll *a* concentration reached 3.0 mg/m^3 . A moderate degree of patchiness for chlorophyll *a* was found during both cruises ($I_d = 1.5$ and 1.9 , $P < 0.05$).

Vermilion Snapper

Summaries of age/length/dry-weight data for vermilion snapper larvae are listed in Appendices P and Q. Vermilion snapper larvae ranged from 4 to

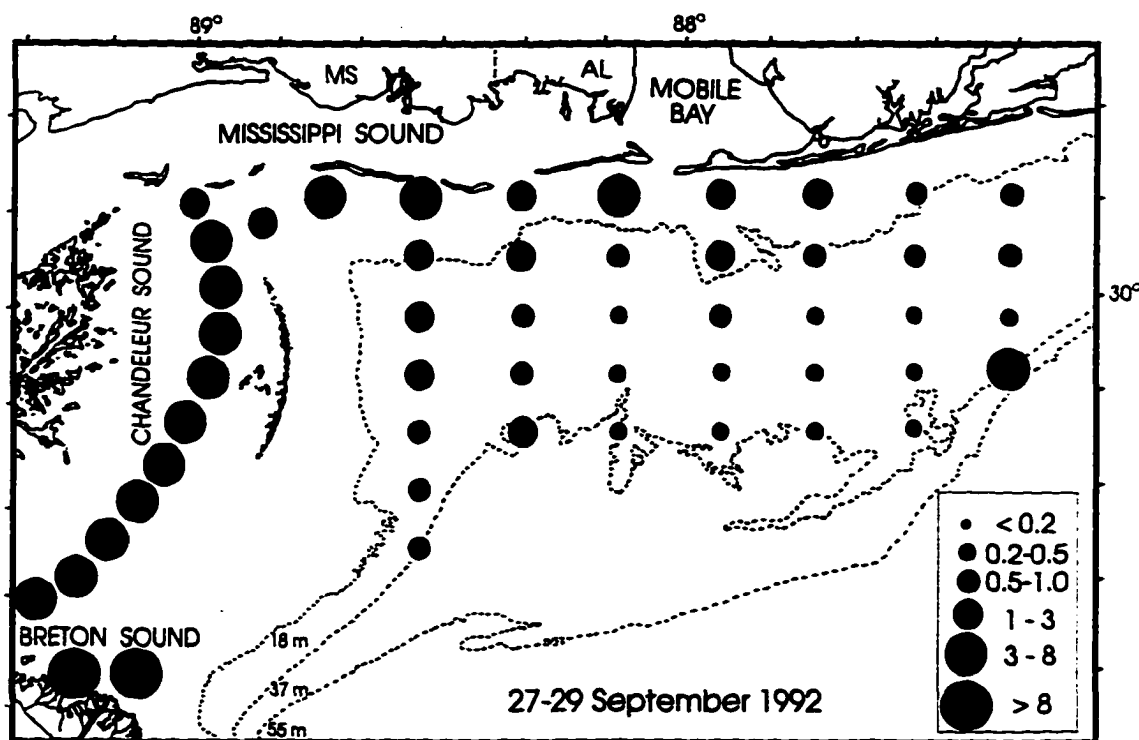
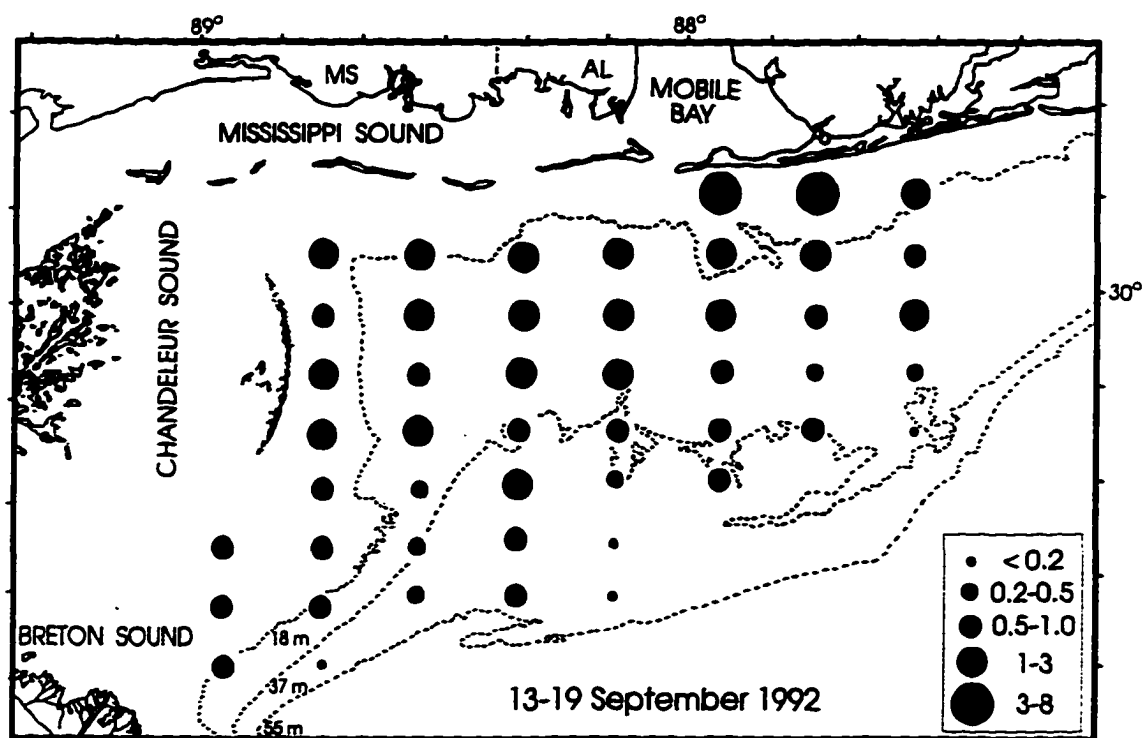


Figure 2.7. Surface chlorophyll a concentrations (mg/m^3) at locations in the northcentral Gulf of Mexico during two plankton surveys in September 1992.

16-d-old, and lengths and dry weights of larvae ranged from 2.5 mm to 6.5 mm, and 0.014 mg to 0.696 mg, respectively. Sagittal otoliths of the smallest larvae were saucer shaped and spherical when viewed in the sagittal plane, and were approximately 0.02 mm in diameter. Otoliths of the largest larvae were slightly oval when viewed in the sagittal plane, and were approximately 0.2 mm in diameter. Growth increments appeared as distinct concentric circles surrounding the core. A scatterplot of otolith increment number (in relation to the otolith core) and corresponding increment width for 101 vermilion snapper larvae showed a steady increase in increment width with increasing distance from the core (Figure 2.8). The steady nature of this increase in increment widths further supports the probability that the periodicity of otolith increment formation was consistent.

Growth rates of vermilion snapper larvae were found to vary with differences in both water temperature and collection location. The greatest difference in water temperature was found between collections taken in May and August 1992. In May, water temperatures ranged between 24° and 25°C, while in August at the same stations, the temperature range had increased from 29°C to 30°C. A *t*-test for equality of regression coefficients (Zar, 1984) showed that growth rates of vermilion snapper larvae were significantly slower ($p < 0.05$) at the cooler temperatures in May (0.3 mm/d) than in August (0.5 mm/d; Figure 2.9). In August vermilion snapper reached a size of 8 mm in approximately 16 d, whereas at the cooler temperatures in May, an 8 mm larva was approximately 22-d-old. Vermilion snapper larvae also gained weight faster at

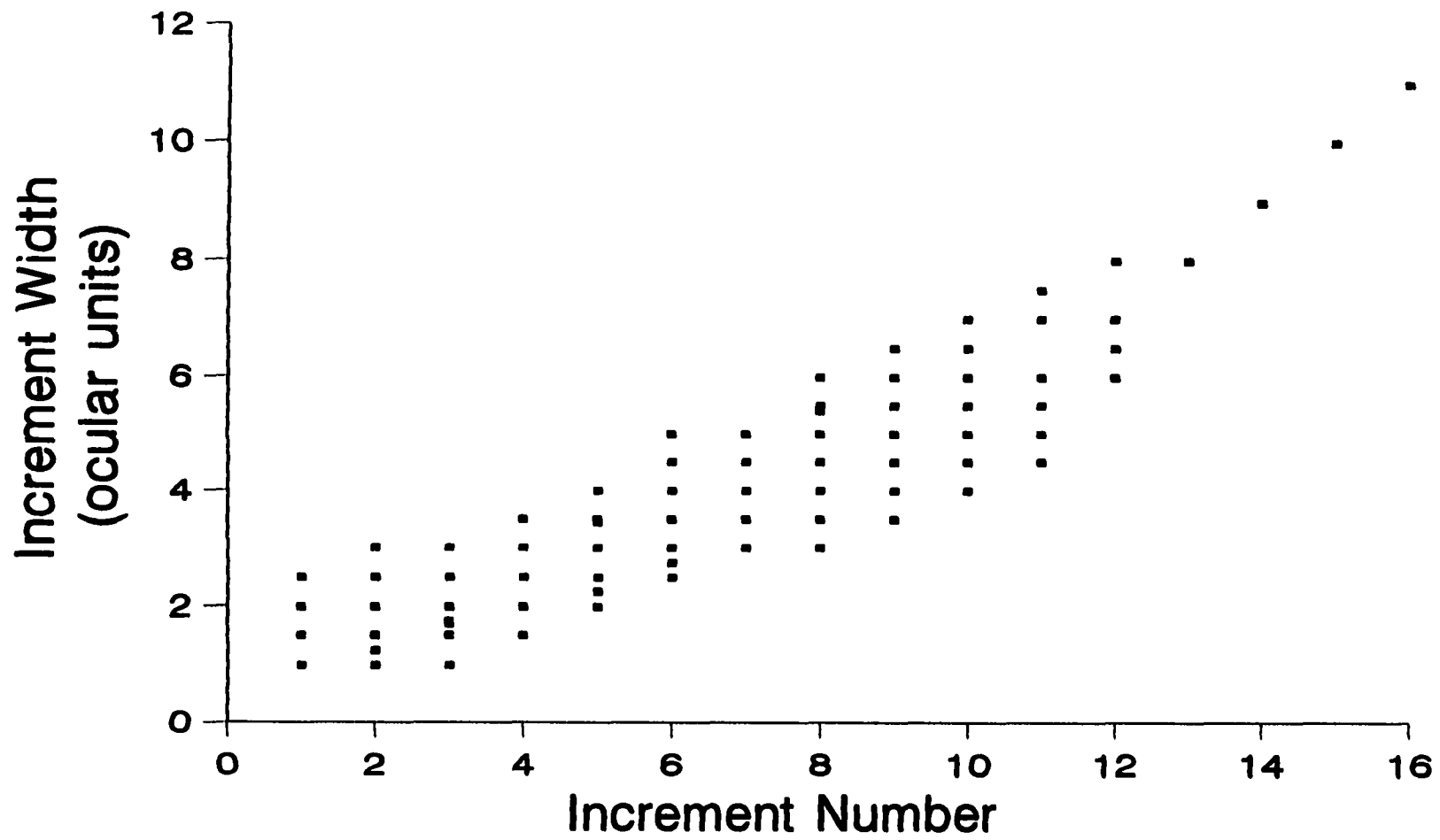


Figure 2.8. Scatterplot of otolith increment widths and increment numbers for 101 vermilion snapper larvae collected during 27-29 September 1992. The increment number refers to the position of the increment in relation to the core of the otolith.

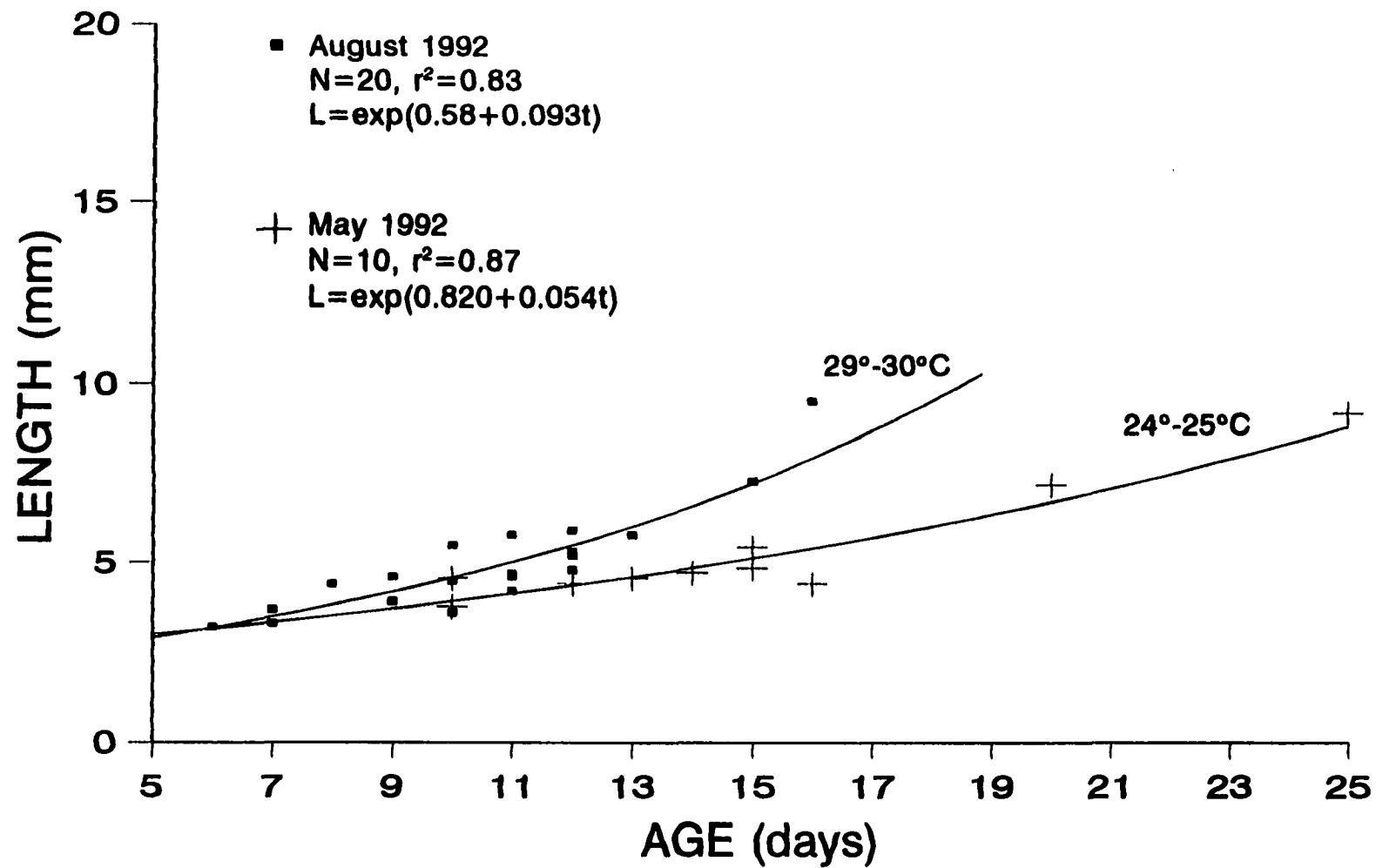


Figure 2.9. Relationship between age and length for larval vermillion snapper collected in the northcentral Gulf of Mexico in May and August 1992. L = notochord or standard length in mm; t = larval age in days. Slopes of regression lines are significantly different ($p \leq 0.05$).

the warmer temperatures. A 13-d-old larva in August weighed approximately the same (0.5 mg dry-weight) as a 17-d-old larva collected in May which reflects the extended stage duration associated with the 5°C temperature differential (Figure 2.10). It is unlikely that food availability caused the faster growth rates in August because macrozooplankton biomass was lower in August ($\bar{x}=2.34$ g/100m³) than in May ($\bar{x}=4.41$). It is possible, however, that factors other than temperature also affected larval growth rates; surface chlorophyll *a* concentrations were higher in August ($\bar{x}=0.50$ mg/m³) than in May ($\bar{x}=0.23$), and surface salinities were lower in August ($\bar{x}=30.2\text{‰}$) than in May ($\bar{x}=33.5\text{‰}$).

The overall age/length regression of vermilion snapper larvae collected from 14-15 September 1991 (Figure 2.11) had a coefficient of determination (r^2) of 0.84, but some of this unaccounted variability in the age/length model resulted from pooling together age-length data from seven different locations (Figure 2.12). When age/length models were examined for each of the seven individual stations, the r^2 values increased dramatically and ranged from 0.90 to 0.97 (Table 2.1). To further demonstrate the station-specificity of larval growth rates, r^2 values (marked with asterisk in Table 2.1) were also determined for each station with a data set in which the actual age composition of larvae collected at a station was maintained, but larval lengths were randomly selected for same-aged larvae from the pooled data set ($n=89$) of all seven stations. This procedure was repeated ten times and reported r^{2*} estimates are mean values. These r^{2*} estimates for the age/length regressions of the constructed

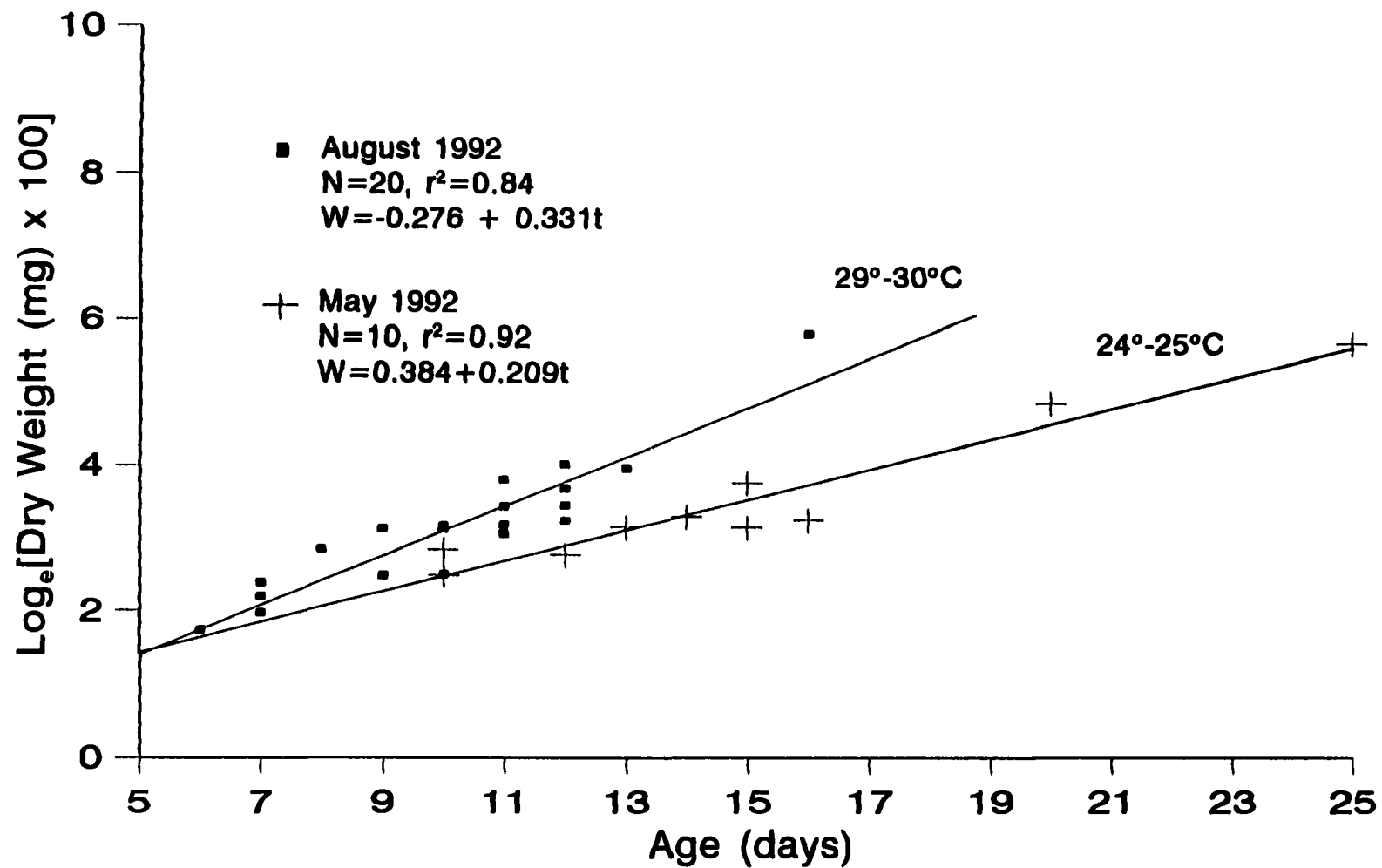


Figure 2.10. Relationship between age and dry-weight for vermilion snapper larvae collected in the northcentral Gulf of Mexico in May and August 1992. $W=\log_e[\text{dry-weight (mg)} \times 100]$; t =larval age in days. Slopes of regression lines are significantly different ($p \leq 0.01$).

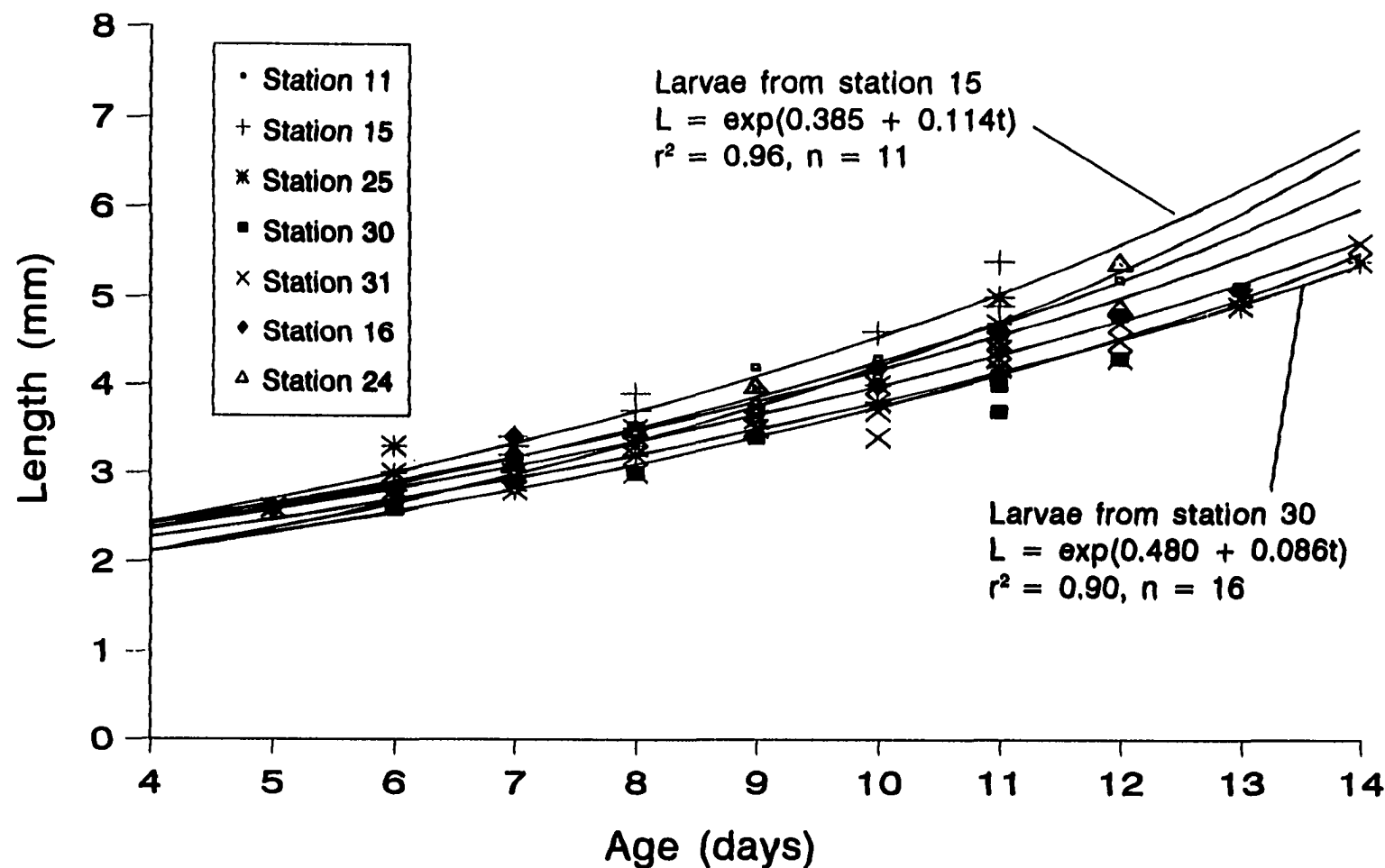


Figure 2.12. Age/length data for vermillion snapper larvae ($n=89$; same data set as summarized in Fig. 2.11) only plotted for the 7 individual stations in the northcentral Gulf of Mexico during the 14-16 September 1991 cruise. L = notochord or standard length in mm; t = larval age in days.

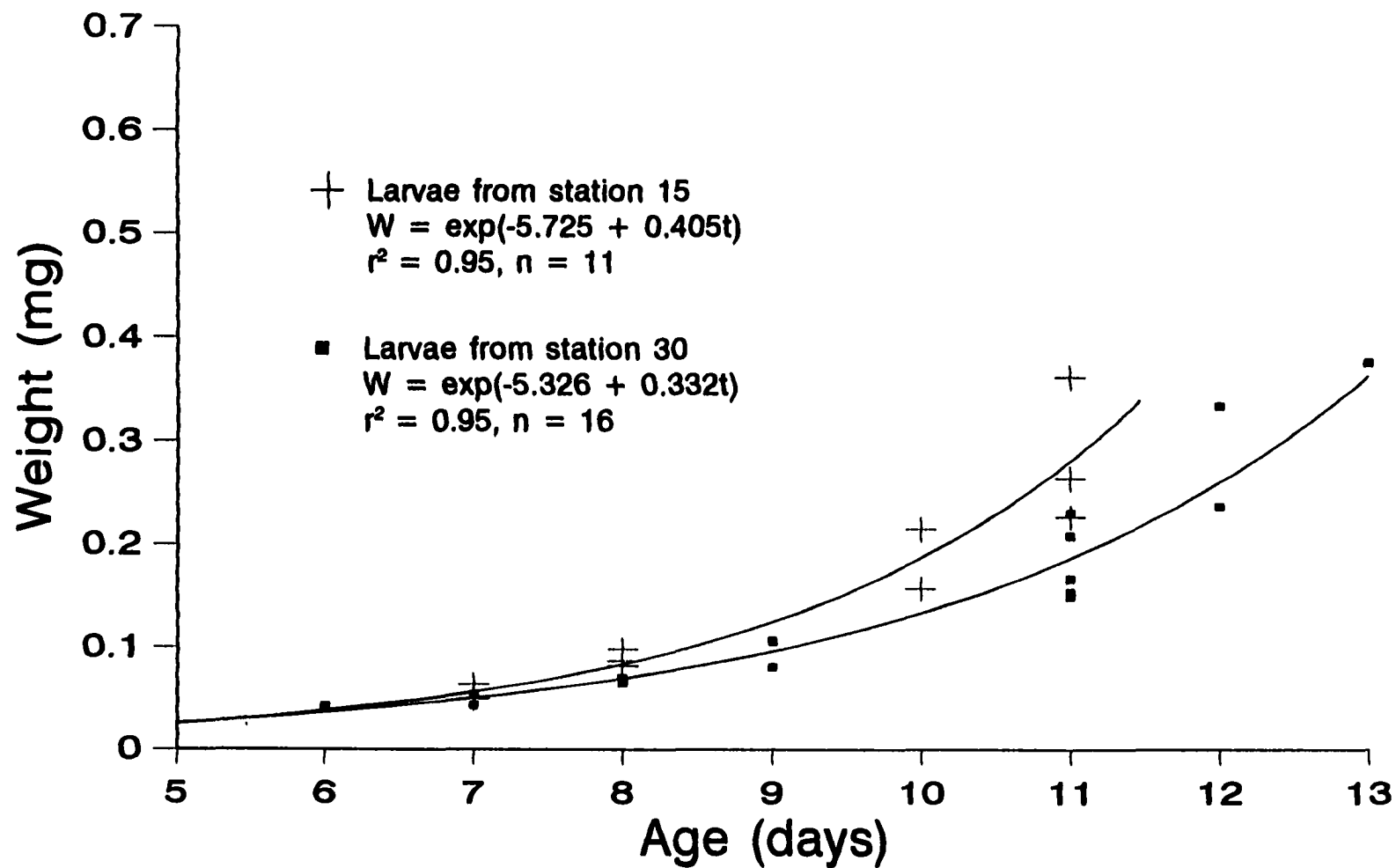


Figure 2.13. Relationship between age and dry weight for larval vermilion snapper collected at stations 15 and 30 (see Fig. 2.1) in the northcentral Gulf of Mexico during 14-15 September 1991. W = dry weight in mg; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).

Table 2.1. Slopes of age/length regressions and corresponding coefficients of determination (r^2) for vermillion snapper larvae collected at seven stations in the northcentral Gulf of Mexico during 14-16 September 1991. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected for same-aged larvae from the pooled data set ($n=89$) of all seven stations combined.

Station No.	Slope of Age/Length Regression	r^2	$r^2 *$	Sample Size
11	0.112	0.92	0.81*	11
15	0.114	0.96	0.82*	11
16	0.090	0.96	0.88*	8
24	0.098	0.97	0.90*	5
25	0.087	0.91	0.88*	23
30	0.086	0.90	0.85*	16
31	0.095	0.96	0.87*	15

data sets consistently decreased at each station (Table 2.1), showing that a tighter age/length relationship existed at the individual station level than at the cruise level, where data from all stations were pooled together. Water temperatures at these seven locations where vermilion snapper larvae were collected were similar.

The largest difference in age/length growth coefficients was found between vermilion snapper larvae collected at inner-shelf (18-37 m depth) stations 15 and 30 approximately 50 km apart (Figure 2.12; Table 2.1). Slopes of the age/length relationships at these two stations were significantly different ($P < 0.05$). Based on their respective growth equations, vermilion snapper larvae collected at station 15 grew to a length of 5 mm in 10.7 d, whereas larvae collected at station 30 larvae did not reach a length of 5 mm until 13.1 d. Differences in age/dry-weight coefficients were also significantly different for larvae collected at these two stations ($P < 0.05$, Figure 2.13). Vermilion snapper larvae gained weight faster at station 15 where an 11.0 d-old larvae had an estimated dry weight of 0.28 mg, whereas at station 30 its estimated dry weight was only 0.18 mg. It must be emphasized that larvae were transported by water currents and consequently did not grow up at the exact location where they were collected.

Differences in growth rates of vermilion snapper larvae over relatively small spatial scales were also found during the 27-29 September 1992 cruise. A total of 148 snapper larvae, collected from 10 stations, were used for age/growth analyses. Station specificity of larval growth rates was again

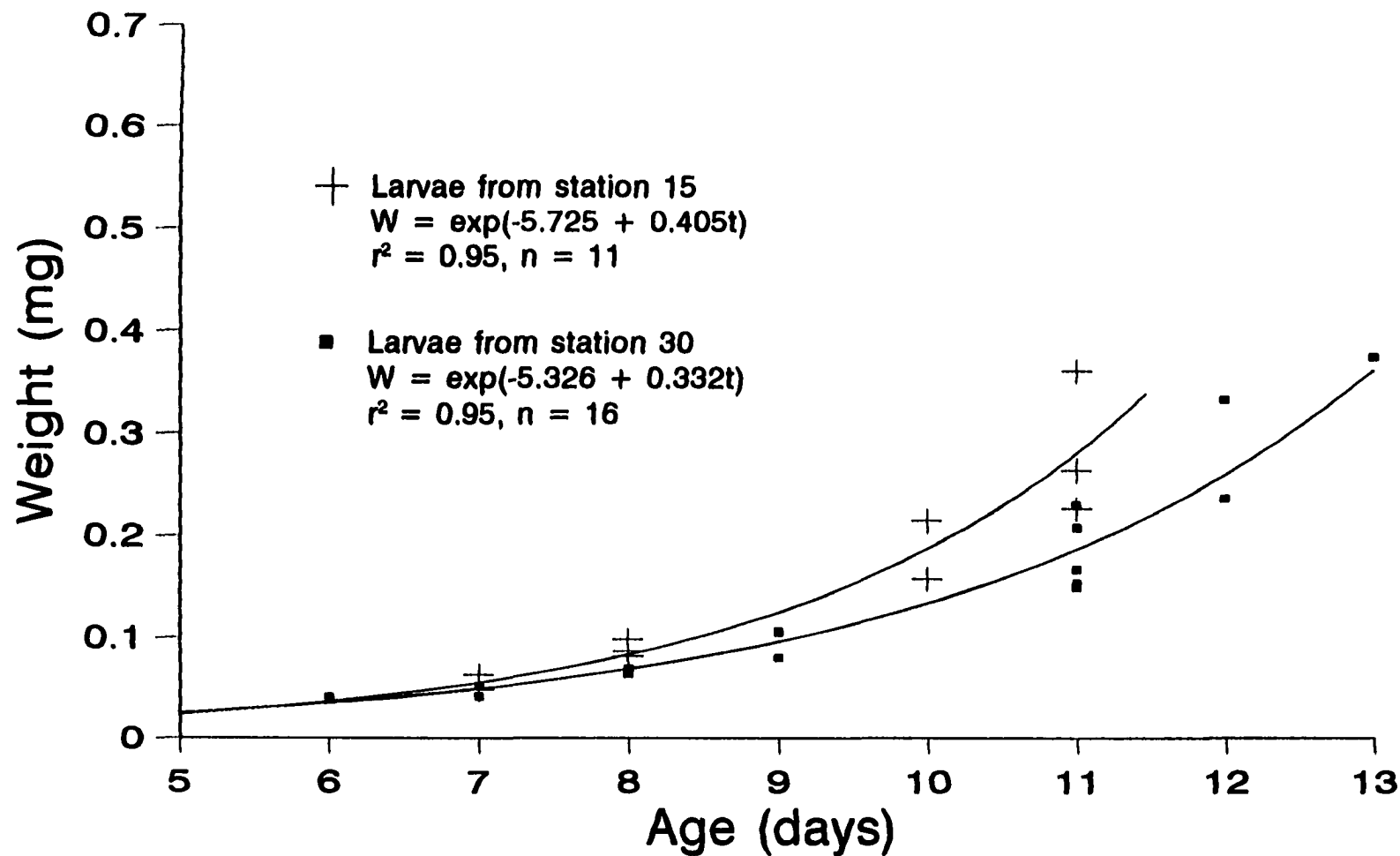


Figure 2.13. Relationship between age and dry weight for larval vermilion snapper collected at stations 15 and 30 (see Fig. 2.1) in the northcentral Gulf of Mexico during 14-15 September 1991. W = dry weight in mg; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).

evidenced by the decreased r^2 values of regressions from constructed age/length data sets at each station, when station age-frequencies were maintained and larval lengths were randomly selected for same-aged larvae from the pooled data set ($n=136$) of all 10 stations (Table 2.2). Differences in larval age/length relationships were particularly evident at stations 13 and 17 (Figure 2.14). Based on the age/length growth coefficients which were significantly different ($P<0.05$), the age of a 5 mm larva collected at station 13 was 14.1 d and at station 17 only 12.0 d old. Age/dry-weight relationships of larvae collected at these two stations were also significantly different ($P<0.01$; Figure 2.15). Vermilion snapper larvae collected at station 17 gained weight faster and by 12 d the estimated dry weight of a larva was 0.25 mg, whereas at station 13 it was only 0.19 mg.

Larval growth rates are primarily influenced by water temperature and food availability. Water temperatures within a cruise were quite similar and at stations where differences in larval growth rates were found, the differences in temperature were $<2^{\circ}\text{C}$. Therefore, these observed differences in larval growth rates were probably caused by differences in availability of suitable prey, although it is also possible that apparent differences in larval growth rates were affected by size-selective mortality. Small zooplankters eaten by larval fish were not quantifiably retained in the $333\mu\text{m}$ mesh plankton nets. Consequently it was only possible to examine indirect factors that may be correlated with small-scale differences in larval growth rates such as station estimates of

Table 2.2. Slopes of age/length regressions and corresponding coefficients of determination (r^2) for vermillion snapper larvae collected at ten stations in the northcentral Gulf of Mexico during 27-29 September 1992. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected for same-aged larvae from the pooled data set ($n=136$) of all ten stations combined.

Station No.	Slope of Age/Length Regression	r^2	$r^2 *$	Sample Size
3	0.092	0.81	0.78*	11
4	0.071	0.93	0.79*	6
12	0.081	0.91	0.81*	14
13	0.075	0.90	0.75*	23
15	0.094	0.82	0.83*	7
17	0.103	0.90	0.79*	17
28	0.068	0.90	0.89*	11
29	0.083	0.98	0.95*	12
31	0.087	0.90	0.82*	25
33	0.084	0.84	0.80*	10

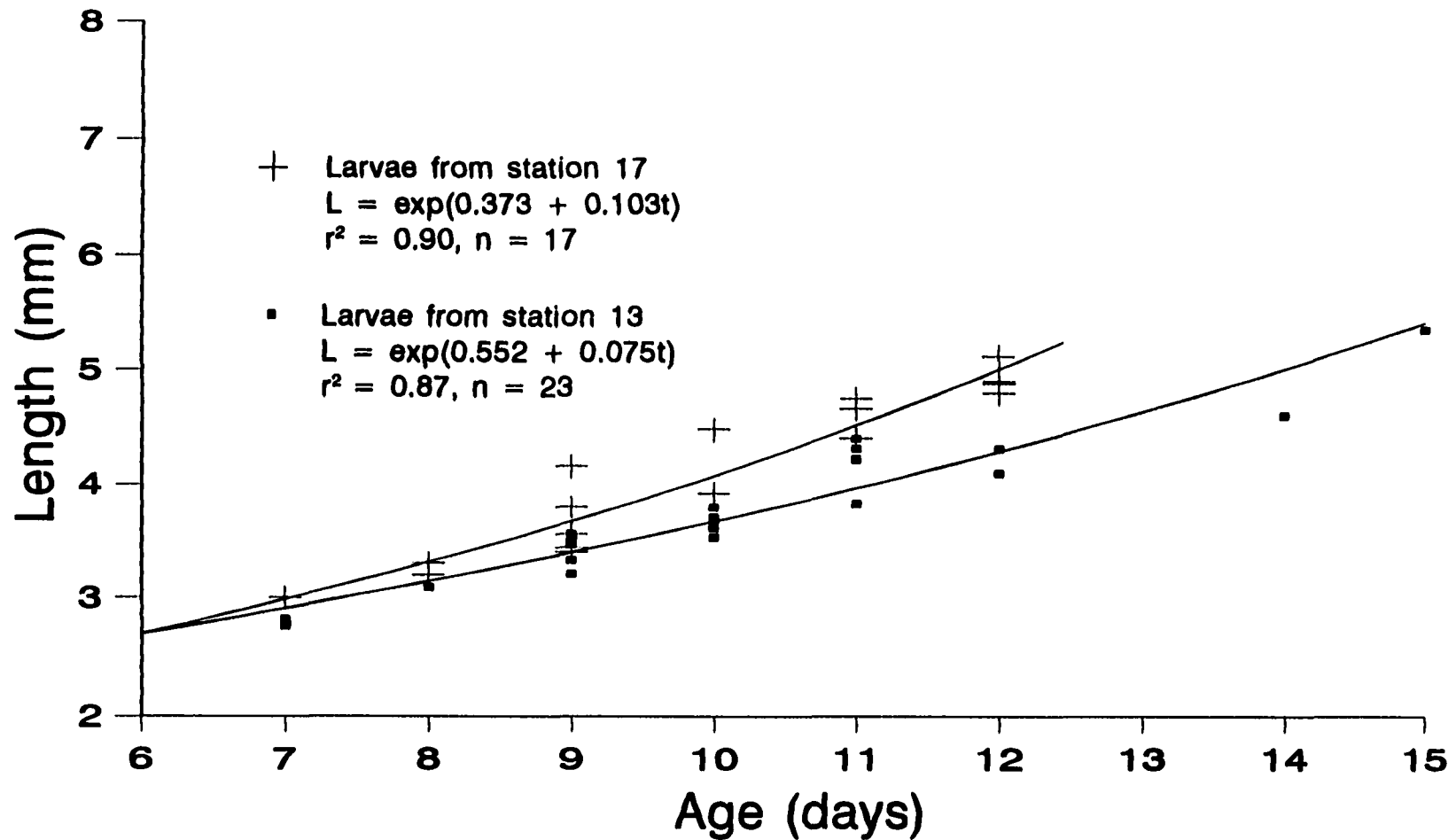


Figure 2.14. Relationship between age and length for larval vermilion snapper collected at stations 13 and 17 (see Fig.2.1) in the northcentral Gulf of Mexico during 27-29 September 1992. L = notochord or standard length in mm; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.05$).

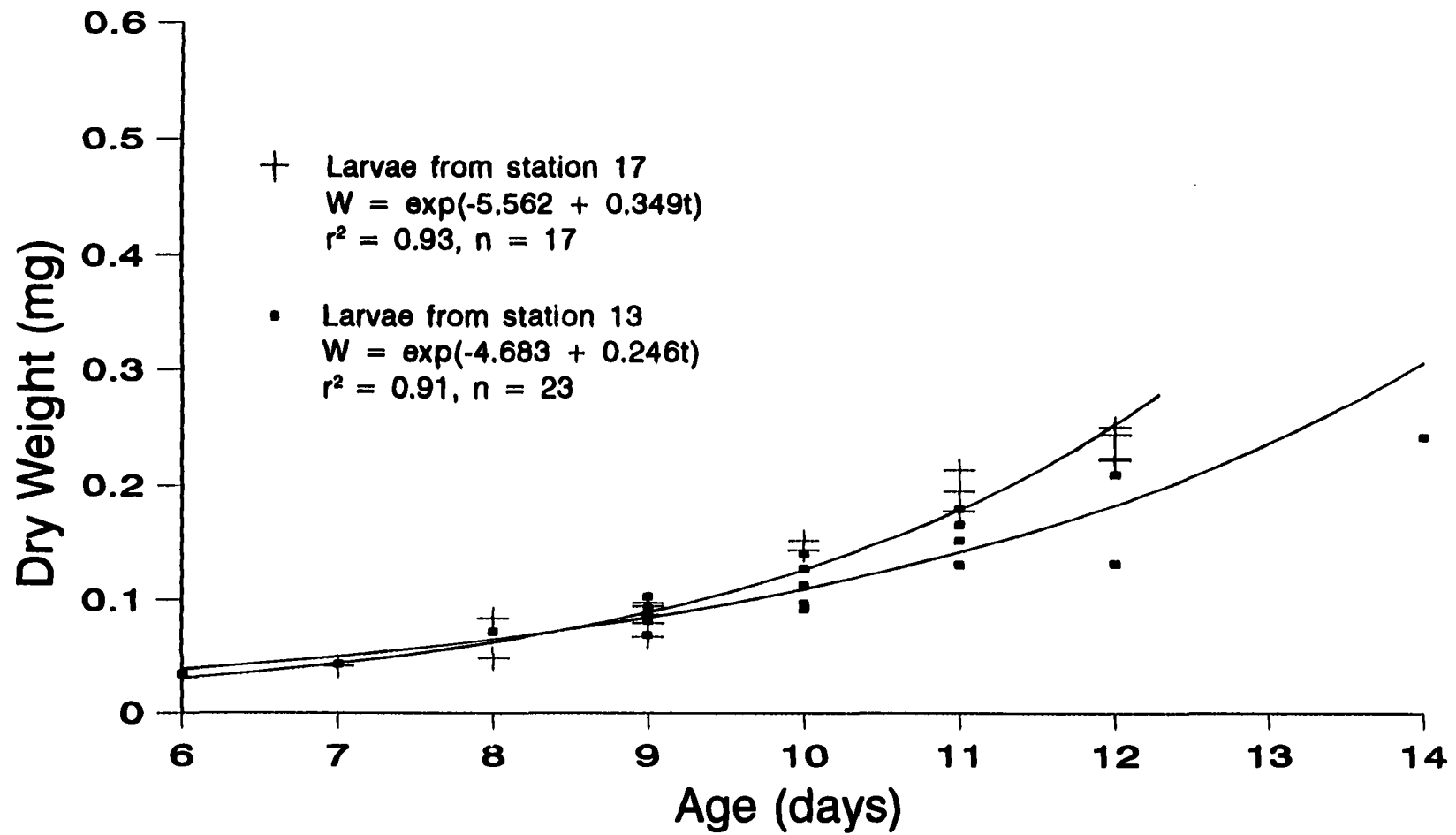


Figure 2.15. Relationship between age and dry weight for larval vermilion snapper collected at stations 13 and 17 (see Fig.2.1) in the northcentral Gulf of Mexico during 27-29 September 1992. W = dry weight in mg; t = larval age in days. Slopes of regression lines are significantly different ($P \leq 0.01$).

surface chlorophyll *a*, macrozooplankton biomass, and adult copepod abundance.

At the seven locations where vermilion snapper larvae were aged in September 1991, a significant positive linear correlation ($P \leq 0.01$) was found between the age/length growth coefficients (ln mm/d) and station estimates of surface chlorophyll *a* concentrations (Figure 2.16). Surface chlorophyll *a* concentrations at the seven stations examined were extremely low and ranged from 0.12 to 0.75 mg/m³. The fastest growing larvae were found at the two stations with surface chlorophyll *a* estimates greater than 0.5 mg/m³ (Figure 2.16). Age/dry-weight growth coefficients of vermilion snapper larvae were also significantly correlated with surface chlorophyll *a* estimates ($P \leq 0.05$; Figure 2.17).

No significant linear correlations were found between station estimates of macrozooplankton standing stocks or adult copepod abundances and either age/length or age/dry-weight growth coefficients of larvae (Figures 2.18 to 2.21). Analyses were restricted to data from these 7 stations because of the limited availability of larvae.

A Pearson product-moment correlation analysis showed no significant correlations between station estimates of surface chlorophyll *a*, macrozooplankton biomass, or copepod abundance (Table 2.3). The significance of the correlation between chlorophyll *a* levels and both age/length

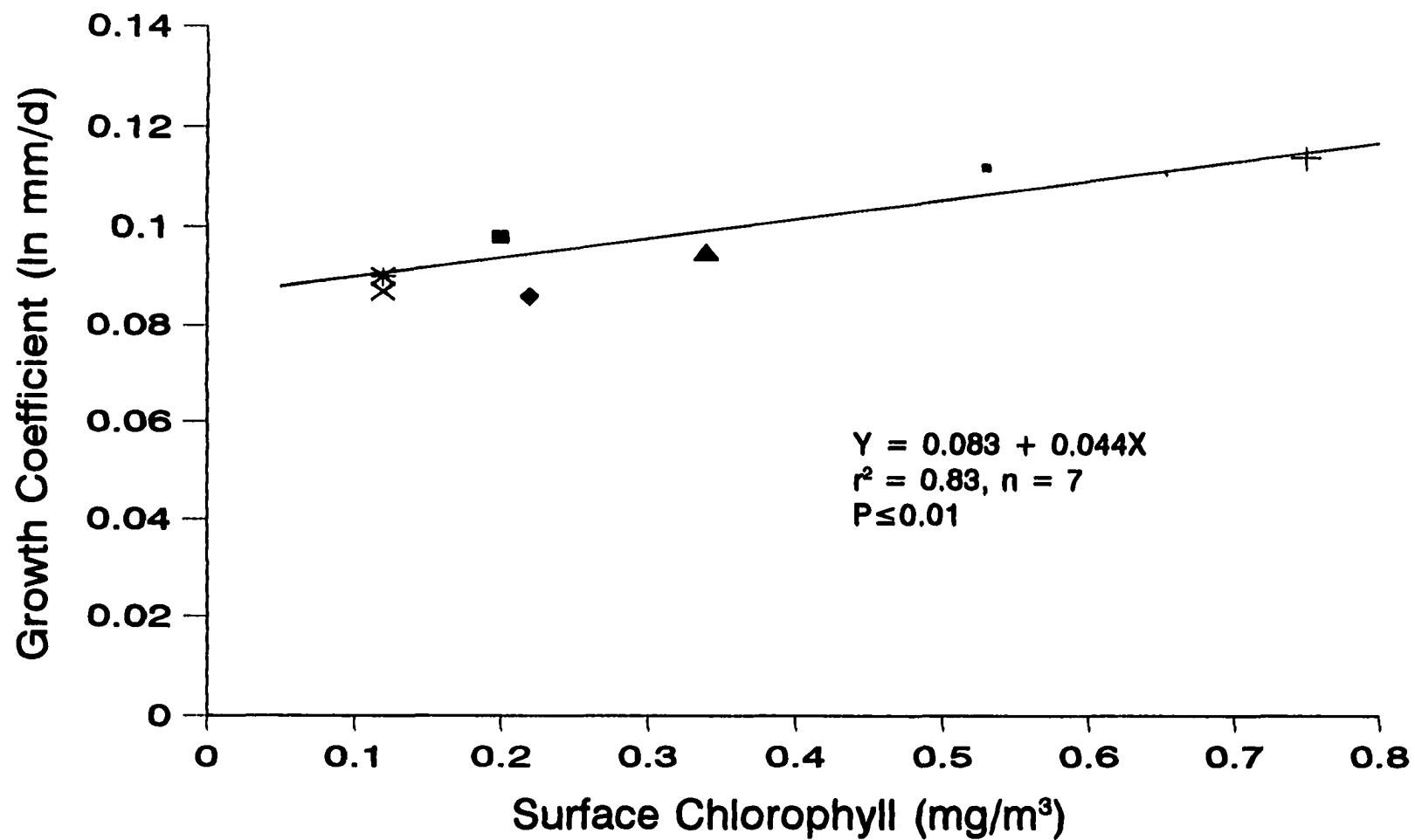


Figure 2.16. Relationship between age/length growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll a (mg/m³) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

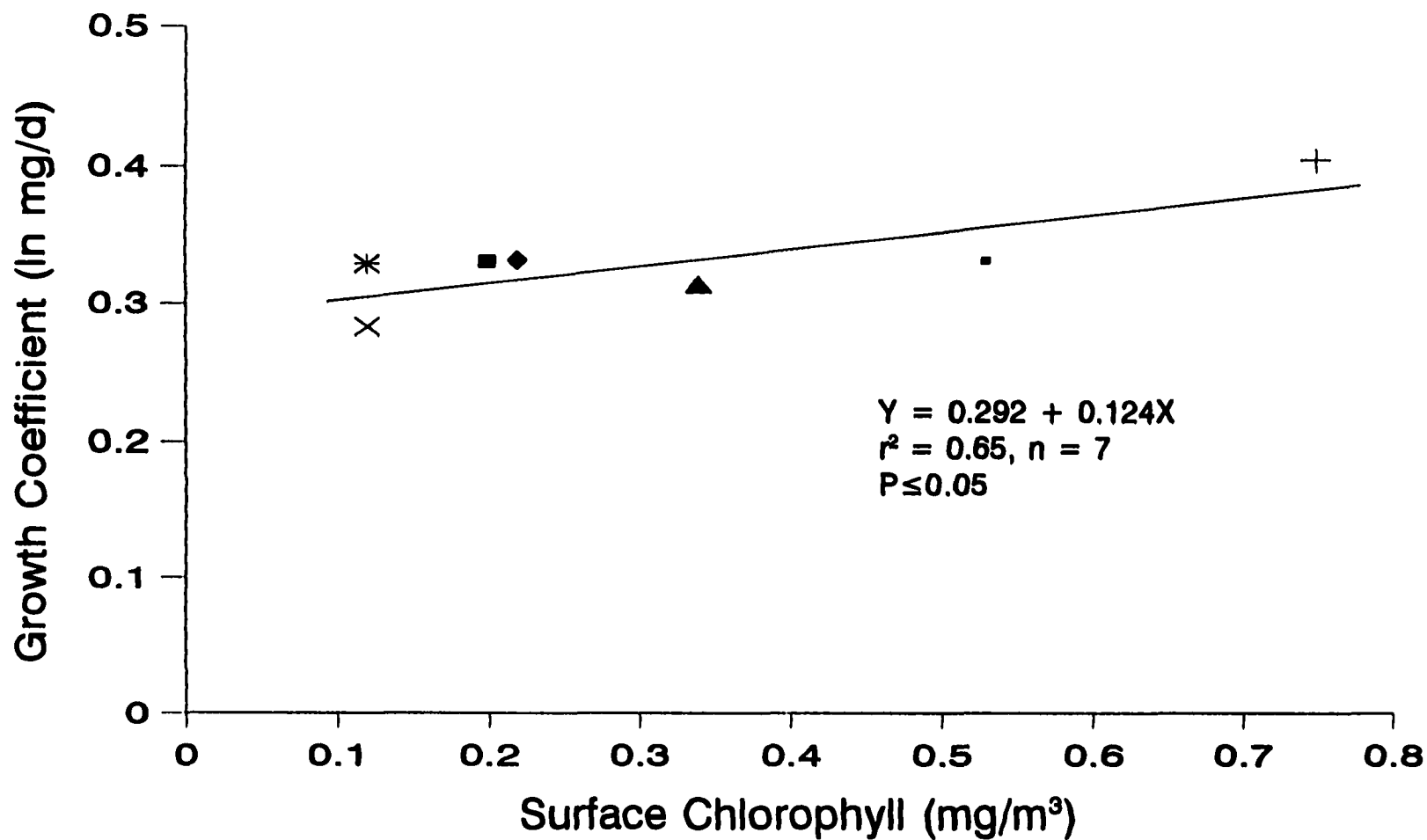


Figure 2.17. Relationship between age/dry-weight growth coefficients of vermilion snapper larvae and estimates of surface chlorophyll *a* (mg/m³) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

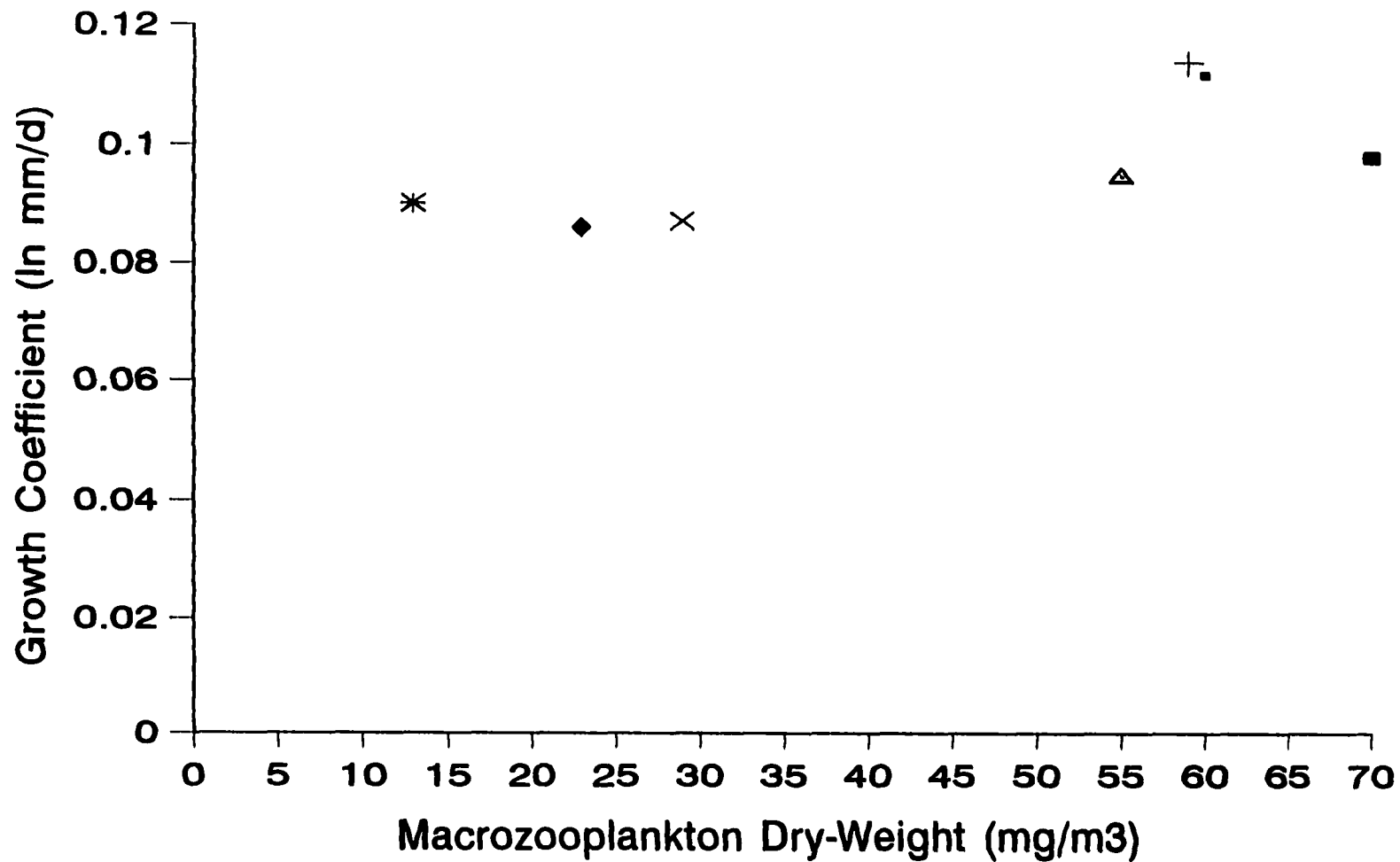


Figure 2.18. Scatterplot of age/length growth coefficients of vermilion snapper larvae and dry-weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

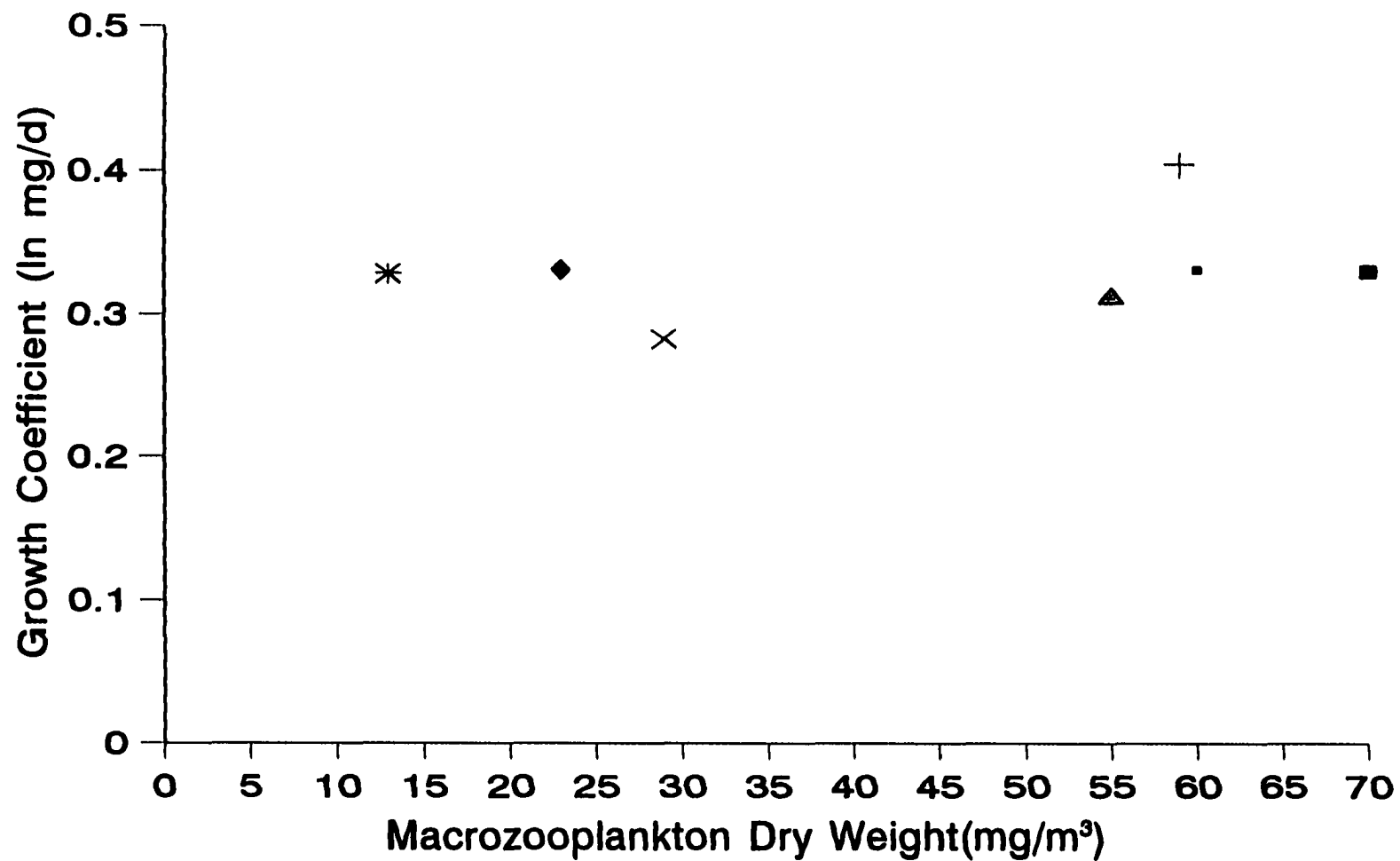


Figure 2.19. Scatterplot of age/dry-weight growth coefficients of vermillion snapper larvae and dry-weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

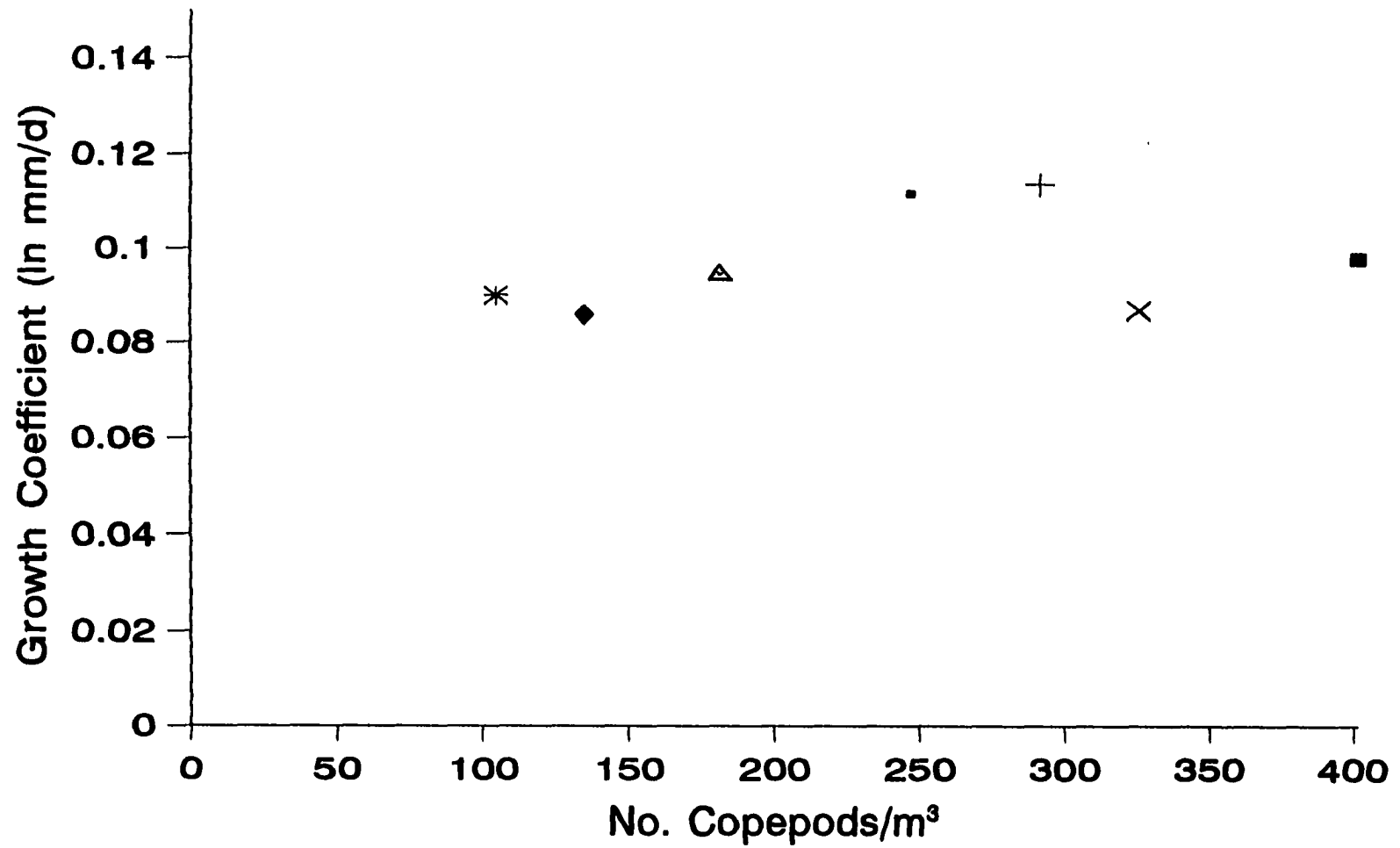


Figure 2.20. Scatterplot of age/length growth coefficients of vermillion snapper larvae and densities of copepods (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

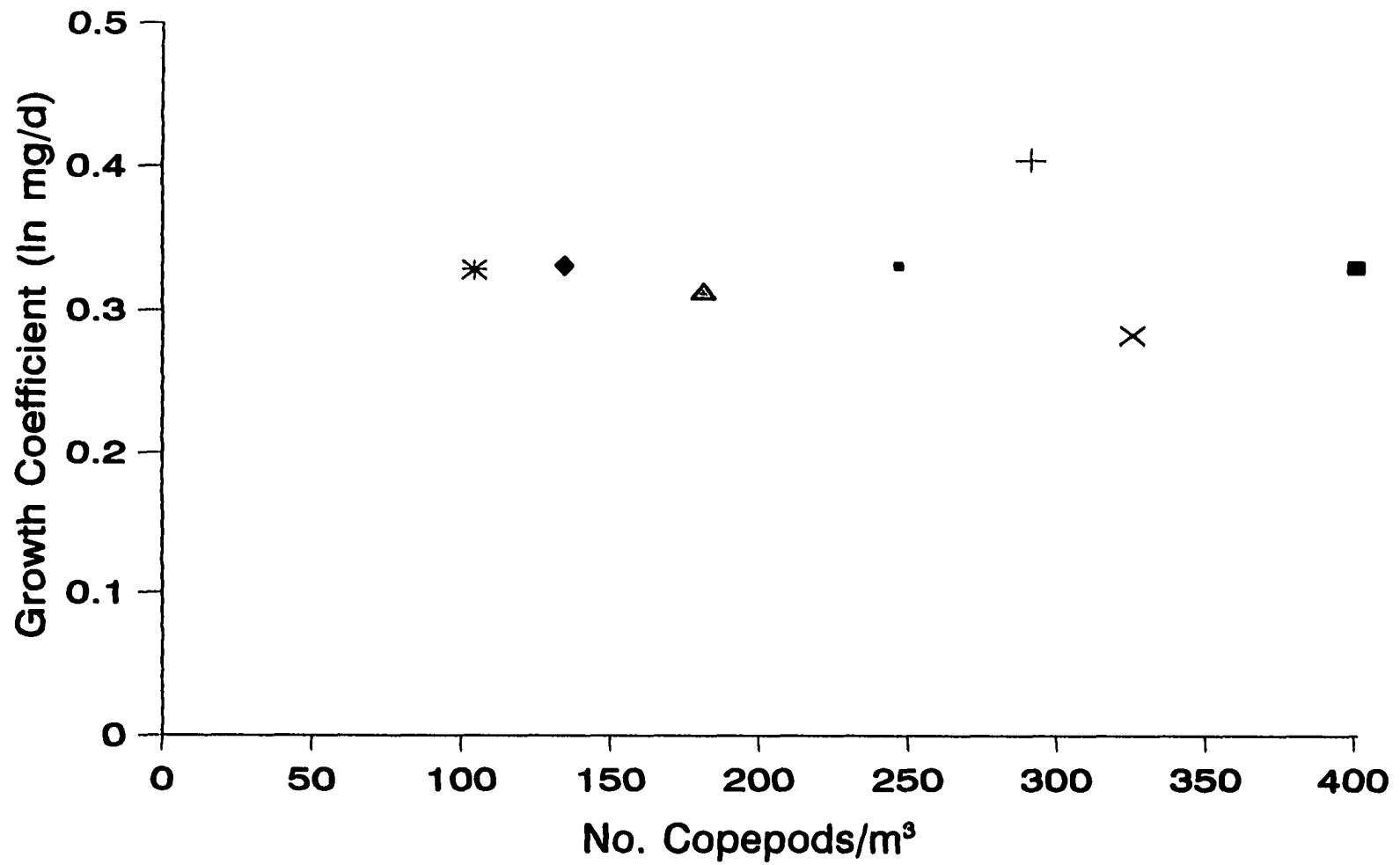


Figure 2.21. Scatterplot of age/dry-weight growth coefficients of vermilion snapper larvae and densities of copepods (retained in 333 μ m mesh net) at 7 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

Table 2.3. Pearson product-moment correlation coefficients for analyses between chlorophyll *a* concentrations, copepod densities, and macrozooplankton biomass estimates at seven stations in the northcentral Gulf of Mexico during 14-16 September 1991. Significance levels are shown below the correlation coefficients for each comparison.

	Chlorophyll <i>a</i> (mg/m ³)	Adult copepods/l	Macrozooplankton biomass (mg/m ³)
Chlorophyll <i>a</i>	1.0000	0.1556	0.5848
	0.0000	0.7391	0.1679
Adult copepods/l	0.1556	1.0000	0.6757
	0.7391	0.0000	0.0957
Macrozooplankton biomass (mg/m ³)	0.5848	0.6757	1.0000
	0.1679	0.0957	0.0000

and age/weight growth coefficients was not improved by including the other two independent variables in a stepwise multiple regression.

In September 1992 vermilion snapper larvae used for age/growth analyses were taken at 10 stations. No statistically significant relationships were found between larval growth coefficients (age/length and age/weight) and either levels of surface chlorophyll *a* (Figures 2.22 and 2.23), or macrozooplankton biomass (Figures 2.24 and 2.25). Station estimates of copepod abundance were not determined for the 27-29 September 1992 cruise.

Morisita's index of dispersion showed the distribution of vermilion snapper larvae to be very patchily distributed. For the three September cruises conducted in 1991 and 1992 when vermilion snapper larvae were abundant, values of I_d ranged from 2.1 to 2.5 and departures from randomness for the distribution of larvae were significant for each cruise ($P < 0.05$). Stations within Chandeleur and Breton Sounds were excluded from the analyses because snapper larvae were not found in these shallow waters.

Atlantic bumper

Summaries of age/length/dry-weight data for Atlantic bumper larvae are listed in Appendix R. Atlantic bumper larvae ranged from 2 to 14-d-old, and lengths and dry weights of larvae ranged from 1.4 mm to 8.1 mm, and 0.003 mg to 1.446 mg, respectively. Sagittal otoliths of the smallest larvae were similar to those of vermilion snapper and were saucer shaped and spherical when viewed in the sagittal plane, and were approximately 0.02 mm

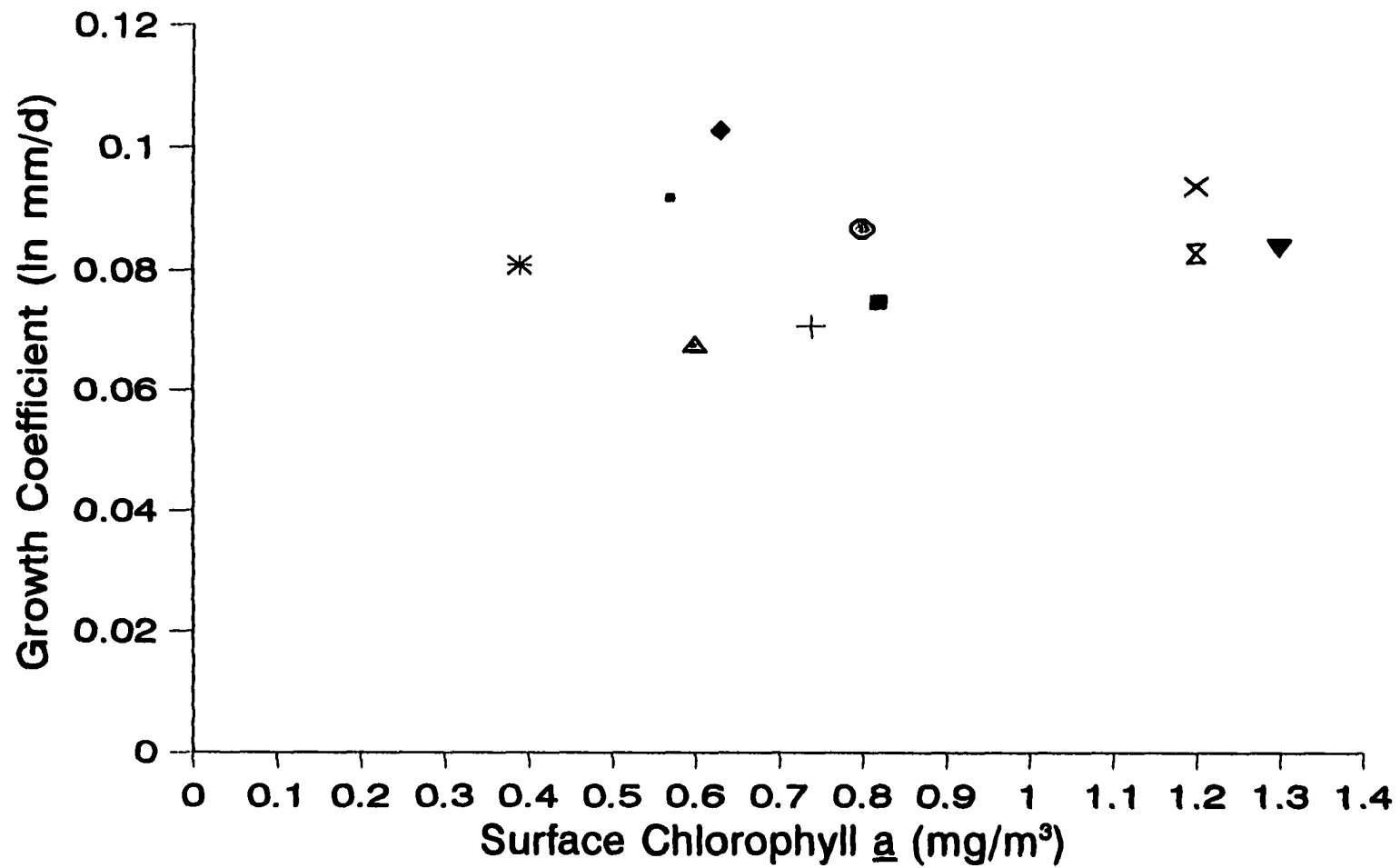


Figure 2.22. Scatterplot of age/length growth coefficients of vermillion snapper larvae and estimates of surface chlorophyll *a* (mg/m³) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.

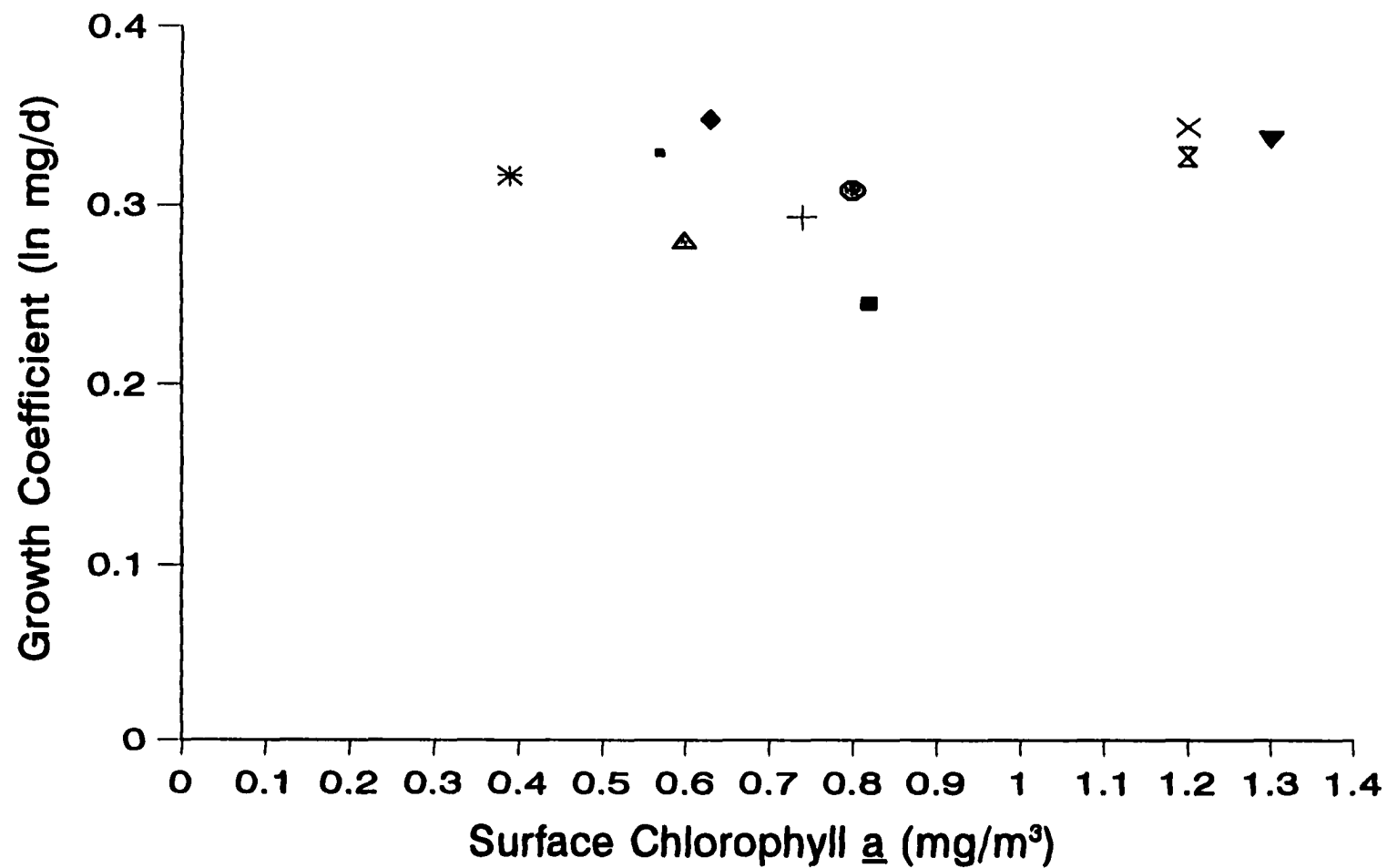


Figure 2.23. Scatterplot of age/dry-weight growth coefficients of vermillion snapper larvae and estimates of surface chlorophyll *a* (mg/m³) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.

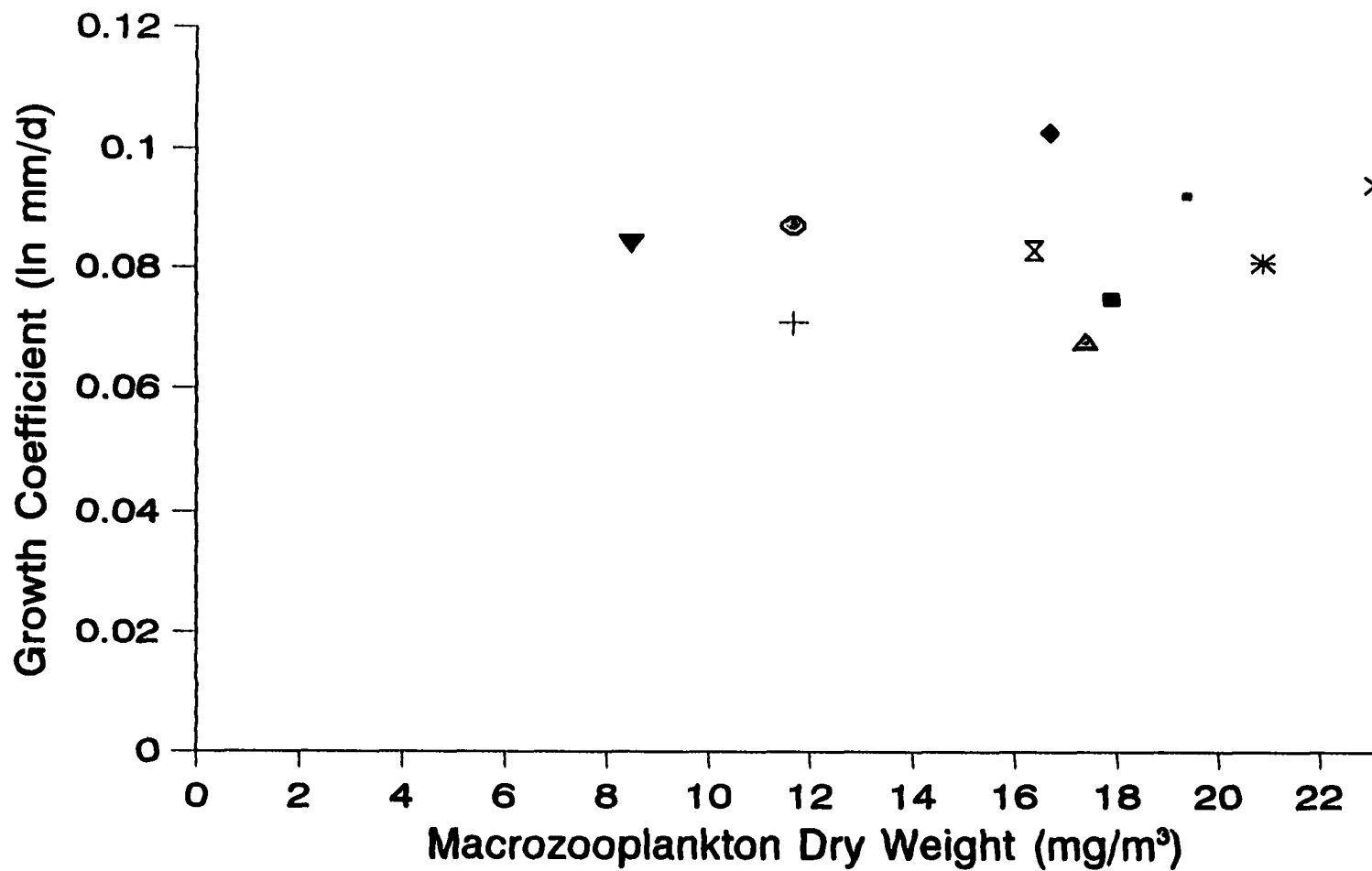


Figure 2.24. Scatterplot of age/length growth coefficients of vermillion snapper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.

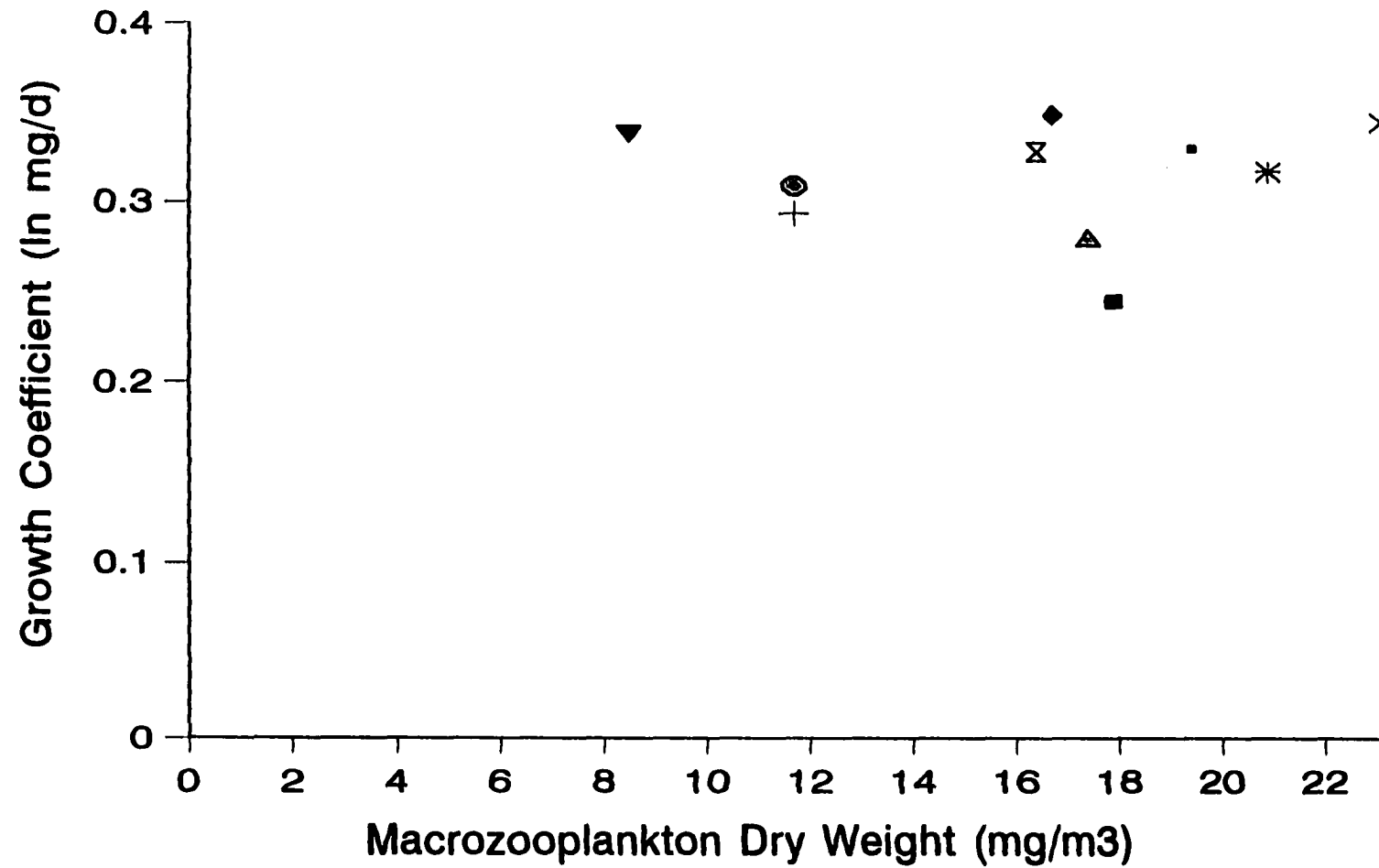


Figure 2.25. Scatterplot of age/dry-weight growth coefficients of vermillion snapper larvae and dry-weight estimates of macrozooplankton standing stock (retained in 333 μ m mesh net) at 10 stations in the northcentral Gulf of Mexico during 27-29 September 1992.

in diameter. Otoliths of the largest larvae were slightly oval when viewed in the sagittal plane and were approximately 0.2 mm in diameter. Growth increments appeared as distinct concentric circles surrounding the core.

Age/length relationships for Atlantic bumper larvae were developed only for the 14–16 September 1991 cruise. A scatter plot of age/length data from 140 larvae collected at 9 stations indicated that larval growth rates began to diverge after larvae were approximately 7–8 days old (Figure 2.26). The largest difference in age/length growth coefficients was found between Atlantic bumper larvae collected at adjacent (10 km apart) inner-shelf stations 41 and 42 (Figure 2.26; Table 2.4). Slopes of the age/length relationships at these two stations were significantly different ($P < 0.01$). Based on their respective growth equations, Atlantic bumper larvae at station 41 grew to a length of 6 mm in 10.4 d, whereas at station 42 it took 13.3 d. Differences in age/weight growth coefficients were also significantly different between larvae collected at these two adjacent stations ($P < 0.01$, Figure 2.27). Atlantic bumper larvae collected at station 41 gained weight faster and by 11 d their estimated dry weight was 0.58 mg. The estimated dry weight of an 11-d-old larva collected at station 42 was only 0.38 mg. Although stations 41 and 42 were located approximately 10 km apart, hydrographic conditions at these two locations were quite similar. Water depth was somewhat deeper at station 42 (21 m vs 15 m), but surface and midwater temperatures at both stations were 28°–29°C, and surface and midwater salinities differed by no more than 2ppt.

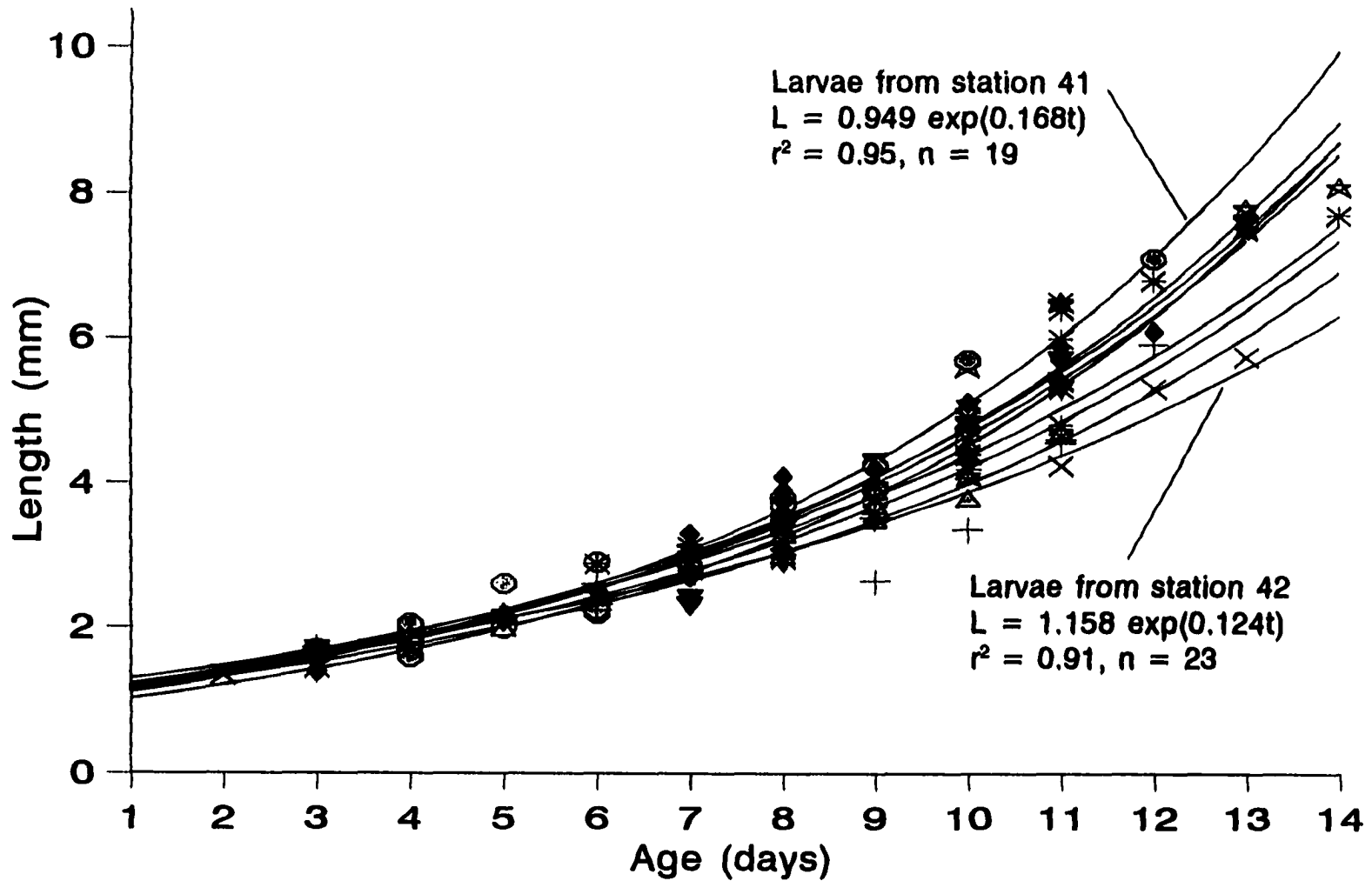


Figure 2.26. Age/length data for Atlantic bumper larvae ($n=140$) collected at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991. L = notochord or standard length in mm; t = larval age in days.

Table 2.4. Slopes of age/length regressions and corresponding coefficients of determination (r^2) for Atlantic bumper larvae collected at nine stations in the northcentral Gulf of Mexico during 14-16 September 1991. Coefficients of determination marked with asterisk were determined for each station by using the actual age composition of larvae collected at a station, but lengths were randomly selected from same-aged larvae from the pooled data set (n=139) of all nine stations combined.

Station No.	Slope of Age/Length Regression	r^2	r^2	Sample Size
12	0.14	0.99	0.98*	8
23	0.16	0.96	0.93*	25
24	0.14	0.96	0.94*	11
34	0.15	0.94	0.93*	13
37	0.15	0.90	0.86*	22
41	0.17	0.95	0.94*	19
42	0.12	0.91	0.94*	23
44	0.14	0.97	0.91*	8
47	0.17	0.96	0.94*	10

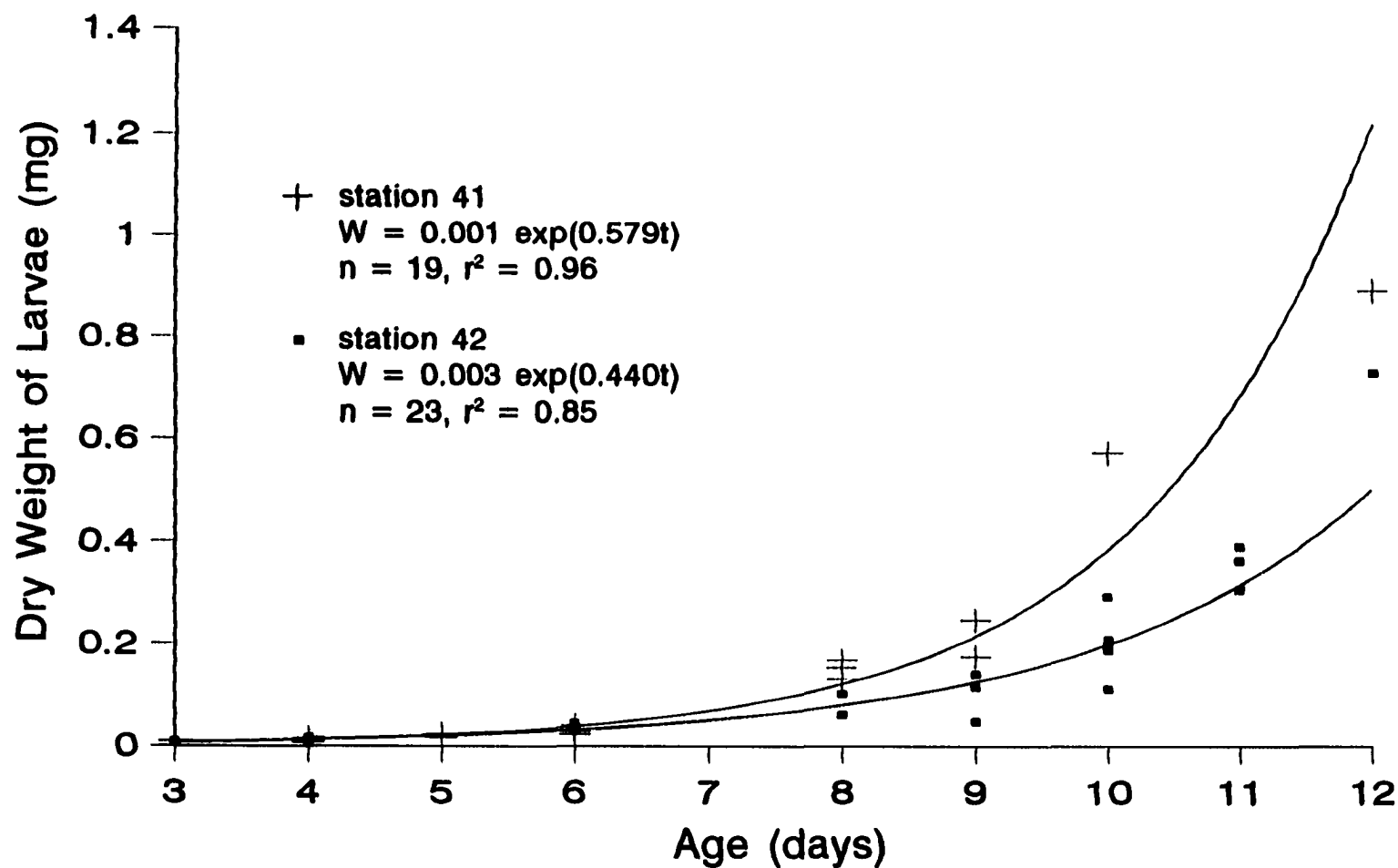


Figure 2.27. Relationship between age and dry weight of Atlantic bumper larvae collected at adjacent stations 41 and 42 in the northcentral Gulf of Mexico, 15 September 1991. Slopes of linearized regression lines are significantly different ($P \leq 0.01$).

No correlations were found between either age/length or age/dry-weight growth coefficients of Atlantic bumper larvae and station estimates of surface chlorophyll *a* concentrations (Figures 2.28 and 2.29) or estimates of macrozooplankton biomass (Figures 2.30 and 2.31). A significant ($P < 0.01$) exponential asymptotic relationship was found between growth coefficients (both length and dry weight) and station estimates of copepod abundances (Figures 2.32 and 2.33).

Atlantic bumper larvae were patchily distributed during all four September cruises when values of I_0 ranged from 2.6 to 3.0 and departures from randomness for the distribution of larvae were significant for each cruise ($P < 0.05$).

DISCUSSION

Growth rates of vermilion snapper larvae were significantly affected by a change in water temperature of approximately 5°C. In May 1992, when water temperatures were relatively cool (24°-25°C), vermilion snapper larvae reached a size of 8 mm in approximately 22 d, whereas at warmer temperatures in August (29°-30°C) an 8 mm larva was only 16-d-old. It is unlikely that food availability caused the faster growth rates in August because macrozooplankton biomass was lower in August ($\bar{x} = 2.34$ g/100m³) than in May ($\bar{x} = 4.41$). It is possible, however, that factors other than temperature also affected larval growth rates; surface chlorophyll *a* concentrations were higher in August ($\bar{x} = 0.50$ mg/m³) than in May ($\bar{x} = 0.23$), and surface salinities were lower in August ($\bar{x} = 30.2$ ‰) than in May ($\bar{x} = 33.5$ ‰). The effects of temperature

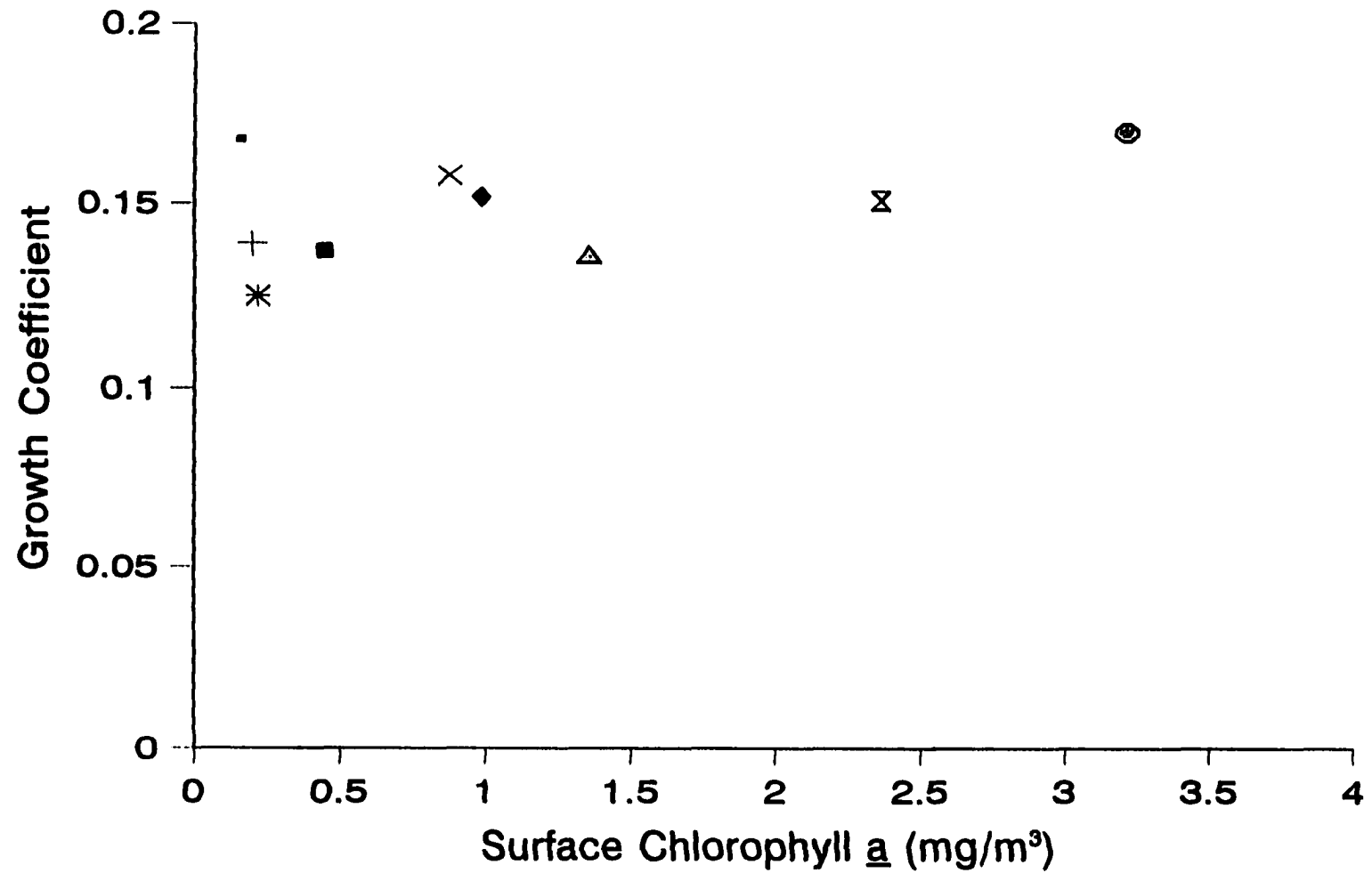


Figure 2.28. Scatterplot of age/length growth coefficients of Atlantic bumper larvae and estimates of surface chlorophyll a (mg/m³) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

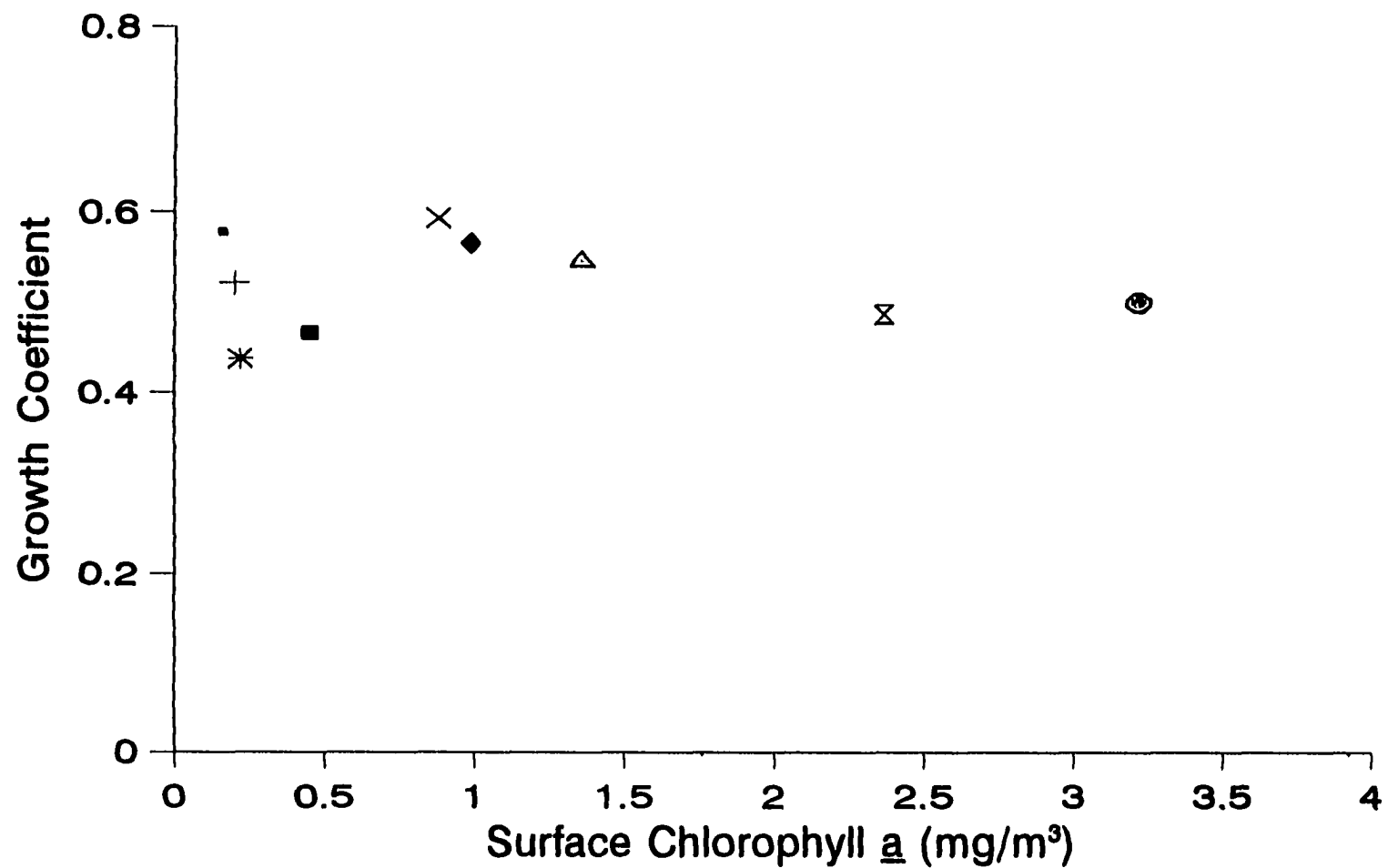


Figure 2.29. Scatterplot of age/dry-weight growth coefficients of Atlantic bumper larvae and estimates of surface chlorophyll a (mg/m³) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

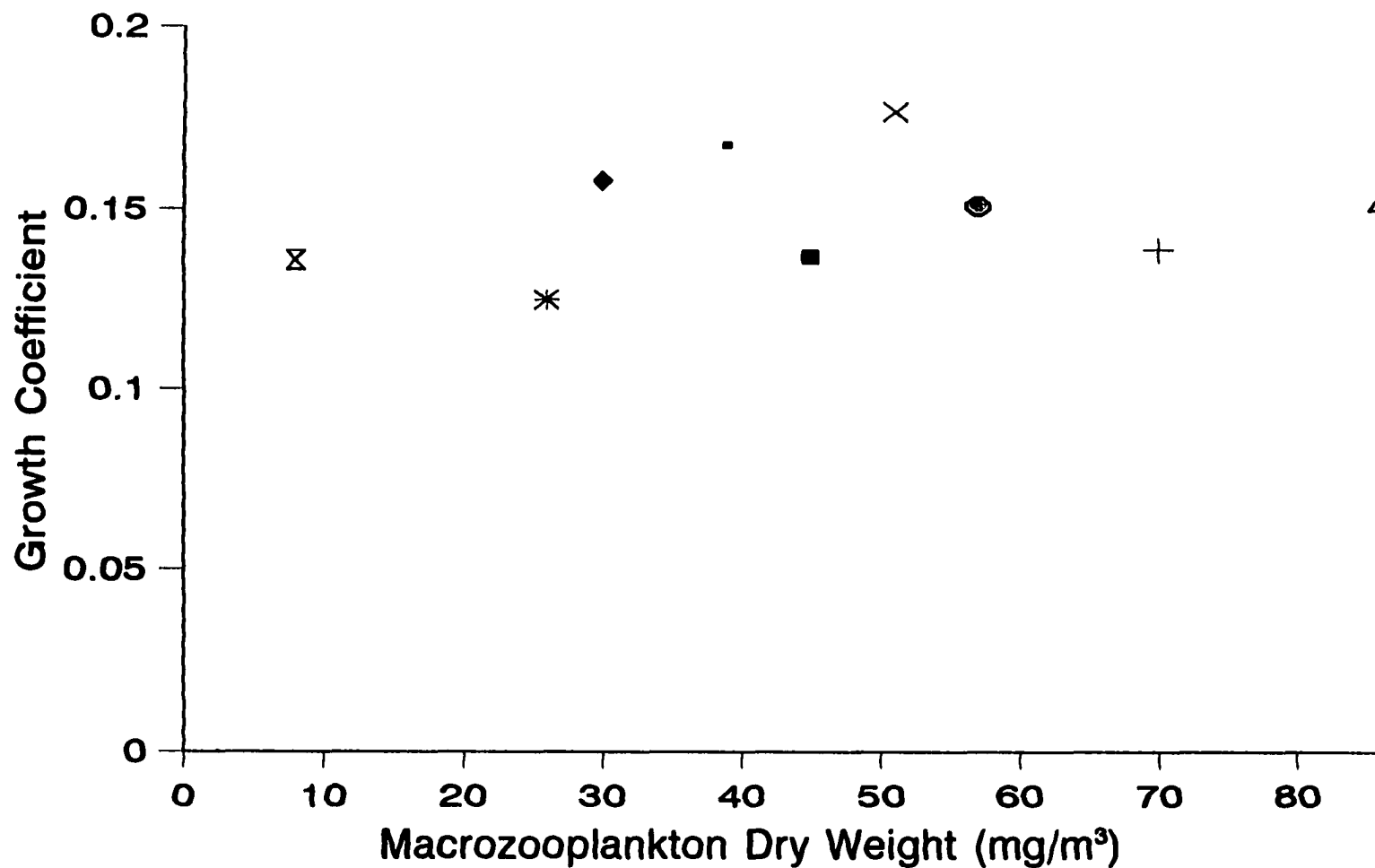


Figure 2.30. Scatterplot of age/length growth coefficients of Atlantic bumper larvae and dry weight estimates of macrozooplankton standing stock (retained in 333um mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

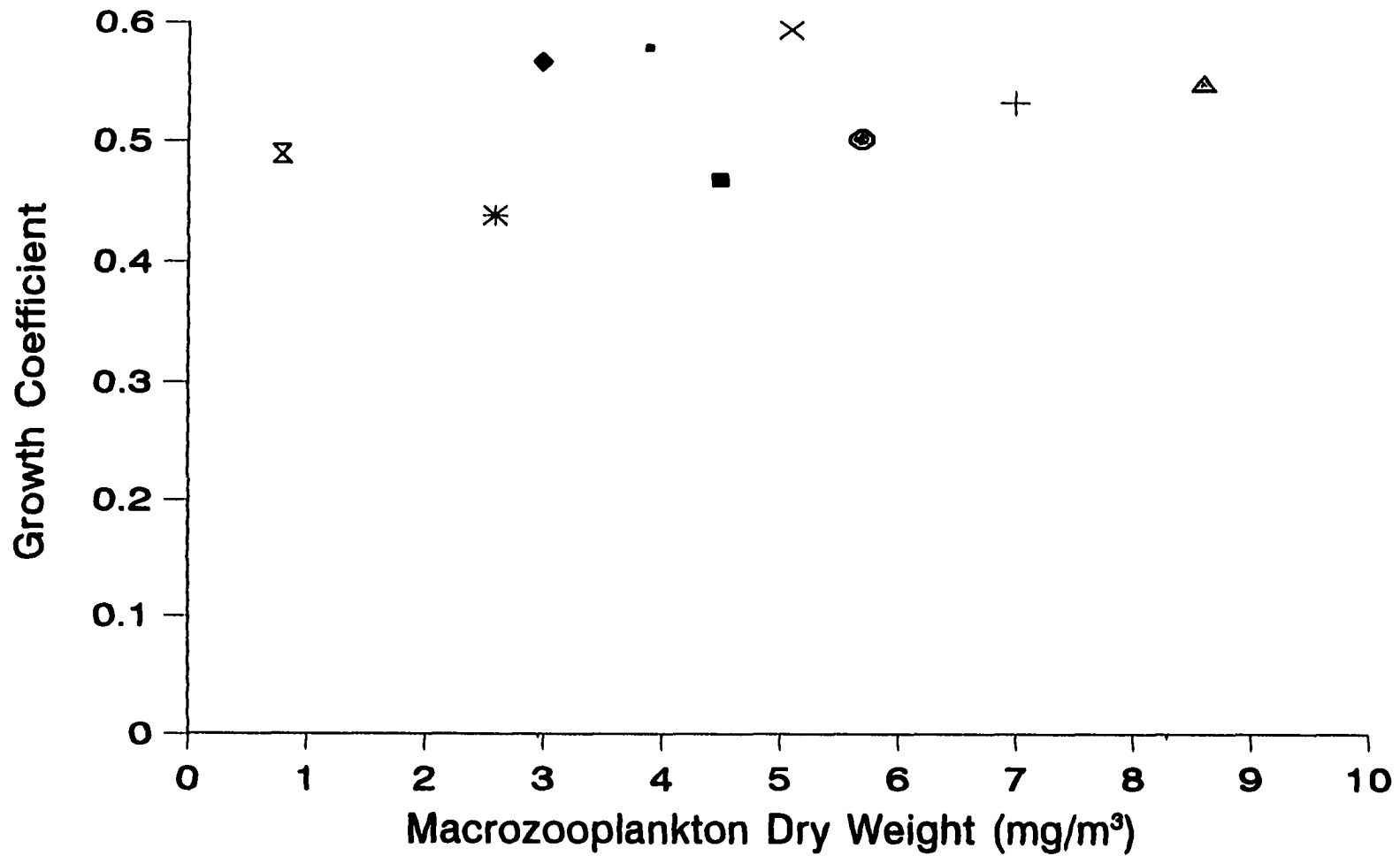


Figure 2.31. Scatterplot of age/dry-weight growth coefficients of Atlantic bumper larvae and dry-weight estimates of macrozooplankton standing stock (retained in 333um mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

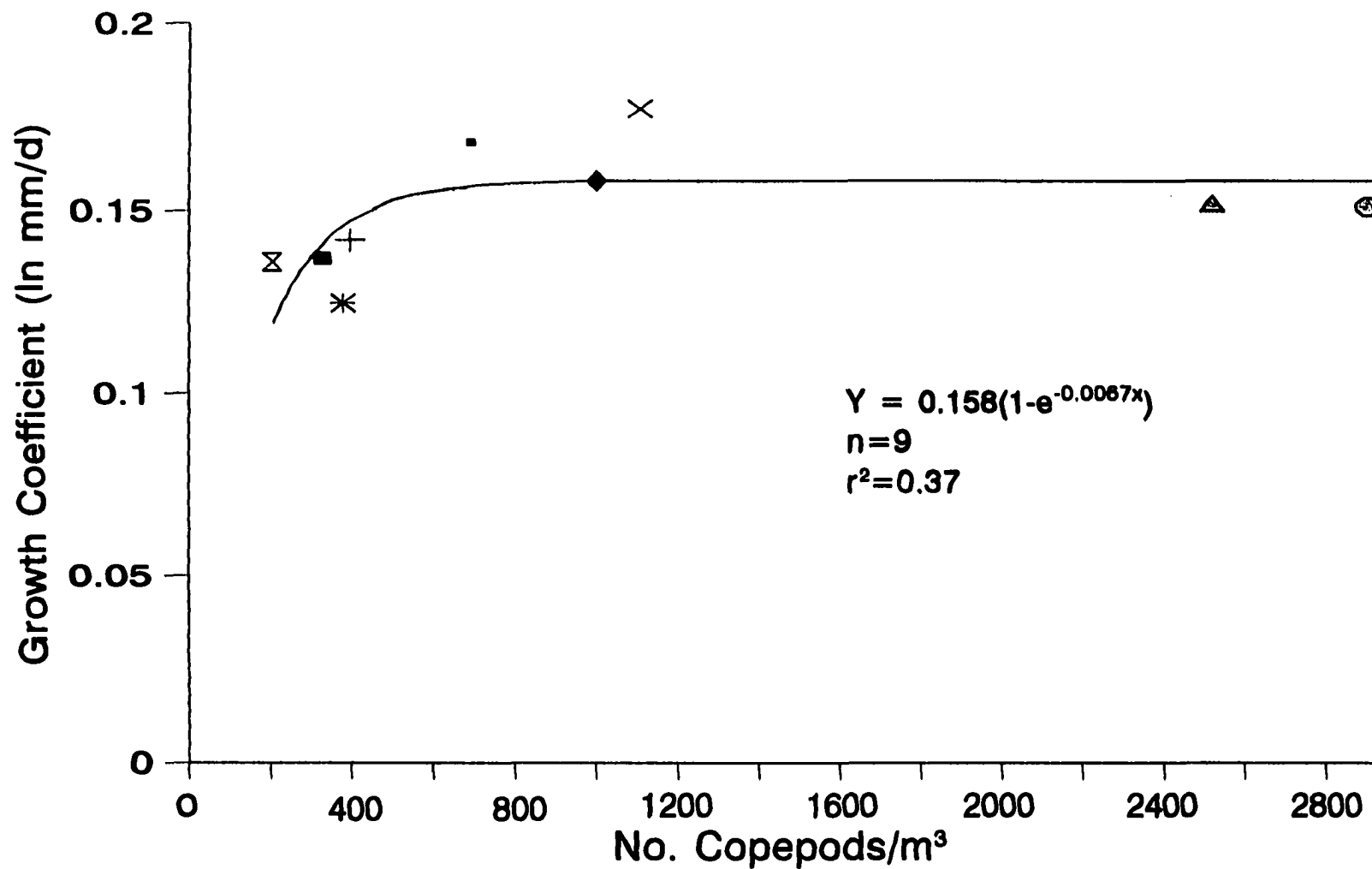


Figure 2.32. Relationship between the age/length growth coefficients of Atlantic bumper larvae and densities of copepods (retained in 333um mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

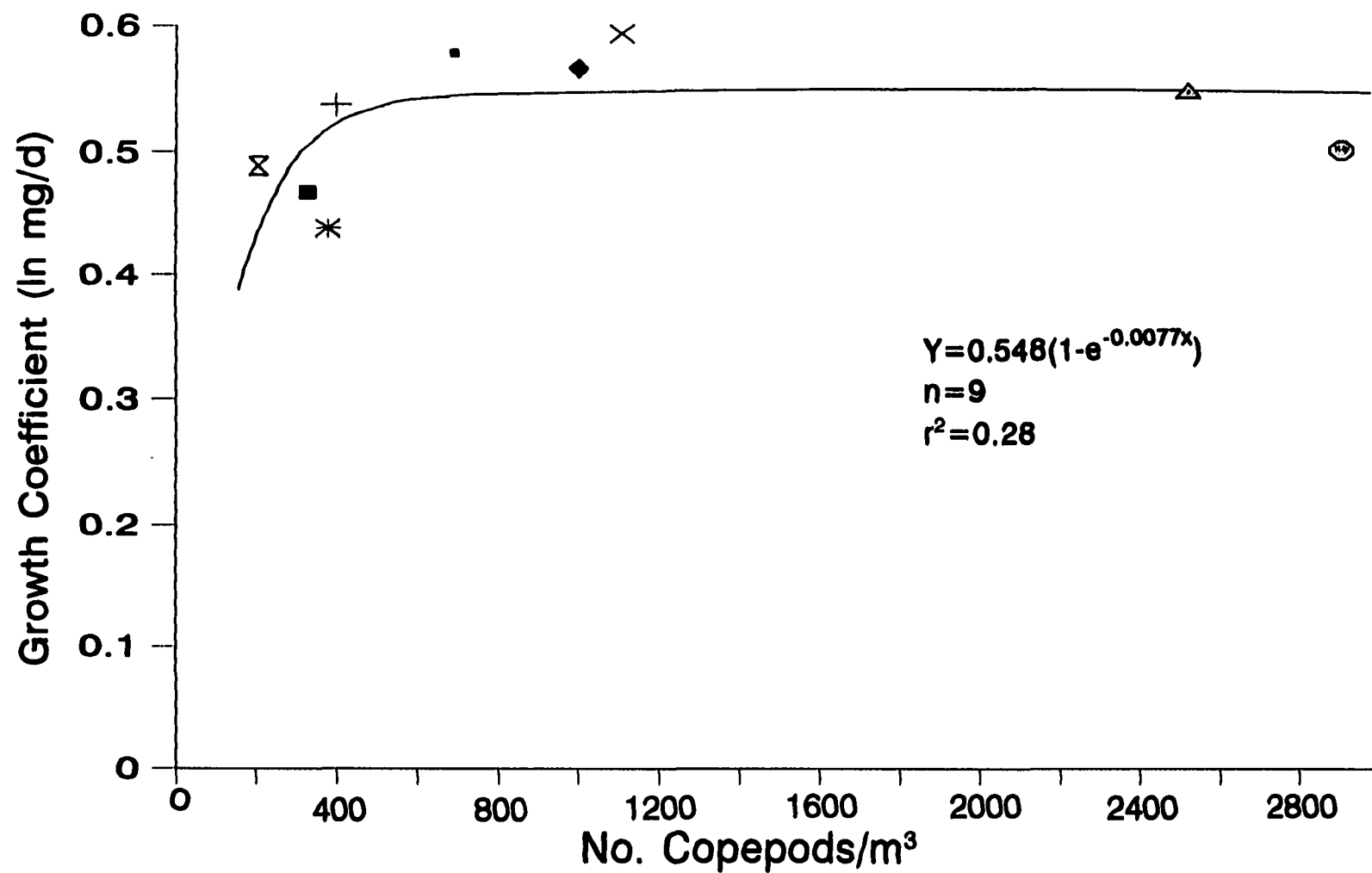


Figure 2.33. Relationship between the age/dry-weight growth coefficients of Atlantic bumper larvae and densities of copepods (retained in 333um mesh net) at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1991.

changes on growth were not determined for Atlantic bumper because larvae were only aged from one September cruise and were not collected earlier in the summer. Leffler and Shaw (1992) found that Atlantic bumper larvae collected off Mississippi and Alabama grew faster in August at 29°-31°C (0.40 mm d⁻¹) than in September (0.26-0.31 mm d⁻¹) when temperatures ranged from 26.5°-29°C.

The relationship between larval growth rates and temperature is well documented in the literature (i.e., Comyns et al. 1989, Gadomski and Caddell, 1991; Pepin, 1991; Francis, 1994). Because water temperature influences the metabolic rate of larvae, temperature also affects the ration required to promote fast growth. Starvation or malnourishment of larvae is, therefore, most likely when prey abundance is low and when warm temperatures increase metabolic rates (Houde, 1989). Starving larvae of northern anchovy, *Engraulis mordax*, and jack mackerel, *Trachurus symmetricus*, have been found in plankton collections (O'Connell, 1980; Hewitt et al., 1985; Theilacker, 1986). Although some species may be highly vulnerable to starvation (Lasker, 1975;1978), predation is probably the major cause of mortality for many species (Bailey and Houde, 1989). It must be emphasized that the "starvation hypothesis" not only addresses the extreme case when larvae die from lack of food, but also effects total mortality because malnourished larvae swim more slowly and are more vulnerable to predators (Fritz et al., 1990).

There is a direct relationship between predation rates and temperature (Pepin, 1991; Francis 1994). Metabolic rates increase with temperature, and

consequently predation rates increase at warmer temperatures because of the increased metabolic requirements (Morse, 1989). Factors other than temperature that affect larval growth rates may have the greatest potential impact on cumulative larval fish survival. As water temperatures decrease, larval growth rates become slower, and larval stage durations increase. This increased duration, however, does not necessarily have to result in a proportional increase in larval mortality because predation rates probably also decrease as water temperatures become colder (Morse, 1989). The relative magnitude between the decreased growth rates of larvae and the decreased predation rates at cooler temperatures is not known, although the scope of modification with respect to predation rates is somewhat dampened by the effect that increased size has on decreasing metabolism, i.e., weight-specific standard metabolism generally decreases with increasing size (Conover, 1992).

Spatial differences in growth rates of vermilion snapper larvae were found which were not explained by temperature. Significant differences in both age/length and age/weight relationships were found for vermilion snapper larvae collected at relatively close stations (i.e., 40-50 km apart) during surveys conducted in September 1991 and 1992. During both years, faster growing larvae reached a length of 5 mm 2-2.5 d sooner than larvae growing in nearby areas. Significant differences were also found in larval weight-gain during both cruises, and in September 1991 station differences in dry weight of 11-d-old larvae differed by up to 50%.

Highly significant between-station differences in growth rates of Atlantic bumper larvae, which were also not explained by water temperature, were similarly found in the northcentral Gulf during 14-16 September 1991. The largest difference in age/length growth coefficients was found between larvae collected at two, adjacent, inner-shelf stations located approximately 10 km apart. Based on growth equations, the faster growing larvae grew to a length of 6 mm 2.9 d sooner than larvae at the adjacent station, while larval weight gain differences as expressed by dry weight of 11-d-old larvae varied by over 30%. Hydrographic conditions at these two locations were quite similar. Water depth differed by 6 m (21 m vs 15 m), but surface and midwater temperatures at both stations were 28°-29°C, and both surface and midwater salinities differed by no more than 2 ppt. It is unlikely that these station differences in growth rates were caused by size-selective mortality because of the clear distinction between the station age-length relationships of larvae. Size-selective mortality can affect the age/length composition of larvae by causing a consistently higher cumulative mortality of either slower or faster growing larvae, but it is unlikely that this process caused the observed station differences in larval growth rates. It is doubtful that most of the faster growing larvae would have been eaten at one station, while most of the slower growing larvae were eaten at the adjacent station.

It must be emphasized that larvae are transported by water currents and consequently did not develop at the station location where they were collected. Larval development, however, did probably occur within the study area.

Movement of water over the inner-shelf in the northcentral Gulf east of the Mississippi River is highly variable. Lyczkowski-Shultz et al. (1988) deployed a total of 15 drogues for periods of 1 or 2 d in my study area during the fall months from 1983 to 1985. Apart from one drogue that in 24 h drifted for ten miles in a southerly direction immediately east of the Chandeleur Islands, movement of the drogues was generally quite random and drogue tracks often reversed direction 180°. Shaw et al. (1988) deployed three drogues on six sampling dates during Fall 1986 in the study area, and these drogue trajectories were also very meandering. These drogue studies were not conducted during atmospheric cold front passages, however, because of the adverse sea conditions caused by the energetic rotation of the wind field. One of the characteristics of these cold fronts are northerly winds which have been shown to cause a westward flow immediately south of the Mississippi-Alabama barrier islands (Schroeder et al., 1985; 1987). This westward flow forms the northern segment of a weak cyclonic gyre that often forms in the northcentral Gulf east of the Mississippi River Delta (Schroeder et al., 1987; Dinnel, 1988).

The other primary factor influencing larval fish growth rates besides water temperature is food availability (Houde and Schekter, 1981; Buckley et al., 1987; Pepin, 1991). Because station differences in larval growth rates were found that were caused by factors other than temperature, it is assumed that these growth differences were mainly caused by differences in prey availability. The significant variability in growth rates observed at relatively small spatial scales (i.e., <10-50 km) indicates the probable existence of patchy

feeding conditions. Calanoid copepods were by far the most common macrozooplankton in the plankton collections, and copepod nauplii are a dominant prey item for many species of larval fishes (Duka and Gordina, 1973; Dagg et al. 1987). Diets of larval vermilion snapper and Atlantic bumper have not been described, but Lyczkowski-Shultz et. al. (1988) found that prey items eaten by red drum larvae (primarily copepod nauplii) collected in the same area were smaller than 333 μm (largest width excluding appendages). Because the prey items normally eaten by small fish larvae are too small to be retained by the 333 μm mesh nets used in ichthyoplankton surveys like this study, it was not possible to examine the relationships between spatial differences in larval growth rates and the relative abundance of the most appropriately-sized prey items. It was possible, however, to examine potential indirect relationships between larval fish growth rates and several other factors that may have either directly affected the trophic or population dynamics of, or coherently varied with, the abundance of prey items (e.g., copepod nauplii) and thereby potentially provide useful information with respect to larval fish growth, i.e., surface chlorophyll *a* levels, abundances of adult copepods, and dry-weight estimates of macrozooplankton biomass.

Surface chlorophyll *a* levels were significantly correlated with both age/length and age/dry-weight relationships of vermilion snapper larvae collected during mid-September 1991, but not in late September 1992. Caution is warranted in interpreting these data given the small sample size in September 1991 ($n=7$ stations and 89 larvae), and the fact that the age/weight

relationship with chlorophyll *a* concentrations explained less variability than the age/length relationship ($r^2=0.65$ and $p \leq 0.05$ vs $r^2=0.83$ and $p \leq 0.01$, respectively). However, a correlation between larval growth rates and chlorophyll *a* levels that is present during one cruise and absent during a subsequent cruise later in the following year is quite possible. For example, high chlorophyll levels and high densities of microzooplankton that are eaten by fish larvae may not always co-occur. No significant relationships were found between growth rates of vermilion snapper larvae and either densities of adult copepods or estimates of macrozooplankton biomass. However, it is possible that the relationships between densities of adult copepods or estimates of macrozooplankton biomass and larval vermilion snapper growth were asymptotic and that my data represent only the flattened portions of the asymptotes. It is also possible that relationships were not detected because of a lack of power. The power (SigmaStat, 1995) of these non-significant relationships (0.03-0.45) was lower than the power for the significant relationships (0.87 and 0.60) found between age/length and age/weight growth coefficients and levels of chlorophyll *a*.

The relationship between both age/length and age/weight growth coefficients of Atlantic bumper larvae and adult copepod abundances were best described by a significant ($P < 0.01$) exponential asymptotic relationship. This is certainly the type of relationship that would be expected; increasing prey concentrations would only foster increasing larval fish growth rates up to a certain level, the feeding saturation point. It must be reiterated that fish larvae

eat the young stages of copepods (nauplii) and that adult copepods, which are far less abundant than nauplii, are used as a possible index of nauplii abundance. No relationships were found between growth coefficients (age/length and age/weight) and levels of surface chlorophyll *a*, or macrozooplankton biomass, but these non-significant findings must be viewed with caution because of the low power of the tests (0.04-0.24).

Although reasons for the observed differences in larval growth rates were not explained, the variability in growth rates at every level investigated (i.e., between stations and cruises) is not unexpected considering the high variability in the spatial and temporal distributions of surface chlorophyll *a* concentrations, macrozooplankton biomass, adult copepod abundance, dispersion of fish larvae, variability in spawning frequency and intensity, and the patchy distributions of spawning aggregations. Morisita's index of dispersion (I_d) indicated that these variables were patchily distributed, particularly the distribution of fish larvae and adult copepod abundances. Evidence of the temporal heterogeneity of plankton distributions was particularly evident in mid-September 1991 when 20 of the 33 stations east of Chandeleur Sound had macrozooplankton dry-weight estimates $>3\text{g}/100\text{ m}^3$, 8 of which exceeded $5\text{g}/100\text{ m}^3$. Seven days later only 5 stations had macrozooplankton dry-weight estimates $>3\text{g}/100\text{ m}^3$ and no station estimates exceeded $5\text{ g}/100\text{ m}^3$.

Several other studies have shown that primary production in the northern Gulf is dynamic and spatially heterogeneous (Lohrenz et al., 1990, 1994; Redalje, 1994), but these studies have focused on coastal areas that are

directly affected by discharge from the Mississippi and Atchafalaya Rivers.

One other study examined the patchiness of fish larvae off the Louisiana-Mississippi barrier islands (Shaw et al. 1988), and found high variability and patchiness in larval red drum abundances at a horizontal scale of 230-700 m.

Several studies have found spatial differences in growth rates of larvae in the field that were caused by factors other than temperature. These reported differences in growth rates have been associated with either different geographical locations (e.g., Mokness, 1992), storm events (e.g., Lasker, 1975; Maillet and Checkley, 1991), or distinct hydrographic features such as tidal fronts (Munk, 1993) and riverine discharge plumes (e.g., Govoni et al., 1985; DeVries et al., 1990). This study found differences in growth rates of larvae within the same, intensively sampled, geographic location that were not associated with obvious hydrographic features or meteorological events other than atmospheric cold front passages. These data indicate the existence of less-recognizeable patches or small areas between which growth rates of larvae differ. This small-scale variability may be far more common than previously thought, and understanding this subtle mosaic may help us to better identify and/or partition the causes of recruitment variability. Future research is needed to further characterize this small-scale variability, particularly with regard to microzooplankton patchiness, the spatial pattern of potential predators, and the spawning behavior of the adults.

Chapter 3. Estimating mortality and subsequent cumulative survival of fish larvae in the sub-tropical climate of the northcentral Gulf of Mexico.

INTRODUCTION

The major cause of variability in the levels of recruitment to many fish stocks is the variability in mortality experienced during the larval and early juvenile stages (Hunter, 1982; Houde, 1987; Fritz et al., 1990; Kendall and Matarese, 1994). Even relatively small changes in mortality rates and/or growth rates during the early life stages can lead to order of magnitude differences between year class abundance (Parish, 1973; Laurence, 1979; Houde, 1987, 1989). Even though much attention during the past two to three decades has focused on reaching a better understanding of the factors affecting the variability in larval fish mortality rates, many fundamental questions still remain (Hunter, 1976; Sissenwine, 1984; Houde, 1987; Miller et al., 1988; Cushing, 1994). These questions persist largely because there are many interrelating factors and subtleties that affect the survivorship of young fishes, and it is extremely difficult to accurately estimate mortality rates of larval and postlarval fishes in the marine environment (e.g., Bailey and Houde, 1989).

Daily mortality rates of fish larvae can be estimated from catch curve analyses of field data. There are two basic methods that have been used to construct catch curves for larval fishes (Essig and Cole, 1986). The first method involves using growth equations to convert length frequency to age frequency and then estimating the mortality rate of larvae from the decrease in abundance of succesively older age classes (e.g., Houde, 1977; Watanabe and

Lo, 1988; Comyns et al., 1991). This methodology requires extensive field efforts to begin to adequately account for the significant spatial and temporal variability in the abundance of larvae (Taggart and Leggett, 1987); to account for large enough geographical coverage to minimize the confounding effects of immigration and emigration within study area; and to spatially average out the potential mozaic of localized spawning grounds or aggregations. The various assumptions associated with this method are described later.

The second catch-curve approach to estimating the daily mortality of fish larvae involves plotting the decay in the relative abundance of larvae through time (e.g., Noble, 1972; Henderson et al., 1984; Graham and Townsend, 1985). In order to follow a group of larvae through time, a particular cohort must be identified, and factors other than mortality that reduce the abundance of larvae (e.g., immigration, emigration, dispersive losses) must be quantified and corrected for.

A third and different approach to estimating field mortality rates involves mesocosm studies, in which large volume enclosures are maintained in the field and stocked with known densities of fish larvae, their predators and prey (e.g., Cowan and Houde 1990). This methodology attempts to bridge the gap between controlled laboratory conditions and the highly variable *in situ* conditions, but unexpected results can be induced by “container” effects (Cowan and Houde, 1990).

The present study assesses the reliability and constraints associated with the first method of mortality estimation derived from length (age)-frequency

data. Many of the plankton collections used for this study were originally taken to develop indices of larval red drum abundance to calculate the adult spawning biomass and then assess changes in stock size of spawning red drum in the northcentral Gulf of Mexico (Gulf) (Comyns, 1995b). This extensive data set provides an opportunity to investigate how : 1) the number and spatial and temporal configurations of the collections used; 2) the number of larvae collected; and 3) the spawning intensity prior to sampling affect the consistency, precision and utility of mortality estimates. Species used to examine the magnitude and variability of mortality estimates in addition to red drum (*Sciaenops ocellatus*), include Atlantic bumper (*Chloroscombrus chrysurus*), vermilion snapper (*Rhomboplites aurorubens*), and red snapper (*Lutjanus campechanus*). Atlantic bumper were chosen because of their high abundance which increases the possibility of being able to determine consistent, precise estimates of daily larval mortality from intensive field collections, since the ability to accurately calculate mortality estimates is strongly influenced by abundance, frequency of occurrence (spatially and temporally), and the spatial extent and frequency of spawning. Larval vermilion and red snappers were included partly because they are of significant commercial and recreational importance, and because they are the most abundant snappers in the northern Gulf (Goodyear and Schirripa, 1991). In addition there is widespread concern that the populations of these snappers may have been reduced to low levels by over-fishing, and studies of the vital

rates of their early life-stages promise to further our understanding of their recruitment variability.

METHODS AND MATERIALS

Sampling Location and Shipboard Procedure

Ichthyoplankton samples were collected during September in the northcentral Gulf from 1988 to 1994. Two or three cruises were conducted each year, except in 1988 when only a single survey was done. Each survey was completed in three days and was conducted in east Louisiana, Mississippi, and Alabama coastal and inner-shelf waters (Figure 3.1). In addition, collections of red snapper larvae were taken during a single cruise in July 1992 (Figure 3.2). Collections were taken with oblique tows to within a few meters of the bottom using a Tucker trawl (1m x 1.4m), and ship speed was maintained at approximately 2 knots (1.0 m/s). The trawl was fitted with a 333 μm mesh nitex net and a mechanical flowmeter (General Oceanics) to measure volume filtered. Samples were stored in 95% ethanol so that otoliths could be preserved for age/growth analyses.

Data from several discrete-depth Tucker trawl collections taken in 1985 within the study area were included to document net extrusion of the smallest larvae. These collections were taken with both 333 μm and 202 μm mesh nets in the vicinity of a subsurface current drogue.

Laboratory Procedure

All fish larvae were removed from either the entire sample or from a one-half aliquot using a Motoda plankton splitter. Only one half of a sample was

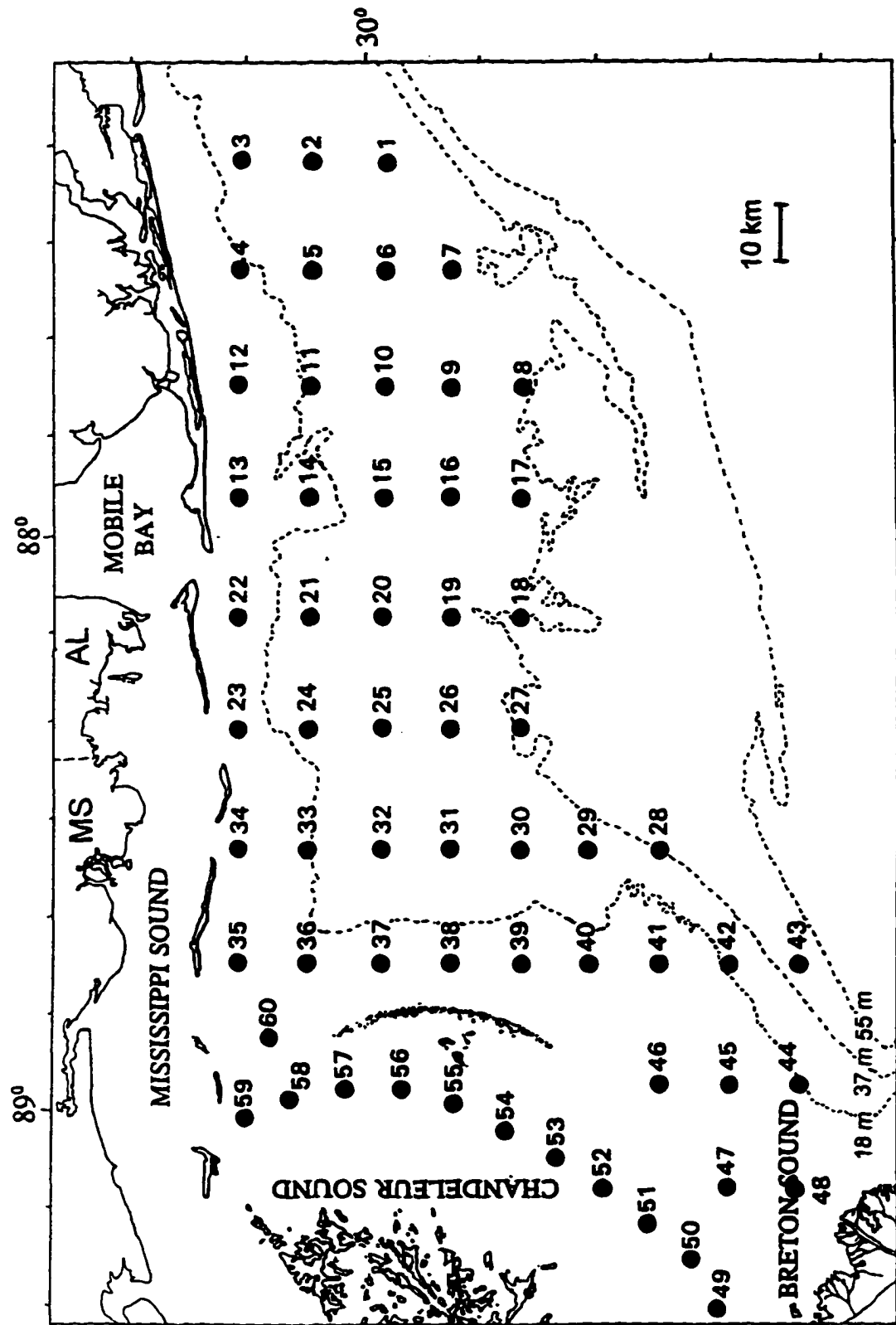


Figure 3.1 Station locations sampled during September 1988-1994 in the northcentral Gulf of Mexico.

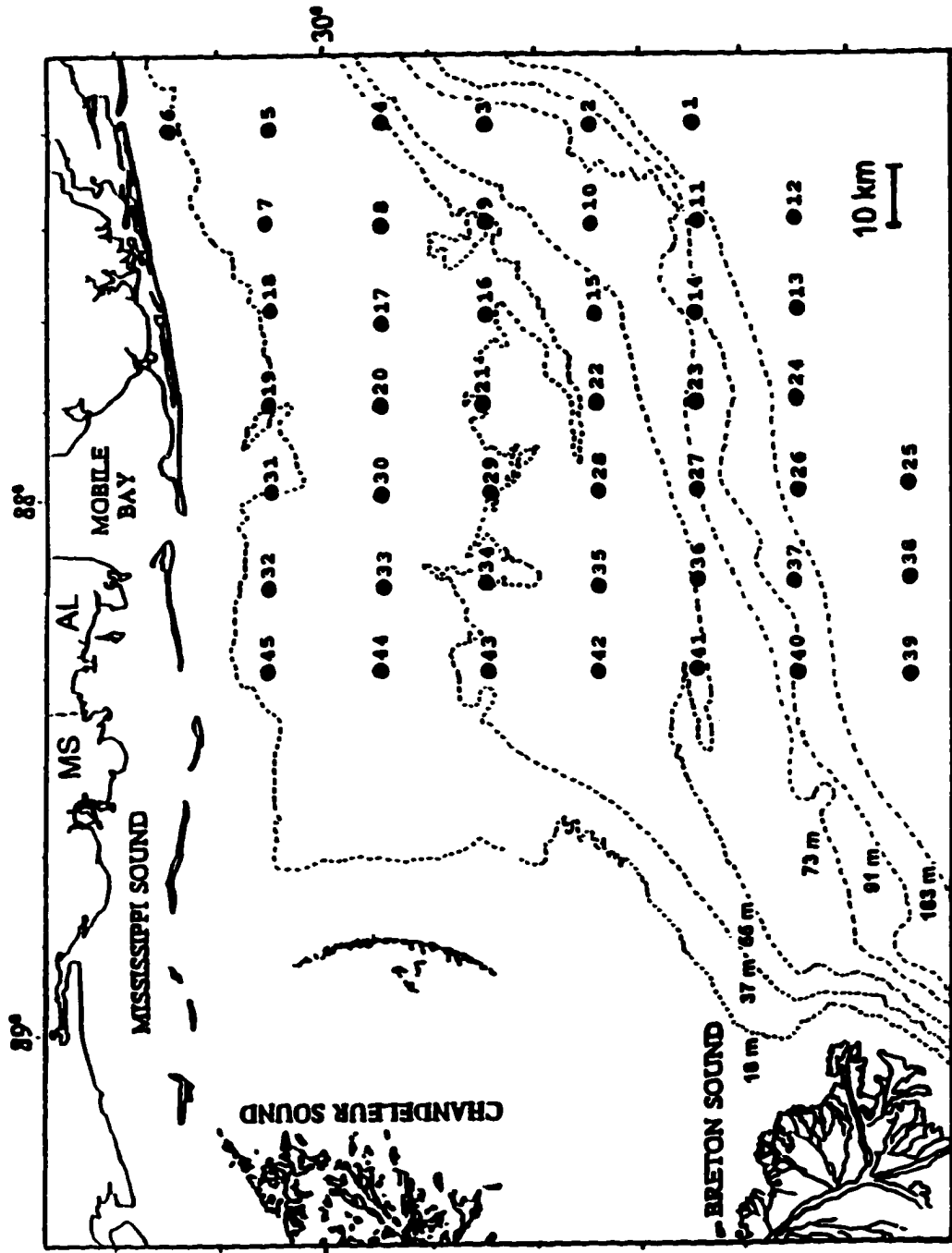


Figure 3.2. Station locations in the northcentral Gulf of Mexico during 6-9 July 1992.

sorted, if the settled volume of the plankton collection exceeded 500 ml.

Lengths of larvae were measured to the nearest 0.1 mm at 12 X or 25 X using a stereomicroscope, and larvae were sorted into 0.5 mm size classes.

Measurements were taken from the tip of the snout to the end of the notochord in pre-flexion larvae (notochord length, NL), and from the tip of the snout to the end of the urostyle or hypural plate (whichever was more distal) in flexion or post-flexion larvae (standard length, SL). Summaries of collection and larval abundance data are listed in Appendices A-O.

Data Analyses

Estimates of total larval abundance for each size class were developed for red drum, Atlantic bumper, and vermilion snapper by summing the abundance estimates of each size class under 10 m² of sea surface from each station. Length-frequency distributions were converted to age-frequency distributions by assigning ages to mid-points of the 0.5 mm size classes. Ages of red drum larvae were assigned to mid-points of the size classes using previously determined age-length relationships for this study area (Comyns et al., 1989). One of three age-length relationships were used, depending upon the water temperature when larvae were collected. Within-cruise station estimates of water temperature were relatively constant, varying by only 1 to 3°C over the 9000 km² surveyed. Age-length relationships of Atlantic bumper and vermilion snapper larvae, which were used to assign ages to the midpoints of the size classes, were described in Chapter 2. Ages of size classes for vermilion snapper larvae collected during a September 1993 cruise were

determined using an age-length relationship for larvae collected in September 1991 when water temperatures were similar, i.e., 28°-30°C. Age-class abundances were corrected for stage duration by dividing the abundance estimate of each age class by their respective durations (Houde, 1977). It is important to correct for stage duration if growth rates are non-linear. The instantaneous mortality rate (Z) was estimated by the slope of the exponential function relating duration-corrected larval abundance and age:

$$D_t = D_0 \exp (-Zt) \quad (\text{Ricker, 1975}),$$

where: D_t = total abundance of larvae at time t ;

D_0 = total abundance of individuals at time 0 (i.e., eggs);

Z = instantaneous mortality rate; and

t = age of size class in days since spawning.

Age and abundance of size classes were fitted to this exponential function with a nonlinear least squares routine, and only the descending limb of the regression was used to estimate mortality rates.

A time-series using cruise estimates of D_0 (index of larval abundance at time zero) and Z was developed for larval red drum and Atlantic bumper. A Pearson product-moment correlation analysis was used to test for a correlation between these two parameters. Because quantitative between-cruise comparisons of D_0 were needed, cruise-estimates of D_0 for these time series were adjusted for the number of stations sampled ($D_0/\text{number stations}$). These adjustments were needed because the number of stations sampled differed between cruises over the years.

To reduce potential problems associated with net avoidance by larger larvae, vermilion snapper and Atlantic bumper were limited to larvae smaller than 6.0 mm and 6.1 mm, respectively. The size for Atlantic bumper was increased to 6.1 mm because the 0.5 mm size-class intervals started at 1.1 mm, the size of the smallest larvae collected. To check the validity of our assumption that the size interval used was appropriate, Kolmogorov-Smirnov two-sample tests were used and showed no significant differences between size-frequency distributions within this size range for day vs night catches of vermilion snapper and Atlantic bumper larvae. A more conservative size-class truncation at 5 mm was used for red drum larvae. These data for larval red drum came from efforts during the past decade to estimate the spawning stock biomass (Comyns, 1995b), and the upper size limit of 5 mm had been adopted for that work.

RESULTS

Red snapper

In July 1992 a total of 56 red snapper larvae were collected at 18 of 45 stations sampled. The overall size-frequency distribution of larvae, obtained by pooling together station estimates of size-class abundance, showed no distinct pattern of decreasing larval abundance with successively larger size classes (Figure 3.3), and it was, therefore, not possible to estimate a mortality rate from these data.

Vermilion snapper

Size-frequency abundance distributions were derived for vermilion snapper larvae ($n=2,581$) taken during two September 1991 cruises, and a

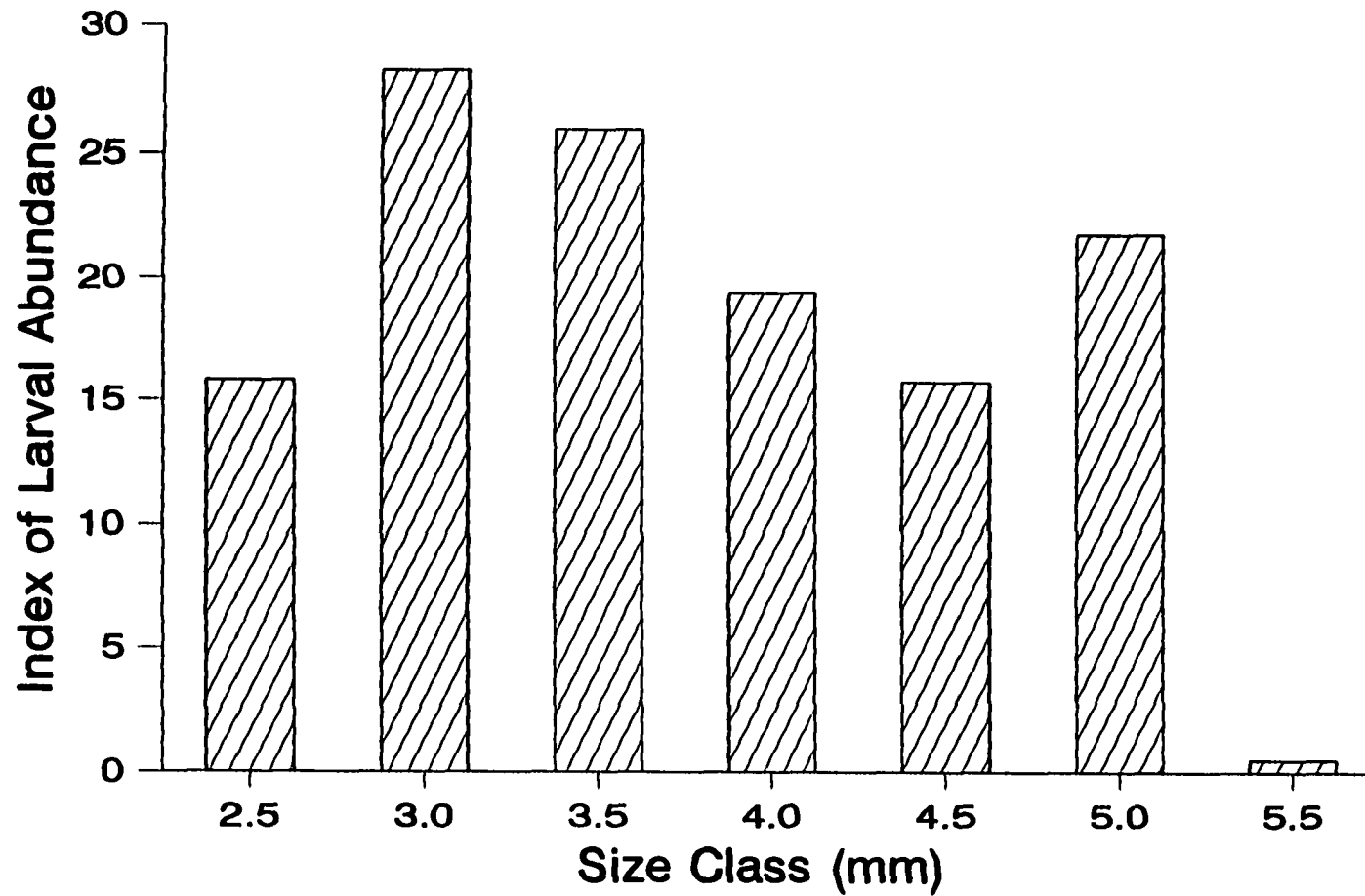


Figure 3.3 Size-frequency distribution of red snapper larvae ($n=56$) collected at 18 of 45 stations in the northcentral Gulf of Mexico during 6-9 July 1992. The index of larval abundance was obtained by pooling station abundances (# larvae under 10 m² of sea surface).

single late-September cruise in both 1992 and 1993 (Figure 3.4). Larvae collected during three of the cruises showed a steady decrease in abundance with successively larger size classes (Figure 3.4; sub-plots A, C and D). During the remaining cruise in late September 1991 (sub-plot B), the size-frequency distribution of larvae showed a distinct peak in abundance of intermediate-sized larvae (4.0 mm size class). Mortality coefficients obtained from duration-corrected age-frequency distributions from the four cruises ranged from 0.19 to 0.30. Standard errors for the mortality coefficients were relatively low, and ranged from 0.02 to 0.05.

Red drum

A total of 13,658 red drum larvae were identified from 15, 2-3 d ichthyoplankton surveys conducted during September 1988 to 1994. Size-frequency abundance distributions of larvae generated by pooling data from all positive stations during a cruise were highly variable (Figure 3.5). Size-frequency distributions from the three cruises when red drum larvae were most abundant show well defined descending limbs (Figure 3.5, sub-plots A, B and C). Estimates of mortality coefficients derived from these three size/age-frequency distributions ranged from 0.32 to 0.53, and standard errors of these estimates of Z were low (0.03-0.06). It should be noted, however, that large sample sizes, which should increase the probability of describing the actual overall size-frequency distribution of larvae from the area at the time of collection, did not always conform to the classic, single cohort exponential decline in abundance with time. For example in early September 1993

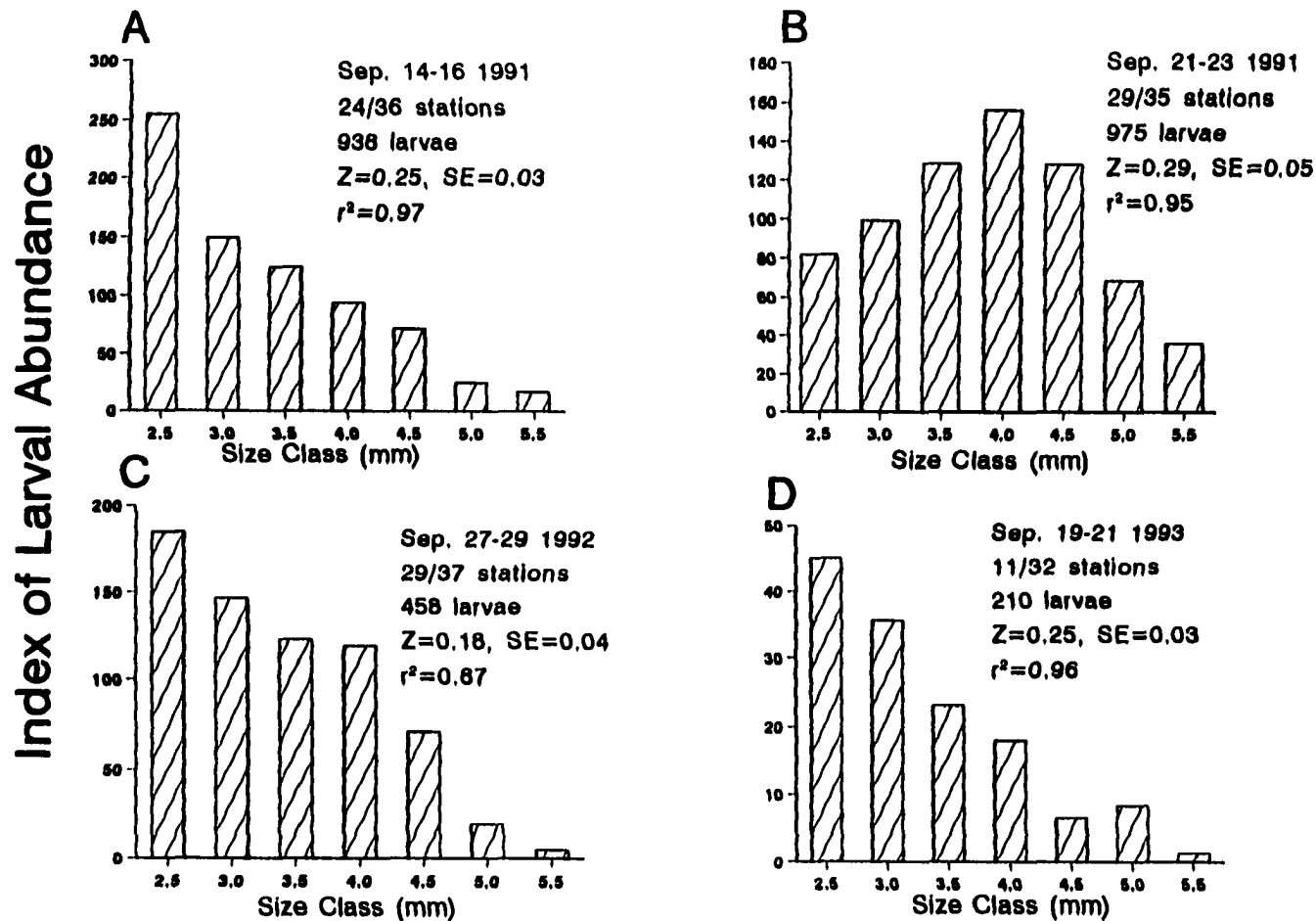


Figure 3.4. Size-frequency distributions of vermilion snapper larvae collected during four cruises conducted in the northcentral Gulf of Mexico during September 1991, 1992, and 1993. Estimates of Z , SE , and r^2 refer to mortality curves produced from the duration-corrected age-frequency distributions. The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (#larvae under 10 m² of sea surface).

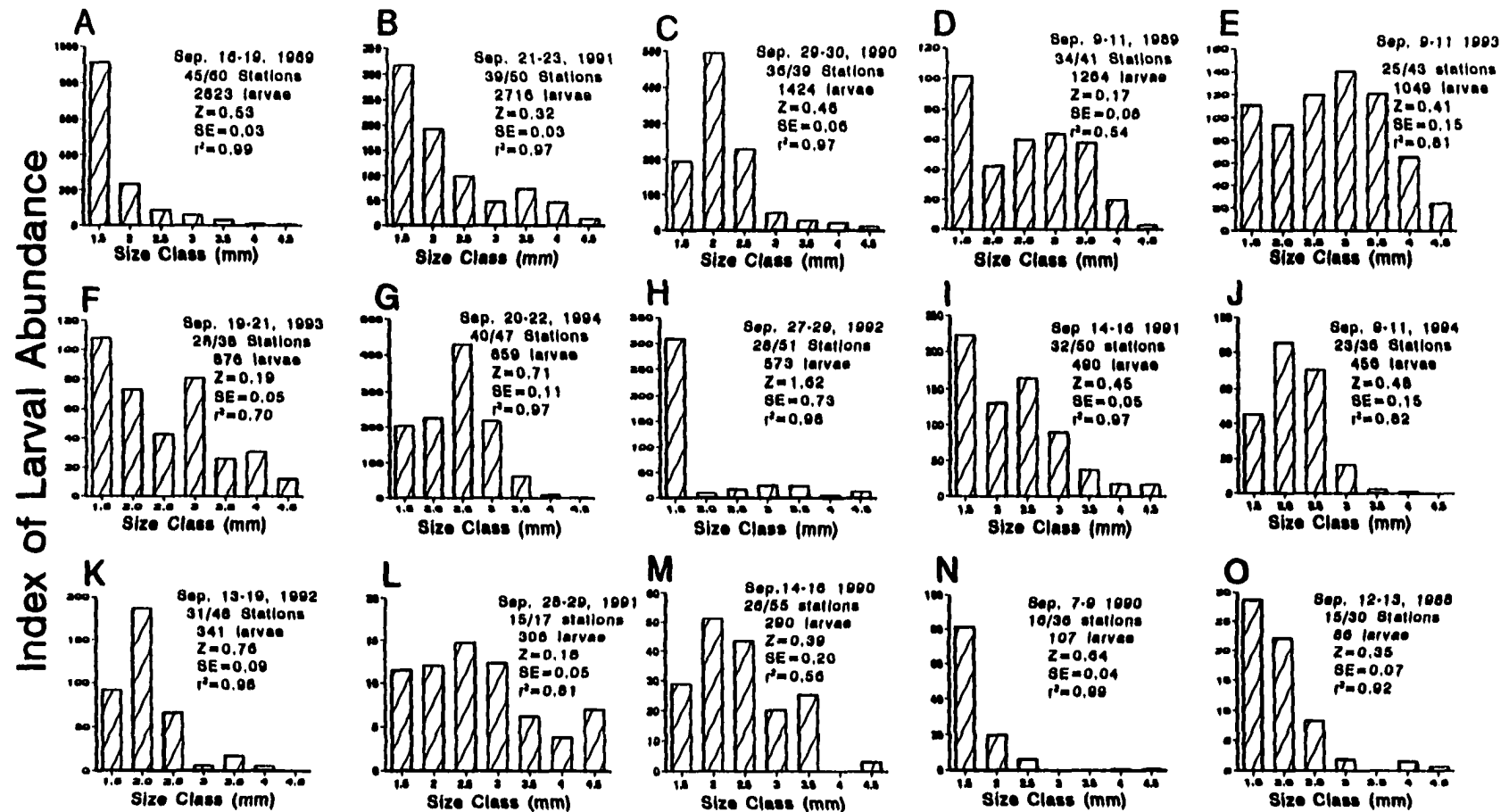


Figure 3.5. Size-frequency distributions of red drum larvae collected during 15 cruises in the northcentral Gulf of Mexico. Values of Z, SE, and r² refer to mortality curves produced from duration-corrected age-frequency distributions. The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (# larvae under 10m² of sea surface). Cruises are arranged in descending order of number of larvae collected.

(Figure 3.5; sub-plot E) over 1,000 red drum larvae were collected at 25 of 43 stations, but despite the large sample size, the mode of the size-frequency distribution was 3 mm. The large sample size and well defined peak in the abundance index of larger larvae, however, probably makes it likely that the size-frequency distribution and calculated mortality estimate reflect the population dynamics of the larger size classes at least. Lower abundances of smaller larvae were probably caused by decreased spawning activity (i.e., larval supply) prior to sampling. A peak in abundance of larger larvae was also found in early September 1989 (Sub-plot D), but during this cruise the smallest size class was also abundant, indicating the presence of two cohorts of larvae. The size-frequency abundance distributions of the remaining cruises are quite variable (Sub-plots F to O), and for many of these cruises the decrease in abundance of successive larger size classes is not very well defined. Estimates of Z from these cruises ranged from 0.18 ($SE=0.05$) to a very high value of 1.62 ($SE=0.73$; Sub-plots L and H). During 27-29 September 1992 (Sub-plot H) when the Z value of 1.62 was estimated, almost all of the fish collected were <2 mm, indicating that most of the larvae captured resulted from very recent spawning.

The most precise overall estimate of the average mortality rate of red drum larvae is probably obtained by combining catch data from numerous cruises, when ambient conditions are somewhat similar. Size-class abundances were combined from seven cruises conducted from September 1989 to 1992. Cruises were limited to surveys that were conducted when water

temperatures were similar (28°-30°C), because in order to estimate an overall mortality rate, the same overall growth equation was needed to convert size-frequency abundance distributions to age-frequencies. This overall size-frequency distribution, which is based upon lengths of 8,713 red drum larvae, shows an extremely consistent decrease in abundance of successively larger size classes (Figure 3.6). The mortality coefficient derived from this composite size-frequency distribution, after converting size classes to age classes, is 0.27, with a very low standard error (0.02). This overall mortality coefficient standard error is in fact lower than the SE estimates for the 15 individual red drum cruises (Table 3.1). All of the above mortality estimates are conservative because net extrusion of the very smallest larvae is not accounted for.

Several Tucker trawl collections taken in the vicinity of a subsurface current drogue in September 1985 with both 333 μ m and 202 μ m mesh plankton nets indicated that extrusion of larvae smaller than 2 mm was substantial (Table 3.2). Catches of this smallest size class (1.5-1.9 mm) were at least five times more abundant in the 202 μ m mesh net than in the 333 μ m mesh net. If abundance of this smallest size class in the overall size-frequency abundance distribution is increased by a factor of 5, the mortality coefficient increases from 0.27 to 0.94, which appears to be high. If the smallest size class is omitted from the overall size-frequency distribution, the Z value increases from 0.27 to 0.33 (with an SE of 0.04). This is probably the most applicable mortality coefficient estimate for red drum larvae within the 2.0-5.0 mm range.

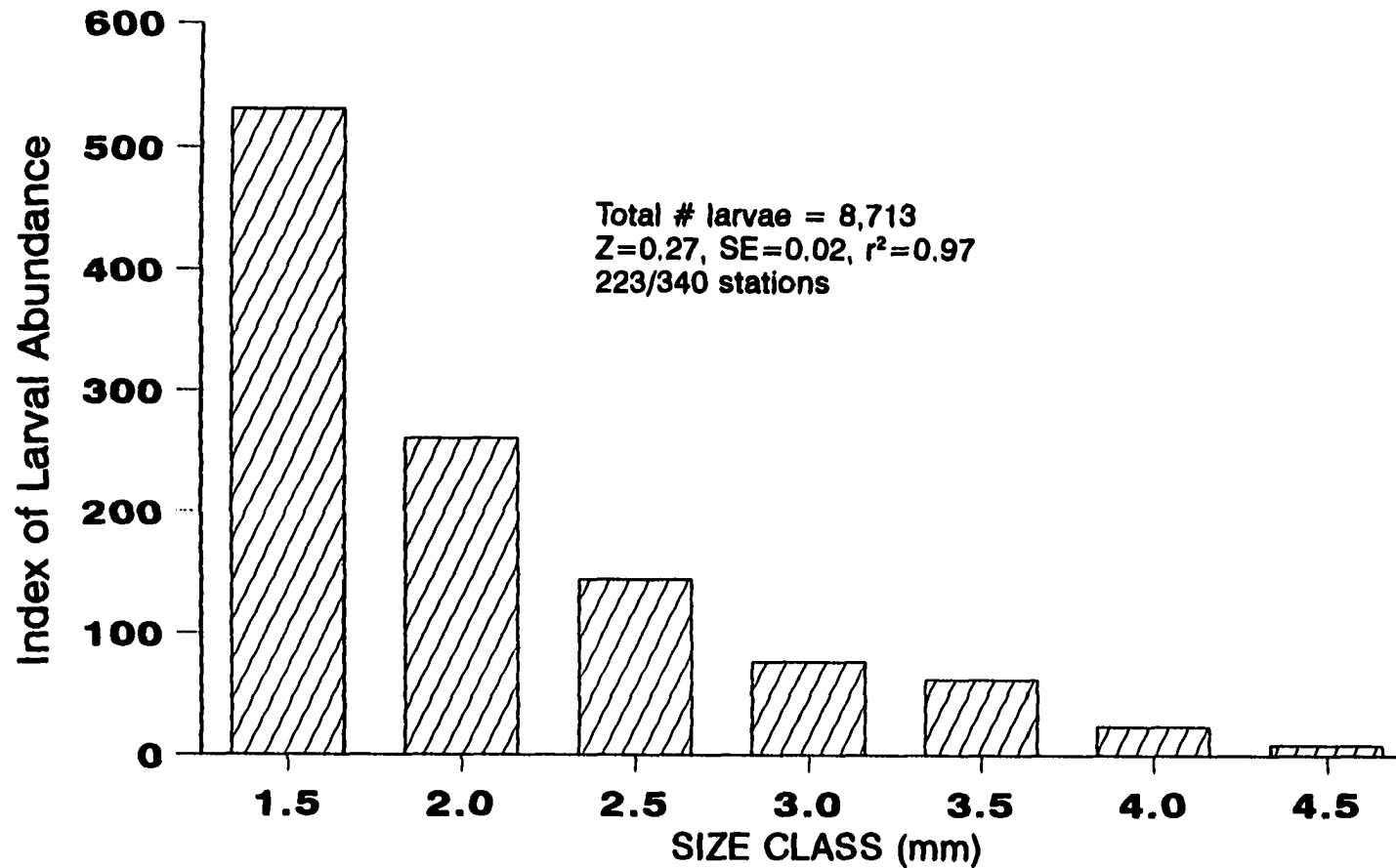


Figure 3.6. Size-frequency distribution of red drum larvae collected during seven plankton surveys conducted in the northcentral Gulf of Mexico during September 1989-1992. The mortality coefficient (Z) is estimated from the slope of the duration-corrected age-frequency distribution. The two station numbers refer to positive/total stations sampled. The index of larval abundance is a pooled estimate of station abundances (# larvae under 10 m² of sea surface).

Table 3.1. Estimates of mortality coefficients, Y-intercepts (adjusted for total # stations), and coefficients of determination for the descending limbs of red drum duration-corrected age-frequency distributions from 15 September cruises conducted from 1988 to 1994.

Cruise Date	Y-intercept of Mort. Curve	Mort. Coeff. (Z)	r² Value of Mort. Curve	# of Age Classes Used To Est. Z	# of Larvae	Pos. Stations/ Total Stations
Sep. 12-13, 1988	2.3, SE=0.5	0.35, SE=0.07	0.92	7	86	15/30
Sep. 9-11, 1989	3.4, SE=1.1	0.17, SE=0.06	0.54	7	1264	34/41
Sep. 16-19, 1989	30.0, SE=2.2	0.53, SE=0.03	0.99	7	2823	45/60
Sep. 7-9, 1990	4.2, SE=0.4	0.64, SE=0.04	0.99	7	107	16/36
Sep. 14-16, 1990	5.3, SE=6.9	0.39, SE=0.20	0.56	5	288	26/55
Sep. 29-30, 1990	49.3, SE=13.2	0.48, SE=0.06	0.97	6	1424	36/39
Sep. 14-16, 1991	31.7, SE=10.1	0.45, SE=0.05	0.97	5	490	32/50
Sep. 21-23, 1991	12.8, SE=1.4	0.32, SE=0.03	0.97	7	2,716	39/50
Sep. 28-29, 1991	2.6, SE=1.1	0.18, SE=0.05	0.81	5	306	15/17
Sep. 13-19, 1992	94.4, SE=37.5	0.76, SE=0.09	0.98	5	341	31/48
Sep. 27-29, 1992	226.3, SE=364.9	1.62, SE=0.73	0.98	7	573	28/51
Sep. 9-11, 1993	62.5, SE=68.7	0.41, SE=0.15	0.79	4	1049	25/43
Sep. 19-21, 1993	4.3, SE=1.1	0.19, SE=0.05	0.70	7	876	28/38
Sep. 9-11, 1994	18.6, SE=13.3	0.48, SE=0.15	0.82	5	456	23/36
Sep. 20-22, 1994	540.5, SE=368.4	0.71, SE=0.11	0.97	5	859	40/47

Table 3.2. Comparison between abundance of 1.5-1.9 mm red drum larvae collected with a Tucker trawl using 333 μm and 202 μm mesh nets. All collections were taken in the vicinity of a subsurface current drogue during 12 September 1985. Mean abundance of larvae per tow (\bar{x}) and associated standard errors (SE) are shown for each mesh size and strata fished.

Mesh Size	Depth Fished (m)	Time of Tow	Abundance of 1.5-1.9 mm Larvae (No. per 100 m³)
333 μm	1 m	0742-0747	5.7
"	"	0747-0752	7.6
"	"	0752-0757	23.6
		0742-0757	$\bar{x}=12.3$, SE=5.7
202 μm	1 m	0808-0814	99.4
"	"	0814-0819	88.9
"	"	0819-0824	21.4
		0808-0824	$\bar{x}=69.9$, SE=24.4
333 μm	5 m	0843-0848	15.0
"	"	0848-0853	26.9
"	"	0853-0859	14.0
		0843-0859	$\bar{x}=18.6$, SE=4.1
202 μm	5 m	0921-0927	94.4
"	"	0927-0932	270.0
"	"	0932-0936	89.6
		0921-0936	$\bar{x}=151.3$, SE=59.3

Individual mortality coefficients (Z) for red drum larvae collected during 15 cruises conducted from 1988 to 1994 ranged from 0.17 to 1.62 (Table 3.1). The Y-intercepts of these mortality curves, which are indices of the number of individuals at time zero, i.e., spawning, ranged from 2.3 to 540.5. The lowest value (2.3) was obtained from a cruise when larval abundance was very low (Table 3.1). If the assumption that predation losses of larvae due to density-dependent factors are minor (Pepin, 1987; Bailey and Houde, 1989) holds true, then there is no obvious reason that a relationship should exist between number of eggs spawned, and subsequent daily mortality rate experienced by developing larvae (≤ 5.0 mm); yet, these data do show such a relationship (Figure 3.7). A Pearson product-moment correlation analysis showed a significant correlation ($P < 0.05$) between the number of individuals at time zero and the subsequent larval mortality estimates. This indicates that estimates of the decrease in abundance of larvae over time were also strongly influenced by factors other than mortality. This relationship persisted even when the highly variable smallest size class was omitted from the analyses (Figure 3.8).

Atlantic bumper

Atlantic bumper larvae were generally the most abundant species in collections, with 39,938 larvae being collected during the eight cruises conducted in September of 1990, 1991 and 1993. Very few Atlantic bumper larvae were collected during the two cruises conducted in September 1992. Variability in the relative abundance of the various size classes from individual stations was high, even at a significant number of the stations where larvae

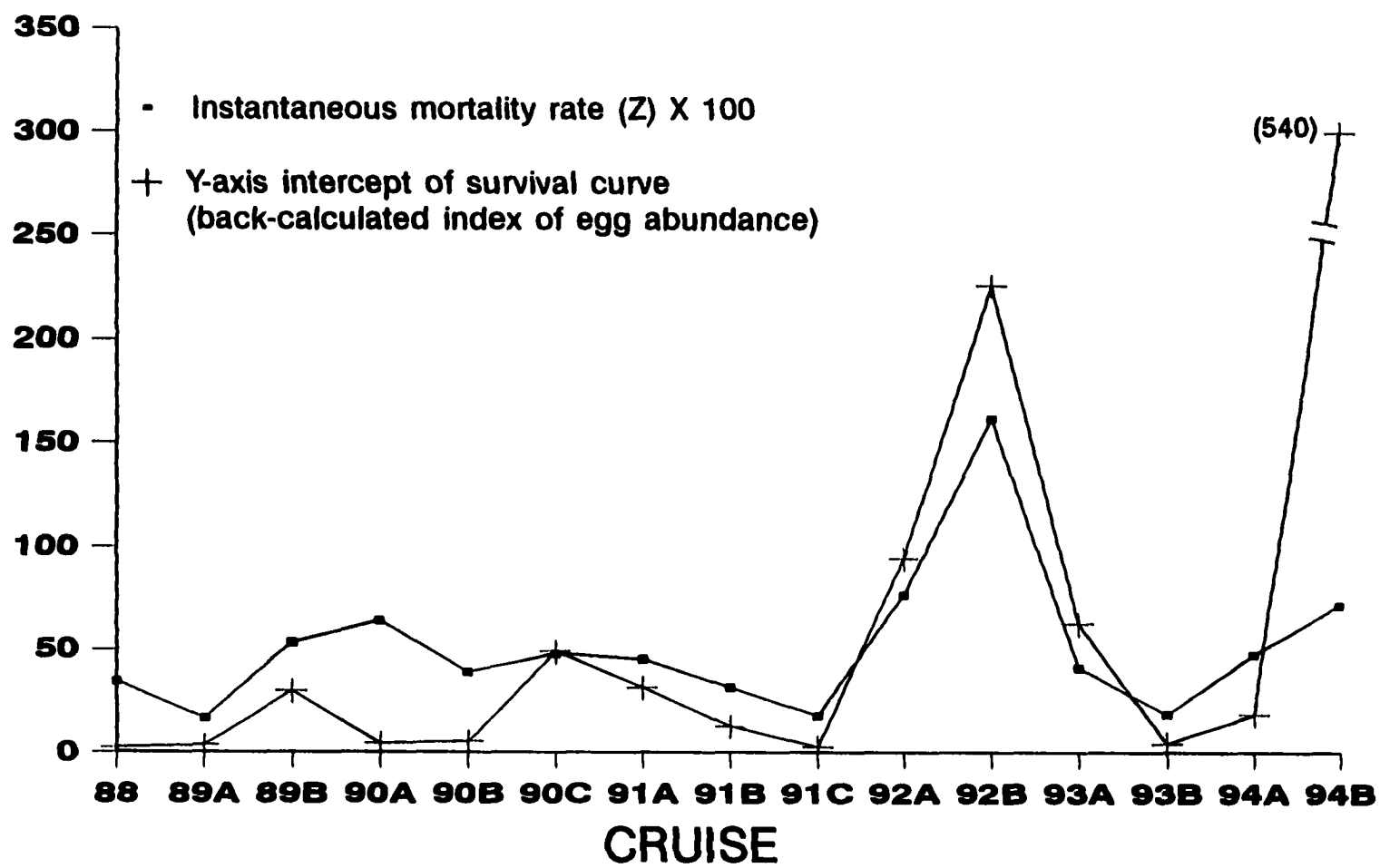


Figure 3.7. Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total # stations) for red drum larvae collected during 15, September plankton surveys, 1988-1994. For scaling purposes, values of Z were increased by a factor of 100.

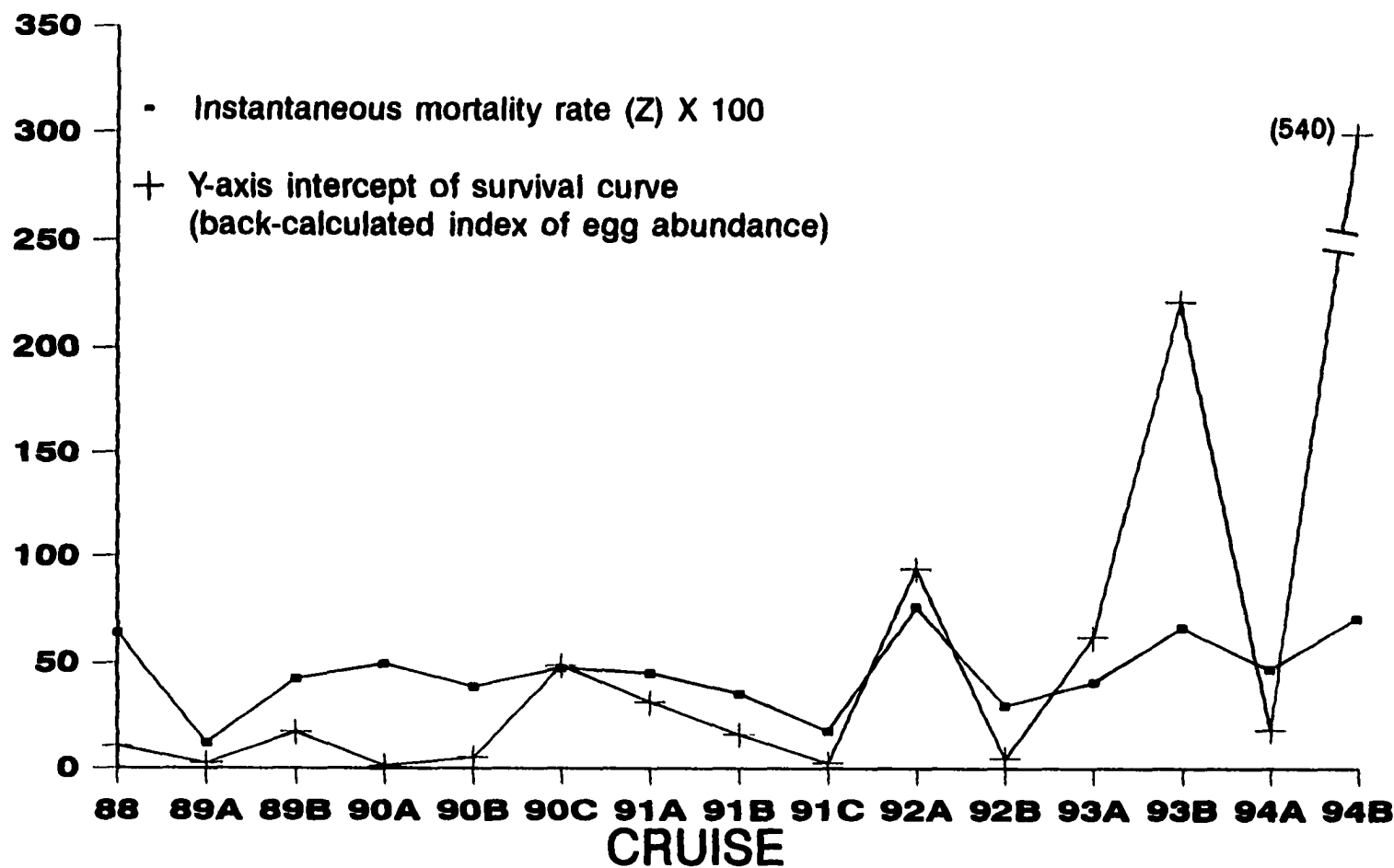


Figure 3.8. Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total # stations) for red drum larvae collected during 15, September plankton surveys, 1988-1994. For scaling purposes, values of Z were increased by a factor of 100. Smallest size class of larvae (1.5 mm) is excluded.

were most abundant during the cruise with the greatest abundance (Figure 3.9). When station abundance data were pooled for each of the eight cruises, size-frequency distributions generally exhibited a similar decrease in abundance with successively larger size classes, however, the smallest size-class (1.1-1.6 mm) was the most abundant in only three of the eight cruises (Figure 3.10; Sub-plots A, B and H). It is likely that low abundances of the smallest size class were caused, in part, by extrusion of larvae through the 333 μ m mesh net. Data to assess the extent of net extrusion for this smallest size class were not available. Cruise-estimates of mortality coefficients, which were derived by pooling data from all stations sampled during a cruise and omitting this smallest size class, ranged from 0.20 to 0.39 (Figure 3.10). Standard errors of Z estimates for seven of the cruises were low, and ranged from 0.02 to 0.05. The standard error of Z for the remaining cruise (Figure 3.10, Sub-plot F) was by comparison relatively high, 0.10, probably because of the small sample size. These estimates of mortality coefficients and their standard errors were more consistent than cruise-estimates of Z and SE for red drum.

A scatter plot displaying mortality coefficients and Y-intercepts of the mortality curves (i.e., number of individuals at time zero or at spawning) for these cruises shows no distinct or consistent relationship between these parameters (Figure 3.11). A Pearson product-moment correlation analysis showed no significant correlation between these two parameters, indicating that these estimates of mortality coefficients for larval Atlantic bumper are probably

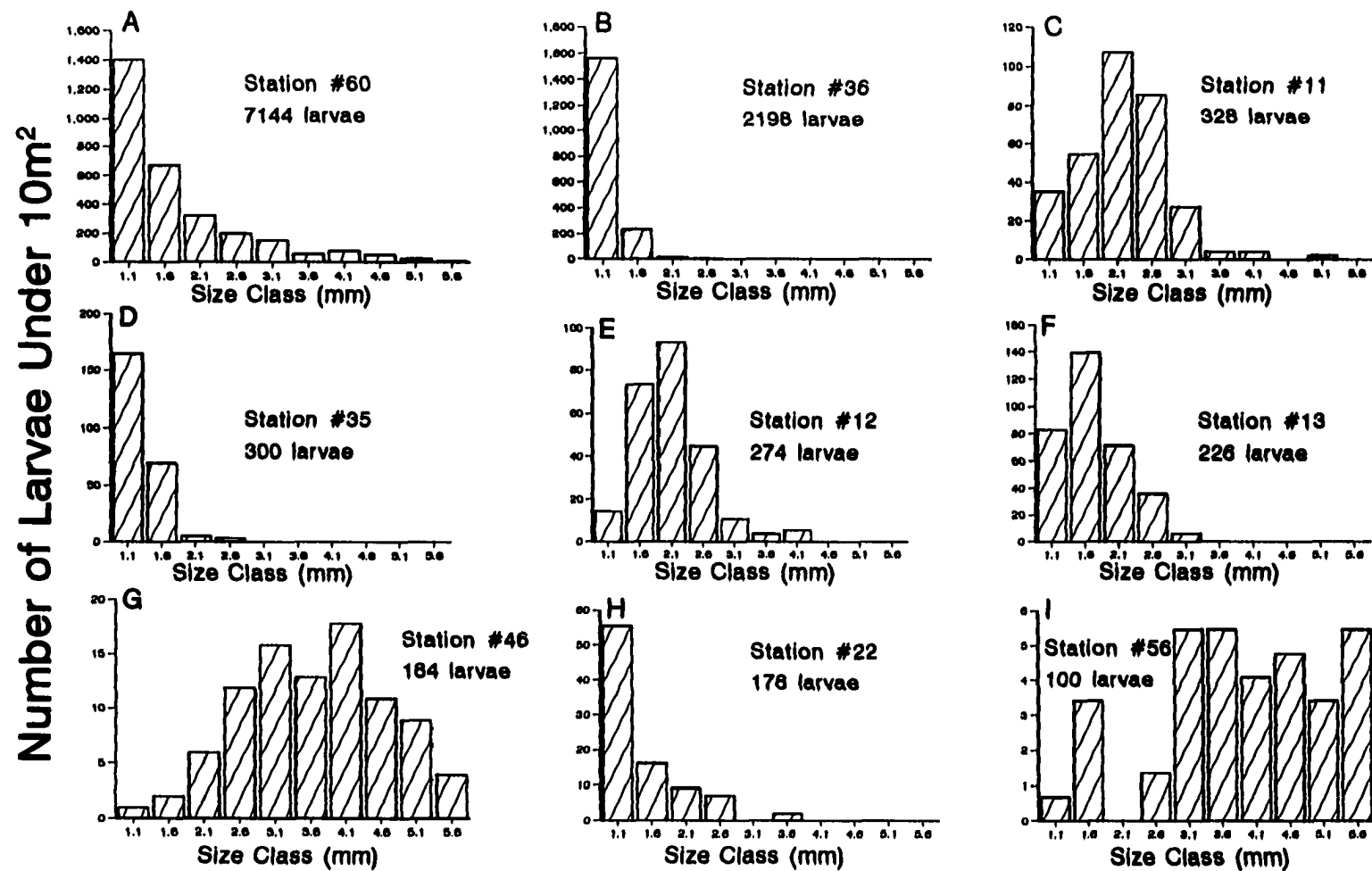


Figure 3.9. Size-frequency distributions of Atlantic bumper larvae collected at 9 stations in the northcentral Gulf of Mexico during 14-16 September 1990. These nine stations were selected because larvae were most abundant in these collections.

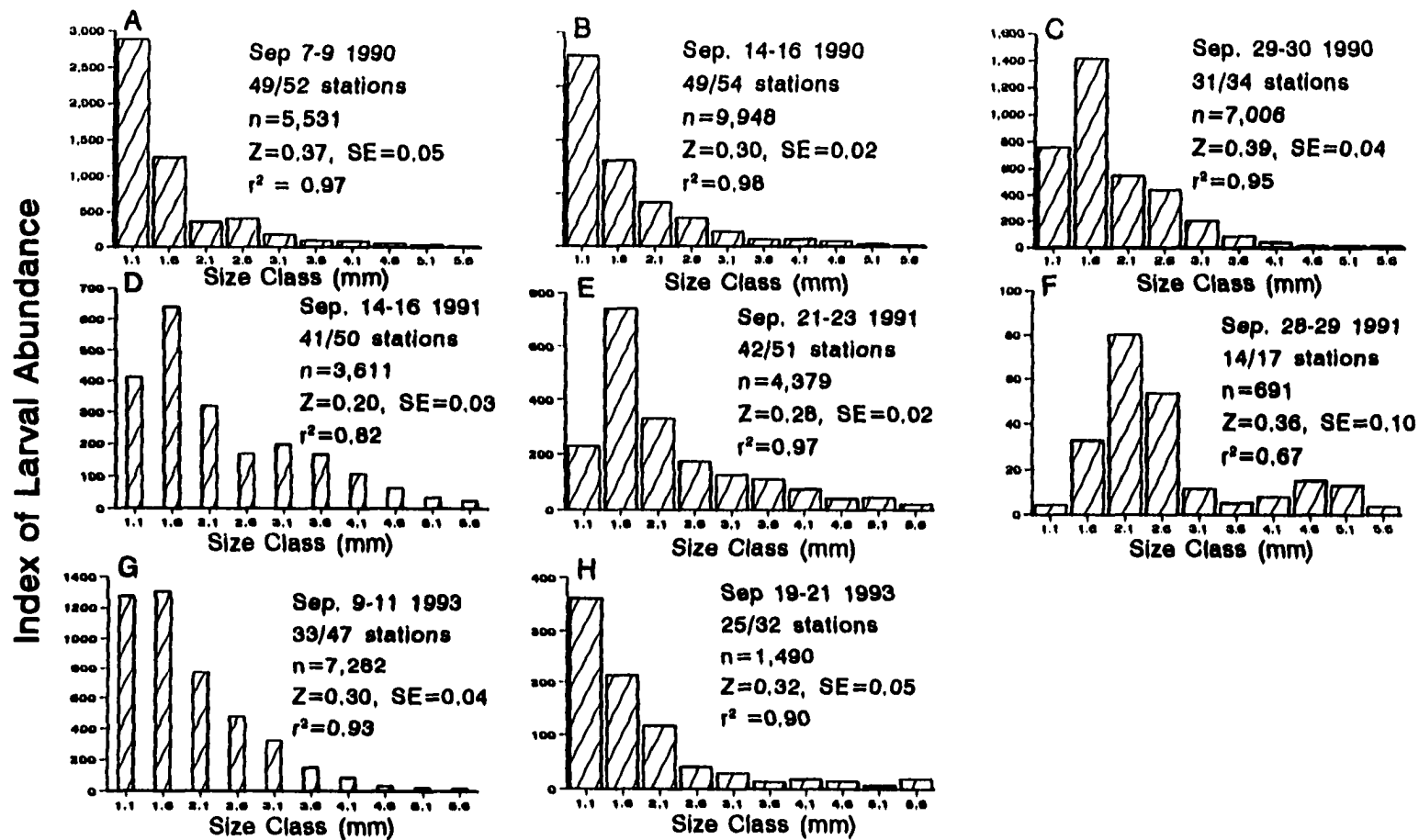


Figure 3.10. Size-frequency distributions of Atlantic bumper larvae collected during eight September cruises in the northcentral Gulf of Mexico. Values of Z , SE , and r^2 refer to mortality curves produced from the duration-corrected age-frequency distributions (omitting the smallest size-class). The two station numbers for each cruise refer to positive/total stations sampled. Indices of larval abundance for each cruise are pooled estimates of station abundances (# larvae under 10 m² of sea surface).

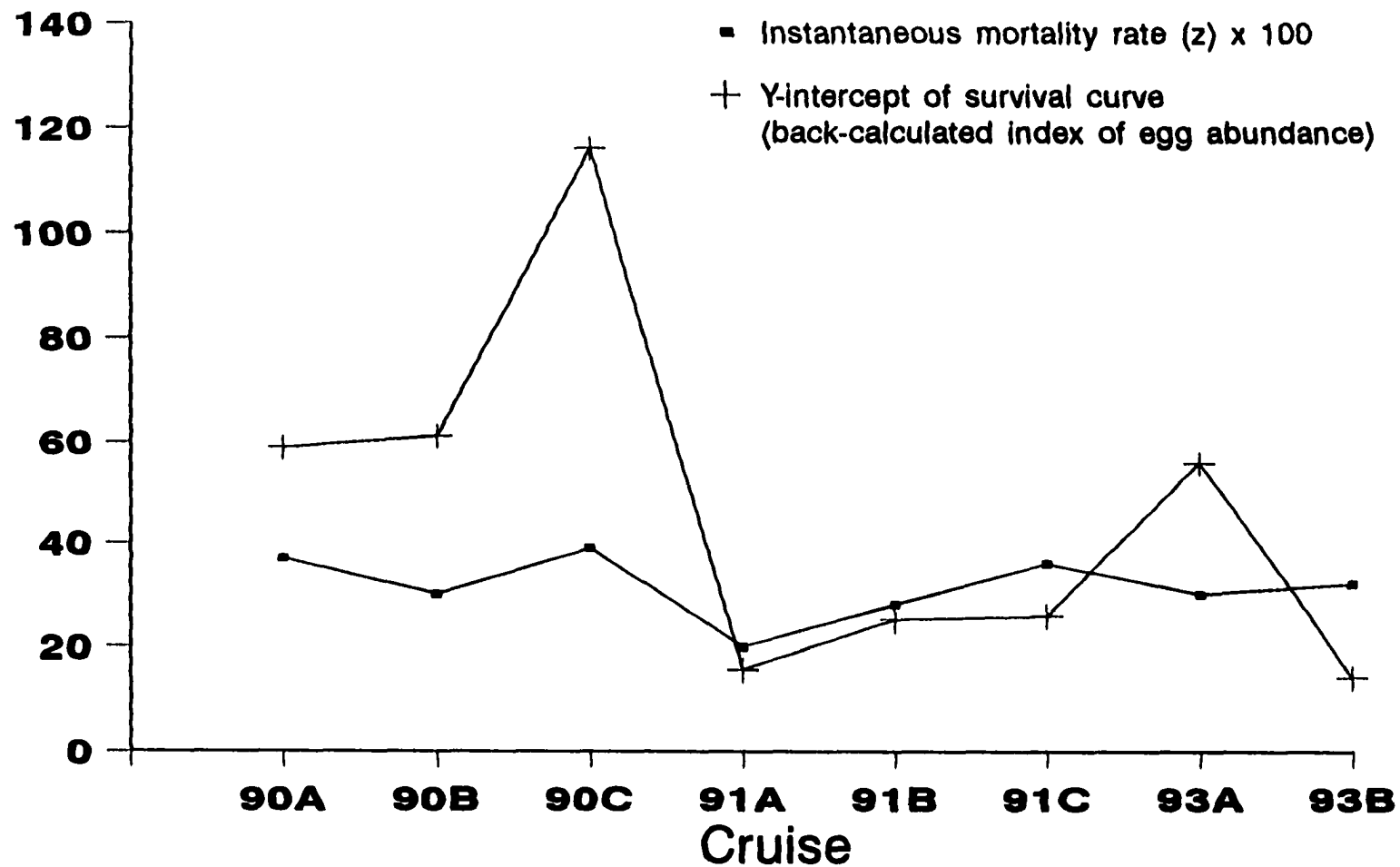


Figure 3.11. Scatter plot of daily mortality coefficients (Z) and Y-intercepts of survival curves (adjusted for total #stations) for Atlantic bumper larvae collected during eight September cruises in the northcentral Gulf of Mexico, 1990-1993. For scaling purposes, values of Z were increased by a factor of 100.

more precise than these estimates for red drum larvae that were correlated with the Y-intercepts of the mortality curves.

DISCUSSION

Two of the greatest challenges in fisheries science are first to understand the causes of recruitment variability, and then to accurately quantify it. The paradigm now established holds that changes in year-class strengths of many fish species are determined by mortality variability during larval and young juvenile stages (e.g., Sissenwine, 1984; Houde, 1987, Bailey and Houde, 1989; Cushing, 1994). Natural variability in recruitment success is expected, but consistently low levels of recruitment due to natural causes can be devastating, if stock sizes and recruitment levels have already been depressed due to anthropogenic factors.

During the past two decades, many studies have estimated mortality rates of fish larvae (i.e., see reviews by Houde, 1989; Morse, 1989), but the accuracy of many of these mortality estimates cannot be determined. These reported mortality rates do show a positive relationship with water temperature (Houde, 1989; Morse, 1989), a trend that is expected because of the increased predator consumption rates at warmer temperatures (Morse, 1989). In the present study, mortality rates of the larvae of several species in the northcentral Gulf are estimated from survey data using the descending limbs of age-frequency abundance distributions. Age-frequency distributions were derived from length-frequency distributions using growth equations developed in chapter 2. Ideally, all fish would be aged, but this was not possible because of

the large sample size and the labor intensive nature of otolith methodologies. Essig and Cole (1986) estimated mortality rates of larval alewives (*Alosa pseudoharengus*) collected in a coastal Massachusetts pond using both converted length-frequency distributions and actual age-frequency distributions, and found no statistical difference between the two methodologies.

The basic premise of using age-frequency distributions to estimate mortality rates for larvae is that the decrease in abundance of successively older age classes is due to mortality. However, as the following examples illustrate, the decrease in abundance of larvae over time can also be affected by other factors, including sample size, number and spatial configuration of stations sampled, and spawning frequency and intensity prior to sampling.

In the present study, relatively few red snapper larvae were collected, and a mortality estimate could not be determined because the overall age-frequency distribution of larvae did not show a decrease in abundance with successively older age-classes. Vermilion snapper were more abundant than red snapper larvae, and the descending limbs of the age-frequency distributions for the four cruises examined provided similar mortality estimates with low standard errors ($Z=0.19$ to 0.30 ; $SE=0.02$ to 0.05).

Red drum larvae were also quite abundant in collections, and 13,658 larvae were identified from 15, 2-3 d cruises conducted during September 1988 to 1994. Despite the abundance of red drum larvae, cruise-estimates of the relative abundance of age-classes were quite variable, and subsequent estimates of Z ranged from 0.17 to 1.62 (SE 0.03 - 0.73). Probably the most

useful or reasonable overall estimate of Z for red drum larvae (0.33, $SE=0.04$) was obtained by pooling all catch data from seven cruises which had similar ambient environmental conditions, and omitting the highly variable smallest size class (1.5-1.9 mm) whose abundance was shown in a gear comparison study involving different net mesh sizes to be strongly influenced by net extrusion.

A significant correlation ($P<0.05$) was found between the Y -intercepts and slopes (Z) of the 15 cruise estimates for red drum larvae. If density-dependent factors did not significantly affect larval mortality, as is currently hypothesized for ichthyoplankton in general (Pepin, 1987; Bailey and Houde, 1989), then this correlation indicates that estimates of the decrease in abundance of red drum larvae over time were also strongly influenced by factors other than mortality, such as fluctuations in spawning frequency, intensity and location prior to sampling that would affect field measurements of the relative abundance of age classes. One of the assumptions when using age-frequency distributions to estimate mortality rates is that the supply of larvae to the study area is somewhat constant, and this assumption cannot be met if there are large fluctuations in spawning frequency, intensity or locations prior to sampling. Such large fluctuations in red drum spawning are likely because this species is a batch, aggregate, synchronous spawner (Wilson and Nieland, 1994). The possibility of density-dependent factors affecting the mortality of red drum larvae is unlikely, but it cannot be discounted. This is because the aggregate, synchronous spawning behavior of red drum might

attract predators that feed upon the eggs and newly hatched larvae, and follow the patch of larvae through time.

Atlantic bumper larvae were extremely abundant ($n=39,938$ for 8 cruises), and cruise estimates of age-frequency distributions showed consistent, well-defined descending limbs. The relative abundance of the smallest 0.5 mm size-class (i.e., 1.1-1.6 mm) was quite variable and probably equally as susceptible to net extrusion as was red drum, therefore, estimates of mortality were obtained by omitting this smallest size-class. Estimates of mortality coefficients (Z) for Atlantic bumper larvae were similar for September cruises conducted within the same year. Mortality coefficients from the five surveys conducted in September 1990 and 1993 ranged from 0.30 to 0.39, and in 1991 the Z values from the two cruises conducted when larvae were relatively abundant were 0.20 and 0.28. Standard errors of these seven mortality estimates were low, and ranged from 0.02 to 0.05. The standard error for the eighth cruise was somewhat higher ($Z=0.36$; $SE=0.1$), probably because this cruise had the smallest sample size ($n=691$). Cruise estimates of Z for Atlantic bumper larvae were not correlated with Y-intercepts of the mortality curves. This strengthens the premise that changes in survey estimates of Z for Atlantic bumper larvae were primarily caused by mortality-induced changes in abundances of age classes.

Leffler and Shaw (1992) estimated mortality rates of Atlantic bumper larvae ($n=3,474$) during five cruises (one August and 4 September) over two years within the study area, and each cruise-estimate of Z was derived from the

pooled age-frequency distribution of larvae collected from approximately 41 samples taken in the vicinity of 3-5 windowshade drogues, i.e., from the same restricted water mass. The range in Z for the four September cruises over the two year period was 0.17-0.35. This range compares favorably with the observed range in Z from this studies eight September cruises over a three year period ($Z=0.20-0.39$). The mortality estimate from the August cruise was high ($Z=0.62$), perhaps due to the limited spatial extent of sampling.

Collections of larvae for this study were taken when water temperatures ranged from 25° to 30°C, and estimated mortality coefficients are similar to those reported in other studies under similar temperature regimes. Cruise estimates of mortality coefficients for vermilion snapper (4 cruises), Atlantic bumper (7 cruises), and the overall mortality estimate for red drum larvae, ranged from 0.19 to 0.39. Houde (1989) summarized vital rates of larval bay anchovy (*Anchoa mitchilli*), sea bream (*Archosargus rhomboidalis*), lined sole (*Achirus lineatus*), Spanish sardine (*Sardinella aurita*), Atlantic thread herring (*Opisthonema oglinum*), and speckled trout (*Cynoscion nebulosus*), from seven studies where the mid-points of water temperatures ranged from 26° to 28°C. Most of these studies generated a range of mortality estimates, and the mid-points of these Z ranges for six of these studies varied from 0.21 to 0.38, values that are very similar to my mortality estimates (0.19 to 0.39). Peebles and Tolley (1988) reported mortality coefficients for speckled trout postlarvae from Naples Bay, Florida, to range from 0.36 to 0.64. The authors hypothesized that the high mortality rates may have been the results of

environmental impacts from the city of Naples and the limited access to seagrass habitats.

Mortality rates have been shown to be positively correlated with both temperature and growth rates (Houde, 1989; Morse, 1989). This relationship could only be assessed for the two cruises for which vermilion snapper were aged because Atlantic bumper were only aged from one cruise, and red drum were not aged for this study. Ages of red drum larvae were assigned to size classes using previously determined age-length relationships for this study area (Comyns et al., 1989). For the two cruises examined, growth rates and mortality rates of vermilion snapper larvae were positively correlated with temperature. During the 14-15 September 1991 cruise when surface water temperatures were warm (28-30°C), the estimated mortality rate (Z) and growth coefficient (ln mm/d) of vermilion snapper larvae was 0.25 and 0.087, respectively. During 27-29 September 1992 when water temperatures were cooler (24-27°C), estimates of the larval mortality rate and growth coefficient were lower, 0.18 and 0.079, respectively. Morse (1989) suggested that it might be possible to predict mortality rates from growth rates which are relatively easy to obtain, but as Houde (1989) explained, it will be necessary to determine the growth rates and mortality rates of many species to establish how reliable this approach might be.

The most reliable estimates of mortality are probably derived by following a well defined cohort of larvae, and describing the decrease in larval abundance over time (adjusting for dispersion, etc.). However, this

methodology is only specific for the limited mass of water sampled, and results cannot be extrapolated to larger areas. Estimating average mortality rates for larger areas using the descending limbs of age-frequency distributions requires extensive field efforts (e.g., a dense grid of stations, multiple cruises during the spawning season, etc.). The size of the area sampled should be sufficiently large as to help mitigate the impacts on mortality estimates due to spatial and temporal fluctuations in spawning frequency, intensity, and areas, or movement of larvae into or out of the study area.

The northcentral Gulf of Mexico east of the Mississippi River is an ideal area for this type of study, because this region affords a "sheltered corner" where sustained directional current movement is minimal. It is therefore assumed that there is relatively little directed transport of larvae into or out of our relatively large study area (i.e., 9000 km²). Lyczkowski-Shultz et al. (1988) deployed a surface water current drogue for a period of 1 to 2 d, fifteen times in my study area during the fall months from 1983 to 1985. Apart from one drogue that in 24 h drifted for ten miles in a southerly direction immediately east of the Chandeleur Islands, drogue trajectories were generally quite random, and drogue tracks often reversed direction 180°. Shaw et al. (1988) deployed 3-5 windowshade drogues during each of five cruises (one August and four September) over two years within the study area, and these drogue trajectories were also very meandering. These drogue studies were not conducted during frontal passages, however, when northerly winds have been shown to cause a westward flow immediately south of the Mississippi-Alabama barrier islands

(Schroeder et al., 1985; 1987). This westward flow forms the northern segment of a weak cyclonic gyre that often forms in the northcentral Gulf east of the Mississippi River Delta (Schroeder et al., 1987; Dinnel, 1988).

However, even though the movement of larvae into or out of the study area is thought to be minimized in this region, meaningful mortality estimates cannot be determined if spawning frequency and intensity (temporal or spatial) prior to sampling is highly variable, as was probably the situation with red drum, a known multiple batch, aggregate, and synchronous spawner (Wilson and Nieland, 1994). It is likely that estimates of Z were most accurate for Atlantic bumper larvae, and that the extensive field collections of these larvae provided data to detect a difference in daily mortality rates of approximately 0.1, i.e., a difference in Z between values of 0.20 and 0.30, or 0.3 and 0.4. For example, in September 1990 the three cruise estimates of Z ranged from 0.30 to 0.39, in 1991 the two estimates of Z from cruises when larvae were abundant were lower, i.e., 0.20-0.28, and in 1993 the two cruise estimates of Z were similar and were again somewhat higher (0.30 and 0.32). However, despite the intensive sampling and large sample sizes for Atlantic bumper, estimates of Z are probably still too imprecise to detect small changes in average mortality rates. It is likely that a true difference between Z values of 0.24 and 0.28, for instance, may not be detected. Even this small change in daily mortality rates can double the number of larvae that survive to an age of 20 d, and so these data indicate that even extensive field efforts can presently only detect relatively large changes in the mortality rates of larvae.

The observed differences in growth rates presented in the previous chapter, and estimates of larval mortality rates presented here, clearly show the potential of causing large differences in cumulative larval survival. For example, station estimates of the age of 6 mm vermilion snapper larvae, based on growth equations, ranged from 12.3 to 15.2 d, and cruise estimates of daily mortality coefficients for vermilion snapper larvae ranged from 0.19 to 0.30.

Initial number in cohort	Instantaneous mortality coefficient (d ⁻¹)	Age of 6 mm larva (d)	Number of 6 mm larvae
1 x 10 ⁶	0.19	12.3	96,617
1 x 10 ⁶	0.19	15.2	55,687
1 x 10 ⁶	0.25	12.3	46,190
1 x 10 ⁶	0.25	15.2	22,371
1 x 10 ⁶	0.30	12.3	24,972
1 x 10 ⁶	0.30	15.2	10,462

Using these vital rates, and a hypothetical initial cohort size of 1 x 10⁶ individuals, 96,617 larvae survive to a length of 6 mm with the scenario of relatively fast growth and low mortality. Conversely, if the slower growing larvae are exposed to the high mortality rate, cumulative survival of larvae decreases by one order of magnitude, and only 10, 462 larvae survive to a length of 6 mm.

These data show that even in a subtropical climate when larval stage durations may be as short as two weeks, relatively small changes in larval growth rates, particularly when combined with differences in mortality, can have a large impact on cumulative larval survival. Understanding the potential relationships

involved, and causes of recruitment variability, however, is only a small step towards developing the capability of accurately and precisely predicting recruitment variability because of the massive logistical task of adequately quantifying the spatial and temporal variability of the many dynamic biological and physical factors affecting spawning adults and resultant egg, larval and juvenile stages.

CONCLUSIONS

Recruitment variability, which remains the single least understood problem in fishery science today (Cushing, 1994; Mertz, 1995), is largely due to factors that affect the survivorship of larvae, postlarvae and young juvenile fishes. Many questions remain concerning the causes of recruitment variability because the many factors are likely to be interrelated, and even subtle variability in these factors may have a significant effect on larval survival. Order of magnitude differences in year class abundance can potentially be caused by even relatively small changes in growth or mortality rates during the early life stages (Parish, 1973; Laurence, 1979; Houde 1987, 1989). Houde (1987) showed how changes in the length of the larval stage can have a great impact on cumulative larval survival, but surmised that this is most likely to occur in temperate or boreal waters where the cool temperatures slow growth rates and increase the length of the larval stage duration, i.e., up to 100 d (Houde, 1989).

The primary purpose of this research was to use extensive plankton collections (i.e., multiple cruises sampling 30 to 60 stations within a 9,000 km² region during the red drum spawning season using the same methodology and personnel) taken in the northcentral Gulf of Mexico to determine the spatial and temporal differences in the growth rates and mortality rates of larvae, and to ascertain whether these differences are great enough to impact the survival of larvae in a subtropical climate where larval stage durations are short (i.e., 2 weeks). In addition, multiple cruise estimates of larval growth and mortality allowed the determination of the amount of inherent variability involved and how

it affects the precision of field estimates of larval mortality for several species which differ in abundance, distribution, and adult spawning behavior. These data provided a unique opportunity to study these vital rates because of the dense station coverage over a relatively large area of the northcentral Gulf (~9,000 km²), and because cruises were conducted at the same time of year (September) during a seven year period.

Significant differences in growth rates were found for both vermilion snapper and Atlantic bumper larvae that were collected at stations where hydrographic conditions were similar, indicating the probable existence of small-scale patchy feeding conditions. Reasons for the differences in larval growth rates were not adequately explained, probably because it was not possible to account for food availability, i.e., prey items such as copepod nauplii were not retained in the 333 μ m mesh nets. The variability in growth rates is not unexpected, however, considering the high variability in the observed spatial and temporal distribution of surface chlorophyll *a* levels, macrozooplankton biomass, copepod abundance, and dispersion of fish larvae. Future research is needed to further characterize this small-scale variability in growth rates of larvae, particularly with regard to microzooplankton patchiness and the temporal and spatial pattern of potential predators. This small-scale spatial variability in larval growth rates may be far more common than previously thought, and understanding this subtle mosaic may help us to better partition the causes of recruitment variability. Pepin (1993) noted that data used to derive general empirical models often come from studies for which

measurements were taken at coarse space and time scales, and consequently the cumulative error associated with such measurements results in relationships that have broad confidence intervals.

Cruise estimates of mortality coefficients (Z) for larval red drum, Atlantic bumper, and vermilion snapper were estimated from the descending limbs of age-frequency distributions (adjusted for stage duration). The inclusion of red drum for mortality estimates and the variability in number of cruises examined for different species is explained in the introduction of this dissertation. Estimates of Z for larval vermilion snapper ($n=2,581$; 4 cruises) and Atlantic bumper ($n=39,247$; 7 cruises) ranged from 0.19 to 0.39 and standard errors of these estimates were low (0.02-0.05). Mortality coefficients for red drum larvae ($n=13,658$) estimated from 15 surveys were highly variable ($Z=0.17-1.62$), and the associated standard errors of these estimates were relatively large (0.03-0.79). The high variability in red drum mortality estimates was likely caused, in part, by the group, synchronous, and multiple spawning behavior of red drum. This spawning behavior would modulate the supply of red drum larvae to the study area in time (frequency and amplitude) and space, and consequently would affect the relative abundance of larval age classes from which mortality is estimated. The overall estimate of Z for red drum larvae (0.31, $SE=0.02$), obtained by pooling all catch data with similar environmental parameters, was very similar to values found for vermilion snapper and Atlantic bumper.

It is likely that cruise estimates of Z were most precise for Atlantic bumper larvae because of both the consistency of these mortality estimates

and their low standard errors. Based on the similarity of Z estimates generated from cruises conducted within the same year (one or two weeks apart), extensive field collections of Atlantic bumper larvae can probably provide data to detect a difference in mortality coefficients of approximately 0.10, i.e., between values of 0.20 and 0.30, or 0.3 and 0.4. However, despite the intensive sampling and large sample sizes encountered for Atlantic bumper, estimates of Z are probably still too imprecise to detect small changes in average mortality rates. It is likely that a true difference between Z values of 0.24 and 0.28, for instance, may not be detected. Even this small change in daily mortality rates can double the number of larvae that survive to an age of 20 d, and so these data indicate that even extensive field efforts can presently only detect relatively large changes in the mortality rates of larvae.

A hypothetical situation involving observed growth rates for vermilion snapper and Atlantic bumper larvae with constant larval mortality showed that twice as many larvae potentially survived to a length of 6 mm at stations with the fastest observed growth rates than at nearby stations with the slowest growth rates. In addition, relatively small differences in larval mortality, when combined with these observed station differences in larval growth rates, could alter potential cumulative larval survival by an order of magnitude. These data show that the survival of larvae can be significantly impacted by relatively small changes in the magnitude of vital rates even in a subtropical climate when larval stage durations may be as short as two weeks compared to as long as 12 weeks in northern latitudes.

It must be emphasized that field efforts for the present study were extensive. Few studies can match the dense station coverage over a relatively large study area (i.e., up to a 60 station grid within a 9,000 km² area), the long term data base (i.e., up to 7 years for red drum), and multiple cruises during the spawning season (up to 15 cruises) that this study provides. However, in spite of these efforts the data presented in this study can only qualitatively show how variability in the vital rates of larvae can influence recruitment variability. The ultimate goal of these types of studies theoretically would be to develop the capability of consistently, precisely and accurately predicting large changes in year-class abundance, but this would require a massive effort to quantitatively assess within a large area the spatial extent, frequency and intensity of spawning, and the spatial and temporal abundance, growth, and survival (and associated variability) of the resultant larvae. In addition, it may be necessary to quantify both the availability of the appropriate prey and the predatory field within the study area. The enormity of this task would be further complicated by the dynamic nature of biological systems which would require sampling to be conducted over an extended period to account for changing environmental factors during the spawning and larval grow-out period. It is doubtful that such a study would be conducted because of the tremendous multi-disciplinary field efforts required, and it is consequently unlikely that studies of the vital rates of fish larvae will successfully develop the necessary precision and accuracy to quantitatively assess recruitment variability in a rigorous fashion.

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Appendix A. Summary of collection and abundance data for *Sciaenops ocellatus* larvae taken in bongo net samples from the northcentral Gulf of Mexico during September 1988.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
1	09/13	11	53.9	0	0
2	"	16	69.4	3	6.9
3	"	16	72.1	3	6.7
4	"	14	36.1	3	11.6
5	"	8	60.9	4	5.3
6	"	50	140.3	5	17.8
7	09/30	50	219.3	0	0
8	09/29	38	157.6	0	0
9	"	33	154.4	0	0
10	09/13	29	79.1	0	0
11	"	9	51.2	13	22.9
12	10/01	9	71.9	3	3.8
13	"	20	110.5	0	0
14	"	30	116.2	0	0
15	09/30	36	152.5	3	7.1
16	"	40	243.0	7	11.5
17	10/01	32	140.3	0	0
18	"	24	93.3	0	0
19	"	9	66.6	1	1.4
20	"	18	78.5	0	0
21	"	25	100.3	0	0
22	09/30	81	240.0	0	0
23	"	105	226.3	0	0
24	09/12	7	101.6	2	1.4
25	"	7	79.9	7	0.9
26	"	4	39.6	0	0
27	"	4	52.2	12	9.2
28	"	4	47.3	17	14.4
29	09/13	5	128.8	0	0

Appendix A (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
30	09/13	7	84.3	3	2.5

Appendix B. Summary of collection and abundance data for *Sciaenops ocellatus* larvae taken in Tucker trawl collections from the northcentral Gulf of Mexico during 9-11 September 1989.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
1	09/09	9	182.3	4	2.0
2	"	15	269.2	0	0
3	"	11	163.7	0	0
4	"	17	252.7	4	2.7
5	"	7	141.6	4	2.0
6	"	14	183.3	18	13.7
7	"	8	144	22	12.2
8	"	24	299.6	10	8.0
9	09/10	18	276.9	28	18.2
10	"	23	390.7	0	0
11	"	27	511.3	0	0
12	"	29	426.7	2	1.4
13	"	33	441.8	26	19.4
14	"	25	371.1	2	1.3
15	"	26	360.2	18	13.0
16	"	32	256.8	2	2.5
17	"	25	401.2	16	10.0
18	"	31	422	0	0
19	"	33	486.4	0	0
20	"	26	336.8	16	12.4
21	"	26	0	0	0
22	"	14	201.4	16	11.1
23	"	5	152	64	21.1
24	09/10	14	261.8	6	3.2
25	09/11	31	459.7	8	5.4
26	"	11	327.2	86	28.9
27	"	16	408.9	88	34.4
28	"	48	362.4	29	38.4
29	"	48	551.3	26	22.6

Appendix B (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
30	09/11	14	276.6	8	4.0
31	"	8	203.5	108	42.5
32	"	8	297.6	40	10.8
33	"	5	244.7	10	2.0
34	"	4	184.3	6	1.3
35	"	3.5	159.2	16	3.5
36	"	3.2	200.8	90	14.3
37	"	4.2	90.7	17	7.9
38	"	4.2	136	26	8.0
39	"	6.5	208.4	316	98.6
40	"	7.5	218.3	46	15.8
41	"	10	146.4	68	46.4

Appendix C. Summary of collection and abundance data for *Sciaenops ocellatus* larvae taken in Tucker trawl collections from the northcentral Gulf of Mexico during 16-19 September 1989.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
1	09/16	28	435.1	0	0
2	"	25	384.6	0	0
3	"	17	373.6	10	4.6
4	"	20	346.7	12	7.0
5	"	25	285.0	0	0
6	"	28	439.5	0	0
7	"	30	461.8	0	0
8	"	33	610.4	0	0
9	"	32	517.5	0	0
10	"	28	339.4	4	3.3
11	"	17	308.9	12	6.6
12	"	9	252.6	0	0
13	09/17	9	142.3	18	11.4
14	"	15	220.2	6	4.1
15	"	23	342.6	64	43.0
16	"	28	406.8	8	5.5
17	"	32	313.4	1	1.0
18	09/17	35	457.1	4	3.1
19	"	32	386.8	16	13.2
20	"	26	334.1	0	0
21	"	17	226.7	5	3.7
22	"	12	215.8	12	6.7
23	"	9	218.4	134	55.2
24	"	16	211.2	394	298.5
25	"	27	376.4	2	1.4
26	"	31	335.3	4	3.7
27	"	33	434.5	0	0
28	09/18	49	588.2	10	8.3
29	09/17	32	325.5	1	1.0

Appendix C (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
30	09/17	29	374.3	2	1.6
31	"	26	303.3	6	5.1
32	"	25	307.8	161	130.8
33	"	15	186.9	149	119.6
34	"	10	160.5	26	16.2
35	09/18	11.5	185.2	38	23.6
36	"	11.5	231.6	154	76.5
37	"	16	252.3	16	10.1
38	"	8	217.6	64	23.5
39	"	16	254.8	14	8.8
40	"	16	263	0	0
41	09/18	11	336.8	12	3.9
42	"	14	253	26	14.4
43	"	48	535.6	8	7.2
45	"	15	285.8	0	0
46	"	7.1	236.8	76	22.8
47	"	6.4	143.2	206	92.1
48	"	7	236.1	62	18.4
49	"	4.2	179.5	2	0.5
51	"	4	169.8	562	132.4
53	09/19	7.1	316.6	130	29.2
54	"	4.2	199.1	4	0.8
56	"	4.2	203.1	16	3.3
57	"	7.1	291.8	104	25.3
59	"	7.5	259.8	186	53.7
60	"	8.8	223	82	32.4

Appendix D. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus* and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 7-9 September 1990.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae under 10 m ²	No. Larvae	No. larvae under 10 m ²
1	09/07	25	187.6	62	82.6	0	0
2	"	23	155.2	50	74.1	2	3.0
3	"	20	95.8	14	29.2	0	0
4	"	14	128.9	38	41.3	2	2.2
5	"	28	120.9	250	579.0	0	0
6	"	29	176.2	352	579.3	0	0
7	"	34	240.7	216	305.1	0	0
8	09/08	32	221.7	98	141.5	0	0
9	"	30	184.6	67	108.9	2	3.3
10	"	28	167.3	59	98.7	1	1.7
11	"	15	154	58	56.5	0	0
12	"	11	205.5	5	2.7	0	0
13	"	11	207.5	72	38.2	0	0
14	"	12	207.4	0	0	0	0
15	"	28	249.1	1	1.1	1	1.1
16	"	26	183.4	1	1.4	0	0
17	"	32	178.8	6	10.7	0	0
18	"	34	273.3	1	1.2	5	6.2
19	"	31	178.1	1	1.7	0	0
20	"	26	199.5	0	0	4	5.2
21	"	18	161	2	2.2	0	0
22	"	11	236.6	3	1.4	0	0
23	"	11	198.1	45	25.0	0	0
24	"	17	266.5	1	0.1	0	0
25	"	28	171.1	0	0	0	0
26	"	32	231.1	0	0	0	0
27	"	35	259.9	22	29.6	0	0
30	"	27	164.3	6	9.9	0	0

Appendix D (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae under 10 m ²	No. Larvae	No. larvae under 10 m ²
31	09/08	25	150.2	2	3.3	0	0
32	"	24	154.5	2	3.1	2	3.1
33	09/09	16	112	4	5.7	0	0
34	"	11	118.2	266	247.5	0	0
35	"	11.5	116	500	495.7	0	0
36	"	12	200.9	48	28.7	6	3.6
37	"	12	137.8	1134	987.5	64	55.7
38	"	11	127.3	174	150.4	2	1.7
39	"	11	115.9	298	282.8	2	1.9
40	"	13	130.7	102	101.5	0	0
41	"	12	180.3	42	28.0	0	0
45	"	10	99.7	174	174.5	0	0
46	"	7.5	54.2	56	77.5	0	0
47	"	5.7	166.6	22	7.5	0	0
50	"	3.1	129.7	4	1.0	2	0.5
51	"	5.2	116.3	14	6.3	0	0
52	"	3.5	123.1	74	21.0	8	2.3
53	"	2.8	110.6	46	11.6	2	0.5
54	"	3.5	113.6	26	8.0	2	0.6
55	"	3.5	124.8	60	16.8	0	0
56	"	4.2	111.8	446	167.5	0	0
57	"	4.2	88.1	94	44.8	0	0
58	"	6.5	88.2	100	73.7	0	0
59	"	7	87.1	291	233.9	0	0
60	"	9	131.8	25	17.1	0	0

Appendix E. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus* and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 14-16 September 1990.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
1	09/14	26	273.9	8	7.6	0	0
2	"	27	245.8	16	17.6	0	0
3	"	19	153.4	16	19.9	0	0
4	"	14	164.7	20	17.0	0	0
5	"	27	169.8	36	57.2	0	0
6	"	29	132.3	8	17.6	0	0
7	"	36	172.9	24	49.9	0	0
8	"	32	289.3	16	17.7	0	0
9	"	29	192.1	24	36.3	0	0
10	"	29	160	16	29.0	4	7.3
11	"	17	173.7	328	320.5	38	37.1
12	"	11	122.6	274	245.0	6	5.4
13	"	12	81	226	334.8	8	11.9
14	09/14	13	138.4	124	116.8	0	0
15	"	27	181.2	2	3.0	2	3.0
16	09/15	26	232.7	2	2.2	0	0
17	"	34	351.8	2	1.9	0	0
18	"	34	274.1	6	7.4	0	0
19	"	32	244.4	0	0	0	0
20	"	26	220	0	0	0	0
21	"	18	225.9	0	0	2	1.6
22	"	12	238.1	178	89.7	0	0
23	"	11	163.8	114	76.5	0	0
24	"	17	260	12	7.8	0	0
25	"	28	279.6	6	6.0	0	0
26	"	32	190.6	2	3.4	2	3.4
27	"	35	177.1	0	0	0	0
29	"	29	280.8	18	18.6	0	0

Appendix E (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
30	09/15	27	305.8	28	24.7	0	0
31	"	25	379.2	86	56.7	2	1.3
32	"	23	349.3	86	56.7	6	4.0
33	"	16	342.3	30	14.0	4	1.9
34	"	11	145.8	32	24.1	0	0
35	"	10	124.4	300	241.9	6	4.8
36	"	12	146.3	2198	1806.6	0	0
37	"	12	165.5	76	54.9	2	1.4
38	"	10	137.8	62	44.9	6	4.3
39	"	11	143.9	52	39.7	2	1.5
40	"	12	151.9	136	107.4	8	6.3
41	"	13	181.1	2	1.4	0	0
45	"	11	229.6	2	1.0	0	0
46	09/16	8.5	172.4	184	90.9	8	4.0
47	"	5.7	37.6	32	48.0	2	3.0
50	"	3.5	108.4	10	3.2	2	0.6
51	"	3.5	130.2	0	0	0	0
52	"	4.2	118.2	12	4.3	4	1.4
53	"	3.1	108.6	14	4.0	2	0.6
54	"	3.6	108.1	70	23.3	50	16.7
55	"	4.0	94.8	146	61.5	18	7.6
56	"	4.5	132.2	100	34.1	4	1.4
57	"	4.6	148.2	22	6.8	6	1.9
58	"	6.5	127.9	112	56.9	2	1.0
59	"	7.8	171.3	192	87.6	0	0
60	"	9.9	239.4	7144	2959.2	94	38.9

Appendix F. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus* and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 29-30 September 1990.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
13	09/29	13	286.7	120	54.4	4	1.8
14	"	14	182.4	6	4.6	0	0
15	"	15	388.7	0	0	4	1.5
18	"	30	86.3	0	0	1	3.5
20	"	30	313.1	42	40.2	12	10.0
21	"	17	209.3	106	86.1	20	16.2
22	"	11	274.8	126	50.4	22	8.8
23	"	11	194.1	86	48.7	160	90.7
24	"	16	172.8	2	1.9	14	13.0
25	"	28	268.1	68	71.0	12	12.5
27	"	36	88.6	0	0	4	16.3
28	"	39	69.3	0	0	18	101.3
29	"	26	64.8	4	16.0	17	68.2
30	"	21	53.5	2	7.90	6	23.6
32	"	23	388.1	102	60.4	12	7.1
33	"	16	248.9	16	10.35	8	5.1
34	"	11	171.3	74	47.5	20	12.8
35	"	11	188.6	626	365.1	10	5.8
36	"	12	169	350	248.5	50	35.5
37	09/30	12	203.3	540	318.7	116	68.5
38	"	11	123.3	314	280.1	128	114.2
39	"	11	164.4	664	444.3	272	182.0
40	"	12	190.5	64	40.3	28	17.6
42	09/29	13	41.7	4	12.5	3	9.4
43	"	45	94.9	3	14.2	3	14.2
44	"	15	47.6	0	0	0	0
46	09/30	8.5	133.4	66	42.1	196	124.9
47	"	5.3	179.2	742	219.5	86	25.4

Appendix F (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
50	09/30	4	154	0	0	4	1.0
51	"	5	164.4	0	0	0	0
52	"	4	174	26	6.0	14	3.2
53	"	2.8	140.8	56	11.1	22	4.4
54	"	3.5	135.7	84	21.7	12	3.1
55	"	4.2	146.3	152	43.6	14	4.0
56	"	4.2	167.1	74	18.6	44	11.1
57	"	4.2	191.1	860	189.0	2	0.4
58	"	6.4	169.9	144	54.2	4	1.5
59	"	7.1	168.1	58	24.5	2	0.8
60	"	9.9	270.1	2186	801.2	80	29.3

Appendix G. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus*, *Rhomboplites aurorubens*, and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 14-16 September 1991.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
8	09/14	37	417.7	1	0.9	22	19.5	0	0
9	"	33	368.8	0	0	11	9.9	0	0
10	"	29	314.3	0	0	5	4.2	0	0
11	"	18	243.7	0	0	82	60.6	4	3.0
12	"	12	140.2	164	140.3	0	0	0	0
13	"	13	230.0	0	0	0	0	0	0
14	"	15	177.8	26	21.9	4	3.4	4	3.4
15	"	28	308.5	0	0	54	49.3	0	0
16	"	27	345.5	0	0	32	25.0	0	0
19	"	33	288.0	1	1.2	10	11.5	0	0
20	"	27	348.2	0	0	100	77.5	0	0
21	"	19	184.5	72	83.2	20	23.1	2	2.3
22	09/15	12	118.4	104	105.4	0	0	0	0
23	"	12	219.5	510	278.9	0	0	164	89.7
24	"	18	157.5	108	123.4	16	18.3	0	0
25	"	19	420.4	6	2.7	154	69.6	0	0
26	"	33	356.3	6	5.6	12	11.1	36	33.3

Appendix G (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
27	09/15	35	483.12	2	1.5	50	36.2	0	0
29	"	30	357.3	48	40.3	30	25.2	0	0
30	"	28	289.9	6	5.8	84	81.1	0	0
31	"	26	319.6	2	1.6	62	50.5	14	11.4
32	"	25	303.4	10	8.2	46	37.9	10	8.2
33	"	17	167.8	136	137.8	0	0	24	24.3
34	"	11	194.9	266	150.1	0	0	14	7.9
35	"	11	108.4	57	57.9	0	0	39	40.6
36	"	13	184.5	122	86.0	0	0	120	84.6
37	"	14	132	76	77.6	2	2.1	40	42.4
38	"	13	140.6	71	65.7	3	2.8	47	43.5
39	"	13	118	69	76.0	0	0	41	45.2
40	"	13	157.9	242	199.3	1	0.8	78	64.2
41	"	14	131	186	198.7	18	19.2	24	25.6
42	"	20	249.3	64	51.3	30	24.1	12	9.6
43	"	48	469.5	120	122.7	90	92.0	4	4.1
44	"	18	266.6	27	18.2	0	0	8	5.4
45	"	15	153.3	0	0	0	0	48	47.0

Appendix G (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
46	09/16	8.5	116.6	5	3.7	0	0	4	2.9
47	"	7.1	126.4	80	44.9	0	0	38	21.3
48	"	7.1	202.8	55	19.3	0	0	18	6.3
49	"	3.5	162.5	6	1.3	0	0	2	0.4
50	"	3.5	167	2	0.4	0	0	8	1.7
51	"	4	159.1	0	0	0	0	0	0
52	"	3.8	159.1	17	4.1	0	0	5	1.2
53	"	3.2	112.0	16	4.6	0	0	22	6.6
54	"	3.8	104.3	14	5.1	0	0	6	2.2
55	"	4.4	157.8	31	8.6	0	0	0	0
56	"	4.4	135.7	46	14.9	0	0	4	1.3
57	"	4.5	146.1	94	29.0	0	0	142	43.7
58	"	5.7	171.7	57	18.9	0	0	10	3.3
59		7.1	149.4	21	11.9	0	0	19	9.0
60	"	9.91	173.6	7	4.0	0	0	0	0

Appendix H. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus*, *Rhomboplites aurorubens*, and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 21-23 September 1991.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
9	09/21	30	355	0	0	2	1.7	0	0
10	"	28	383.5	0	0	18	12.3	0	0
11	"	15	147.9	0	0	30	30.4	12	12.2
12	"	12	187.1	51	32.7	0	0	0	0
13	"	13	180.7	76	54.7	4	2.9	0	0
14	"	14	243	0	0	44	25.3	8	4.8
15	"	25	352.3	0	0	0	0	16	11.4
16	"	29	273.3	0	0	6	5.7	0	0
17	"	29	374.8	0	0	20	15.5	0	0
19	"	32	490.7	2	1.3	30	19.8	0	0
20	"	25	367.2	3	2.0	122	83.1	18	12.3
21	"	18	235.4	58	44.4	18	13.8	2	1.5
22	"	12	240.8	90	44.9	12	6.0	4	2.0
23	09/22	12	160.8	48	35.8	2	1.5	20	14.9
24	"	18	219.7	44	36.0	113	92.6	0	0
25	"	28	390.2	2	1.4	42	30.1	28	20.1
26	"	31	401.8	0	0	42	32.4	0	0

Appendix H (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
27	09/22	35	335.1	1	1.0	68	71.0	11	11.5
28	"	38	511.7	42	31.2	24	17.8	12	8.9
29	"	28	371.8	4	3.0	14	10.5	23	17.3
30	"	26	333.3	101	78.8	37	28.9	28	21.8
31	"	24	266.4	12	10.8	90	81.1	150	135.1
32	"	23	291.8	74	58.3	80	63.1	36	28.4
33	"	16	274.7	18	10.5	15	8.7	27	15.7
34	"	11	188.3	243	142.0	0	0	114	68.6
35	"	12	239	99	49.7	0	0	3	1.5
36	"	13	183.5	97	68.7	1	0.6	13	9.2
37	"	13	197.9	0	0	35	23.0	21	13.8
38	"	12	209.4	11	6.3	33	18.9	1	0.6
39	"	12	238.1	10	5.0	14	7.1	60	30.2
40	"	12	233.7	78	40.1	26	13.4	522	268.0
41	"	12	180.2	78	51.9	28	18.6	7	4.7
42	"	20	274.5	66	48.1	1	0.7	48	35.0
43	"	47	462.2	126	128.1	0	0	70	71.2

Appendix H (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
44	09/22	17	306.9	204	113.0	0	0	26	14.4
45	09/23	11	193.8	60	34.1	0	0	262	148.7
46	"	7.1	219	86	27.9	0	0	140	45.4
47	"	6.4	230.1	52	14.5	0	0	24	6.7
48	"	7.1	157	0	0	0	0	38	17.2
49	"	3.5	190.6	2	0.4	0	0	0	0
50	"	4.2	165.1	2	0.5	0	0	120	30.5
51	"	4.7	152.5	88	27.1	0	0	382	117.7
52	"	4.2	120.9	816	283.5	0	0	216	75.0
53	"	4.2	133.4	1010	318.0	0	0	195	62.0
54	"	4.2	132.4	312	99.0	0	0	42	13.3
55	"	4.9	150.9	12	0.3	0	0	0	0
56	"	5.7	141.1	32	12.9	0	0	4	1.6
57	"	4.9	113.3	84	36.3	0	0	4	1.7
58	"	5.7	130.2	4	1.8	0	0	0	0
59	"	7.1	112.8	14	8.8	0	0	2	1.3
60	"	9.9	186.7	167	88.6	0	0	7	3.7

Appendix I. Summary of collection and abundance data for *Lutjanus campechanus* larvae taken in Tucker trawl collections from the northcentral Gulf of Mexico during 6-9 July 1992.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
1	7/06	100	385.6	3	7.78
2	"	100	463.4	0	
3	"	84	508.3	0	
4	"	27	191.7	2	2.81
5	"	27	146.5	2	3.69
6	"	12	77.4	0	
7	"	25	106.8	2	4.68
8	"	32	208.83	4	6.13
9	7/07	35	224.7	0	
10	"	64	373.3	0	
11	"	100	363.6	0	
12	"	100	394.3	0	
13	"	100	453.5	2	4.41
14	"	84	389.7	0	
15	"	43	224.1	1	1.91
16	"	37	215.9	0	
17	"	28	130.9	2	4.28
18	"	22	57.8	0	
19	"	16	59.3	0	
20	"	31	95.7	10	32.40
21	"	37	114.9	2	6.44
22	"	38	223.3	2	3.40
23	"	69	227.1	0	
24	7/08	100	428.3	0	
25	"	100	460.7	0	
26	"	100	410.0	0	
27	"	66	297.2	0	
28	"	40	177.9	0	

Appendix I (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
29	7/08	33	135.7	2	4.87
30	"	30	106.5	0	
31	"	17	47.8	0	
32	"	17	103.3	0	
33	"	29	97.0	10	29.91
34	"	34	159.0	2	4.28
35	"	36	205.2	0	
36	"	50	140.0	0	
37	"	100	298.9	1	3.35
38	"	100	500.4	0	
39	"	100	470.7	2	4.25
40	"	78	291.1	4	10.72
41	7/09	49	229.0	2	4.28
42	"	37	194.9	0	
43	"	35	122.5	0	
44	"	30	149.8	2	4.01
45	"	17	100.7	1	1.68

Appendix J. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus*, *Rhomboplites aurorubens*, and *Sciaenops ocellatus* taken in Bongo and Tucker trawl collections from the northcentral Gulf of Mexico during 13-20 September 1992.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
4	09/16	9.9	57.8	0	0	0	0	0	0
5	09/17	25	194.9	0	0	2	2.6	1	1.3
6	"	25	195.4	2	2.6	0	0	0	0
7	09/18	34	292.8	4	4.6	1	1.2	20	23.2
8	"	30	112.7	1	2.7	0	0	0	0
9	"	30	127.7	0	0	0	0	0	0
10	"	25	112.9	1	2.2	1	2.2	0	0
11	"	13	79	0	0	0	0	0	0
12	09/16	15	79.1	0	0	0	0	0	0
13	"	11	57.8	6	11.4	0	0	35	66.6
14	09/18	9.9	229.9	9	3.9	0	0	0	0
15	"	19	147.5	1	1.3	2	2.6	4	5.2
16	"	28	231.2	1	1.2	0	0	0	0
17	09/18	32	316.8	0	0	0	0	0	0
18	09/19	30	241.6	10	12.4	1	1.2	8	9.9
19	"	35	332.6	4	4.2	0	0	13	13.7
20	"	22	235.9	7	6.5	0	0	2	1.9

Appendix J (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
21	09/16	23	234.8	4	3.9	1	1.0	0	0
24	"	16	176.9	8	7.2	0	0	1	0.9
25	09/19	27	224	17	20.5	0	0	4	4.8
26	"	28	234.7	10	11.9	1	1.2	4	4.8
27	"	28	186	6	9.0	0	0	0	0
28	09/20	38	276.7	0	0	0	0	4	5.5
29	"	30	218	0	0	0	0	4	5.5
30	"	25	214	4	4.7	1	1.2	26	30.4
31	"	22	177.9	23	28.4	1	1.2	82	101.4
32	09/20	16	175.1	1	0.9	1	0.9	43	39.3
33	09/14	14	132.7	19	20.0	0	0	12	12.7
36	"	9.9	75.5	22	28.8	0	0	0	0
37	"	9.9	63.9	8	12.4	0	0	1	1.5
38	"	9.9	86.9	10	11.4	0	0	1	1.1
39	"	9.9	117.1	51	43.1	0	0	33	27.9
40	"	13	180.9	87	62.5	0	0	7	5.0
41	"	13	181.8	30	21.5	0	0	2	1.4
42	09/13	15	280.2	7	3.7	0	0	0	0

Appendix J (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
43	09/13	36	355.5	0	0	0	0	0	0
44	"	13	258.7	49	24.6	0	0	0	0
45	09/14	9.9	150.5	15	9.9	0	0	4	2.6
46	"	7.8	132.5	39	23.0	0	0	11	6.5
C1	09/18	33	298.6	1	1.1	1	1.1	8	8.8
C2	"	30	208.5	1	1.4	0	0	3	4.3
C3	09/19	30	177.4	5	8.5	0	0	88	148.8
C4	"	35	154.6	3	6.8	0	0	6	13.6
C5	"	40	341.5	2	2.3	0	0	0	0
C6	"	28	211.9	12	15.9	0	0	63	83.2
C7	"	40	436.7	4	3.7	0	0	7	6.4
C8	"	45	285.4	2	3.2	0	0	1	1.6
C9	"	48	470.7	14	14.3	1	1.0	4	4.1

Appendix K. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus*, *Rhomboplites aurorubens*, and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 27-29 September 1992.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
1	09/27	38	139.3	2	5.5	2	5.5	1	2.7
2	"	26	131.1	2	4.0	0	0	1	2.0
3	"	26	148	0	0	27	47.4	1	1.8
4	"	20	126.2	0	0	12	19.0	0	0
5	"	14	101	7	9.7	5	6.9	13	18.0
6	"	28	186.2	0	0	7	10.5	0	0
7	"	33	128.6	0	0	11	28.2	0	0
8	"	36	126.8	0	0	8	22.7	0	0
9	"	39	149.2	0	0	0	0	0	0
10	"	34	117.1	0	0	7	20.3	0	0
11	"	33	108	0	0	13	40.5	0	0
12	"	31	181	0	0	29	49.7	0	0
13	"	17	113	16	24.1	64	96.3	2	3.0
14	"	11	84	4	5.2	1	1.3	4	5.2
15	09/28	13	120	16	17.3	12	13.0	10	10.8
16	"	14	112.1	17	21.2	5	6.2	2	2.5
17	"	26	162.2	0	0	29	46.5	6	9.6

Appendix K (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
18	09/28	28	105.5	2	5.3	3	8.0	0	0
19	"	35	109.5	3	9.6	3	9.8	0	0
20	"	36	134.9	1	2.7	4	10.7	0	0
21	"	34	122.7	1	2.8	0	0	0	0
22	"	28	98.9	2	5.7	8	22.6	80	226.5
23	"	20	90.7	0	0	5	11.0	133	293.3
24	"	11	122.2	8	7.2	1	0.9	1	0.9
25	"	10	110.6	12	10.9	0	0	1	0.9
26	"	18	430.7	12	5.0	1	0.4	157	65.6
27	"	27	235.9	0	0	5	5.7	15	17.2
28	"	31	367	7	5.9	27	22.8	0	0
29	"	34	415.9	7	5.7	24	19.6	21	17.2
30	"	39	295.9	1	1.3	21	27.7	60	79.1
31	"	31	324.2	10	9.6	101	97.6	22	21.0
32	"	29	225.7	3	3.9	5	6.4	12	15.4
33	09/29	24	297.1	2	1.6	18	14.5	2	1.6
34	"	23	340.3	0	0	0	0	5	3.4
35	"	16	229.5	0	0	0	0	7	4.9

Appendix K (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>R. aurorubens</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
36	09/29	10	183.7	3	1.6	0	0	0	0
37	"	13	105.8	2	2.5	0	0	0	0
51	"	4.2	120.2	0	0	0	0	0	0
52	"	4.2	118.6	0	0	0	0	0	0
53	"	4.2	167.8	0	0	0	0	0	0
54	"	3.5	134	1	0.3	0	0	0	0
55	"	4.2	128.6	0	0	0	0	0	0
56	"	4.2	135.3	4	1.2	0	0	0	0
57	"	3.5	151.0	24	5.8	0	0	0	0
58	"	4.2	131.8	2	0.6	0	0	1	0.3
59	"	4.2	129.9	0	0	0	0	1	1.9
60	"	4	121.6	8	2.6	0	0	1	0.3
61	"	4.2	46.2	1	0.9	0	0	5	4.5
62	"	4.9	54.1	4	3.6	0	0	3	2.7
63	"	6.4	80.4	6	4.8	0	0	0	0
64	"	9.3	122.9	1	0.8	1	0.8	1	0.8

Appendix L. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus* and *Sciaenops ocellatus* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 9-11 September 1993.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
9	09/09	30	234.0	(not sorted)			
10	"	20	238.5	(not sorted)			
11	"	13	242.4	(not sorted)			
12	"	12	102.3	(not sorted)			
13	"	12	106.7	14	15.7	2	2.2
14	"	13	179.4	0	0	0	0
15	"	26	202.5	0	0	0	0
16	"	26	300.0	0	0	0	0
19	"	29	160.1	2	3.6	0	0
20	"	26	172.4	4	6.0	0	0
21	"	18	168.8	0	0	0	0
22	"	11	113.5	144	139.6	0	0
23	"	11	136.0	260	210.3	0	0
24	09/10	18	271.3	38	25.2	62	41.1
25	"	30	283.8	0	0	0	0
26	"	31	236.2	0	0	0	0
27	"	33	274.0	6	7.2	0	0
29	"	28	316.0	0	0	0	0
30	"	27	285.8	0	0	90	85.0
31	"	25	242.2	2	2.1	0	0
32	"	24	267.7	198	177.5	0	0
33	"	16	213.5	1070	802.0	6	4.5
34	"	9.9	145.9	68	46.1	3	2.0
35	"	11	286.5	134	51.4	4	1.5
36	"	12	280.2	416	178.2	8	3.4
37	"	13	205.3	856	542.0	24	15.2
38	"	12	186.2	986	635.4	72	46.4
39	"	14	127.0	0	0	0	0

Appendix L (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²
40	09/10	12	118.1	144	146.3	0	0
41	"	13	142.5	82	74.8	0	0
42	"	19	204.2	516	490.1	8	7.4
44	"	17	302.8	8	4.5	0	0
45	"	10	129.8	(not sorted)			
46	"	8	135.9	234	137.8	64	37.7
47	09/11	8.5	230.7	298	109.8	58	21.4
48	"	4.2	190.8	1	0.2	8	1.8
49	"	3	181.2	1	0.2	1	0.2
50	"	3.5	181.1	5	1.0	103	19.9
51	"	4.2	116.9	16	5.7	63	22.6
52	"	2.8	68.2	38	15.6	110	45.2
53	"	2.8	95.3	72	21.2	564	165.7
54	"	3.5	67.5	142	73.7	258	133.8
55	"	4.2	107.7	340	132.6	416	162.3
56	"	5.5	110.9	242	120.0	128	63.5
57	"	4.2	177.5	34	12.2	22	5.2
58	"	4.9	132.3	446	165.2	152	56.3
59	"	7.1	185.4	471	180.4	2	0.8
60	"	9.3	253.3	0	0	17	6.2

Appendix M. Summary of collection and abundance data for the larvae of *Chloroscombrus chrysurus*, *Sciaenops ocellatus*, and *Rhomboplites aurorubens* taken in Tucker trawl collections from the northcentral Gulf of Mexico during 19-21 September 1993.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>		<i>R. aurorubens</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²	No. Larvae	No. Larvae Under 10m ²
10	09/19	26	463.9	(not sorted)					
11	"	17	248.8	(not sorted)					
12	"	9.9	361.6	(not sorted)					
13	"	13	180.5	(not sorted)					
14	"	14	290.1	(not sorted)					
15	"	23	419.1	(not sorted)					
16	"	30	474.9	(not sorted)					
19	"	31	400.3	0	0	0	0	24	18.6
20	"	25	341.9	(not sorted)					
21	"	18	281.1	2	1.3	2	1.3	42	26.9
22	"	11	231.8	100	47.5	8	3.8	0	0
23	"	11	178.3	34	21.0	0	0	0	0
24	"	17	271.5	2	1.3	6	3.8	48	30.1
25	09/20	27	414.8	4	2.6	0	0	62	40.4
26	"	30	248.6	0	0	2	2.4	0	0
27	"	32	258.6	0	0	0	0	0	0
29	"	28	337.1	2	1.7	14	11.6	0	0

Appendix M (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>		<i>R. aurorubens</i>	
				No. Larvae	No. Larvae Under 10 m ²	No. Larvae	No. Larvae Under 10m ²	No. Larvae	No. Larvae Under 10m ²
30	09/20	27	333.5	2	1.6	20	16.2	4	3.2
31	"	25	315.6	0	0	12	9.5	4	3.2
32	"	24	306.8	0	0	0	0	2	1.6
33	"	15	176.4	0	0	4	3.4	10	8.5
34	"	9.3	187	342	170.1	2	1.0	0	0
35	"	9.9	186.8	318	168.6	0	0	0	0
36	"	13	126.3	136	140.0	0	0	0	0
37	"	13	123.3	(not sorted)					
38	"	13	238.8	202	110.0	2	1.1	0	0
39	"	13	227.8	64	36.5	8	4.6	0	0
40	09/20	13	194.4	26	17.4	0	0	4	2.7
41	"	13	195.7	8	5.3	24	15.9	6	4.0
42	"	17	221.7	2	1.5	330	253.1	4	3.1
44	"	16	283	0	0	8	4.5	0	0
45	"	9.9	148.9	42	27.9	16	10.6	0	0
46	"	8.5	70.6	48	57.8	0	0	0	0
47	"	8.5	129.3	12	7.9	60	39.4	0	0
48	09/21	7.8	206	4	1.5	4	1.5	0	0

Appendix M (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	<i>C. chrysurus</i>		<i>S. ocellatus</i>		<i>R. aurorubens</i>	
				No. Larvae Under 10 m ²	No. Larvae Under 10m ²	No. Larvae Under 10m ²	No. Larvae Under 10m ²	No. Larvae Under 10m ²	No. Larvae Under 10m ²
49	09/21	4.9	253.1	3	0.6	3	0.6	0	0
50	"	4.2	105.5	0	0	6	2.4	0	0
51	"	4.9	88.4	18	10.0	26	14.4	0	0
52	"	3.5	81	0	0	1	0.4	0	0
53	"	3.5	101.9	0	0	0	0	0	0
54	"	4.2	61.3	0	0	1	0.7	0	0
55	"	3.5	60.4	1	0.6	66	36.2	0	0
56	"	4.2	87.3	5	2.4	129	62.1	0	0
57	"	4.9	37.1	0	0	48	63.4	0	0
58	"	4.9	77.7	0	0	8	5.0	0	0
59	"	7.1	141.2	22	11.1	50	25.1	0	0
60	"	9.9	156.4	16	10.1	16	10.1	0	0

Appendix N. Summary of collection and abundance data for *Sciaenops ocellatus* larvae taken in Tucker trawl collections from the northcentral Gulf of Mexico during 9-11 September 1994.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
10	09/09	28	452.5	(not sorted)	
11	"	15	256.8	"	
12	"	9.9	162.7	"	
13	"	12	141.2	"	
14	"	14	218.9	"	
15	"	23	286.2	"	
16	"	30	350.6	"	
19	"	32	417.2	"	
20	"	25	410.2	"	
21	"	18	243.6	0	0
22	"	11	220.6	0	0
23	"	11	141.8	16	12.4
24	"	17	335	63	32.0
25	"	26	446.1	23	13.4
26	"	31	374.6	2	1.7
27	09/10	34	506.3	8	5.4
29	"	29	256	1	1.1
30	"	27	433.8	0	0
31	"	25	417.6	19	11.4
32	"	24	435.5	62	34.2
33	"	15	191.5	34	26.6
34	"	9.9	172.2	8	4.6
35	"	9.9	145.2	18	12.3
36	"	13	181	(not sorted)	
37	"	13	186.6	(not sorted)	
38	"	13	194.5	10	6.7
39	"	13	202.2	0	0
40	"	13	207.3	0	0
41	"	14	199.6	1	0.7

Appendix N (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
42	09/10	17	195.3	1	0.9
44	"	16	218.5	46	33.7
45	"	9.9	130.1	120	91.3
46	"	8.5	122.5	52	36.1
47	"	7.1	182.5	28	10.9
48	"	7.1	181.8	6	2.3
49	"	4.9	163.5	0	0
50	09/11	4.2	155.9	0	0
51	"	4.2	180.3	0	0
52	"	4.2	215	0	0
53	"	3.5	185.7	0	0
54	"	4.2	199.2	2	0.4
55	"	4.9	230.8	0	0
56	"	4.9	207.6	16	3.8
57	"	4.9	146.7	72	24.0
58	"	4.9	186.8	0	0
59	"	6.4	210.7	0	0
60	"	9.3	307.6	6	1.8

Appendix O. Summary of collection and abundance data for *Sciaenops ocellatus* larvae taken in Tucker trawl collections from the northcentral Gulf of Mexico during 20-22 September 1994.

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
10	09/22	22	190	22	25.5
11	"	15	178	118	99.4
12	09/21	14	111.6	62	77.8
13	"	17	90.1	6	11.3
14	"	13	103.7	142	178.1
15	"	22	155.9	77	108.7
16	09/22	28	199.9	46	64.4
19	09/21	31	209.3	4	5.9
20	"	25	187.4	118	157.4
21	"	17	174.6	143	139.2
22	"	10	92	4	4.3
23	"	11	117.7	7	6.5
24	"	16	144.3	105	116.4
25	"	27	230.1	49	57.5
26	"	30	205	49	71.7
27	"	32	184	14	24.3
28	"	36	272.6	12	15.9
29	09/20	29	240	224	270.7
30	"	21	232.6	9	8.1
31	"	24	179.8	5	6.7
32	"	23	175.8	71	92.9
33	"	15	124.6	22	26.5
34	"	11	120.9	28	25.5
35	"	10	95.3	10	10.5
36	"	13	212.9	10	6.1
37	"	15	183.1	1	0.8
38	"	13	200	0	0
39	"	15	171.3	3	2.6
40	"	14	248.4	26	14.7

Appendix O (cont'd).

Station	Date	Maximum Depth Fished (m)	Vol. Filtered (m ³)	No. Larvae	No. larvae under 10 m ²
41	09/20	12	124.9	36	34.6
42	"	18	136.43	7	9.3
43	"	44	239.1	25	46.0
44	"	16	55.47	11	31.9
45	09/21	9.9	397.9	8	2.0
46	"	8.5	283.3	10	3
47	"	8.5	337.6	2	0.5
50	"	4.2	186.3	0	0
51	"	4.2	188.7	14	3.1
52	"	3.5	134.7	14	3.6
53	"	3.5	208.8	24	4.0
54	"	4.2	161.8	0	0
55	"	4.2	171.4	3	0.7
56	"	4.2	163	0	0
57	"	4.9	141.5	0	0
58	"	6.4	231.7	3	0.8
59	"	7.8	293.4	0	0
60	"	9.3	282.0	0	0

Appendix P. Summary of age/length/dry-weight data for vermilion snapper larvae collected in the northcentral Gulf of Mexico at seven stations during the 14-16 September 1991 cruise.

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
11	14 Sept.	191B	12	5.1	0.3111
"	"	192B	9	3.6	0.0817
"	"	193B	9	4.2	0.1343
"	"	194B	9	3.8	0.0934
"	"	195B	10	4.1	0.1337
"	"	196B	10	4.3	0.1460
"	"	197B	10	4.1	0.1172
"	"	198B	9	3.7	0.0845
"	"	199B	8	3.5	0.0707
"	"	200B	7	3.0	0.0566
"	"	201B	7	2.8	0.0533
15	14 Sept.	202B	11	5.4	0.3616
"	"	203B	11	5.0	0.2643
"	"	204B	10	4.6	0.2148
"	"	205B	11	5.0	0.2264
"	"	206B	10	4.2	0.1579
"	"	207B	8	3.6	0.0814
"	"	208B	8	3.7	0.0980
"	"	209B	8	3.7	0.0864
"	"	210B	7	3.1	0.0489
"	"	211B	7	3.2	0.0490
"	"	212B	7	3.3	0.0631
16	14 Sept.	267B	10	4.2	0.1393
"	"	269B	10	4.0	0.1265
"	"	270B	10	4.2	0.1040
"	"	271B	7	3.2	0.0583
"	"	272B	6	2.8	0.0337
"	"	273B	7	3.4	0.0647
"	"	274B	5	2.6	0.0215

Appendix P (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
24	15 Sept.	275B	12	5.4	0.3199
"	"	277B	12	4.9	0.2307
"	"	278B	9	4.0	0.0994
"	"	279B	8	3.5	0.0747
"	"	280B	7	3.1	0.0510
25	15 Sept.	213B	14	5.4	0.4010
"	"	214B	13	5.0	0.2946
"	"	215B	11	5.0	0.2045
"	"	216B	11	4.5	0.2027
"	"	217B	11	4.7	0.1621
"	"	218B	11	4.4	0.1987
"	"	219B	11	4.2	0.1738
"	"	220B	10	4.0	0.1313
"	"	221B	10	4.0	0.1037
"	"	222B	10	3.8	0.1036
"	"	223B	9	3.6	0.0979
"	"	224B	8	3.5	0.0712
"	"	225B	8	3.3	0.0756
"	"	226B	8	3.4	0.0766
"	"	227B	6	3.3	0.0462
"	"	228B	6	3.0	0.0461
"	"	229B	8	3.2	0.0723
"	"	230B	7	2.8	0.0524
"	"	231B	6	2.8	0.0416
"	"	232B	5	2.6	0.0382
"	"	233B	7	3.0	0.0531
"	"	234B	7	2.8	0.0541
"	"	235B	7	2.8	0.0374
30	15 Sept.	236B	13	5.1	0.3752
"	"	237B	12	4.8	0.3332
"	"	238B	11	4.1	0.1494

Appendix P (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
30	15 Sept.	239B	11	4.6	0.2308
"	"	240B	11	4.0	0.1541
"	"	241B	8	3.0	0.0641
"	"	242B	11	3.7	0.1670
"	"	243B	9	3.4	0.1067
"	"	244B	12	4.3	0.2367
"	"	245B	11	4.0	0.2081
"	"	246B	9	3.4	0.1054
"	"	247B	9	3.7	0.0804
"	"	248B	8	3.5	0.0696
"	"	249B	7	3.1	0.0422
"	"	250B	7	2.9	0.0527
"	"	251B	6	2.6	0.0415
31	15 Sept.	252B	14	5.6	0.5128
"	"	253B	13	5.0	0.3601
"	"	254B	12	4.5	0.2215
"	"	255B	12	4.7	0.2478
"	"	256B	12	4.5	0.2430
"	"	257B	11	4.3	0.2324
"	"	258B	12	4.3	0.2399
"	"	259B	10	3.7	0.1337
"	"	260B	10	3.8	0.1403
"	"	261B	9	3.5	0.1001
"	"	262B	10	3.4	0.1091
"	"	263B	8	3.3	0.0721
"	"	264B	8	3.0	0.0601
"	"	265B	7	2.8	0.0621
"	"	266B	7	2.8	0.0528

Appendix Q. Summary of age/length/dry-weight data for *Rhomboplites aurorubens* larvae collected in the northcentral Gulf of Mexico at 10 stations during the 27-29 September 1992 cruise.

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
3	27 Sept.	65B	10	4.3	0.1571
"	"	66B	10	4.4	0.1984
"	"	67B	7	3.6	0.0835
"	"	68B	8	3.3	0.0570
"	"	69B	8	3.2	0.0605
"	"	70B	9	3.8	0.1083
"	"	72B	11	4.7	0.2492
"	"	281B	11	4.7	0.1978
"	"	282B	9	4.2	0.1165
"	"	284B	9	4.6	0.1362
"	"	285B	6	3.0	0.0426
"	"	286B	8	3.7	0.0790
4	27 Sept.	74B	10	4.0	0.1509
"	"	75B	8	3.3	0.0801
"	"	76B	7	3.3	0.0665
"	"	77B	9	3.6	0.0904
"	"	78B	6	3.1	0.0436
"	"	79B	5	2.7	0.0309
12	27 Sept.	109B	13	5.1	0.3501
"	"	110B	10	4.2	0.1562
"	"	111B	10	4.3	0.1627
"	"	112B	8	3.1	0.0739
"	"	113B	8	3.0	0.0690
"	"	114B	7	3.4	0.0565
"	"	115B	12	4.7	0.2648
"	"	116B	11	4.5	0.2151
"	"	117B	9	3.7	0.1114
"	"	118B	8	3.6	0.0800
"	"	119B	6	3.0	0.0431

Appendix Q (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
12	27 Sept.	119B	6	3.0	0.0431
"	"	120B	6	3.2	0.0473
"	"	287B	6	2.9	0.0361
"	"	288B	6	2.8	0.0395
13	28 Sept.	121B	9	3.6	0.0820
"	"	122B	10	3.8	0.1402
"	"	123B	10	3.6	0.1131
"	"	124B	7	2.8	0.0439
"	"	125B	9	3.5	0.0917
"	"	127B	10	3.7	0.1273
"	"	128B	9	3.5	0.0921
"	"	129B	8	3.1	0.0728
"	"	131B	11	3.8	0.1658
"	"	132B	12	4.1	0.2104
"	"	133B	9	3.3	0.1031
"	"	134B	9	3.2	0.0836
"	"	135B	11	4.3	0.1805
"	"	137B	11	4.2	0.1311
"	"	138B	11	4.2	0.1522
"	"	139B	10	3.7	0.0923
"	"	140B	12	4.3	0.1320
"	"	142B	10	3.5	0.0975
"	"	145B	7	2.8	0.0439
"	"	290B	14	4.6	0.2426
"	"	291B	9	3.9	0.0696
"	"	292B	9	3.5	0.0931
"	"	293B	6	2.7	0.0349
15	28 Sept.	147B	11	4.5	0.1661
"	"	148B	9	3.7	0.0833
"	"	149B	8	3.2	0.0397
"	"	150B	10	3.9	0.1124

Appendix Q (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
15	28 Sept.	151B	10	3.7	0.1140
"	"	152B	12	4.1	0.1687
"	"	153B	7	2.6	0.0386
17	28 Sept.	26B	12	4.8	0.2232
"	"	27B	12	4.9	0.2510
"	"	28B	8	3.2	0.0842
"	"	29B	9	3.4	0.0874
"	"	30B	10	3.9	0.1433
"	"	31B	12	5.1	0.2448
"	"	157B	11	4.7	0.1953
"	"	158B	11	4.7	0.1779
"	"	159B	10	4.5	0.1518
"	"	160B	9	3.6	0.0947
"	"	161B	9	4.2	0.0978
"	"	294B	12	4.9	0.2244
"	"	295B	7	3.0	0.0421
"	"	296B	9	3.4	0.0680
"	"	297B	8	3.3	0.0494
"	"	298B	9	3.8	0.0800
"	"	299B	11	4.4	0.2142
28	28 Sept.	300B	14	4.5	0.2146
"	"	301B	14	4.7	0.1860
"	"	302B	11	4.0	0.1550
"	"	303B	12	4.4	0.1726
"	"	304B	11	4.4	0.2209
"	"	305B	11	4.3	0.1872
"	"	306B	9	3.8	0.0603
"	"	307B	9	3.2	0.0955
"	"	308B	9	3.7	0.0636
"	"	309B	7	2.9	0.0356
"	"	310B	4	2.4	0.0140

Appendix Q (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
29	28 Sept.	312B	16	6.5	0.6957
"	"	313B	12	4.4	0.1682
"	"	314B	12	4.5	0.2402
"	"	315B	11	4.2	0.1435
"	"	316B	12	4.7	0.2208
"	"	317B	12	4.4	0.1886
"	"	318B	12	4.4	0.1690
"	"	319B	9	3.7	0.0751
"	"	320B	10	3.8	0.0543
"	"	321B	8	3.2	0.0326
"	"	322B	6	2.6	0.0314
"	"	323B	5	2.7	0.0216
"	"	343B	12	4.2	0.1848
"	"	344B	9	3.8	0.0903
"	"	345B	12	4.6	0.2027 *
"	"	346B	10	3.9	0.1301
"	"	347B	10	3.8	0.0963
"	"	348B	6	2.6	0.0275
31	28 Sept.	35B	13	5.6	0.4712
"	"	36B	11	4.3	0.1888
"	"	37B	13	5.1	0.3080
"	"	38B	11	4.3	0.1965
"	"	39B	11	4.0	0.1795
"	"	40B	11	4.1	0.1838
"	"	41B	10	3.5	0.1156
"	"	42B	6	2.9	0.0471
"	"	324B	9	3.6	0.1078
"	"	325B	10	3.7	0.0946
"	"	326B	14	5.5	0.4325
"	"	327B	13	4.4	0.2402
"	"	328B	12	4.5	0.2131

Appendix Q (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
31	28 Sept.	329B	11	4.3	0.1899
"	"	330B	10	3.9	0.1444
"	"	331B	10	4.2	0.1745
"	"	332B	10	4	0.1296
"	"	333B	9	3.8	0.1097
"	"	334B	10	3.6	0.1075
"	"	335B	7	2.8	0.0444
"	"	336B	8	3.3	0.0676
"	"	337B	8	3	0.0525
"	"	338B	10	3.5	0.0976
"	"	339B	6	2.8	0.407 ?
"	"	340B	7	2.9	0.0443
33	29 Sept.	173B	13	4.5	0.3247
"	"	174B	11	4	0.1767
"	"	175B	13	4.6	0.294
"	"	176B	12	5.1	0.3601
"	"	177B	11	4.2	0.1445
"	"	178B	11	4.1	0.1787
"	"	180B	12	4.6	0.2414
"	"	181B	10	3.8	0.1015
"	"	341B	7	2.8	0.0484
"	"	342B	10	4	0.1113

Appendix R. Summary of age/length/dry-weight data for *Chloroscombrus chrysurus* larvae collected in the northcentral Gulf of Mexico during the 14-16 September 1991 cruise.

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
12	14 Sept.	146D	13	5.8	0.7721
"	"	147D	12	5.3	0.2756
"	"	148D	11	4.3	0.1859
"	"	149D	9	3.8	0.1813
"	"	150D	8	3.4	0.0484
"	"	151D	4	1.7	0.0072
"	"	152D	2	1.4	0.0032
"	"	153D	3	1.5	0.0073
23	15 Sept.	155D	11	5.9	0.7938
"	"	156D	12	6.1	0.8723
"	"	157D	11	5.7	0.9336
"	"	158D	11	5.4	0.7613
"	"	159D	10	5.1	0.497
"	"	160D	10	4.4	0.3917
"	"	161D	10	4.3	0.326
"	"	162D	9	4.2	0.3136
"	"	163D	8	3.8	0.2048
"	"	164D	8	3.9	0.2012
"	"	165D	8	3.8	0.1164
"	"	166D	8	3.5	0.1414
"	"	167D	8	3.6	0.1081
"	"	168D	8	3.4	0.1407
"	"	169D	7	3.3	0.1113
"	"	170D	8	3.1	0.0881
"	"	171D	8	4.1	0.2066
"	"	172D	7	3	0.0871
"	"	173D	7	2.7	0.0492
"	"	174D	7	2.7	0.0556
"	"	175D	6	2.5	0.0365
"	"	176D	5	2.1	0.0193

Appendix R (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
23	15 Sept.	177D	3	1.4	0.0064
"	"	178D	3	1.7	0.012
"	"	179D	3	1.6	0.0074
24	15 Sept.	180D	10	4.4	0.2674
"	"	181D	9	3.7	0.2123
"	"	182D	8	3.6	0.2005
"	"	183D	8	3.3	0.1083
"	"	184D	10	3.8	0.2014
"	"	185D	9	3.9	0.1401
"	"	186D	9	3.5	0.1448
"	"	187D	8	3	0.0723
"	"	188D	5	2	0.0119
"	"	189D	4	1.9	0.012
"	"	190D	4	1.8	0.0128
34	15 Sept.	191D	14	8.1	1.4459
"	"	192D	13	7.8	1.5048
"	"	193D	13	7.5	1.0227
"	"	194D	11	6.5	
"	"	195D	10	5.6	0.4459
"	"	197D	10	5.1	0.3303
"	"	200D	11	4.7	0.3345
"	"	202D	10	4.1	0.214
"	"	204D	8	3.7	0.0918
"	"	205D	7	3	0.0638
"	"	206D	7	2.8	0.0624
"	"	208D	7	3.1	0.0624
"	"	210D	5	2.2	0.0178
37	15 Sept.	62D	11	6	0.572
"	"	63D	11	6.4	0.7307
"	"	64D	14	7.7	1.493
"	"	65D	11	6.5	0.8236

Appendix R (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
37	15 Sept.	66D	11	5.4	0.5528
"	"	67D	11	5.3	0.3371
"	"	68D	10	4.8	0.3748
"	"	69D	10	4.6	0.3724
"	"	70D	10	4.9	0.2554
"	"	71D	8	3	0.0731
"	"	72D	7	3.1	0.0729
"	"	73D	8	3.4	0.1046
"	"	74D	6	2.9	0.0218
"	"	211D	12	6.8	0.9345
"	"	212D	11	4.8	0.3606
"	"	213D	10	4.4	0.3461
"	"	214D	10	4.9	0.3186
"	"	215D	10	4.2	0.2113
"	"	216D	9	3.8	0.1596
"	"	217D	9	3.6	0.1538
"	"	218D	8	3.2	0.0804
"	"	219D	7	2.9	0.0512
41	15 Sept.	220D	12	7.1	0.8934
"	"	221D	10	5.7	0.5736
"	"	222D	9	4.3	0.1751
"	"	223D	8	3.7	0.1309
"	"	224D	6	2.9	0.0401
"	"	225D	6	2.3	0.0219
"	"	226D	6	2.2	0.0284
"	"	227D	4	2.1	0.0168
"	"	228D	3	1.6	0.0088
"	"	229D	3	1.7	0.0094
"	"	230D	5	2.1	0.0170
"	"	231D	5	2.6	0.0231
"	"	232D	4	1.6	0.0068

Appendix R (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
41	15 Sept.	233D	4	1.8	0.0114
"	"	234D	4	2.0	0.0093
"	"	235D	5	2.0	0.0229
"	"	248D	8	3.8	0.1679
"	"	249D	8	3.8	0.1536
"	"	250D	9	3.9	0.2472
42	15 Sept.	48D	9	3.5	0.1149
"	"	49D	11	4.5	0.3074
"	"	50D	11	4.6	0.3913
"	"	51D	12	5.9	0.7299
"	"	52D	10	3.4	0.1112
"	"	53D	6	2.6	0.0441
"	"	54D	11	4.6	0.3644
"	"	55D	4	1.9	0.0166
"	"	56D	9	2.6	0.0480
"	"	57D	6	2.5	0.0385
"	"	58D	6	2.2	0.0285
"	"	59D	6	2.3	0.0298
"	"	60D	4	1.9	0.0092
"	"	61D	3	1.7	0.0087
"	"	257D	10	4.0	0.2083
"	"	258D	10	4.0	0.1988
"	"	259D	10	4.2	0.1885
"	"	260D	8	3.9	0.1660
"	"	261D	9	3.4	0.1015
"	"	262D	10	3.5	0.1408
"	"	263D	8	4.3	0.2928
"	"	264D	6	2.9	0.0603
"	"	265D	6	2.5	0.0293
44	15 Sept.	40D	10	4.4	0.3329
"	"	41D	9	4.0	0.2257

Appendix R (cont'd).

Station	Date	Specimen Number	Age (days)	Length (mm)	Dry-weight (mg)
44	15 Sept.	42D	7	2.6	0.0481
"	"	43D	5	2.2	0.0273
"	"	44D	5	2.2	0.0262
"	"	45D	5	2.2	0.0224
"	"	46D	5	2.2	0.0268
"	"	47D	4	2.1	0.0223
47	16 Sept.	236D	13	7.0	1.0916
"	"	237D	11	5.7	0.6661
"	"	238D	11	5.3	0.3985
"	"	239D	10	4.8	0.4107
"	"	240D	9	4.3	0.2143
"	"	241D	9	3.9	0.1493
"	"	242D	7	2.9	0.0672
"	"	243D	7	2.4	0.0320
"	"	244D	7	2.3	0.0319
"	"	246D	4	1.7	0.0087

VITA

Bruce Henry Comyns was born in Pasadena, California, 7 January 1954. He received his elementary and intermediate education in England, and graduated from Westfield High School, Westfield, New Jersey, in June 1972. Mr Comyns received a Bachelor of Science degree from the University of Maine at Orono in May 1977 with a major in Zoology, and graduated in 1987 from the College of William and Mary - Virginia Institute of Marine Science with a Master of Arts degree in Marine Science. He entered the doctoral program in the Department of Oceanography and Coastal Sciences at Louisiana State University in 1990, and plans to graduate in August 1997. Mr Comyns has headed the Ichthyoplankton Section at the Gulf Coast Research Laboratory in Ocean Springs, Mississippi, since 1992, and plans to continue building this research program after graduation.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Bruce Henry Comyns

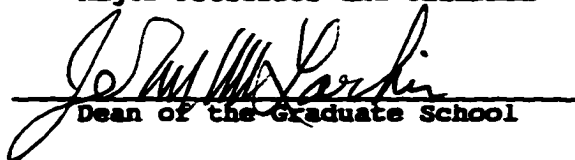
Major Field: Oceanography and Coastal Sciences

Title of Dissertation: Growth and Mortality of Fish Larvae in the Northcentral Gulf of Mexico and Implications to Recruitment

Approved:

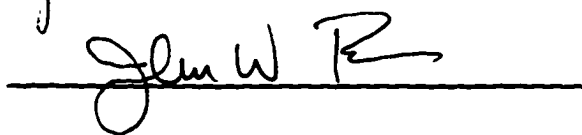
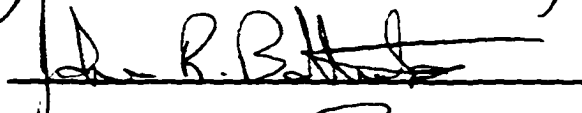
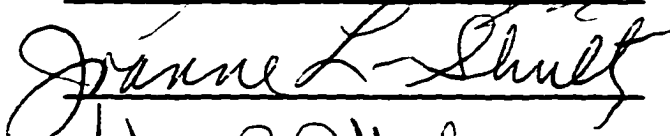
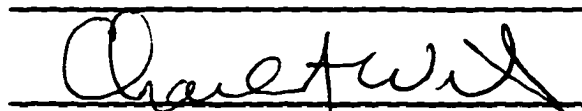


Major Professor and Chairman



Dean of the Graduate School

EXAMINING COMMITTEE:



Date of Examination:

March 31, 1997