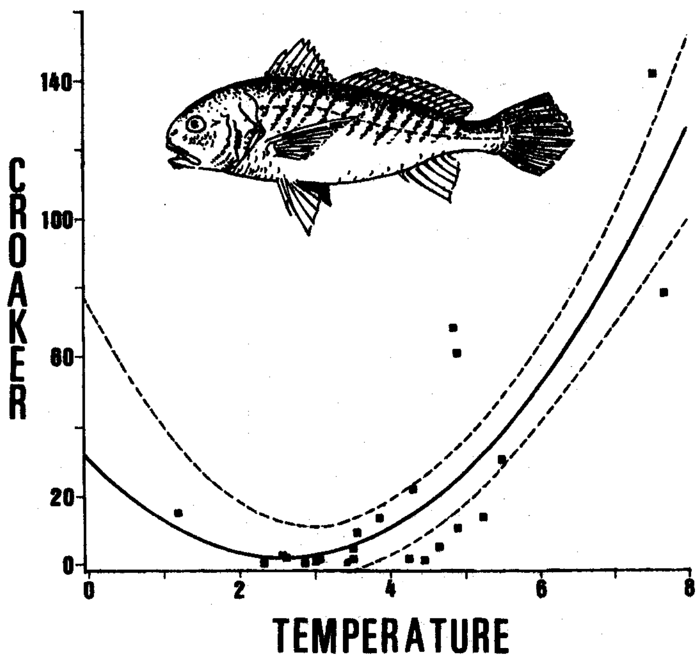
CLIMATE SCALE ENVIRONMENTAL FACTORS AFFECTING YEAR CLASS FLUCTUATIONS OF CHESAPEAKE BAY CROAKER

Micropogonias undulatus



by

B. L. Norcross and H. M. Austin

SPECIAL SCIENTIFIC REPORT NO. 110

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

MAY 1981

Climate Scale Environmental Factors Affecting Year Class Fluctuations of Chesapeake Bay Croaker *Micropogonias undulatus*

Brenda L. Norcross

and

Herbert M. Austin

Division of Fisheries Science and Services
Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

VIMS Special Scientific Report No. 110

This work was supported by the National Marine Fisheries Service and the Office of Sea Grant, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, with funding from Grant No. NA-080-AA-D-00021 to the Virginia Institute of Marine Science.

EXECUTIVE SUMMARY

Abundance of young-of-the-year croaker, *Micropogonias undulatus*, in the York River correlate with VIMS pier average January-February temperature (R^2=0.734) allowing a prediction of summer abundance of the young-of-the-year croaker. Autoregressive analyses were done on both young-of-the-year and commercial catch. No statistically significant autoregressive relationships were found. Autocorrelative analyses suggest the presence of another variable. Previous studies have shown experimentally and empirically that temperatures below 4°C can cause croaker mortalities.

Direct correlation analyses of young-of-the-year abundance and commerical catch lagged by 2 or 3 years (1^+ - 2^+ fish) show little statistical validity. This is due to the persistence of large year classes in the commercial catch over a 2 to 3 year period. Small year classes are only represented during a single year of commercial catch. The relative contribution of a year class to commercial catch was examined by constructing an empirical year class contribution curve which provided a better fit than the young-of-the-year to commerical catch. Hypothetical year class contributions to commercial catch are predicted from regressions on the summer year class index.

From these relationships, a statistical model was developed using winter temperatures to predict young-of-the-year survival and hence, the commercial catch contribution of each year class over a 1-3 year period. Possible sources of error in the relationships have been

identified in the data bases. These must be corrected before examining other environmental parameters in order to produce the final model which will predict yearly commercial catch from juvenile indices and environmental interactions.

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF APPENDICES

Appendices available under separate cover.

INTRODUCTION

Contemporary fisheries assessment (yield and quotas) is dependent upon environmentally static yield models (Austin and Ingham, 1978) which often produce large residuals due to environmental fluctuations acting on recruitment or availability. Fishery yield models do not usually consider effects on fluctuating environments (Sissenwine, et al., 1978). There is some recognition among biologists that highly variable yields may be caused by environmental fluctuations. For example, the Fishery Management Plan for Atlantic mackerel prepared by the Mid-Atlantic Fishery Management Council contains the following statement, ". . .it is clear that environmental factors are significant in controlling recruitment, . . ." (p. 91 MAFMC, 1978).

Also, an ad hoc group of the Ocean Sciences Board has prepared a report on fisheries ecology which states, "for a full understanding of processes controlling stock abundance, it will be necessary to separate trends due to alteration in climate from effects due to fishing. . .knowledge of the way physical factors, ultimately based on climate variation, affect food supply is likely to be of major importance. . ." (p. 7 NRC, 1980). These serve to support the contention that environmental-yield models are needed for operational fisheries management.

Marine resources can no longer withstand an unregulated harvest, and management agencies are being pressed to develop quotas and allocations. To do this they need accurate estimates of future stock biomass that will be available to the fishery. Static yield models based on "average" conditions are not usually accurate enough to meet these needs. Though the environment may not be a significant factor when stock size is high, its impact may be critical when stock size is low, which is just when accurate yield models are most crucial. Austin and Ingham (1978) have said, "Future efforts directed at predicting the abundance and distribution of stocks must give careful consideration to the abiotic factors that act as forces, how they occur, and what the forcing function is."

According to Cushing and Dickson's match-mismatch hypothesis (1976), knowledge of the environmental factors driving the production cycle, combined with measurements of the climatic factors affecting the larval fish distribution and abundance, can be used to estimate match or mismatch overlap, and thus, larval recruitment. Loucks and Sutcliffe (1978) have suggested that variation in ocean climate triggers corresponding fluctuations in fish, stock-recruitment and subsequent abundance and catch. However, their population dynamics models only used linear regression techniques to establish simple equations for fish catch based on local sea surface temperatures and fishing effort. Nelson, Ingham, and Schaaf (1977) undertook a modelling effort where yield was coupled with physical environmental data. Their multiple regression model of the Atlantic menhaden is a spawner-recruit relationship that has been adjusted to include a survival index derived from Ekman transport. Parrish and MacCall (1978) have developed a recruit model which includes environmental factors linked with the degree of density independence for the Pacific mackerel.

Two types of "recruitment" need to be recognized--to the stock as eggs and larvae and into the fishery as adults. Significant relationships have been demonstrated between environmental effects and larval recruitment (Cushing and Dickson, 1976; Hunter, 1976; Nelson, Ingham and Schaaf, 1977; Lasker, 1978; Lough, Bolz, Grosslein, and Potter, 1979; IOC, 1980). Growth rates are strongly temperature dependent and natural mortality may be linked to environmental temperatures and anomalies (IOC, 1980), thus affecting recruitment to the fishery. The current practice is to integrate processes of available catch data (stock size) with juvenile assessment data (recruitment) and, by means of stock-recruitment functions develop catch curves. These functions may provide poor fits due to unaccounted for environmental effects (Sissenwine, Brown, and Brennan-Hoskins, 1978), especially on the juvenile stage.

MATERIALS AND METHODS

Among the reasons for choosing the Atlantic croaker for this study is its commercial importance, as seen in Table 1. The documented environmentally-induced fluctuations (Massman and Pacheco, 1960; Richards, 1965; Joseph, 1972; Wojcik, 1978) gave indications that at least one climate factor would be able to be incorporated into the model. The 25-year juvenile trawl survey in the York River is a unique data set, providing a rare opportunity to study a single

TABLE 1. 1979 Virginian Commercial Croaker Catch (VMRC, 1979).

	Thousands of pounds	Thousands of dollars	Rank
Atlantic Ocean	1,647.7	324.7	3
Chesapeake Bay	4,414.7	678.5	2
James River Basin	*	*	
York River Basin	1,504.5	321.7	1
Rappahannock River Basin	181.2	19.2	4
Potomac River Basin	350.6	66.4	5
Totals	8,098.7	1,410.5	

*Closed to taking croaker

species in the same locality over a long period of time with a concurrent physical data set. The data were expected to be reliable and consistent because the croaker is a bottom-dwelling fish found in the deep channels of the river, where the gear sampled most efficiently.

Biological Data

Of special interest and importance is the availability of the long term data sets. The York River data set is proposed as the primary base from which to build the model because of its duration and continuity, which is unique on the east coast. It is especially fortuitous that this survey encompasses the disappearance, absence and resurgence of the Atlantic croaker in the Bay region. Austin and Ingham (1978) have noted that time series analyses on biological data sets are often difficult due to their poor quality and short duration.

Initial efforts were directed toward identifying, acquiring and transforming data sets into usable and compatible formats. Due to the large data volume of the VIMS Trawl Survey, the first data set run exceeded the limit of the William and Mary computer. This resulted in reprogramming the time and space requirements. The original format of this data set had one card image observation for each species caught at each tow. This format duplicated the cruise and hydrographic data on each observation portion. The data were reformated so that there was only one observation per tow which included all cruises, hydrographic and species data (Appendix A). The species data now include all species of the river systems, with zeros recorded when none were caught in a tow. Incorporating the zero catch data created a programming stumbling block. However, especially when studying distribution, it is just as important to know when an area was sampled and no fish were caught as it is to know when they were present. These data were not available previously. This greatly increases the data set length, but allows accurate averaging of species. It is important to establish a data set of such resolution so in the future it can be used to its full potential more efficiently.

Because the station code and/or sampling location in the river were not the same over the 25 year survey period, it was necessary to redesign the concept of station locality without losing the integrity of the original data set. In order to do this, Virginia's major Chesapeake Bay tributaries were separated by arbitrary lines. Equations based on latitude and longitude were developed which could separate data from the York, James, Rappahannock, and Potomac rivers, and Chesapeake and Mobjack bays (Table 2). This was necessary because not all river station codes are distinctive or readily interpretable. The equations of these lines can now be used, given latitude and longitude, to separate the rivers. This equation/separator concept was extended to operate within the York River. York River hydrographic data were used to plot latitudes and longitudes of stations by hand. The collecting sites appeared to aggregate, which allowed arbitrary lines to be drawn to separate the York River system, including the Pamunkey and Mattaponi, into approximately 5 mile

TABLE 2. SECTION EQUATIONS.

Arithmetic Corrections to use the Following Equations to Section Rivers:

```
LAT=LAT/100;
LONG=LONG/100;
LATDEG=FLOOR (LAT);
LATMIN=(LAT-LATDEG)*100/60;
LATCT=LATDEG+LATMIN;
LONGDEG=FLOOR(LONG);
LONGMIN=(LONG-LONGDEG)*100/60;
LONGCT=LONGDEG+LONGMIN;
```

Equations:

```
EQUA1=(.673*LONGCT)-14.332;
EQUA2=(.471*LONGCT)+1.485;
EQUA3=(.823*LONGCT)-25.1;
EQUA4=(0.5*LONGCT)-0.839;
EQUA5=(.45*LONGCT)+2.88;
EQUA9=(-1*LONGCT)+114.59;
EQUA10=(-0.5*LONGCT)+75.939;
EQUA11=(-1*LONGCT)+114.388;
EQUA12=(-1.32*LONGCT)+139.022;
EQUA13=(-1.24*LONGCT)+132.929;
EQUA14=(-1.367*LONGCT)+142.759;
EQUA15=(-0.52*LONGCT)+77.410;
EQUA16=(-0.515*LONGCT)+76.976;
EQUA17=(-.667*LONGCT)+88.56;
EQUA18=(-0.941*LONGCT)+109.461;
EQUA19=(-0.807*LONGCT)+99.072;
EQUA20=(-4.882*LONGCT)410.235;
EQUA21=(-7.545*LONGCT)+613.356;
```

Sectioning by Equations:

```
IF LONG<7622.0 THEN RIVER=CHESAPEAKE BAY;
IF LONG>7622.0 THEN THE FOLLOWING--
IF LATCT<EQUA1 THEN RIVER=JAMES;
IF EQUA1<=LATCT<EQUA2 THEN RIVER=YORK;
IF EQUA2<=LATCT<EQUA3 THEN RIVER=RAPPAHANNOCK;
IF EQUA3<=LATCT THEN RIVER=POTOMAC;
IF EQUA5<=LATCT<EQUA2 THEN RIVER=MOBJACK BAY;
IF EQUA1<=LATCT<EQUA5 AND EQUA21<LATCT<=EQUA20 THEN SECTION='Y00';
IF EQUA1<=LATCT<EQUA5 AND EQUA20<LATCT<=EQUA19 THEN SECTION='Y05';
IF EQUA1<=LATCT<EQUA5 AND EQUA19<LATCT<=EQUA18 THEN SECTION='Y10';
IF EQUA1<=LATCT<EQUA2 AND EQUA18<LATCT<=EQUA17 THEN SECTION='Y15';
IF EQUA1<=LATCT<EQUA2 AND EQUA17<LATCT<=EQUA16 THEN SECTION='Y20';
IF EQUA1<=LATCT<EQUA2 AND EQUA16<LATCT<=EQUA15 THEN SECTION='Y25';
IF EQUA1<=LATCT<EQUA2 AND EQUA15<LATCT<=EQUA10 THEN SECTION='Y28';
IF EQUA1<=LATCT<EQUA4 AND EQUA10<LATCT<=EQUA11 THEN SECTION='P30';
IF EQUA1<=LATCT<EQUA4 AND EQUA11<LATCT<=EQUA12 THEN SECTION='P35';
IF EQUA1<=LATCT<EQUA4 AND EQUA12<LATCT<=EQUA13 THEN SECTION='P40';
IF EQUA1<=LATCT<EQUA4 AND EQUA13<LATCT<=EQUA14 THEN SECTION='P45';
IF EQUA1<=LATCT<EQUA4 AND EQUA14<LATCT<=EQUA9 THEN SECTION='P50';
IF EQUA4<=LATCT<EQUA2 AND EQUA10<LATCT<=EQUA11 THEN SECTION='M10';
IF EQUA4<=LATCT<EQUA2 AND EQUA11<LATCT<=EQUA12 THEN SECTION='M20';
IF EQUA4<=LATCT<EQUA2 AND EQUA12<LATCT<=EQUA13 THEN SECTION='M25';
IF EQUA4<=LATCT<EQUA2 AND EQUA13<LATCT<=EQUA14 THEN SECTION='M30';
```

"sections." These sections, as determined by equations using latitude and longitude (Table 2), can now be used to spatially compare any data taken from the York River system. This concept is very important to make use of existing, corresponding hydrographic data of the York River.

All cruise, hydrographic and croaker data were extracted from this York River data set. Abundance values for croaker were corrected to "number per 10 minute tow." This necessitated identifying erroneous tow times and converting tow lengths. Thus, the quality of the data was further improved. The specifics are documented in Appendix B. A croaker biological year was designated as October-September. This designation was assigned because October is the peak of spawning and, as such, considered the "birthday" when aging a croaker. Abundance was averaged over all collections for the entire York River system. These were reported as number per month, quarter, half, and bio-year. The same time divisions were applied to the data and an average number of croaker was obtained for each river section. Upon examination of these it was decided that the juvenile data set was incomplete. Therefore, this data set was supplemented with additional VIMS croaker collections. Unpublished VIMS juvenile croaker data from 1951-1954 (D. Haven, pers. comm.) by year, month, and station were located on handwritten sheets and entered into the computer. The VIMS crab cruise data collections include fish data which were not previously combined with the ichthyological trawl data. The croaker data, by month, from 1974 to 1977, were read off a microfiche and entered into the monthly croaker/York River trawl data (Appendix C).

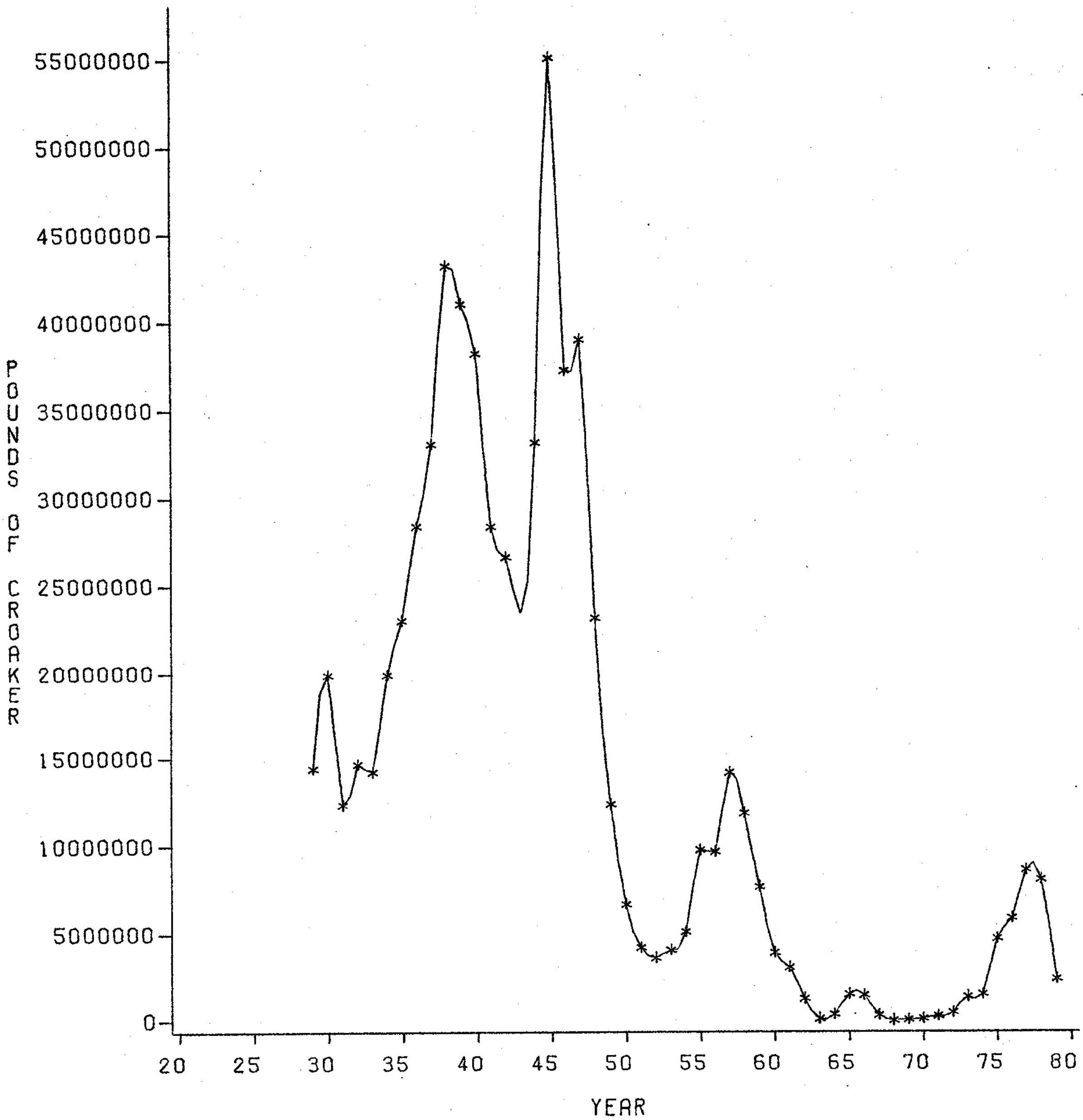
This improved and expanded the data set, as few VIMS Ichthyology trawl surveys were conducted during the 1974 to 1977 time period. These data were also averaged over the whole river by year and month. This resulted in one number representing the juvenile croaker abundance each year (Figure 3). A fall croaker index (FALLCR) was created by averaging the October, November, and December collections only (Figure 7). Similarly, the summer juvenile croaker index (SUMMERCR) is the average abundance in the York River from April through September (Figure 8).

NMFS provided a tape of annual commercial croaker landings data (1962-1976) by state and by water body for the East Coast. This was transformed into a SAS data set. Only Virginia landings were used with no consideration given to gear or water body fished. Correlations were run between juveniles and this commercial data set and it was determined that a longer commercial data set was needed. NMFS yearly commercial landings for Virginia (1929-1976) were obtained (Lowell Fritz, pers. comm.) as were 1977-1979 data from the Virginia Marine Resources Commission (VMRC) (Figure 1). Figure 2 shows the commercial landings 1951-1979 in a time frame to correspond to the juvenile data. Table 3 and Appendices A, B, C, G, and H describe the contents and form of these data sets.

FIGURE 1

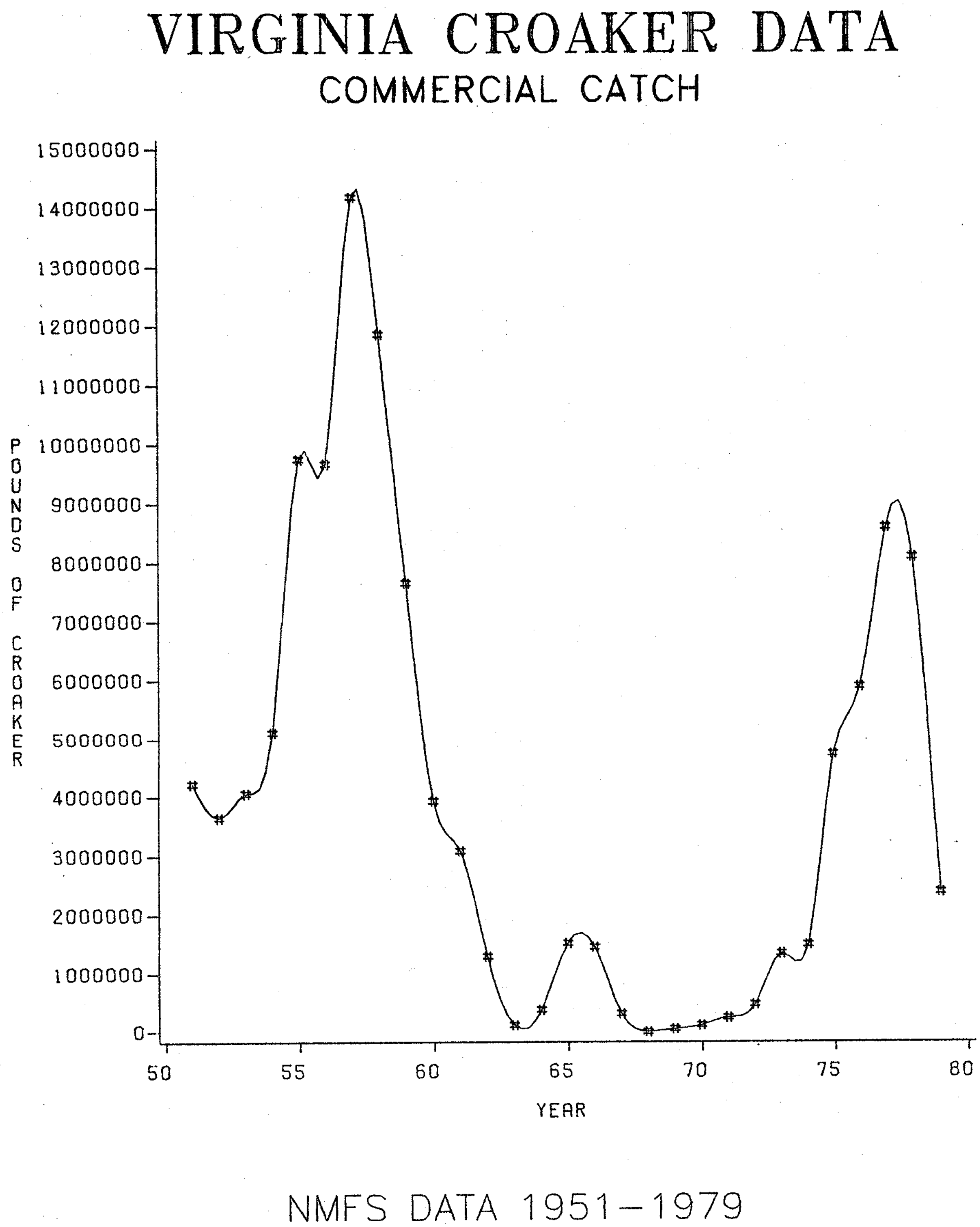
VIRGINIA CROAKER DATA

COMMERCIAL CATCH



NMFS DATA 1929–1979

FIGURE 2


VIRGINIA CROAKER DATA
COMMERCIAL CATCH
15000000
14000000
13000000
12000000
11000000
10000000
9000000
8000000
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
POUNDS OF CROAKER
50
55
60
65
70
75
80
YEAR
NMFS DATA 1951-1979

Environmental Data

Steyeart (EDIS, 1980) notes that the limitations of data sets ". . .frequently preclude the development of a traditional regression type climate/crop yield model." As a result, acquisition of historical and proxy data often becomes necessary before modelling efforts can begin. Historical physical data were obtained that had time and space relationships with the York River Trawl Survey. These include VIMS pier and Kiptopeake Beach (on the Virginia Eastern Shore) water temperatures and the York River hydrographic file. Table 3 contains a listing of these and their present status.

Work was initiated on the VIMS York River hydrographic file tape. Attempts were made to average hydrographic parameters over time and river section, however, due to the JCL time and space constraints and the terminal limitations, the data have not yet been accessed by section to correspond to the juvenile data.

September, October, and average September-October sea surface temperature anomalies (Figure 9) were developed from monthly Kiptopeake Beach temperatures obtained from data drawn together by the crab-climate study (Harris and Van Engel, 1981). Also, VIMS pier water temperature data (1958-1975) are readily available on the computer as monthly averages from the Crustaceology Department at VIMS (Harris and Van Engel, 1981). Microfiches of additional data were obtained and added to extend this data base from 1954 to 1977.

TABLE 3. DATA BASES

Data Base	Time Period	Content	Accessibility*
VIMS Juvenile trawl survey	1955-78 (York R.) 1955-78 (Chesapeake Bay) 1964-78 (James R.) 1967-78 (Rappahannock R.) 1970-78 (Mobjack Bay) 1976-78 (Potomac R.)	Cruise information (often monthly): date, station, salinity, temperature, etc. Number of each species of juvenile fish caught per trawl, including zero when none caught. Corresponding total weights after 1973.	Sequential file and SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Appendix A, Part 2 shows contents. Appendix A, Part 3 is the code for the standard Ichthyological format codes.
York River trawl survey (croaker only)	1955-1978	A subset of the VIMS juvenile trawl survey. Equations were developed to form approximately 5 mile sections of the river, thus allowing spatial correlation with any data from the York River. Croaker abundance was standardized to number per 10 minute tow.	SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Appendix B shows contents.
Monthly Croaker York River trawl data	1951-1978	VIMS York River trawl survey (1955-78), unpublished VIMS data (D. Haven, pers. comm.) (1951-54) and VIMS crab cruise data (1974-77) - averaged over entire length of York River by month and standardized to number of croaker per 10 minute tow.	SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Hard copy in Appendix C.
VIMS Pier water temperature	1954-1977	Mean monthly temperatures from daily averages (1958-1975): (Harris and Van Engel, 1981, p. 32).	SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Hard copy in Appendix D. 1958-1975 only in sequential file available from Crustaceology Department, VIMS.
Kiptopeake Beach water temperature	1958-1975	Mean monthly temperatures. (Harris and Van Engel, 1981, p. 22).	SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Hard copy in Appendix E. Sequential file available through the Crustaceology Department, VIMS.
VIMS York River Hydrographic File	1955-1979	Bottom and surface temperature and salinity with intermittent nutrient, tide, wind, etc. data. From all VIMS cruises done on the York. Intended to be averaged by month and separated by section.	SAS data set on offline disk on NOAA's computer at Suitland through EDIS and Sequential file on tape available through the Division of Fisheries Science and Services, VIMS. Appendix F shows contents.
NMFS Atlantic Commercial croaker catch data	1962-1978	Annual landings of croaker in Delaware, Florida (deleted), Georgia (deleted), Maryland, New Hampshire, New Jersey, North Carolina, South Carolina, and Virginia.	Sequential file and SAS data set on tape available through the Division of Fisheries Science and Services, VIMS. Appendix G shows contents.
Virginia Commercial croaker catch (NMFS and VMRC)	1929-1979 (no data available for 1943)	Landings by year and total gear.	Sequential file and SAS data set on tape. Available through the Division of Fisheries Science and Services, VIMS. Hard copy Appendix H.

*SAS data sets are readily accessible by any parameter.

Monthly average temperatures were used because the daily temperatures are not yet computerized.

These data were readily available and, therefore, used. However, because this study uses previously existing data, appropriate data are not always available. Austin and Ingham (1978) have pointed out that, "Rarely are two matching sets available, and 'proxy' data must be used." It is necessary to understand the errors and deficiencies of the available data and to glean from it whatever is worthwhile. Additional ancillary, or proxy, data will be obtained, e.g., Norfolk airport air temperatures, and correlated with the existing physical data that, thus expanding the available physical data. In this study there are concurrent physical and biological data bases available, allowing for a check on alternative physical data bases. This is a luxury not often available when dealing with lengthy time series of biological and physical data.

Data Analysis

The data sets used in this study (Table 3) were reworked into compatible and accessible forms using SAS (1979) (Statistical Analyses System) programs. All data manipulations and analyses were carried out by SAS, either on an IBM 370/158 computer at the College of William and Mary or an IBM 360/195 computer located in Suitland, Maryland, used cooperatively with the NOAA/EDIS/CEAS/CIAD Models Branch (Columbia, Missouri).

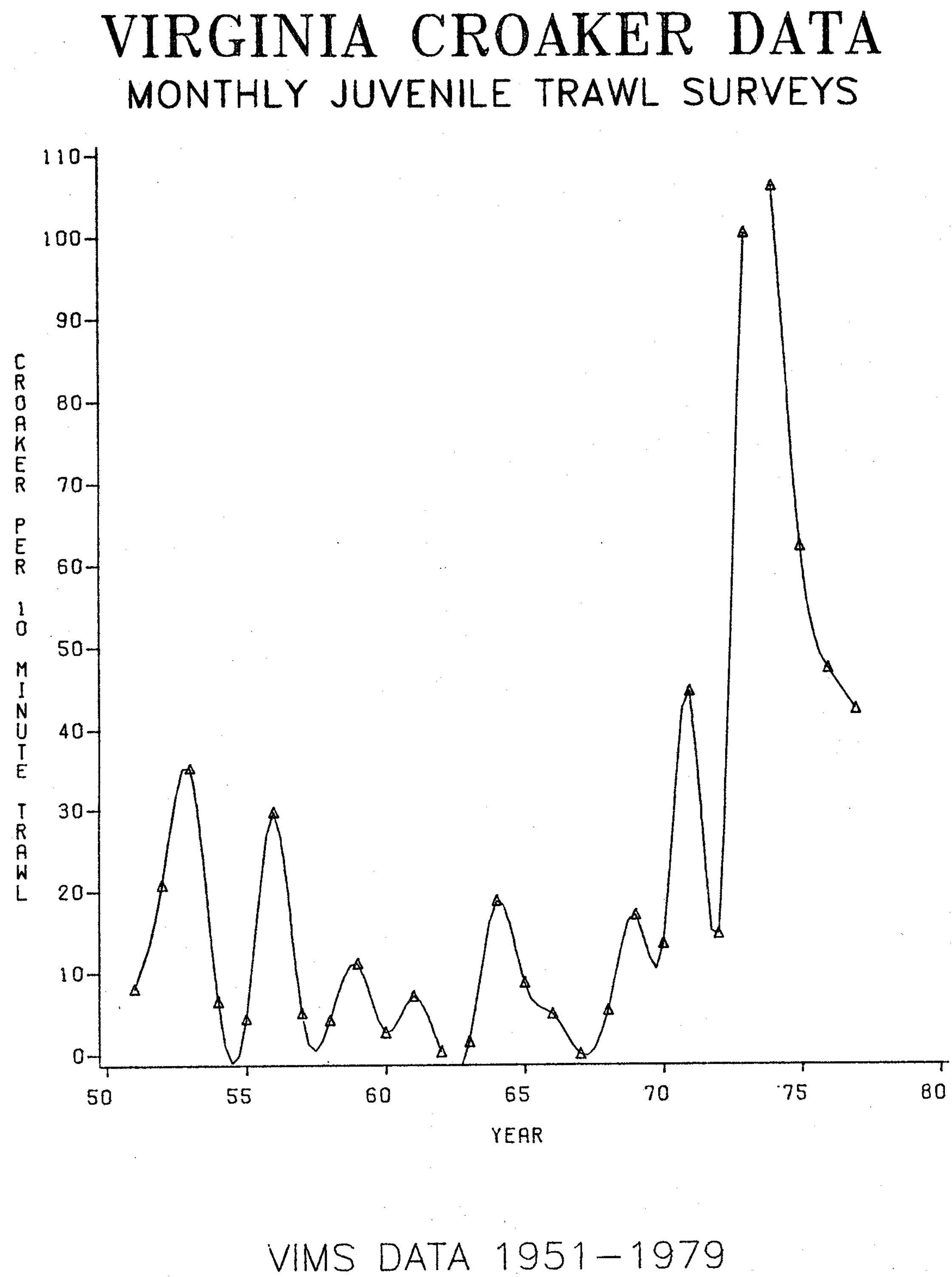
Graphical analyses were done on a Calcomp 1051 plotter using SAS/GRAPH (1980) at the College of William and Mary.

RESULTS

The juvenile trawl survey data were tested for autoregressive tendencies which would allow predictions of abundance to be made based on present or some defined past abundance. These results were nonsignificant (t=2.189, p=0.0378). Only lag#1 was slightly significant (t=-2.978), indicating that next year's abundance will be lower than it was this year. There is no biological basis for this as it is an artifact of the data which contains an overall decreasing trend (Figure 3). Because abundance of juvenile croaker cannot be used to predict future abundance of juveniles, the necessity for predictor variables to be identified and tested in a predictive model is indicated.

The results were similar, but more speculative, for the commercial catch data from 1929 to 1979, which had the 1942-1944 average substituted for the missing 1943 value. There were no significant autoregressive properties demonstrated (t=1.650, p=0.105) but lag#1 (t=-6.818) was highly significant. This is probably a result of the long term negative trend of the data. The pattern in Figure 1 indicates there may be an approximate 10 year periodic component in the data which did not recover to take its characteristic upward swing in the 1960's. This has not been substantiated statistically. Although lag#10 has a slightly higher t value (-0.689)

FIGURE 3



VIRGINIA CROAKER DATA
MONTHLY JUVENILE TRAWL SURVEYS
CROAKER PER 10 MINUTE TRAWL
0
10
20
30
40
50
60
70
80
90
100
110
50
55
60
65
70
75
80
YEAR
VIMS DATA 1951—1979

than lag#9 or lags#11-14, other t values, especially lags#1-3, are much more significant (-6.505, -2.159, 2.584). However, there is no discernible pattern in the statistical analysis. Therefore, the commercial data are not autoregressively capable of predicting future catch and independent predicator variables are needed to make a predictive model.

Next, the juvenile index was tested as a predictor for commercial catch in later years. Correlations were run using the yearly commercial croaker data and VIMS juvenile trawl survey by bio-year based on apparent relationships in Figures 4, 5, and 6. Commercial catch was correlated with young-of-the-year indices lagged 0 to 5 years (YOY, YOY1, YOY2, YOY3, YOY4, YOY5) (Table 4). Using nonparametric statistics, the results are more significant than those of the parametric, indicating a nonlinear relationship. Lags of 2, 3, 4 and 5 years correlated relatively well (p=0.01 to 0.04), however, no single year class produced the "best" fit to predict commercial catch. These results are taken to indicate that no single year class alone is a significant predictor of the commercial catch.

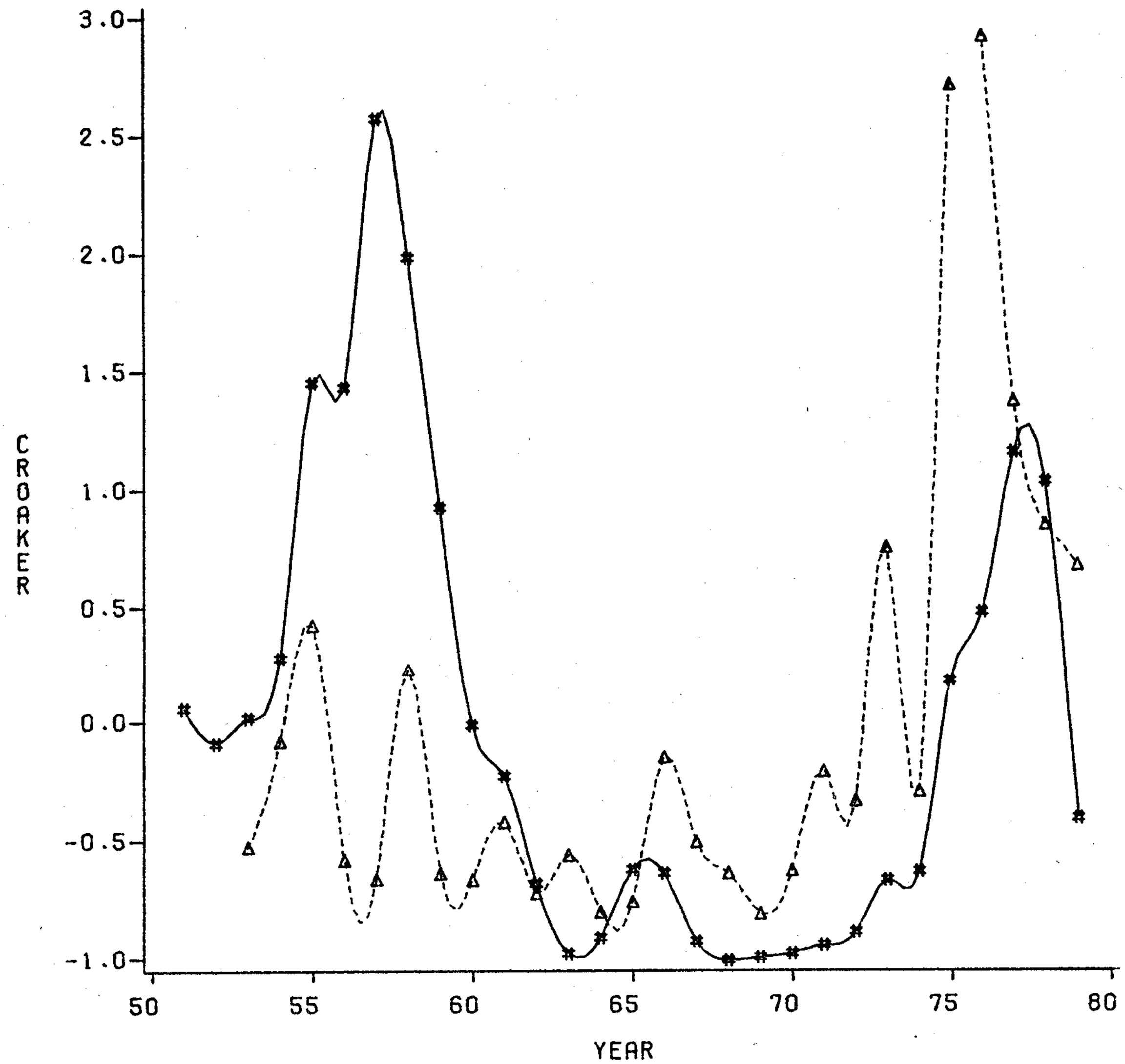
The juvenile abundance was separated into fall (October-December) (FALLCR) (Figure 7) and summer (April-September) (SUMMERCR) (Figure 8), because using all juvenile averaged over a biological year produced no significant correlations and because winter temperatures less than 1.5°C have been documented to kill young-of-the-year croaker (Wojcik, 1978). No significant correlations were found between the Kiptopeake Beach temperature anomalies (Figure 9) and either all the

FIGURE 4

VIRGINIA CROAKER DATA

COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY

JUVENILES TWO YEARS PRECEEDING



NMFS AND VIMS DATA (1951−1979)

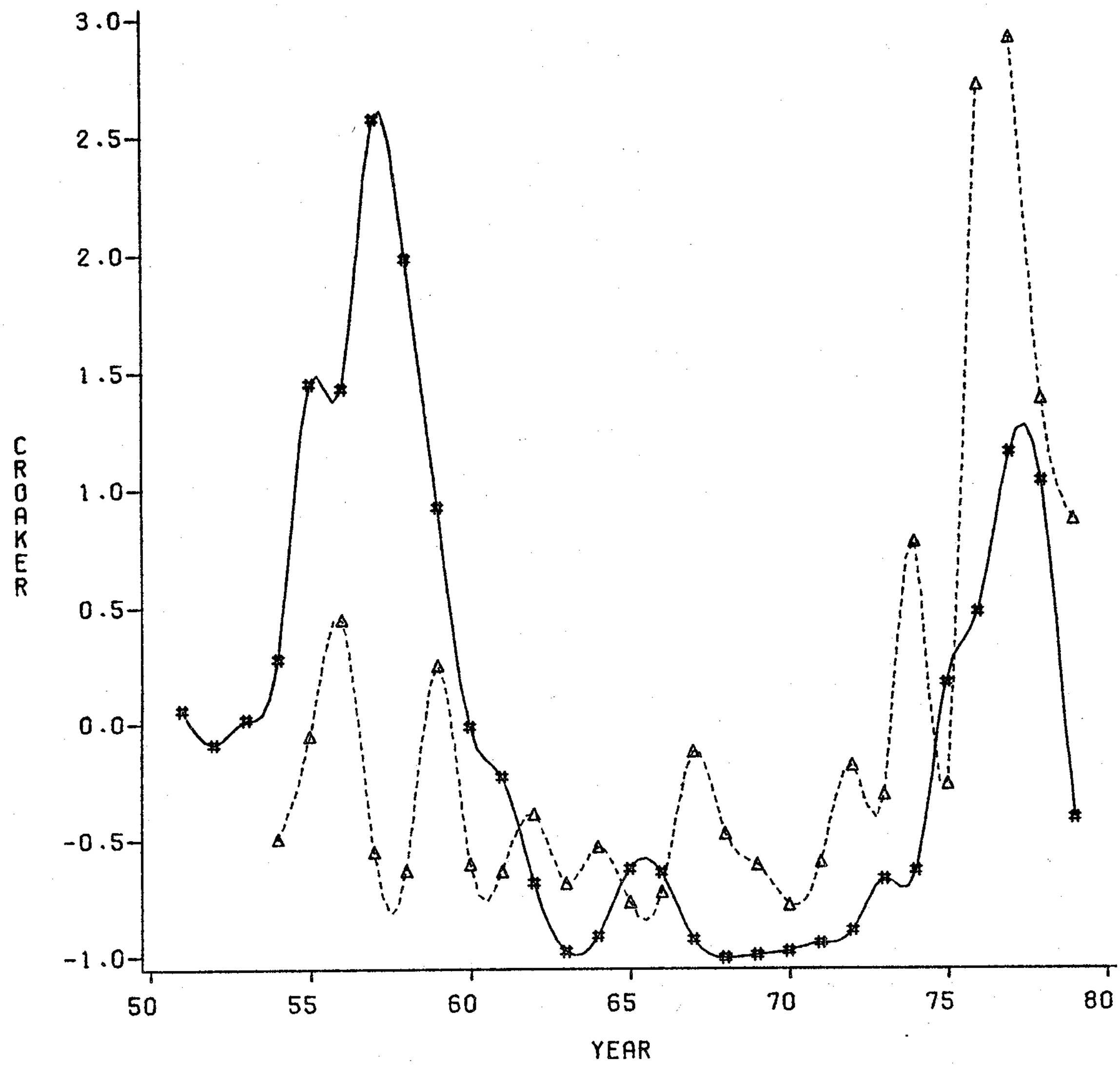
STANDARDIZED SCALE
POUNDS OF COMMERCIAL CROAKER−−SOLID LINE
JUVENILE CROAKER PER 10 MINUTE TRAWL−−DASHED

FIGURE 5

VIRGINIA CROAKER DATA

COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY

JUVENILES THREE YEARS PRECEEDING



NMFS AND VIMS DATA (1951–1979)

STANDARDIZED SCALE

POUNDS OF COMMERCIAL CROAKER--SOLID LINE

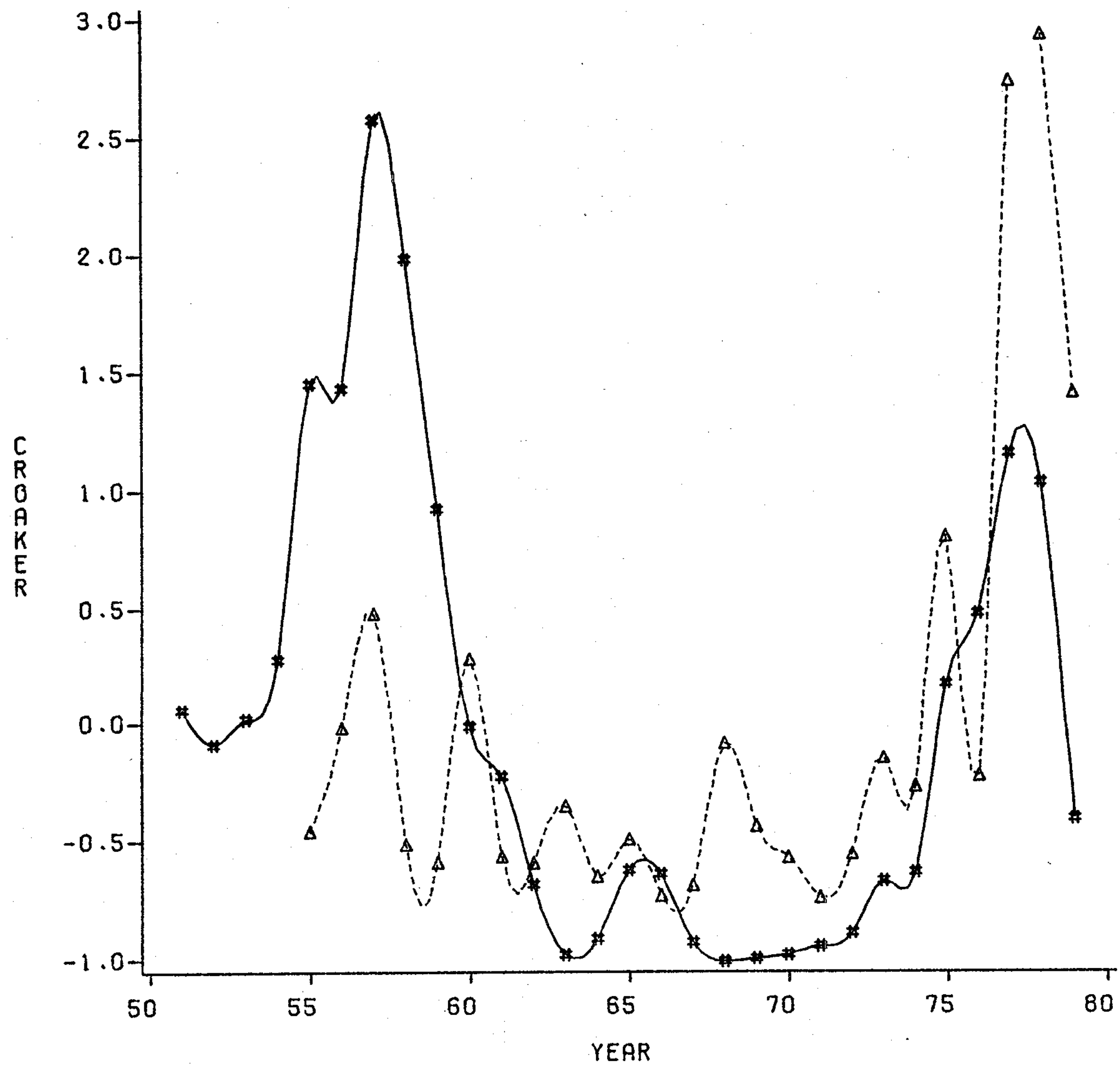
JUVENILE CROAKER PER 10 MINUTE TRAWL--DASHED

FIGURE 6

VIRGINIA CROAKER DATA

COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY

JUVENILES FOUR YEARS PRECEEDING



NMFS AND VIMS DATA (1951–1979)

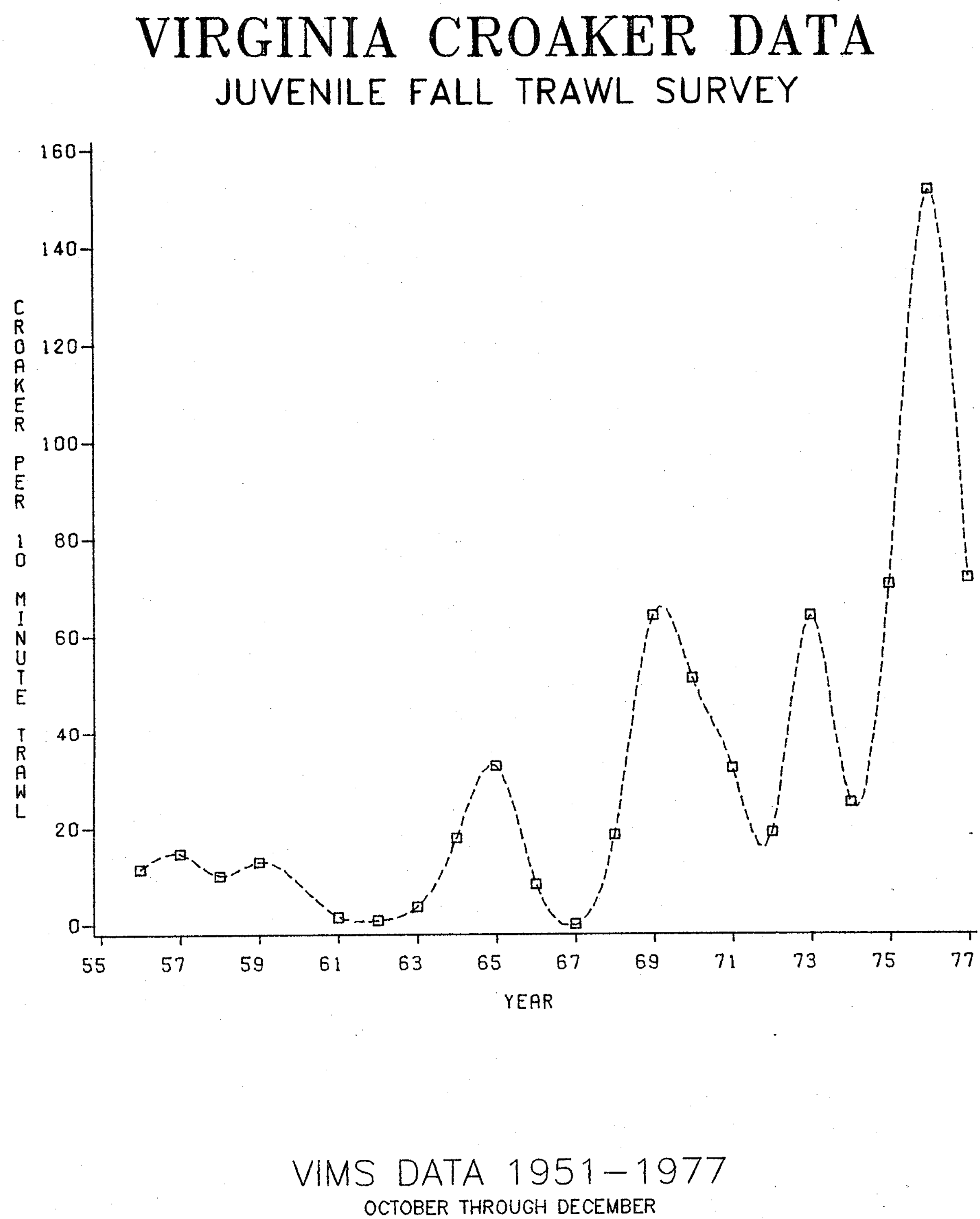
STANDARDIZED SCALE
POUNDS OF COMMERCIAL CROAKER--SOLID LINE
JUVENILE CROAKER PER 10 MINUTE TRAWL--DASHED

TABLE 4. CORRELATIONS: Commercial catch vs. All young-of-the-year croaker (simultaneously and 1-5 years previously)

		YOY	YOY1	YOY2	YOY3	YOY4	YOY5
R	Pearson	-0.099	0.104	0.267	0.327	0.390	0.291
p	Corr. Coef.	0.62	0.61	0.18	0.10	0.05	0.17
n	(parametric)	27	27	27	26	25	24
R	Spearman		0.319	0.407	0.398	0.441	0.539
p	Corr. Coef.		0.11	0.04	0.04	0.03	0.01
n	(non-parametric)		27	27	26	25	24

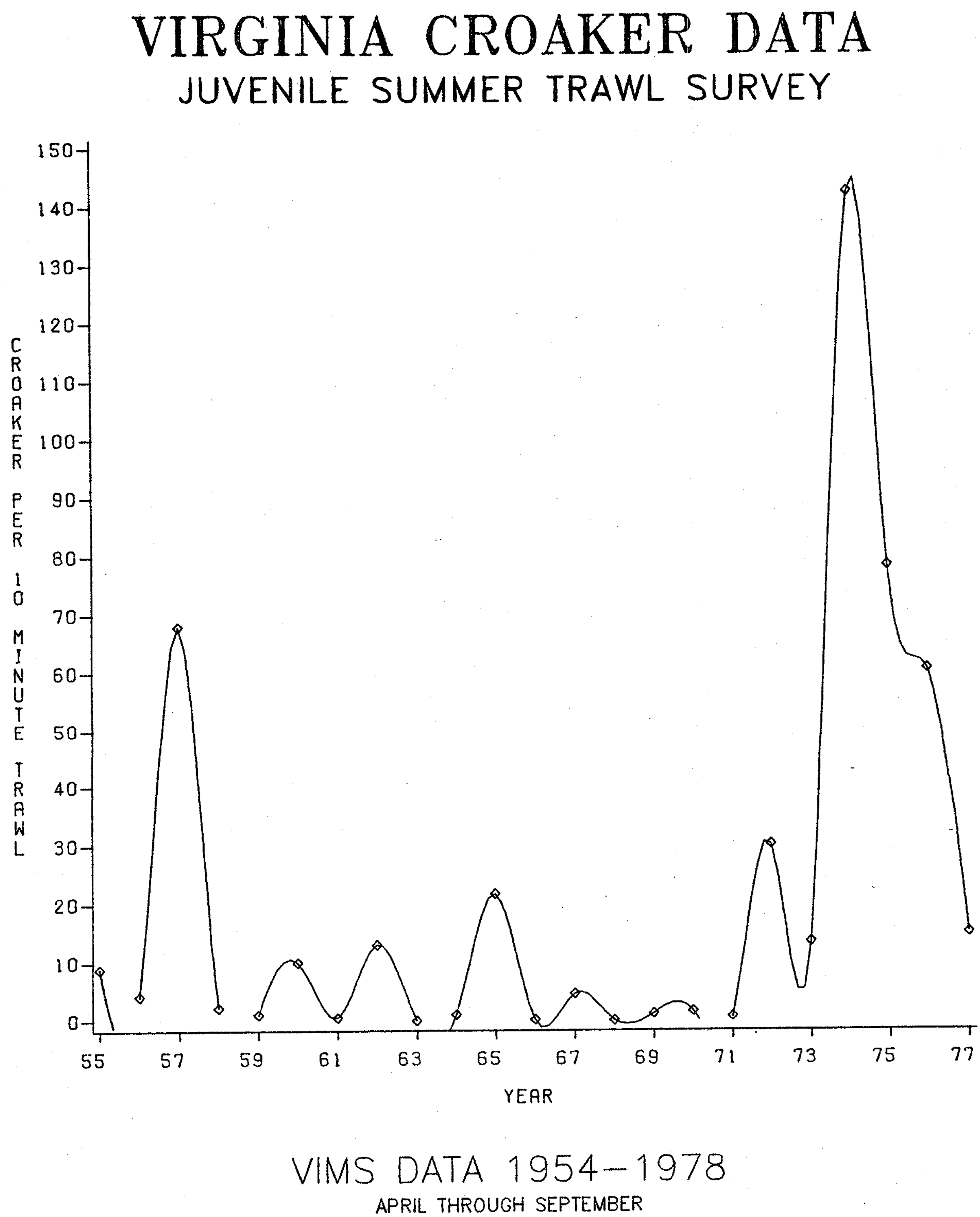
		2-3	3-4	4-5	2-3-4	3-4-5	2-3-4-5
F	Multiple	1.46	2.17	2.49	1.40	1.67	
p	Regression	0.25	0.14	0.11	0.27	0.21	
R^2		0.113	0.165	0.192	0.167	0.201	
t-2		0.382			0.243		
t-3		1.023	0.569		0.354	0.470	
t-4			1.1795	1.670	1.126	0.167	
t-5				0.117			
F	Stepwise	2.87	4.14	5.20	4.14	5.20	5.20
p	Regression	0.10	0.05	0.03	0.05	0.03	0.03
R^2		0.106	0.152	0.191	0.152	0.191	0.191
Selected		YOY2	YOY4	YOY4	YOY4	YOY4	YOY4
Variables		Only	Only	Only	Only	Only	Only

FIGURE 7



VIRGINIA CROAKER DATA
JUVENILE FALL TRAWL SURVEY
CROAKER PER 10 MINUTE TRAWL
160
140
120
100
80
60
40
20
0
55
57
59
61
63
65
67
69
71
73
75
77
YEAR
VIMS DATA 1951–1977
OCTOBER THROUGH DECEMBER

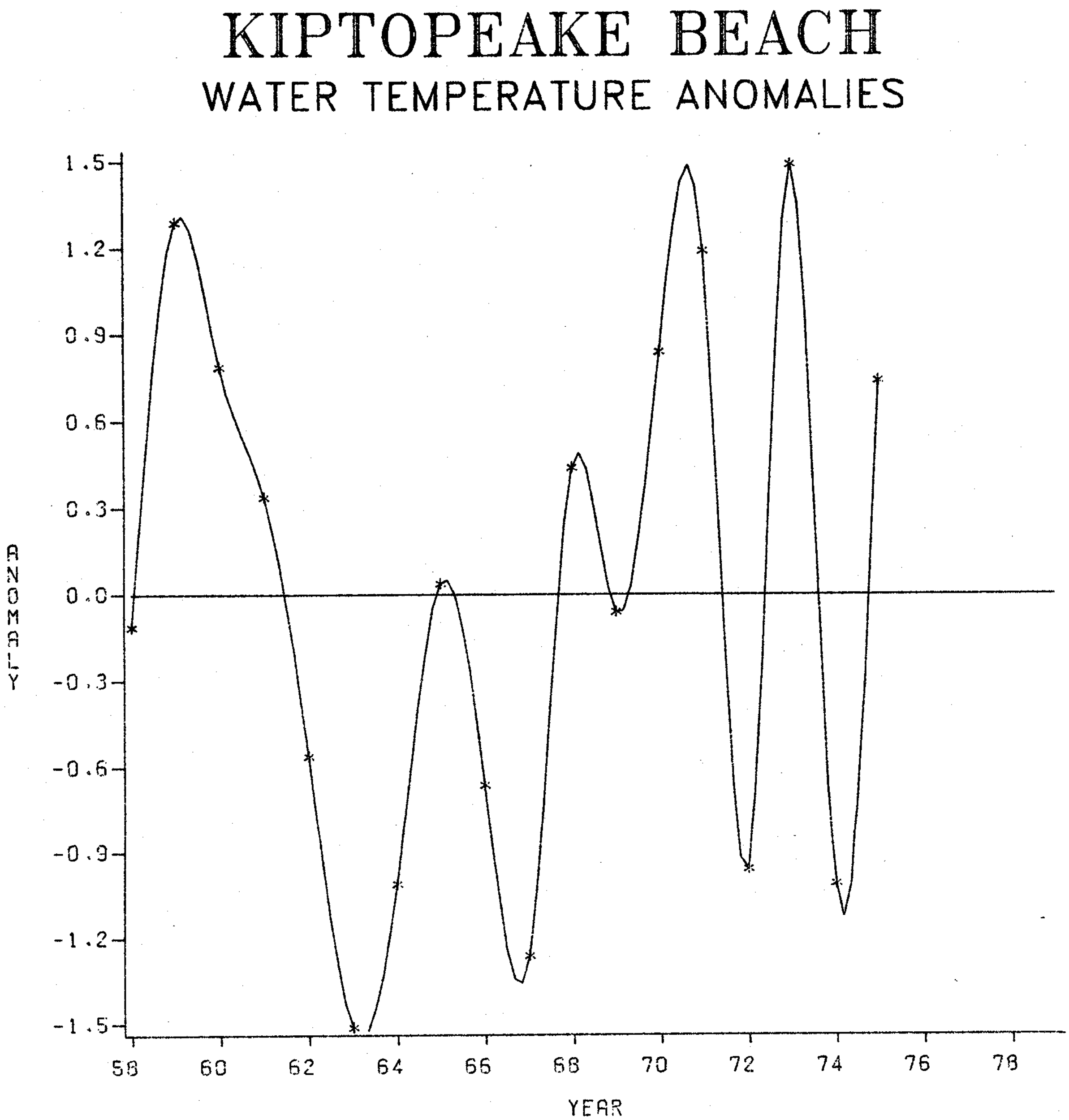
FIGURE 8


VIRGINIA CROAKER DATA
JUVENILE SUMMER TRAWL SURVEY
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CROAKER PER 10 MINUTE TRAWL
55
57
59
61
63
65
67
69
71
73
75
77
YEAR
VIMS DATA 1954-1978
APRIL THROUGH SEPTEMBER

juveniles or lagged commercial croaker abundance (Table 5); however, the correlations indicate that the number of fall croaker is more closely related to Kiptopeake Beach water temperature anomalies than are all juvenile croaker averaged over a bio-year (YOY) or the commercial catch 2, 3, or 4 years later (COM2, COM3, COM4).

The correlations were not significant, so, based upon the work of Wojcik (1978) and others, minimum winter (MIN), January (JAN), February (FEB) and January-February average (Figure 10) (JFAVG) temperatures from VIMS pier were examined. A plot of these winter temperatures and following summer young-of-the-year croaker (Figure 11) gives an empirical "clue" to a statistical relationship. Correlations between various winter temperature combinations as the independent variables, and the juvenile croaker index as the dependent variable for the following summer are shown in Table 6. All correlations, except April temperature and fall croaker index, are significant ($p<0.001$), indicating that abundance of summer juveniles is dependent on winter temperatures (January through March) but not on April temperatures or fall croaker. The fall young-of-the-year croaker index and the winter temperature were used as independent variables in a multiple regression with the summer juvenile croaker index to determine if summer juvenile abundance is dependent upon a combined effect of winter temperatures and fall juvenile abundance. Fall croaker index turned out not to be a significant predictor. The overall significance of the multiple regression is attributable to the winter temperature variable. Quadratic regressions were run using

FIGURE 9



SEPTEMBER AND OCTOBER COMBINED

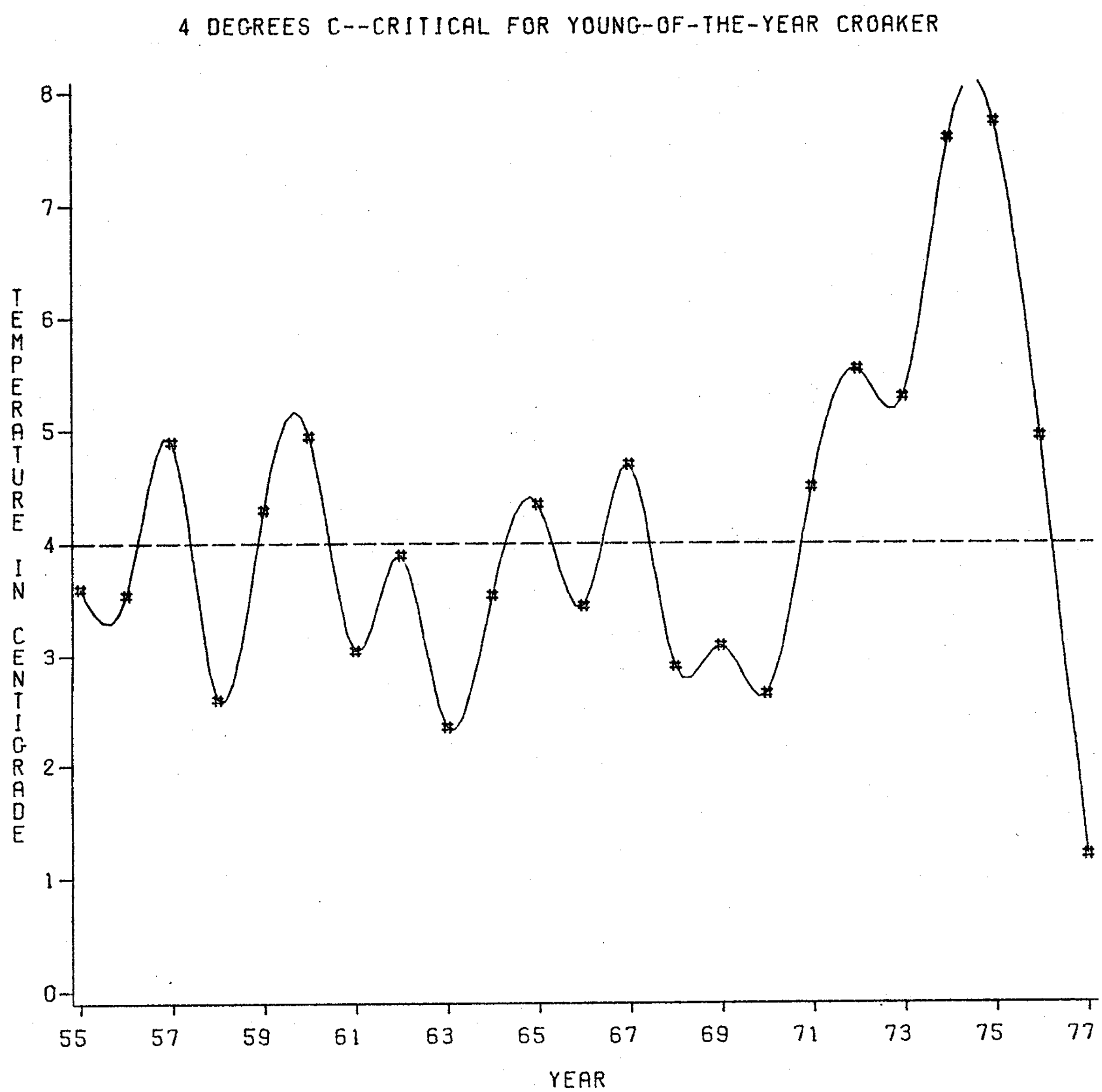
TABLE 5. CORRELATIONS: CROAKER (all juveniles, fall juveniles, and commercial 2-4 years later) vs. KIPTOPEAKE BEACH WATER TEMPERATURE (September, October, and Sept.-Oct. average)

		YOY	FALLCR	COM2	COM3	COM4
R*	September	0.099	0.516	0.191	0.115	0.265
p		0.70	0.04	0.45	0.65	0.29
n		18	16	18	18	18
R*	October	-0.193	0.456	0.195	-0.007	0.024
p		0.44	0.07	0.44	0.98	0.93
n		18	16	18	18	18
R*	Sept.-Oct.	-0.068	0.556	0.050	0.211	0.093
p		0.79	0.03	0.86	0.45	0.74
n		18	16	15	15	15

R* = Pearson Correlation Coefficient

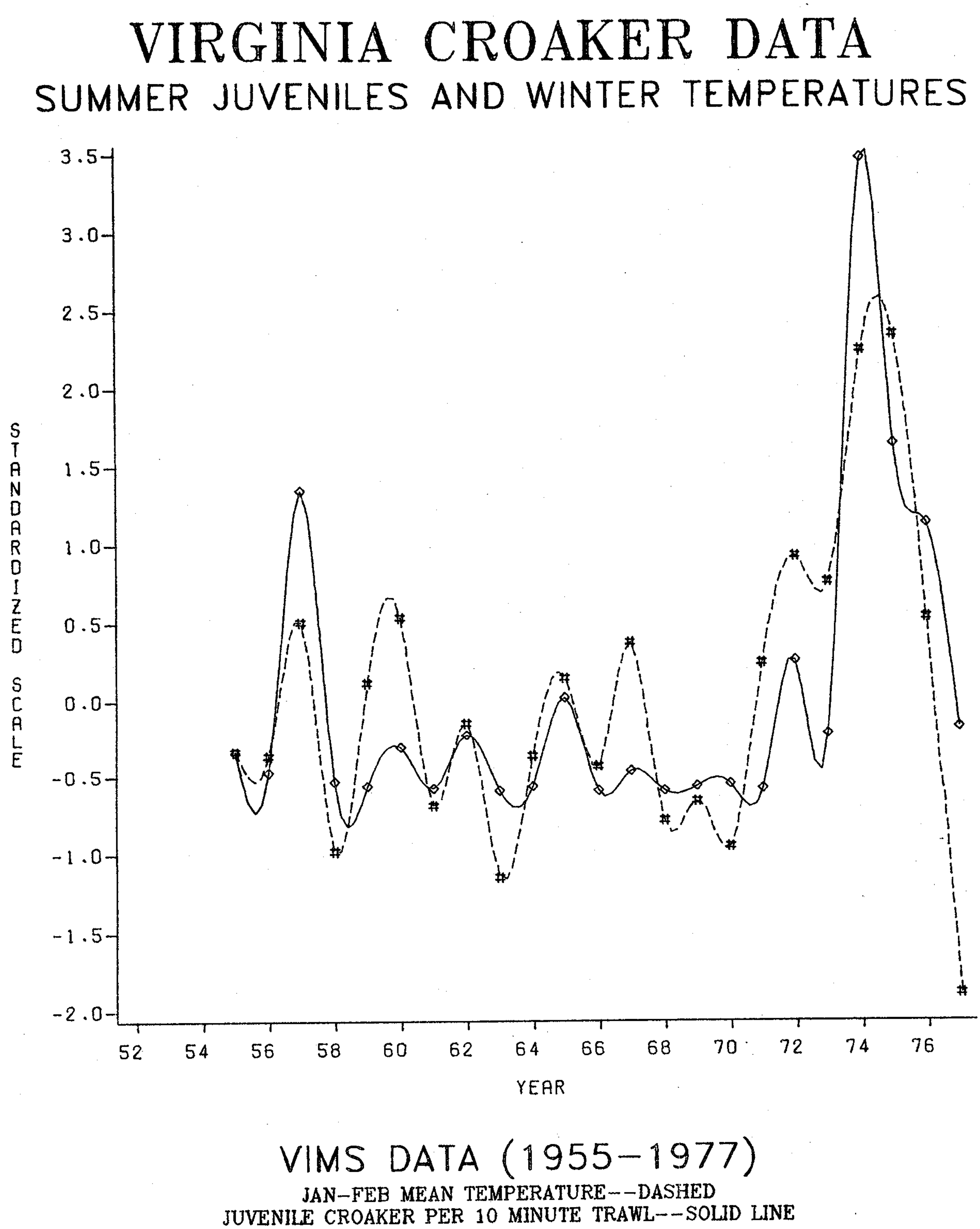
FIGURE 10

VIMS PIER
WATER TEMPERATURES



JANUARY–FEBRUARY MEAN

FIGURE 11



VIRGINIA CROAKER DATA
SUMMER JUVENILES AND WINTER TEMPERATURES
STANDARDIZED SCALE
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
52
54
56
58
60
62
64
66
68
70
72
74
76
YEAR
VIMS DATA (1955–1977)
JAN–FEB MEAN TEMPERATURE--DASHED
JUVENILE CROAKER PER 10 MINUTE TRAWL--SOLID LINE

TABLE 6. CORRELATIONS: Summer juvenile croaker vs. winter temperatures/fall croaker

	Minimum	Min/fall	Jan	Jan/fall	Feb	Feb/fall	JFavg	JF/fall	DJFavg	DJF/fall	DJFMavg	DJFM/fall	April	Fall
R	0.720		0.642		0.745		0.755		0.751		0.811		0.268	0.297
p	0.0001		0.001		0.0001		0.0001		0.0001		0.0001		0.241	0.190
n	23		23		23		23		23		23		21	21

R* = Pearson Correlation Coefficient

F	19.87	12.30	12.44	10.01	23.18	11.67	24.07	14.63	23.54	14.18	35.22	17.51	1.47	
p	0.0003	0.0004	0.0023	0.0012	0.0001	0.0006	0.0001	0.0002	0.0001	0.0002	0.0001	0.0001	0.241	
R	0.511	0.578	0.396	0.527	0.550	0.565	0.559	0.619	0.553	0.612	0.650	0.661	0.072	
t(temp)	4.458	4.568	3.527	4.082	4.814	4.437	4.906	5.008	4.852	4.926	5.935	5.508	1.212	
t(fall)		1.559		1.808		0.330		1.161		1.238		0.548		

	Min	$Min^2/fall$	Jan^2	$Jan^2/fall$	Feb^2	$Feb^2/fall$	JF^2	$JF^2/fall$	DJF^2	$DJF^2/fall$	$DJFM^2$	$DJFM^2/fall$
F	33.76	19.87	23.60	14.30	40.30	19.09	44.12	22.58	42.11	21.11	56.65	24.28
p	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
R	0.634	0.677	0.554	0.613	0.680	0.680	0.699	0.715	0.667	0.701	0.730	0.730
$t(temp^2)$	5.812	5.881	4.858	4.948	6.349	5.764	6.642	6.291	6.489	6.075	7.526	6.533
t(fall)		1.467		1.668		−0.025		1.006		1.138		0.369

	$Min^2/fall^2$	$Jan^2/fall^2$	$Feb^2/fall^2$	$JF^2/fall^2$	$DJF^2/fall^2$	$DJFM^2/fall^2$
F	20.84	15.78	19.11	23.57	21.43	23.36
p	0.0001	0.001	0.0001	0.0001	0.0001	0.0001
R	0.698	0.637	0.680	0.724	0.716	0.733
$t(temp^2)$	6.106	5.283	5.837	6.506	6.222	6.503
$t(fall^2)$	1.869	2.207	0.110	1.269	1.244	0.282

	Log(min)	Log(min)/ log(fall)	Log(Jan)	Log(Jan)/ log(fall)	Log(Feb)	Log(Feb)/ log(fall)	Log(JF)	Log(JF)/ log(fall)	Log(DJF)	Log(DJF)/ log(fall)	Log(DJFM)	Log(DJFM)/ log(fall)	Log(fall)
log(SUMMERCR)													
F	2.19	2.88	1.73	2.71	10.84	6.08	7.27	5.17	15.50	8.10	28.72	12.30	3.05
p	0.16	0.084	0.21	0.096	0.004	0.010	0.015	0.018	0.001	0.003	0.0001	0.0005	0.098
R^2	0.109	0.253	0.088	0.241	0.376	0.417	0.288	0.378	0.463	0.488	0.578	0.5913	0.145
t_1	1.480	1.567	1.314	1.472	3.293	2.817	2.696	2.527	3.937	3.666	5.360	4.597	
t_2		1.813		1.858		1.092		1.574		0.920		0.513	1.745

temperature squared (SUMMERCR = a + b(temp)^2) and in a multiple regression with the fall juvenile index (SUMMERCR = a + b(FALLCR) + c(temp)^2) or the square of that index (SUMMERCR = a + c*(FALLCR)^2 + c(temp)^2). The quadratic regressions are more highly significant (e.g., January-February average squared (JFAVG)^2: F=44.12, R^2=0.699, t=6.642) than are the linear regressions (e.g., January-February average (JFAVG): F=24.07, R^2=0.559, t=4.906). This result holds true for all winter temperature combinations (e.g. December-January-February (DJF), December-January-February-March (DJFM)). Fall croaker index is also not a significant predictor for the summer croaker index in a quadratic regression. Regressions between the log of summer juvenile index and the log of winter temperature alone or combined with the log of the fall index are less significant than the linear regression with the squares of the variables in all cases. There is also no statistical significance in the linear relation between the logarithms of the summer and of the fall young-of-the-year croaker indices.

The time series of summer juvenile croaker has no statistically significant autoregressive predictors (i.e., lag#1: t=1.490, lag#2: t=0.749). Based on this and the results of the correlations and regressions in Table 6, autoregressive analyses were conducted using additional predictor winter temperatures and the fall croaker index (Table 7). The results are similar to those of the linear and quadratic regressions (Table 6) in that all temperature variables are highly significant ($p<0.002$), but the fall juvenile index does not

TABLE 7. AUTOREGRESSIONS: Summer croaker (dependent) vs. winter temperature/fall croaker (indepdendent)

	No Predictors	Minimum	Min/fall	Jan	Jan/fall	Feb	Feb/fall	JFavg	JF/fall	DJFavg	DJF/fall	DJFMavg	DJFM/fall
F	0.00	23.45	14.67	12.21	9.36	42.25	23.20	26.03	18.35	26.41	16.88	34.86	24.04
P	1.000	0.0001	0.0001	0.0002	0.0015	0.0001	0.0001	0.0001	0.0001	0.0001	0.000	0.0001	0.0001
R^2		0.528	0.607	0.368	0.496	0.668	0.710	0.554	0.659	0.557	0.640	0.624	0.717
lag#	1/-1.490	2	2	1	2	1	1	2	1	1	1	2	1
t	2/-0.749	-1.427	-1.125	-0.985	-0.026	0.962	1.149	-0.223	0.650	-1.025	0.575	-0.722	0.612
t(temp)		4.842	5.248	3.494	3.987	6.500	5.661	5.102	5.334	5.139	5.255	5.905	6.076
p		0.0001	0.0001	0.0022	0.0008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
t(fall)			1.665		1.775		0.760		1.589		1.705		0.857
p			0.112		0.092		0.457		0.129		0.105		0.402

	Min^2	$Min^2/fall^2$	Jan^2	$Jan^2/fall^2$	Feb^2	$Feb^2/fall^2$	JF^2	$JF^2/fall^2$	DJF^2	$DJF^2/fall^2$	$DJFM^2$	$DJFM^2/fall^2$
F	46.11	28.51	24.42	14.77	131.82	59.05	52.31	31.38	40.55	25.76	64.20	30.94
P	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
R^2	0.687	0.750	0.505	0.609	0.863	0.862	0.714	0.768	0.659	0.731	0.754	0.7651
lag#	2	1	2	1	2	1	1	1	2	1	1	1
t	-1.445	-1.419	-0.576	0.405	2.160	2.020	0.562	1.032	-0.752	0.753	0.432	0.601
t(temp)	6.791	7.358	4.628	5.051	11.482	8.768	7.233	7.025	6.368	6.618	8.012	7.079
p	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
t(fall)		1.881		1.765		0.218		1.393		1.623		0.596
p		0.075		0.094		0.830		0.180		0.121		0.558

	$Min^2/fall^2$	$Jan^2/fall^2$	$Feb^2/fall^2$	$JF^2/fall^2$	$DJF^2/fall^2$	$DJFM^2/fall^2$
F	1.99	2.90	3.60	0.64	29.42	31.84
P	0.4479	0.3833	0.349	0.547	0.0001	0.0001
R^2	0.799	0.853	0.878	0.125	0.756	0.770
lag#	2	2	2	1	1	1
t	0.675	0.662	0.668	-2.391	0.836	0.608
t(temp)	0.502	0.773	-0.926	-1.033	6.976	7.261
p	0.704	0.581	0.524	0.329	0.0001	0.0001
t(fall)	-0.144	0.776	2.008	-0.326	1.896	0.668
p	0.909	0.580	0.294	0.752	0.073	0.512

contribute to the overall significance of the multiple regression. As expected, in agreement with multiple regression results, the quadratic regression using temperature as the predictor variable is more significant than the linear regression. Examinations of the parameters for using various lagged values as predictors (lag#) and their corresponding t values in Table 7 reveals no significance, thus no autoregressive properties.

Commercial catch was correlated with the summer juvenile croaker index 2 to 5 years preceding (SUM2, SUM3, SUM4, SUM5) (Table 8). As shown in Table 4, a nonlinear relationship is indicated because the nonparametric results are more significant than the parametric ones. These correlations between commercial catch and summer juveniles are more significant than those in Table 4 with all juveniles (e.g., YOY2: R=0.407, p=0.04; SUM2: R=0.547, p=0.004). The correlation results in Table 8, together with the empirical lagged plots (Figures 12, 13, and 14) provided the rationale for the development of the year class contribution concept, a subjective determination for a year class contributing to multiple commercial catches which will more appropriately be covered in the Discussion.

Modelling efforts were begun using the statistical results above as an empirical foundation. Mean January-February temperature (t) was chosen from Table 6 to be the predictive parameter for summer juvenile croaker abundance (x). The data were plotted (Figure 15) so that the empirical relationship could be examined. Although a quadratic relationship had been indicated in regression analyses, to insure

TABLE 8. CORRELATIONS: Commercial Catch vs. Summer croaker (2-5 years previously)

		SUM2	SUM3	SUM4	SUM5
R	Pearson	0.344	0.339	0.271	0.040
p	Corr. Coef.	0.09	0.10	0.20	0.86
n	(parametric)	26	25	24	23
R	Spearman	0.547	0.535	0.511	0.417
p	Corr. Coef.	0.004	0.006	0.011	0.048
n	(non-parametric)	26	25	24	23

FIGURE 12

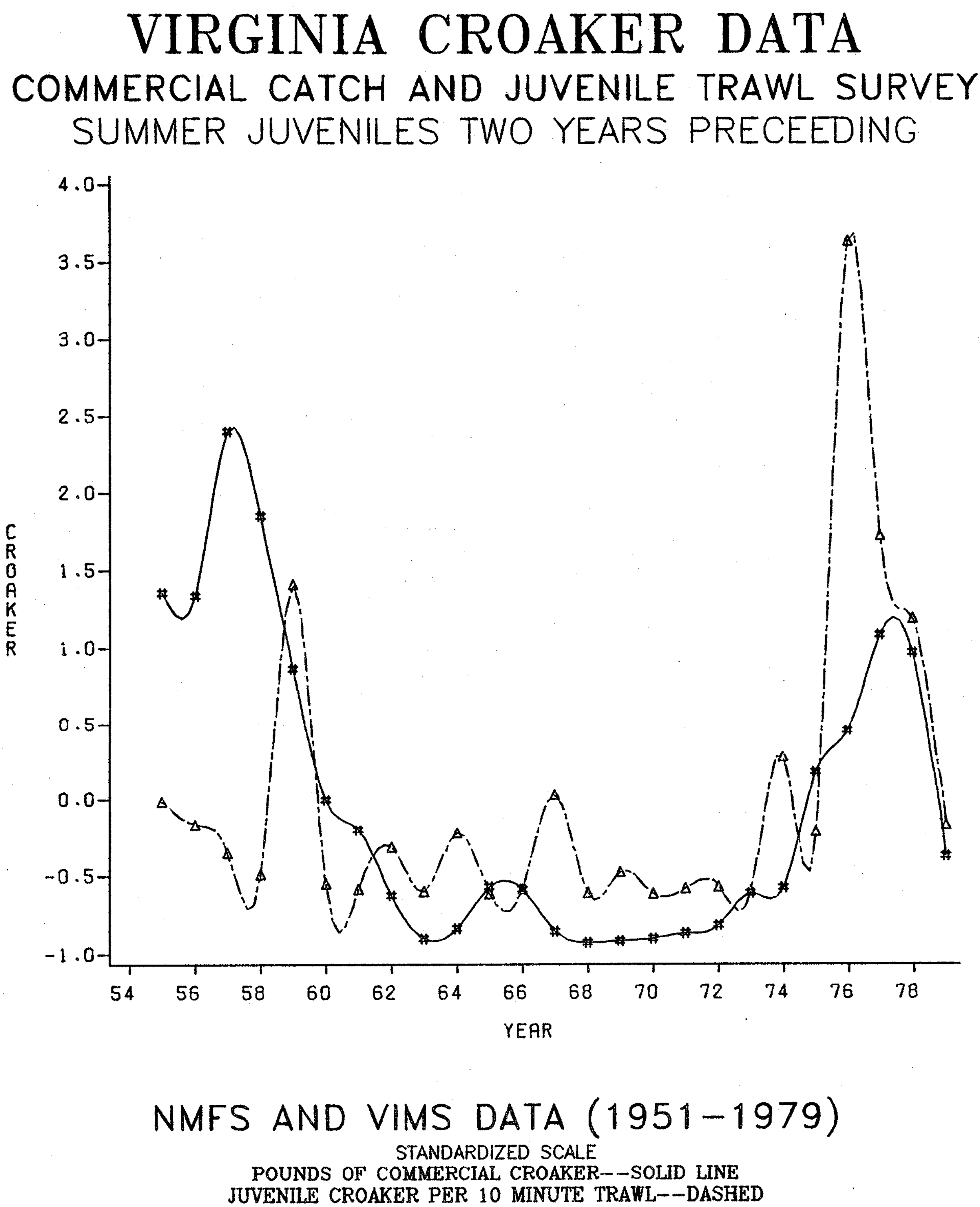
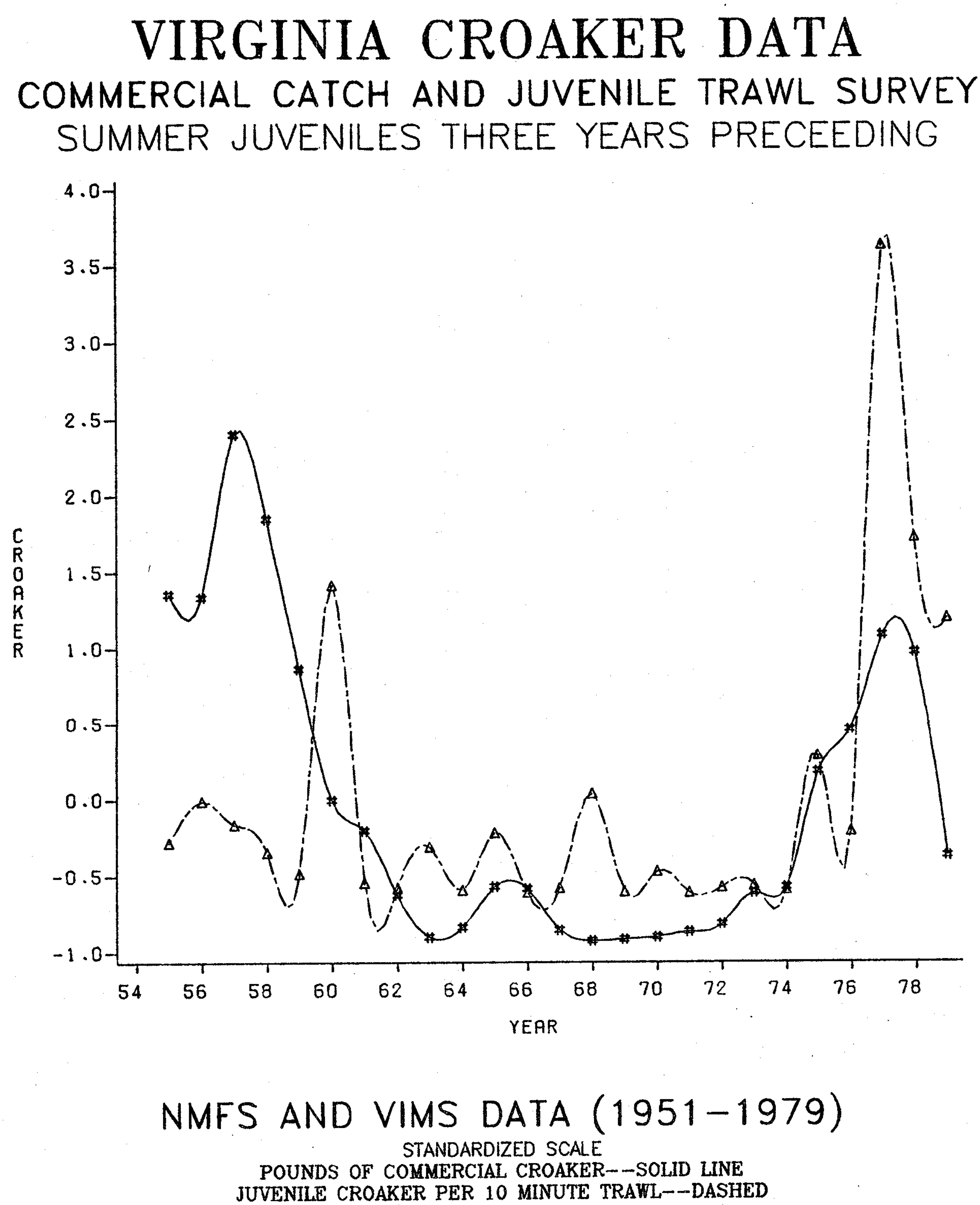

VIRGINIA CROAKER DATA
COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY
SUMMER JUVENILES TWO YEARS PRECEEDING
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
CROAKER
54
56
58
60
62
64
66
68
70
72
74
76
78
YEAR
NMFS AND VIMS DATA (1951-1979)
STANDARDIZED SCALE
POUNDS OF COMMERCIAL CROAKER--SOLID LINE
JUVENILE CROAKER PER 10 MINUTE TRAWL--DASHED

FIGURE 13



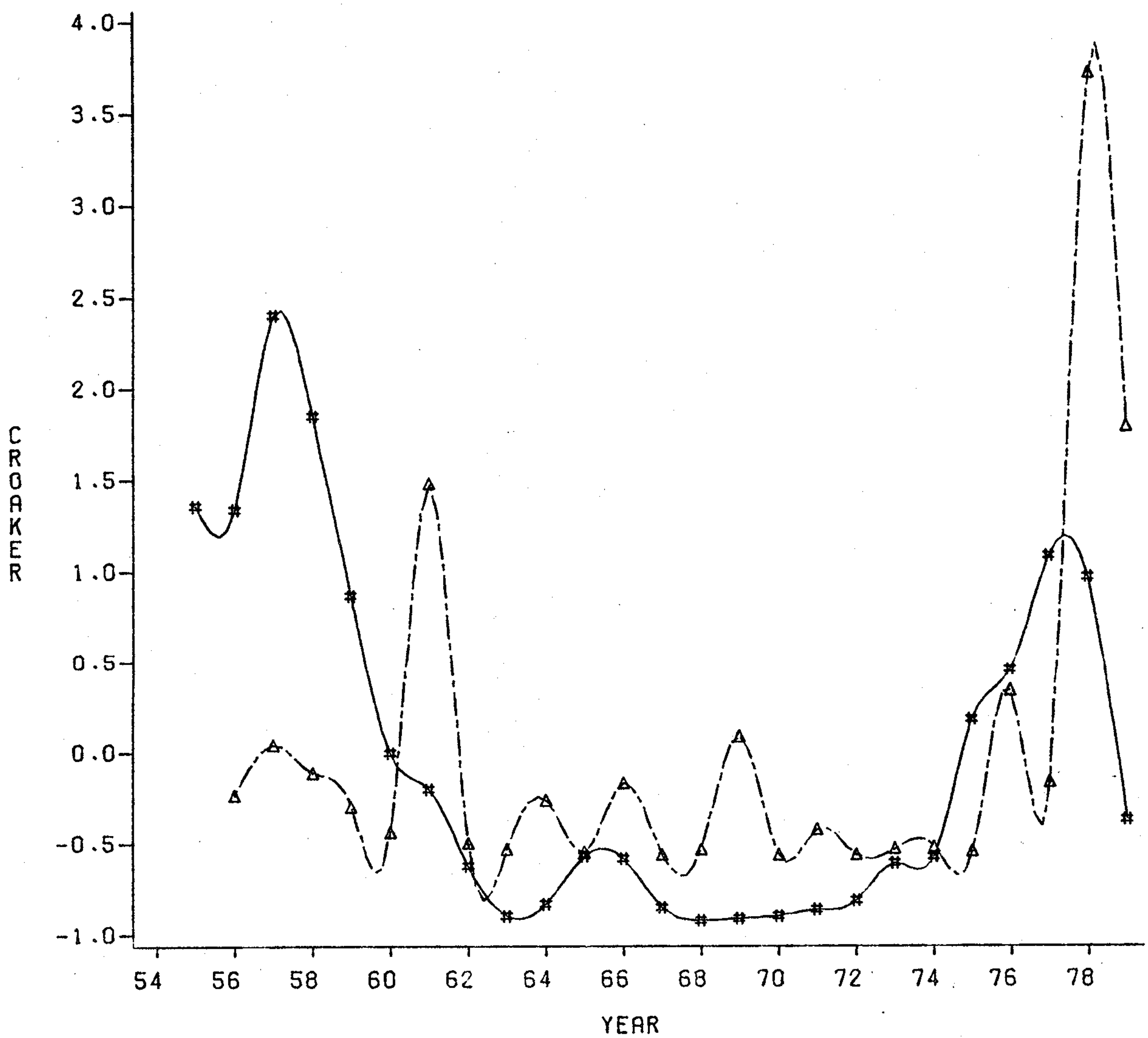
VIRGINIA CROAKER DATA
COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY
SUMMER JUVENILES THREE YEARS PRECEEDING
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
CROAKER
54
56
58
60
62
64
66
68
70
72
74
76
78
YEAR
NMFS AND VIMS DATA (1951-1979)
STANDARDIZED SCALE
POUNDS OF COMMERCIAL CROAKER--SOLID LINE
JUVENILE CROAKER PER 10 MINUTE TRAWL--DASHED

FIGURE 14

VIRGINIA CROAKER DATA

COMMERCIAL CATCH AND JUVENILE TRAWL SURVEY

SUMMER JUVENILES FOUR YEARS PRECEEDING



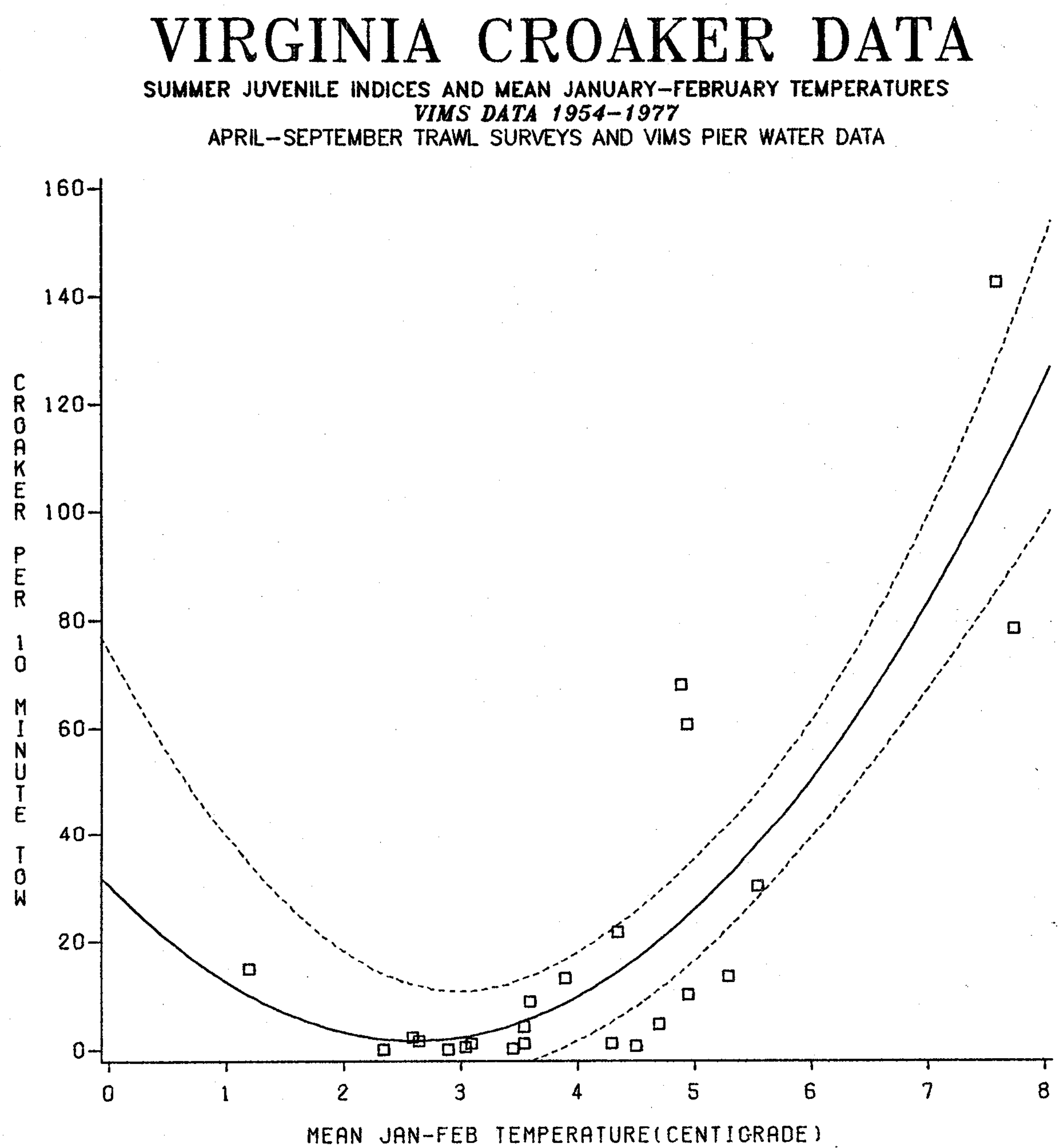
NMFS AND VIMS DATA (1951–1979)

STANDARDIZED SCALE
POUNDS OF COMMERCIAL CROAKER--SOLID LINE
JUVENILE CROAKER PER 10 MINUTE TRAWL--DASHED

thorough investigation, the following linear transformations were examined: exponential [$\ln x = a + bt$]; logarithmic [$x = a + b(\ln t)$]; power [$\ln x = \ln a + b(\ln t)$]; and special inversion [$x = {}^1/(a - be^{-t}$]. Plots revealed the exponential, quadratic without the linear term [$x = a + ct^2$] and quadratic with the linear term [$x = a + bt + ct^2$] to be better. The mean square errors, mean absolute values, and estimated regression values are shown in Table 9. Using these results as criteria, the 2-factor quadratic equation was chosen to model the relationship between January-February average VIMS pier temperature and juvenile croaker abundance the following summer. This quadratic curve is shown in Figure 15. From this model, summer juvenile abundance was hindcast for the 1954-1977 time period. The actual data (squares) and the predicted data (solid line) are seen in Figure 16.

Similarly, a model was sought for the subjective croaker year class contribution (y) predicted from summer juvenile abundance (x). Based on the actual data points (squares in Figure 17), the linear transformations of power [$\ln y = \ln a_1 + b_1(\ln x)$], logrithmic [$y = a_1 + b_1(\ln x)$], hyperbolic [$1/y = a - b/x$], and special [$\ln y = \ln (a + b/x$] functions were fit and tested. Only the power and logarithmic functions appeared reasonable when plotted, although it was apparent that the logarithmic was the better fit. This was also evident from the regression analysis, the R^2 for the logarithmic and power relations being 0.30 and .25, respectively (Table 9). The

FIGURE 15



QUADRATIC REGRESSION MODEL

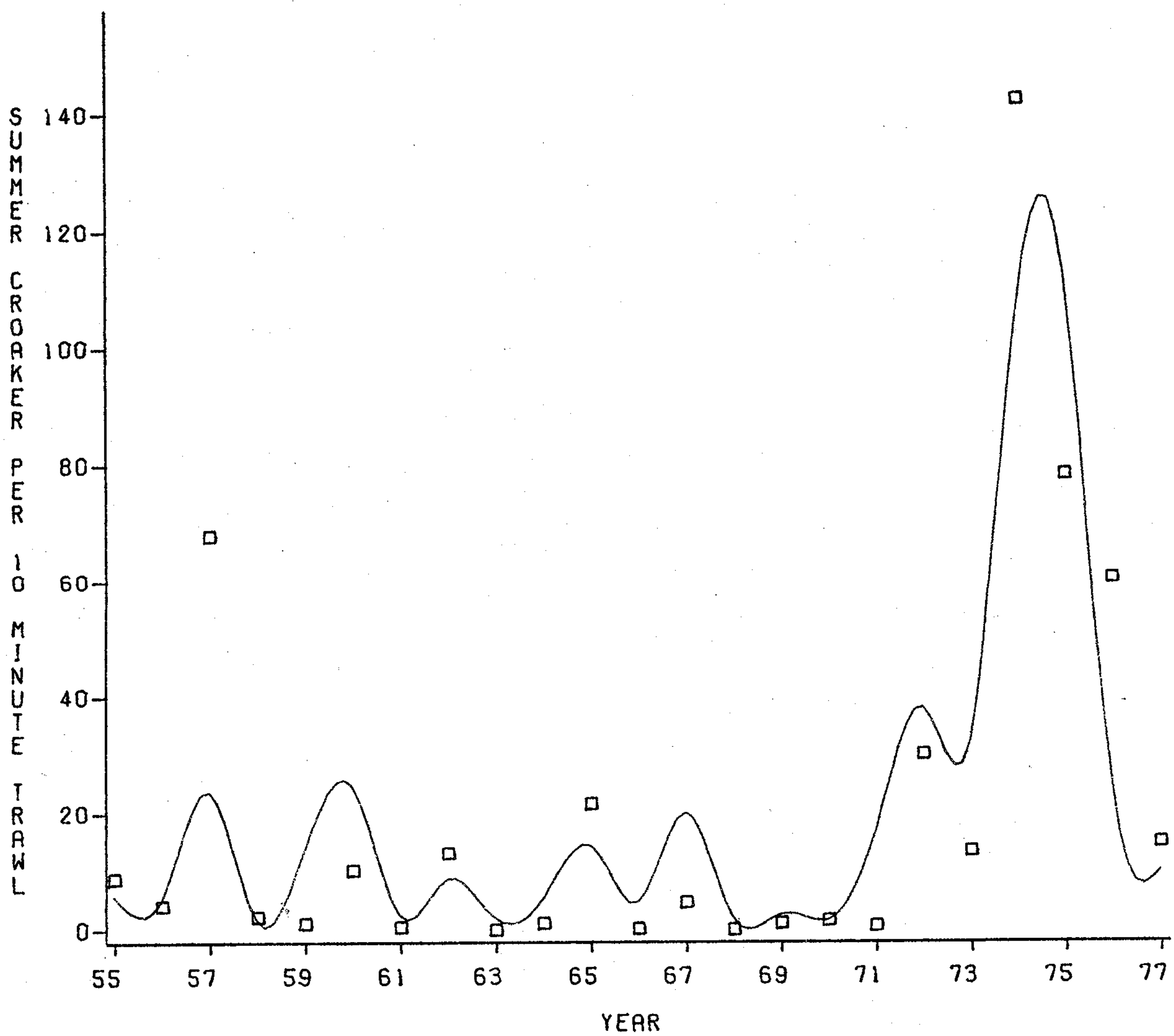
ACTUAL DATA--SQUARES
#CROAKER=A+B(TEMP)+C(TEMP)(TEMP)--SOLID
90 PERCENT CONFIDENCE LIMITS--DASHED

FIGURE 16

VIRGINIA CROAKER DATA

SUMMER JUVENILE ABUNDANCE INDEX

PREDICTED SUMMER JUVENILE ABUNDANCE--SOLID LINE
ACTUAL DATA--SQUARES



FROM QUADRATIC REGRESSION MODEL

BASED ON VIMS TRAWL AND TEMPERATURE DATA 1954-1977 logarithmic model was chosen to represent the relationship between the summer juvenile abundance of young-of-the-year croaker and the year class content. The curve is shown as a solid line in Figures 17 and 18. From this model the year class content of croaker was predicted from 1954 to 1975 (Figure 19).

These two models were combined by substituting the predicted value for the summer index as a predictor in the predictive equation for the year class content. The result is the equation $y = a_1 + b_1(\ln (a - bt + ct^2))$ which allows year class content (y) to be predicted from the January-February mean VIMS pier temperatures (t) (Figures 20 and 21). The predicted and actual points and 3-point moving averages of those points are plotted in Figure 22 and the results of the regression analyses are shown in Table 9.

An attempt was made to determine if variances in the fit of the line to the data were related to the Trawl Survey gear. Only one gear was used from 1955 through 1970--an unlined 30 foot otter trawl. Gear comparisons were made of croaker data from 1971-1978 based on gear. Five separate gears were used during this time, with the unlined 16 foot otter trawl and unlined 30 foot semi-balloon trawl, each used only in 1972 and 1973, respectively. Table 10 shows, by year and gear, the number of tows taken, the number of croaker caught per tow, the percent of croaker per tow captured by each gear within a year and the chi-square value of this percent. While there is no significant difference among gear used in 1971, 1972, and 1976, the chi-square values for 1973 (25.0), 1975 (36.0), and 1977 (46.3) are highly

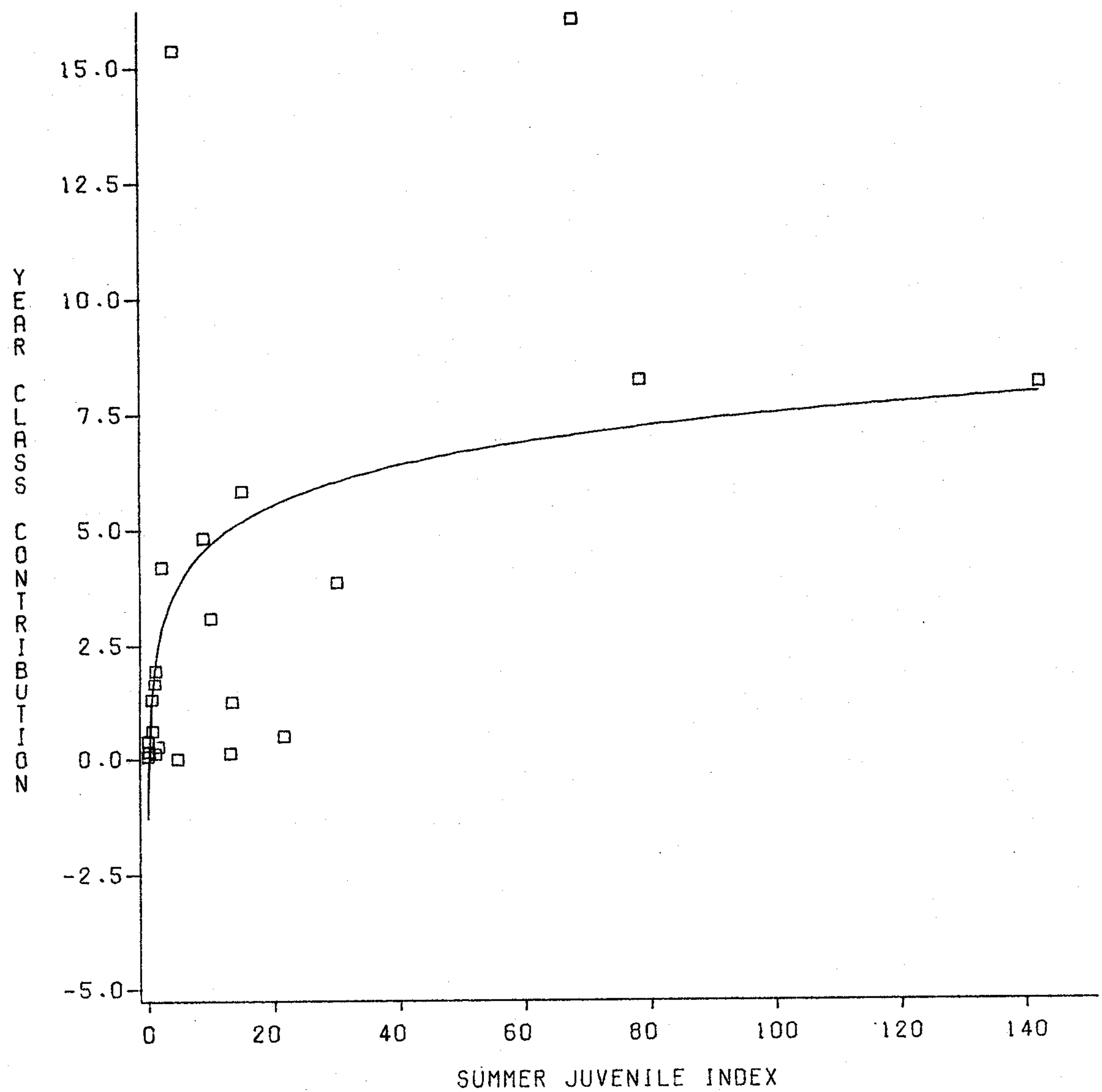
FIGURE 17

VIRGINIA CROAKER DATA

NMFS AND VIMS DATA 1954-1975

YEAR CLASS CONTRIBUTION TO COMMERCIAL CATCH AND SUMMER JUVENILE INDICES

CALCULATED CONTRIBUTIONS AND APRIL-SEPTEMBER TRAWL SURVEYS



LOGARITHMIC REGRESSION MODEL

SQUARES--ACTUAL DATA

SOLID LINE--YEAR CLASS CONTRIBUTION = A + B (LOG OF SUMMER INDEX)

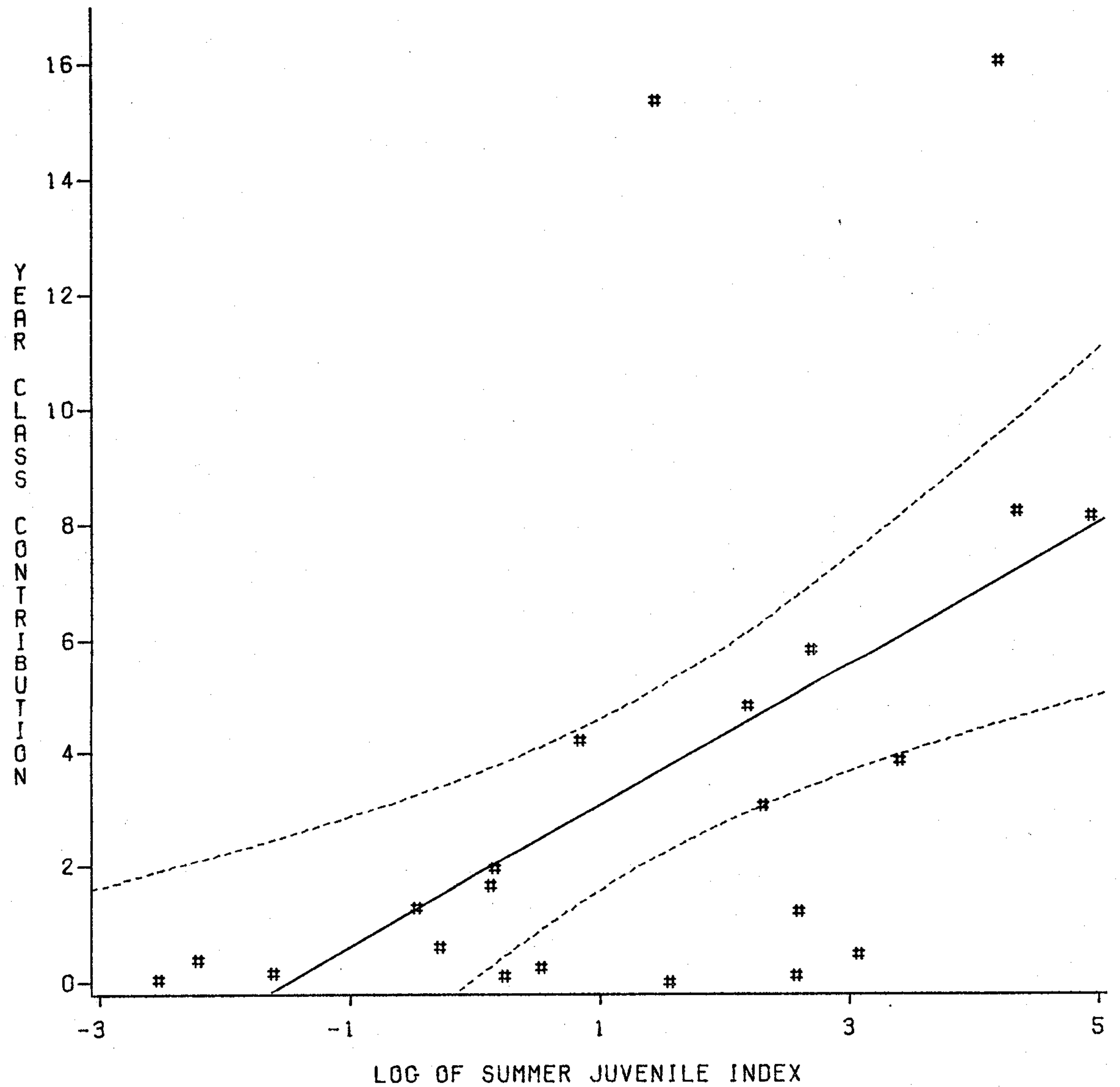
FIGURE 18

VIRGINIA CROAKER DATA

NMFS AND VIMS DATA 1954–1975

YEAR CLASS CONTRIBUTION TO COMMERCIAL CATCH AND SUMMER JUVENILE INDICES

CALCULATED CONTRIBUTIONS AND APRIL–SEPTEMBER TRAWL SURVEYS



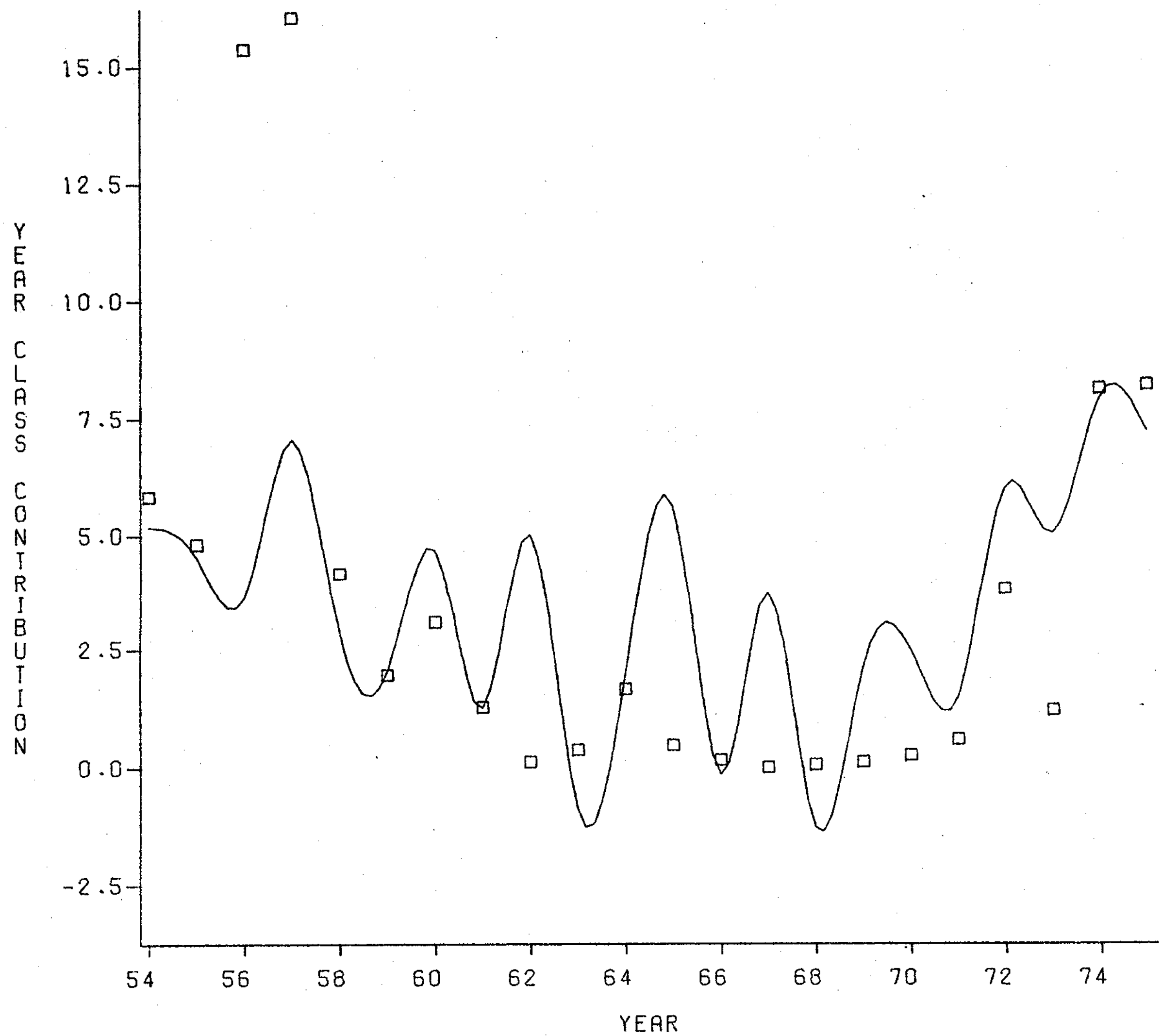
LOGARITHMIC REGRESSION MODEL—LINEARIZED

YEAR CLASS CONTRIBUTION=A+B(LOG OF SUMMER INDEX)—SOLID LINE
90 PERCENT CONFIDENCE LIMITS—DASHED

FIGURE 19

VIRGINIA CROAKER DATA
YEAR CLASS CONTRIBUTIONS

CALCULATED YEAR CLASS CONTRIBUTIONS--SQUARES
PREDICTED YEAR CLASS CONTRIBUTION--SOLID LINE



FROM LOGARITHMIC REGRESSION MODEL

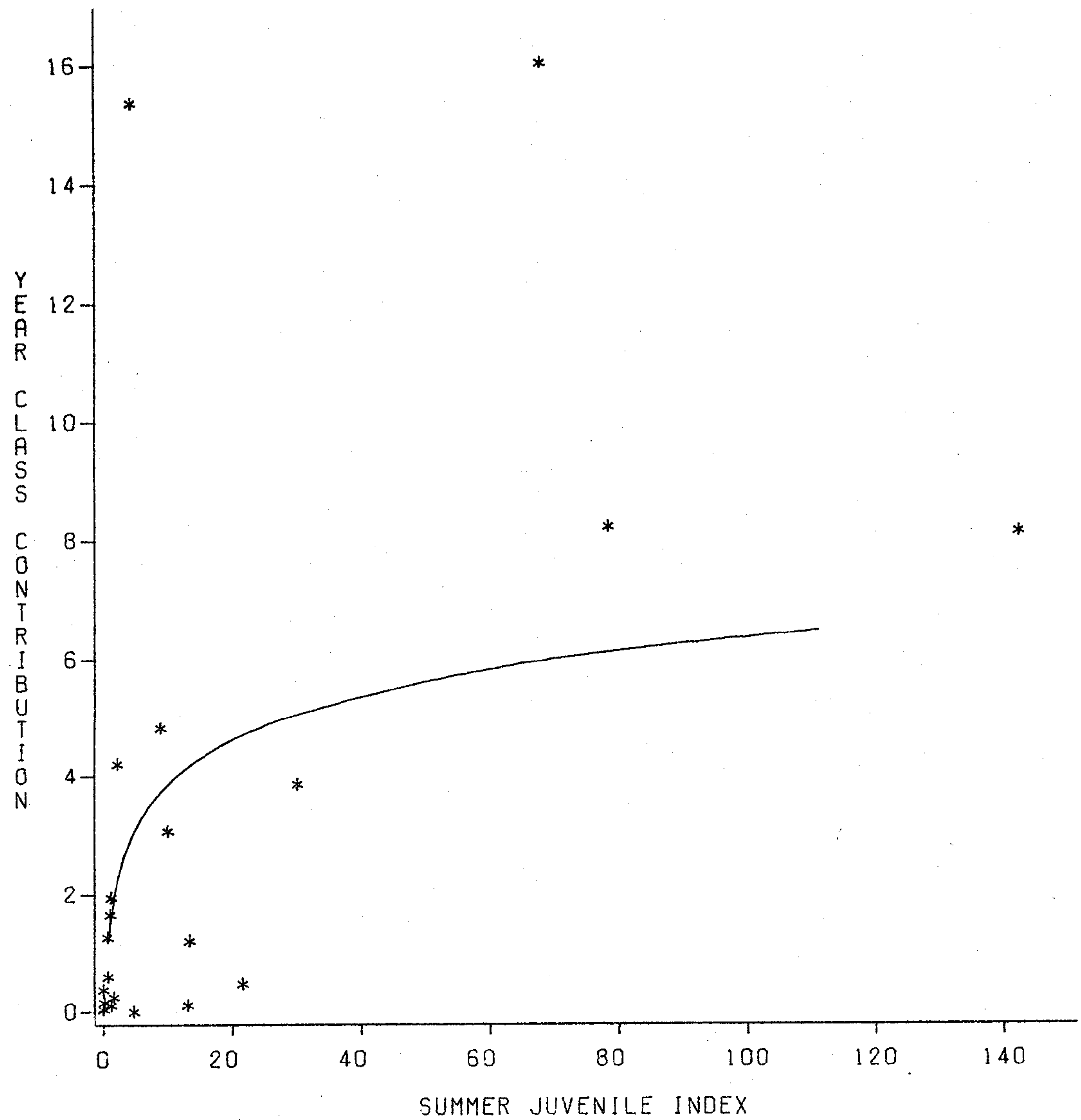
BASED ON NMFS AND VIMS DATA 1954–1975

FIGURE 20

VIRGINIA CROAKER DATA

NMFS AND VIMS DATA 1954-1975

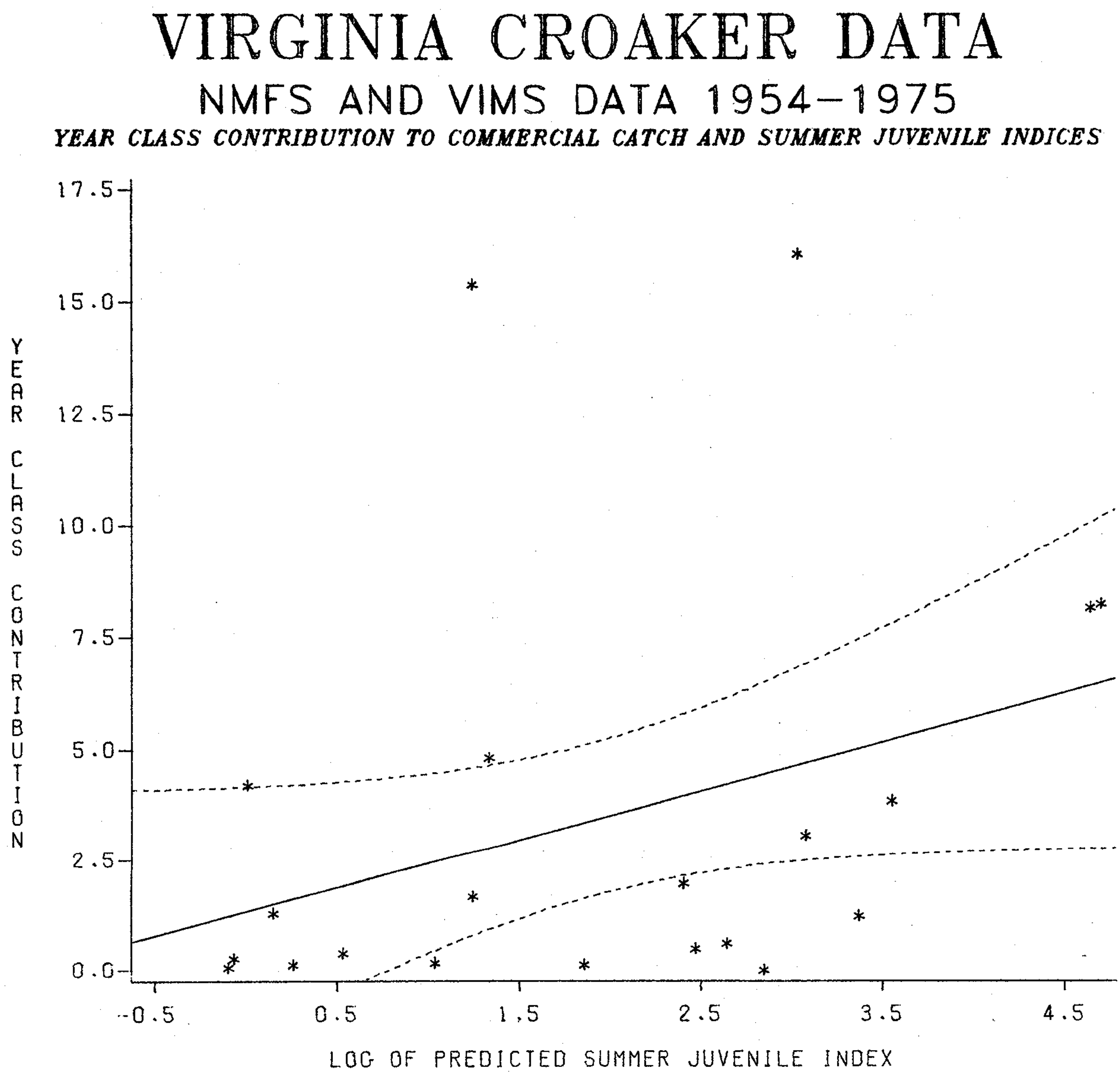
YEAR CLASS CONTRIBUTION TO COMMERCIAL CATCH AND SUMMER JUVENILE INDICES



LOGARITHMIC REGRESSION MODEL

STARS--CALCULATED CONTRIBUTIONS AND SUMMER INDEX
SOLID LINE--PREDICTED YEAR CLASS CONTRIBUTION =
A + B(LOG OF PREDICTED SUMMER INDEX)

FIGURE 21



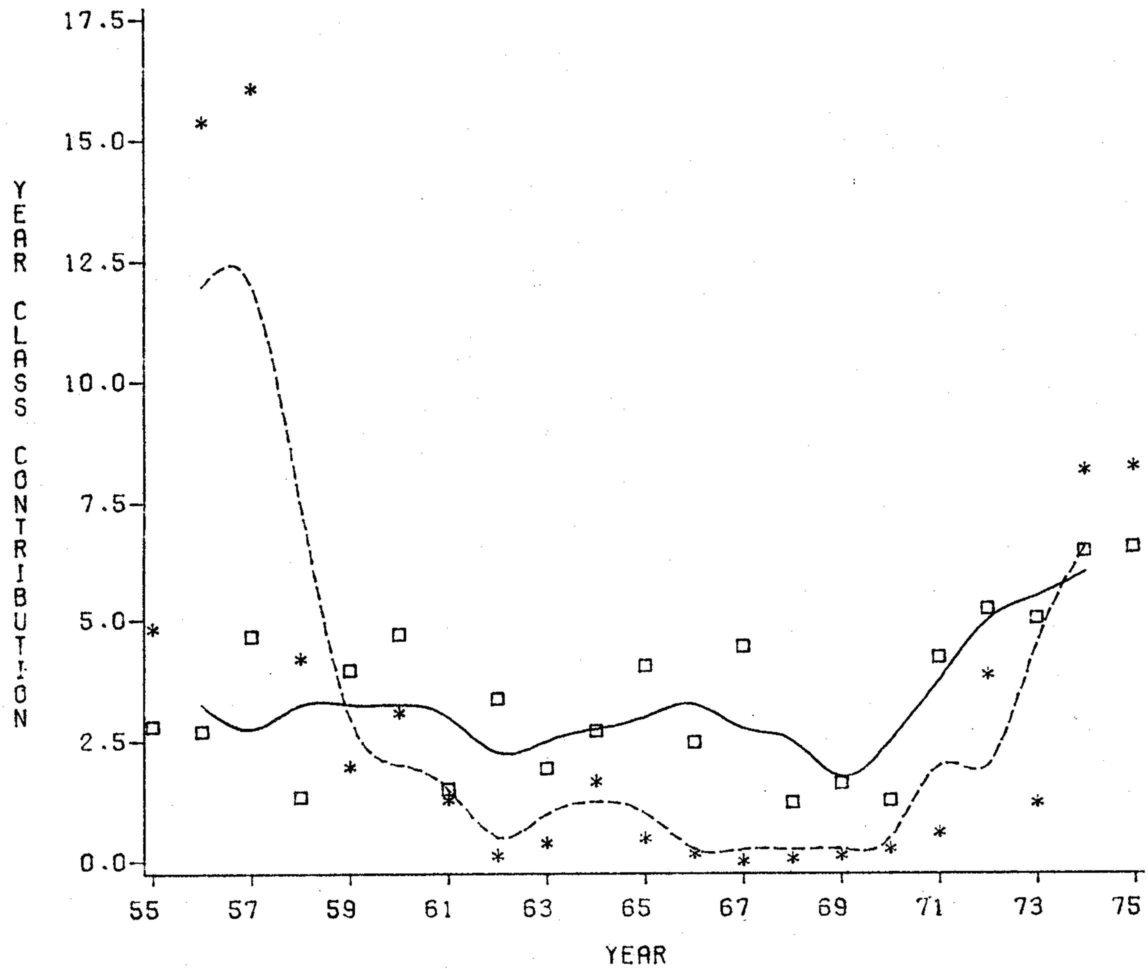
LOGARITHMIC REGRESSION MODEL--LINEARIZED

STARS--CALCULATED CONTRIBUTIONS AND SUMMER INDEX
SOLID LINE--PREDICTED YEAR CLASS CONTRIBUTION =
A + B(LOG OF PREDICTED SUMMER INDEX)
DASHED--90 PERCENT CONFIDENCE LIMITS

FIGURE 22

VIRGINIA CROAKER DATA
YEAR CLASS CONTRIBUTIONS

PREDICTED YEAR CLASS CONTRIBUTIONS FROM PREDICTED SUMMER INDICES
SOLID LINE---3 POINT MOVING AVERAGE
SQUARES---PREDICTED POINTS
CALCULATED YEAR CLASS CONTRIBUTIONS
DASHED LINE---3 POINT MOVING AVERAGE
STARS---CALCULATED POINTS



FROM QUADRATIC AND LOGARITHMIC REGRESSION MODELS
BASED ON NMFS AND VIMS DATA 1954–1975

TABLE 9. CROAKER MODEL TESTING

Summer croaker = a - b(Jan-Feb) + c(Jan-Feb)^2

	Exponential	1-factor Quadratic	2-factor Quadratic
MSE	438.843	396.451	311.396
MAV	11.919	14.085	11.879
F	15.60	45.61	27.61
p	0.0007	0.0001	0.0001
R^2	0.4262	0.6848	0.7341
t	3.9498	6.7539	(JF)1.9270
			(JF)^{2}3.5173

Year class content = a_1 + b_1(ln (summer croaker))

	Logarithmic	Power
MSE	14.680	
MAV	2.464	
F	8.66	6.63
p	0.008	0.018
R^2	0.3022	0.2489
t	2.9433	2.5747

Year class content = a_1 + b_1(ln (a - b(Jan-Feb) + c(Jan-Feb)^2))

	Logarithmic (2-factor quadratic)
F	2.61
p	0.1224
R^2	0.1210
t	1.6170

Jan-Feb = January-February average temperature

MSE = Mean Square Error

MAV = Mean Absolute Value

TABLE 10. YORK RIVER TRAWL SURVEY GEAR EFFICIENCY FOR CROAKER (1971-1978)*

Year	Gear	# Tows	# Croaker/Tow	% C/T by Gear/year	X^2	df	Probability
71	Unlined 16 foot otter trawl	112	12.43	54%	0.32		
	Lined 16 foot otter trawl	264	10.38	46%	0.32		
					0.64	1	NS
72	Unlined 16 foot otter trawl**	8	20.25	20%	5.31		
	Unlined 30 foot otter trawl	82	41.65	41%	1.78		
	Lined 16 foot otter trawl	373	39.54	39%	0.98		
					8.07	2	NS
73	Lined 16 foot otter trawl	600	28.08	75%	12.5		
	Unlined 30 foot semi-balloon trawl**	16	9.25	25%	12.5		
					25.0	1	<0.0005
74	Lined 16 foot otter trawl	- - - - - - - - -	- 100% -	- - - - - - - - -			
75	Lined 16 foot otter trawl	79	73.14	20%	18.0		
	Lined 30 foot otter trawl	94	301.51	80%	18.0		
					36.0	1	<0.0005
76	Lined 16 foot otter trawl	98	59.88	52%	0.08		
	Lined 30 foot otter trawl	25	55.49	48%	0.08		
					0.16	1	NS
77	Lined 16 foot otter trawl	95	4.29	84%	23.12		
	Lined 30 foot otter trawl	76	0.82	16%	23.12		
					46.24	1	<0.0005
78	Lined 30 foot otter trawl	- - - - - - - - -	- 100% -	- - - - - - - - -			
					116.11	12	<0.0005

* 1955-1970: Only 1 gear used - unlined 30 foot otter trawl
** Indicates gear used during one year only.

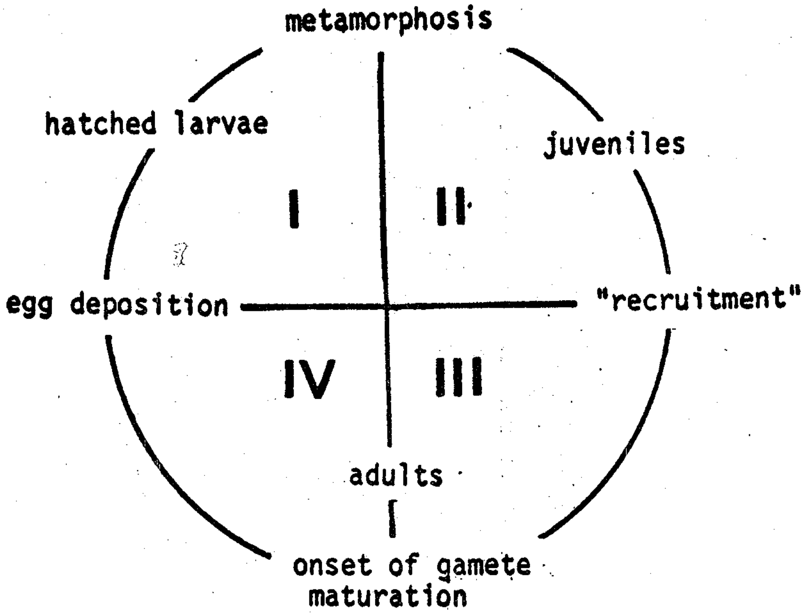
significant (p=0.0005). These results are contradictory regarding the efficiency of the lined 16 foot otter trawl and the lined and unlined 30 foot otter trawls. No conclusions resulted from these tests, thus no provisions were made for gear efficiency in these analyses and resulting models.

DISCUSSION

This project was originally designed to develop a predictive model of croaker based on fluctuations in juvenile abundance in the York River. Gaps in the life history of the croaker have revealed needed areas of investigation and possible sources of error in the model's predictability. To enable the pursuit of a comprehensive predictive model, a conceptual model of croaker life history was developed. Immediately following is a discussion of that conceptual life history. The actual work on this project focused on one segment of this conceptual model. The discussion relates the section that has been investigated to the overall croaker life history which will form the framework for further modelling efforts.

The joint IOC/FAO Meeting of experts on Ocean Sciences in Relation to Living Resources (OSLR) held in Rome, October 1980, sponsored a "Group of Four Scientists" (A. Bakun, J. Beyer, D. Pauly, and J. Pope) who produced a schematized life cycle of fishes (Figure 23). An amended scheme of these life stage designations to represent a conceptual model of Atlantic croaker life history is proposed in Figure 24. The model starts with the spawning adult in quadrant I as

FIGURE 23



Schematized life cycle of fishes

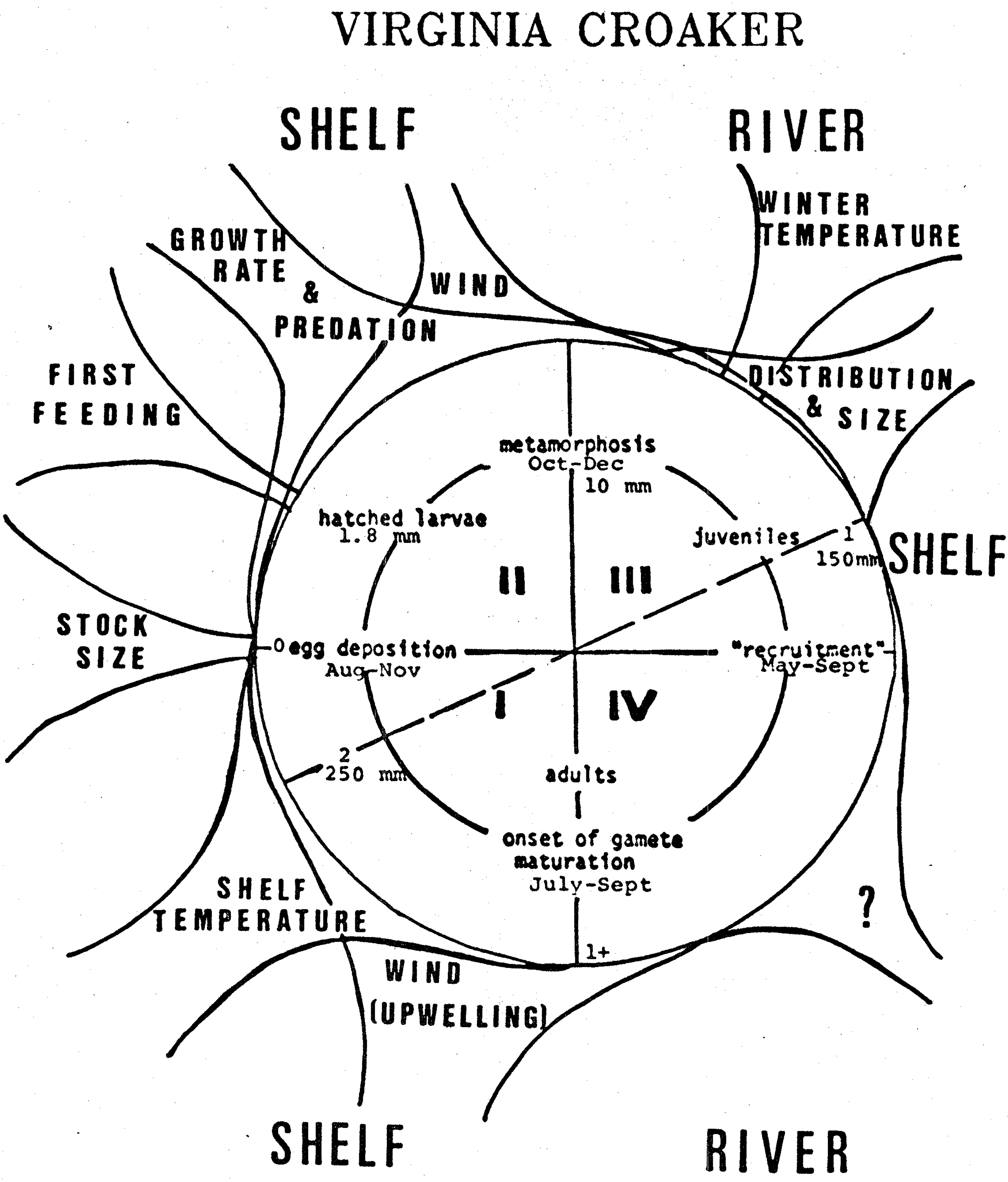
Stage I comprises entry of the egg into the environment, fertilization and subsequent pre-hatch larval development; hatching of the larvae and subsequent development up through metamorphosis (to be loosely defined here as where scales form or where dominant respiration is via gills).

Stage II includes the post-transformation developmental stages which precede entry of the fish into vulnerability to fishery operations. This is the least understood stage in the life history cycle of many fish because there is no appropriate gear to sample them during this stage.

Stage III includes the period from initial entry of the fish into fishery or sampling operations, of juvenile to adult fishes before they mature.

Stage IV is defined as that period from the onset of gamete differentiation and fabrication to the end of the reproductive period of the individual. This may be seasonal, annual or continuing over varying time scales, depending upon the species.

FIGURE 24



VIRGINIA CROAKER
SHELF
RIVER
GROWTH RATE & PREDATION
WIND
WINTER TEMPERATURE
FIRST FEEDING
DISTRIBUTION & SIZE
metamorphosis Oct-Dec 10 mm
hatched larvae 1.8 mm
juveniles
1 150mm
SHELF
II
III
STOCK SIZE
0 egg deposition Aug-Nov
"recruitment" May-Sept
I
IV
2 250 mm
adults
onset of gamete maturation July-Sept
SHELF TEMPERATURE
?
1+
WIND (UPWELLING)
SHELF
RIVER

opposed to the OSLR designation of IV. It is believed to be the first step, rather than last, to be considered in a croaker model. Preliminary analysis of unpublished NMFS plankton data (P. Berrien, pers. comm.) and R/V Dolphin cruise data (Clark, et al., 1969 and 1970; Berrien, et al., 1978) indicate shelf water temperature and wind-induced upwelling (Figure 24) may be important factors determining where and when croaker spawn. Other factors which have been identified as having potential effect on the size of larval croaker recruitment are the availability of food to and the size of the spawning stock (Figure 24).

Stage II (OSLR Stage I) covers the time from the entrance of the egg into the environment through larval metamorphosis. For the croaker, this means movement from some site of deposition in shelf waters to the Chesapeake Bay. OSLR (IOC, 1980) recognizes this as a time of "extreme vulnerability and high rates of mortality. . . most critical to eventual recruitment." Accordingly, OSLR considers successful first feeding to be possibly the single most important determinant of larval success, despite its brief duration, followed by predation. Next, the direction of the wind driven transport determines if the larvae will be transported onshore to a suitable nursery ground. Predation and growth rate, although most important during the earlier stages of development, are still significant factors throughout most of the juvenile stage.

Once the croaker enters the Bay system as juveniles, in addition to predation, the size of the fish and its distribution within the river become factors in its existence. These, coupled with the winter temperature (Joseph, 1972), determine if the croaker will survive the first year to return to shelf waters to spend their second winter. From that time through Stage IV (adults recruited to the fishery, but not in spawning condition) the environmental factors which may affect distribution and abundance have not been identified and probably exert a lesser impact. It is known that croaker are recruited commercially as early as age 1^+ (Massman and Pacheco, 1960). The significance of this is that when stock size is small and the young fish are actively pursued commercially, they may be harvested before they have spawned. At 2 years croaker goes onto the shelf to spawn and the circle is completed. The adult fish is then only in the lower half of the circle, stages I and IV, for the rest of its existence.

Examination of some parts of this conceptual model are made in more detail. Initial inspection of Atlantic shelf ichthyoplankton and fecundity data (W. Morse, pers. comm.) from Cape Hatteras to Cape May indicates that the position of the croaker on the shelf during spawning is closely related to temperature. In the "cold" years of the 60's, when the commercial catch of croaker in Virginia hit an all time low (6200 pounds in 1968), croaker larvae were found near or south of Cape Hatteras. Temperatures indicate that the larvae south of the Cape were being lost offshore in the Gulf Stream, and thus lost to recruitment as juveniles into the Chesapeake Bay. In the warmer years of the 70's, ripe croaker and ichthyoplankton were collected north of Cape Hatteras, and in some cases, even north of the

Chesapeake Bay. The commercial catch of croaker increased during this time to 8,600,191 pounds (1977), near what it had been in the late 50's. Based on laboratory investigations, (W. Hettler, NMFS Beaufort, pers. comm.) croaker require 18°C for spawning. This temperature approximates the range in which the croaker were sampled; however no determination of "critical" temperatures has been attempted.

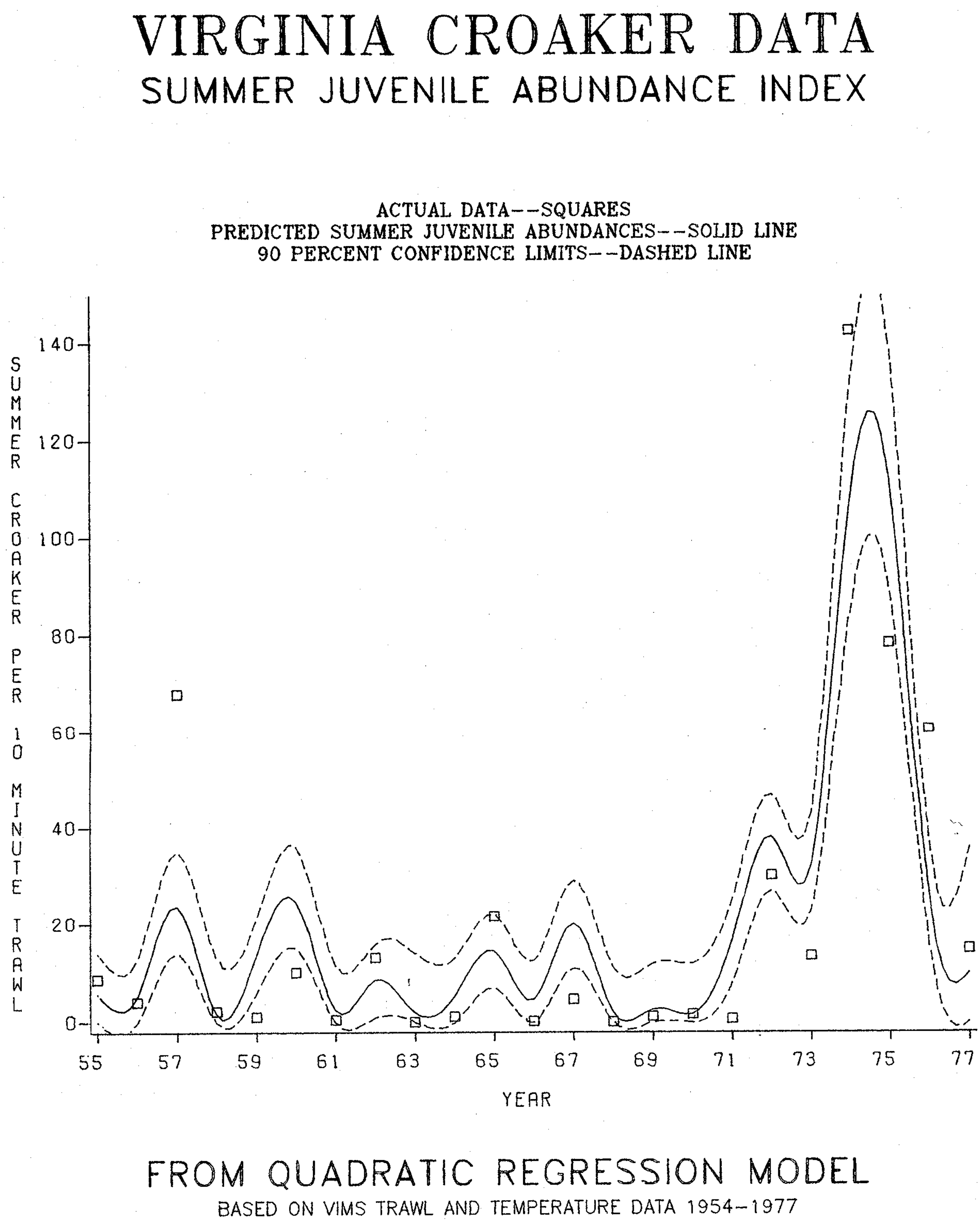
Conceptually, if the larvae/juveniles are found north of the offing of Chesapeake Bay, the environmental forcing factor becomes the wind. Timing of spawning may be most important in relation to the seasonal fall wind change. Lettau, Brower, and Quayle (1976) show "summer" winds as being less favorable for larval recruitment, because they blow out of the southwest, carrying croaker eggs and larvae offshore and away from the Chesapeake Bay. After the seasonal wind shift to the "winter" pattern takes place in the fall, the mean wind direction is northwest, with a southerly and onshore component of drift. The further north of the Chesapeake Bay the larvae are, the better chance they have of withstanding periods of unfavorable winds and of reaching the Chesapeake Bay mouth.

Wind is also an important factor in the vertical thermal stratification of water column and its relation to first feeding (Lasker, 1978) and the larvae-food source match/mis-match hypothesis (Cushing, 1976). Vertical stability necessary for the micro-scale layering of food particles is adversely affected by wind produced turbulence as the wind disperses patches of food and larvae so that they no longer come together in space and time, referred to as "windows" in OSLR (IOC, 1980).

Once inside the Bay system, juveniles are vulnerable to cold winter temperatures which have been documented to be lethal (Wojcik, 1978). Laboratory studies in 1962 showed that feeding activities of post larvae could be regulated by altering the temperature. At 5°C or less feeding activity ceased. Distress was noted at 1.5°C, and 1.0–0.5°C produced death within 24 hours (Joseph, 1972). A temperature of 4°C for an indefinite period of time is generally accepted as critical (Wojcik, pers. comm.). This relationship has been quantified (R^2=0.734) using a quadratic regression model ($x = a - bt + ct^2$) with number of 0^+ summer croaker (x) dependent on the previous January–February average temperature (t) (Table 9). Figure 25 shows 90% confidence limits around the line of predicted summer juvenile croaker abundance. Over and underestimation which occurred in 1957, 1960, 1967, 1971, 1973 and 1974, indicates that additional factors had significant impact on abundance in these years, and need to be incorporated into the model.

The results of correlating summer abundance of juvenile croaker to commercial catch 2, 3, or 4 years later (Table 4; Figures 12, 13, and 14) showed little statistical coherence. Logic dictates that no single years class of young-of-the-year croaker wholly makes up a future year's commercial catch; however, data suggest that during years of low recruitment the fishery was almost entirely 1^+ fish (Massman and Pacheco, 1960). The length frequency distribution by

FIGURE 25



VIRGINIA CROAKER DATA
SUMMER JUVENILE ABUNDANCE INDEX
ACTUAL DATA--SQUARES
PREDICTED SUMMER JUVENILE ABUNDANCES--SOLID LINE
90 PERCENT CONFIDENCE LIMITS--DASHED LINE
SUMMER CROAKER PER 10 MINUTE TRAWL
140
120
100
80
60
40
20
0
55
57
59
61
63
65
67
69
71
73
75
77
YEAR
FROM QUADRATIC REGRESSION MODEL
BASED ON VIMS TRAWL AND TEMPERATURE DATA 1954-1977

month for 1958 commercial catch shows a sudden shift to larger fish in August and September (Table 11), indicating that most of the 1^+ fish had been fished out, or had migrated. From this information, the summer juvenile abundance index (mean number of croaker averaged per month, April through September) and commercial data, were used to form an empirical formula for croaker year class contribution based on how many years a given juvenile year class is expected to remain as a contributor to the commercial catch (Table 12).

The calculations that produced the numbers used to represent croaker year class contribution (i.e., the number of croaker that a specific young-of-the-year year class contributed to the commercial catch 1 to 3 years in the future) are depicted in Table 13. In years when the summer index is large, the young-of-the-year make up almost 100% of the catch 1 and 2 years later, but are not fished out so remain commercially available up to 3 years later. For example, the young-of-the-year from 1957 yielded 10.67×10^6 pounds in 1958, 3.827×10^6 pounds in 1959, and 1.573×10^6 pounds in 1960, totaling 16.07×10^6 pounds which is designated as the 1957 year class contribution.

The hypothesis is that in years when the spawning stock is precipitously low, environmental conditions can potentially cause large year class fluctuations but in years when the stock size is high, the environment is less significant. This may account for "bonus" year classes, such as 1957, which were available to the fishery for several years and mask the effect of unusually low larval

TABLE 11. VIMS TRAWL AND COMMERCIAL POUND NET CATCHES OF CROAKER 1956-1958. (MASSMAN AND PACHECO, 1960)

Year	Month	Modal Size	Assigned Year Class
	October	16mm	0
	October	20mm	0
1957	May	50	0^+
1956	July	80	0^+
1957	July	110	0^+
1956	August	120	0^+
1957	August	140	0^+
1956	September	150	0^+
1957	September	170	0^+
1956	May	220	1^+
1956	June	180	1^+
1956	July	190	1^+
1956	July	230	1^+
1957	July	250	1^+
1958	July	250	1^+
1956	August	230	1^+
1957	August	250	1^+
1958	August	270	1^+
1956	September	270	1^+
1957	September	280	1^+
1958	September	280	1^+
1957	May	270	2^+
1958	May	250-270	2^+
1956	September	300	2^+
1957	September	310	2^+
1958	August	340	2^+

TABLE 12. CROAKER YEAR CLASS CONTRIBUTION FORMULAE*

Year Class Code	Description	Formula
0	Small YC preceded by 2 small YC's	100% LAG 1
1	Small YC preceded 1 year ago by large YC, 2 years ago by small YC	50% LAG 1 50% LAG 2
2	Small YC preceded 1 year ago by small YC, 2 years ago by large YC	50% LAG 1 10% LAG 2 40% LAG 3
3	Small YC preceded by 2 large YC's	20% LAG 1 50% LAG 2 30% LAG 3
4	Large YC preceded by 2 small YC's	90% LAG 1 10% LAG 2
5	Large YC preceded 1 year ago by large YC 2 years ago by small YC	50% LAG 1 50% LAG 2
6	Large YC preceded 1 year ago by small YC, 2 years ago by large YC	50% LAG 1 10% LAG 2 40% LAG 3
7	Large YC preceded by 2 large YC's	33-1/3% LAG 1 33-1/3% LAG 2 33-1/3% LAG 3

*Note: Large here means summer index $\geq$ 20, small < 20.

TABLE 13. YEAR CLASS CONTRIBUTION CALCULATIONS

Year Class	Code	Summer Juvenile Index	Recruitment Year	Actual Commercial Catch (million pounds)	%/Year Class	Calculated Commercial Catch (million pounds)	Year Class/Year Content Caught	Calculated Year Class Contribution (million pounds)
54	1	15.0	55	9.752	50%/54	4.88	4.88/55	5.85
					50%/53	4.88	0.97/56	
55	2	8.95	56	9.668	50%55	4.83	4.83/56	4.83
					10%/54	0.97		
					40%/53	3.87		
56	0	4.3	57	14.198	100%/56	14.198	14.198/57	15.384
							1.286/58	
57	4	68.02	58	11.856	90%/57	10.67	10.67/58	16.07
					10%/56	1.186	3.827/59	
							1.573/60	
58	1	2.34	59	7.655	50%/58	3.827	3.827/59	4.22
					50%/57	3.827	0.393/60	
59	2	1.18	60	3.933	50%/59	1.967	1.967/60	1.967
					10%/58	0.393		
					40%/57	1.573		
60	0	10.13	61	3.082	100%/60	3.082	3.082/61	3.082
61	0	0.63	62	1.294	100%/61	1.294	1.294/62	1.294
62	0	13.20	63	0.122	100%/62	0.122	0.122/63	0.122
63	0	0.11	64	0.394	100%/63	0.394	0.394/64	0.394
64	0	1.14	65	1.532	100%/64	1.532	1.532/65	1.678
65	4	21.75	66	1.463	90%/65	1.317	1.317/66	.481
					10%/64	0.146	0.162/67	
							0.0024/68	
66	1	0.20	67	0.324	50%/66	0.162	0.162/67	.163
					50%/65	0.162	0.0006/68	
67	2	4.76	68	0.006	50%/67	0.003	0.003/68	0.003
					10%/66	0.0006		
					40%/65	0.0024		
68	0	0.08	69	0.063	100%/68	0.063	0.063/69	.063
69	0	1.27	70	0.128	100%/69	0.127	0.127/70	.127
70	0	1.70	71	0.265	100%/70	0.265	0.265/71	.265
71	0	0.76	72	0.484	100%/71	0.484	0.484/72	0.62
							0.136/73	
72	4	30.17	73	1.358	90%/72	1.222	1.222/73	3.861
					10%/71	0.136	0.751/74	
							1.888/75	
73	1	13.49	74	1.502	50%/73	0.751	0.751/74	1.223
					50%/72	0.751	0.472/75	
74	6	142.6	75	4.721	50%/74	2.361	2.361/75	8.174
					10%/73	0.472	2.949/76	
					40%/72	1.888	2.864/77	
75	5	78.53	76	5.898	50%/75	2.949	2.949/76	8.243
					50%/74	2.949	2.864/77	
							2.43/78	
76	7	60.69	77	8.6	33-1/3%/76	2.864	2.864/77	
					33-1/3%/75	2.864	4.05/78	
					33-1/3%/74	2.864		
77	3	14.97	78	8.10	20%/77	1.62	1.62/78	
					50%/76	4.05		
					30%/75	2.43		

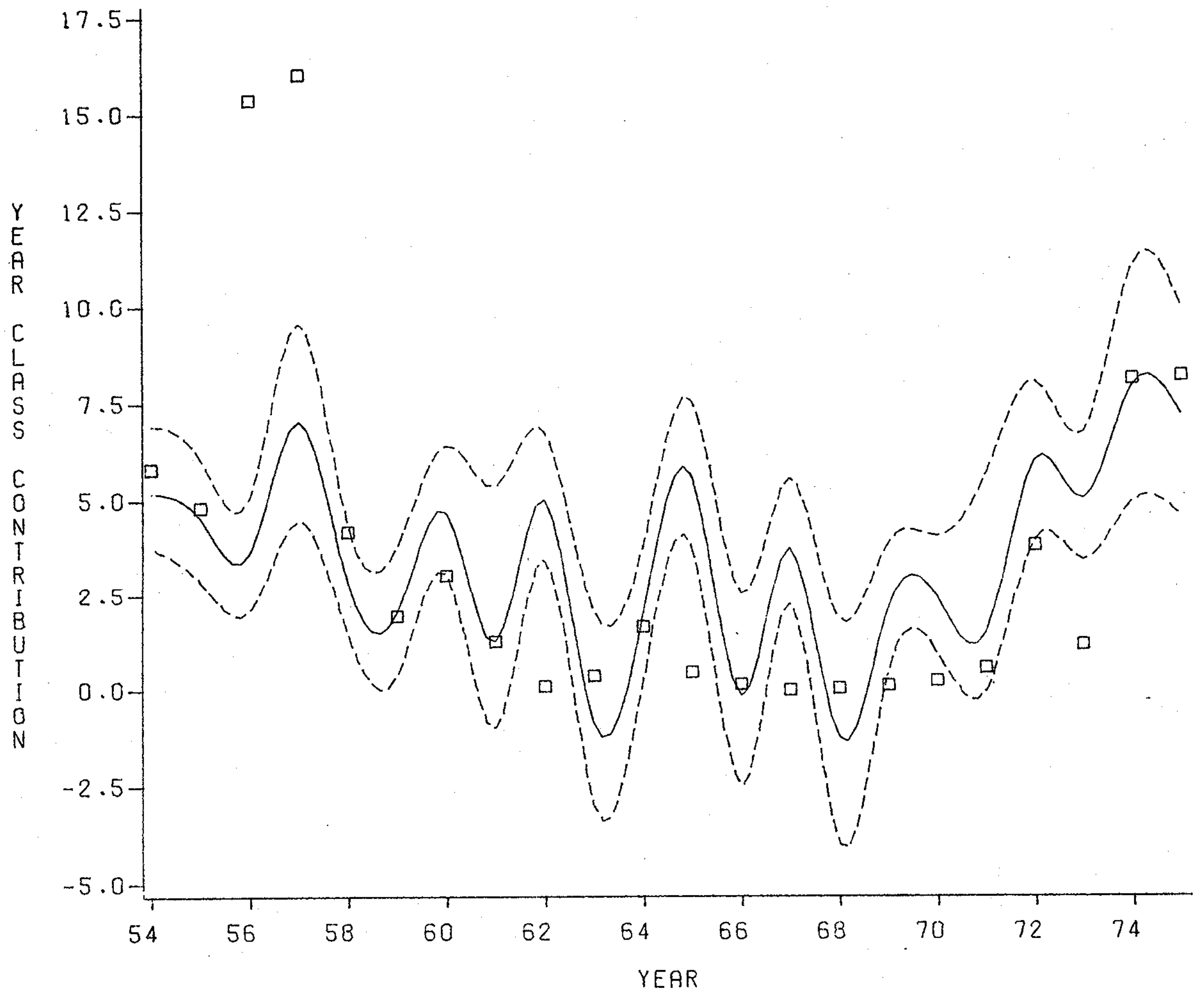
recruitment in subsequent years. However, several bad year classes in a row (1960-64, and 1968-71) could exacerbate the effect as indicated based on commercial catch and spawning size (Massman and Pacheco, 1960 and Morse, 1980) by the harvesting of 1^+ fish which have never spawned. This agrees with Cushing's concept (1971) that recruitment is more variable for a population comprised of fewer year classes. Here, the density-dependent factor of larval recruitment based on spawning stock size becomes significant. Correlations between commercial catch, an index of stock size, and young-of-the-year (Table 4) were highly non-significant (p=0.62), indicating no direct density-dependent relationship.

The preliminary model, developed to predict year class content, is based solely on the number of summer juvenile (0^+) croaker with no other predictors ($\dot{R}^2$=0.302). Figure 26 shows the actual data and the predicted data with 90% confidence limits. From this it is apparent that the model underestimated 1956 and 1957 and overestimated 1962, 1965, 1967, 1969, 1970 and 1973. This overestimation is to be expected because there are other environmental factors, operating between age 0^+ and commercial catch. A growth curve becomes more stable as the age of a species increases because there are fewer factors acting on it (Cushing, 1975, pp. 124-125). Before considering other parameters to add to the model, it may be necessary to explain, based on the data sets, the outliers that exist. The underestimation may be a result of bias in the commercial data that have been used.

VIRGINIA CROAKER DATA

YEAR CLASS CONTRIBUTIONS

CALCULATED YEAR CLASS CONTRIBUTIONS--SQUARES
PREDICTED YEAR CLASS CONTRIBUTION--SOLID LINE
90 PERCENT CONFIDENCE LIMITS--DASHED LINE



FROM LOGARITHMIC REGRESSION MODEL

BASED ON NMFS AND VIMS DATA 1954-1975

These data are total Virginia landings per year without regard for gear type, catch-per-unit-effort, or geographical distribution.

The final model results from the incorporation of the quadratic temperature-dependent and logarithmic summer croaker dependent models $y = a_1 + b_1 (\ln (a - bt + ct^2))$ (R^2=0.12). A plot of these data, with 90% confidence limits is shown in Figure 27. It is a preliminary model, and the first to quantitatively demonstrate a relationship between winter York River temperature and commercial catch several years later. Investigations of the possible sources of error that have been described above for the two major components of this model may greatly increase its accuracy. The outliers in this final model are essentially the same years as the logarithmic summer index/year class content model: 1956 and 1957 are underestimated while 1962, 1965, 1967, 1969, 1971 and 1973 are overestimated. This is very important, because it indicates more confidence in the first part of the model relating summer juvenile abundance to VIMS pier January-February average temperatures. Also, there are several other factors in all or some of the four life stages that have been identified as potential parameters to be added to the model.

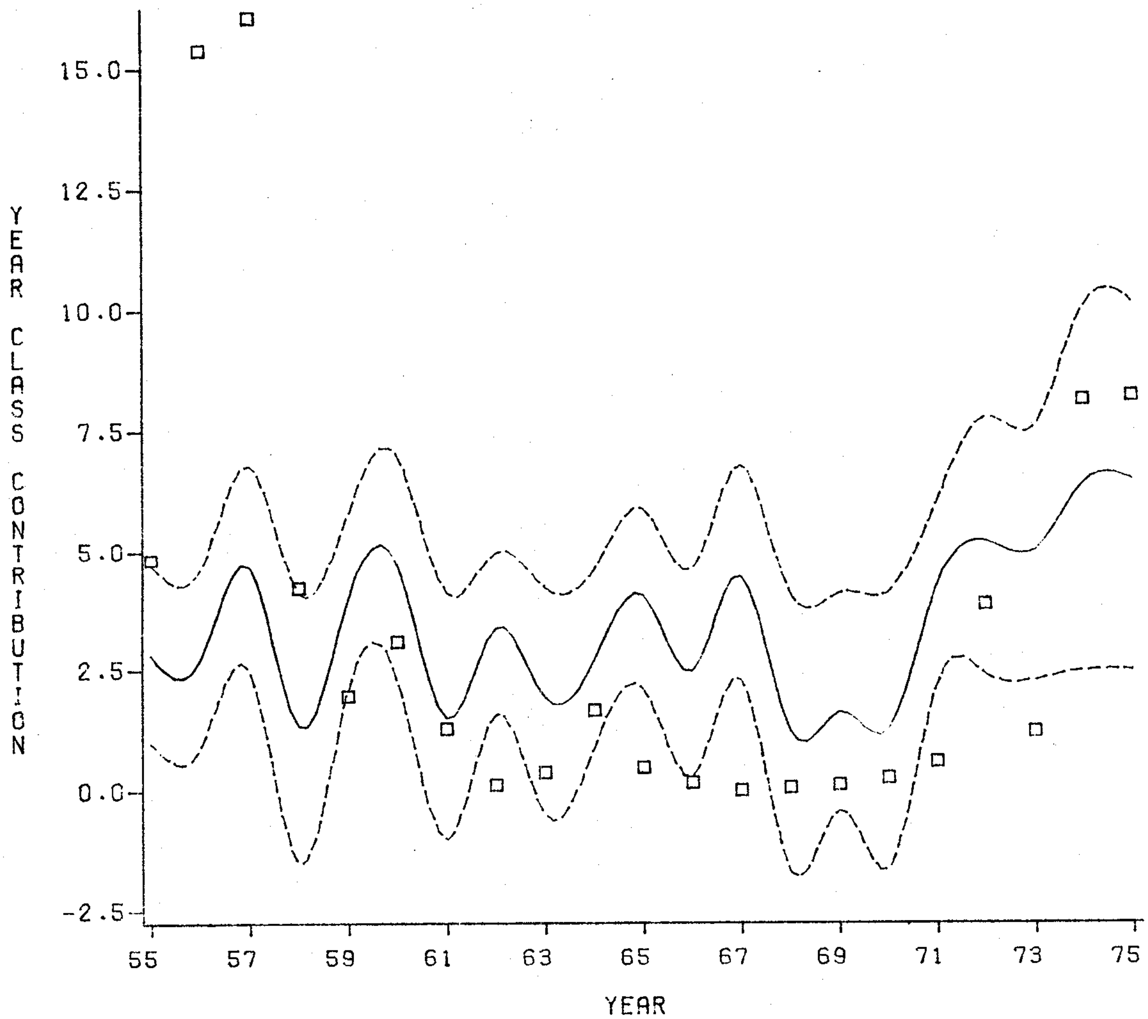
RECOMMENDATIONS

The hypothesis of shelf water temperatures determining spawning location of croaker and thereby influencing the possibility of larval recruitment to the Chesapeake Bay has never been proposed before, because these data have not been made available previously. It is

FIGURE 27

VIRGINIA CROAKER DATA
YEAR CLASS CONTRIBUTIONS

CALCULATED YEAR CLASS CONTRIBUTIONS--SQUARES
PREDICTED YEAR CLASS CONTRIBUTIONS FROM PREDICTED SUMMER INDICES--SOLID LINE
90 PERCENT CONFIDENCE LIMITS--DASHED LINE



FROM QUADRATIC AND LOGARITHMIC REGRESSION MODELS
BASED ON NMFS AND VIMS DATA 1954–1975

intended to further investigate this hypothesis to see if it can be related to long-term global warming (1920's-1945) and cooling (since 1945) or persistence of westerly winds (Cushing, 1975). Such a spawning temperature or wind hypothesis may explain in part the continuous decline of croaker catch in Virginia since the period of the 50's as evidenced in Figure 1. Cushing (1971) has said that recruitment is usually more variable at the edge of the range of a species, and this is evidenced in the Atlantic croaker, a southern species in which the Chesapeake Bay is the northernmost extent of its range. This range has been extended further north, however, during climatically warmer time periods. The surviving juveniles that enter the Chesapeake are those that came from spawning north of Cape Hatteras.

In 1935, 8 million pounds of croaker were landed in the New York Bight area while there were zero commercial landings recorded from 1962-1969, and in 1971 (McHugh and Ginter, 1978). Croaker commercial catch statistics for other Atlantic states will be studied in relation to Virginia's catch to determine if the croaker decline is a Virginia anomaly or an East Coast phenomenon. The non-significant correlation with Kiptopeake Beach water temperature anomalies (Table 5) does not discount this hypothesis as it may not have been an adequate representative of shelf-bottom temperatures. Ancillary data sets will be sought if direct temperature observations are not available.

Predation on larvae, specifically on croaker larvae on the Atlantic shelf, is not known. Preliminary results of studies on the role of jellyfish and chaetognaths as planktonic predators of marine fish larvae show that they prey on larval fish, but the significance of this predation under natural conditions with patchy plankton masses is unclear (L. Coston-Clements, and S. Ferraro, pers. comm.). Further study of predation, and possible correlation with croaker, as a factor in recruitment is needed. Another unknown which must be considered during this stage of development is growth rate. NMFS (S. Warlen, pers. comm.), Beaufort has initiated a daily aging of otoliths of croaker larvae. The Laird-Gompertz growth model currently being used will yield an age of up to 60 days for a standard length up to 15 mm. Using this information, together with data for winds, temperature, and probable spawning site as determined from ichthyoplankton and spawning data, relationships with larval recruitment will be developed. Such relationships will be expanded utilizing the juvenile length data from the VIMS juvenile trawl survey. Use of this growth curve will allow back extrapolation of the juvenile croaker data to time of spawning. Such identification of spawning time will be used to investigate the relationship of the shelf environment at the time to larval recruitment.

The quadratic model overestimation of the summer juvenile croaker abundance indicates that their survival is not solely determined by winter water temperatures. Other possible factors include those previously discussed with the reference to larval recruitment. For example, Dovel's (1968) hypothesis of predation on juvenile croaker by striped bass must be considered. Correlations by lagging Maryland DNR young-of-the-year striped bass survey data one year with respect to the croaker (0^+) will be run; and in addition VIMS trawl survey data for striped bass and croaker will be examined for the period 1954-1980.

The underestimation in 1957 and 1974 must be examined. Massman and Pacheco (1960) noted that the fall trawl surveys in 1957 had unusually large numbers of young-of-the-year croakers and that 1958 commercial catch was composed of large croakers. This implies a density-dependent relationship. These may actually be artifacts of the data sets, however, as field experience and Joseph (1972) reveal that, as the water nears the winter temperature, the juvenile croaker move downstream and aggregate near the mouth where it is warmer. It is not known if they are reacting to a temperature change or if they are being passively carried down-river as they become moribund. Juvenile croaker distribution in the York River with respect to temperature and season will be examined next to define the extent of the problem.

The juvenile data must also be sorted by body length, to ascertain that those that have been collected are all of the same year class. Although the gear used is designed to catch young-of-the-year, larger fish are often caught also. This will be initiated as soon as all length-frequency data are entered into the computer. The temperature data also need to be re-examined. If one accepts the data for croaker abundance during 1957 through 1974 then the VIMS pier temperature should have been higher, suggesting this temperature may not be the appropriate data set. Temperatures from the sections where the fish are found can be obtained from the York River hydrographic file. These data do not go back previous to 1955, so proxy temperature data from the same time period (Norfolk Airport air temperature) will be correlated with the VIMS pier water temperatures to see if they can be used. Based on the VIMS pier data, and summer croaker data held in VIMS files, one would expect to find average January-February temperatures in 1952, 53, and 54 to be between 4° and 5°C. Deviations from VIMS pier data in 1957 and 1974 will be scrutinized in an attempt to explain these outliers. The appropriate time scale may not have been used so daily changes and persistence in temperature will be investigated in addition to last minute results indicating that an average temperature over December, January, February, and March may better fit the model. These improved data sets are expected to make the number of fall croaker, which now displays no pattern with respect to the outliers in Figure 25, a viable predictor.

Conceptually, the juvenile croaker leave the Bay as 0^+ fish in fall and migrate onto the shelf. There has been no quantification of those factors affecting survival and abundance of juvenile croaker either during summer, or until they are caught commercially. However, a recent newspaper article (17 January, 1981, Virginian-Pilot) revealed that yearling, 1^+, 4 to 8 inch croaker had been found dead in Pamlico Sound, N.C. This phenomenon has been previously recorded by Hildebrand and Cable (1930) and is not considered unusual by fisheries personnel in North Carolina (Mike Street, pers. comm.). North Carolina data on these fish kills will be examined to determine if North Carolina winter temperatures are affecting Chesapeake Bay commercial croaker catch by killing one-year old croaker that over-winter in Pamlico Sound.

The model will be amended by using a recently acquired data set (Walt Hoagman, unpublished MS) which breaks the catch down by method: haul seines and pound nets operating within the Bay. Catch-per-unit-effort is based on units of licensed gear equalling yearly effort. Jackson Davis (pers. comm.) and Joseph (1972) have indicated that the offshore North Carolina otter trawl fishery was especially active prior to 1960, therefore many croaker could have been caught there and recorded, especially in 1956 and 1957, as landed in Virginia. In support of this hypothesis are the 1956 sport-fishery landings data (Richards, 1965) showing the largest CPUE of croaker from 1955 to 1962. This is based on Seaside-Virginia landings. This, together with trawl reports, indicates the correlations may be better by restricting them to catch within the Bay. This may be a significant enough change to account for the underestimation of the year class contribution in 1956 and 1957. Either or both the over and underestimations may be altered when the year class contribution formula is refined based on new length-frequency commercial data (1978-80) from North Carolina (Doug DeVries, pers. comm.), or from field work on Virginia's 1981 commercial croaker catch. The present formulae are based solely on Massman and Pacheco (1960).

The next step will be to test for density-dependence by correlating only those years with anomously low or high spawning populations, based on year class contribution corrected for non-spawning 1^+ catch, with abundance of fall juveniles. As with the quadratic model, additional parameters will not be tried until after the inconsistencies in the data are corrected. Special attention will be given to filling in the "gap" in knowledge of the life history of the croaker which is represented by a question mark in quadrant IV, Figure 24.

CONCLUSIONS

1. The VIMS Juvenile Trawl Survey tape has been reworked so that any parameter can be accessed. It now includes "zero" data (when species were not caught). York River croaker data have been standardized for abundance indices, i.e., number per 10 minute tow.

2. A conceptual model of croaker life history including the environmental factors affecting it was developed and is shown schematically in Figure 24.

3. Neither juvenile croaker nor commercial croaker catch display autoregressive properties. This means that future croaker abundance can not be predicted accurately given only the number at present and in the past.

4. Croaker abundance can not be presented as a single year number or index due to the changes overwinter. Therefore the abundance data have been compiled seasonally (e.g. Fall: Oct-Dec, Summer: April-Sept).

5. A quadratic model was developed between winter temperature and summer croaker abundance (R^2=0.73). Summer croaker abundance (x) equals the sum of a constant (a) minus a constant (b) multiplied by the January-February averge water temperature at VIMS pier (t), plus a constant (c) multiplied by the January-February average water temperature at VIMS pier (t) squared. ($x = a - bt + ct^2$).

6. A logarithmic model was developed between the summer juvenile abundance and the year class contribution of croaker (R^2=0.30): year class contribution (y) equals the sum of a constant (a_1), plus a constant (b_1) multiplied by the natural logarithm of the summer juvenile abundance (x). [$y = a_1 + b_1 (\ln x)$]

7. A model to predict croaker year class contribution to the commercial catch from winter temperatures when they were juveniles was developed by incorporating these two models (R^2=0.12): year class contribution (y) equals the sum of a constant (a_1) plus a constant (b_1) multiplied by the logarithm of the quantity: a constant (a), minus a constant (b) multplied by the January-February average temperature, plus a constant (c) multiplied by the January-February average temperature squared. [$y = a_1 + b_1 (\ln (a - bt + ct^2)$)].

REIMBURSIBLES

1) A listing of the physical data files that VIMS will make available to any investigator on a cost reimbursible basis is found in Harris, R. E. and W. A. Van Engel. 1981. Relationship between the Chesapeake Bay Blue Crab and its Climatological Environment: Oceanographic and Atmospheric Data. VIMS, Data Rept. No. 15, 41 p. and supplemented with listings in Table 2 and appendices, this report.

2) A listing of York, James, Rappahannock and Potomac rivers data survey files contained in the accompanying magnetic tape. Codes for the tape and a sequential file listing are found in Appendix A, this report.

3) A data file of commercial croaker from Virginia, Maryland and North Carolina was not obtained as the data that proved to be most applicable were NMFS landings.

LITERATURE CITED

Ad Hoc Group of the Ocean Sciences Board/National Research Council. 1980. Fisheries Ecology: Some constraints that impede advances in our understanding. National Academy of Sciences, Washington, D.C. 16 p.

Anon. 1980. Massive Fish Kills: Cold Spell Hurts N.C. Fisheries. Virginian-Pilot. 17 January.

Austin, H. M. and M. C. Ingham. 1978. Use of environmental data in the prediction of marine fisheries abundance. In: Climate and Fisheries -- Proc. 1978. Cont. Ocean Mgmt. Stud., URI. pp. 93-106.

Berrien, P. L., M. P. Fahay, A. W. Kendall, Jr., and W. G. Smith. 1978. Ichthyoplankton from the R/V Dolphin Survey of Continental Shelf waters between Martha's Vineyard, Massachusetts and Cape Lookout, North Carolina, 1965-66. Sandy Hook Laboratory, NEFC/NMFS/NOAA Tech. Series Rept. No. 15., 152 p.

Clark, J., W. G. Smith, A. W. Kendall, Jr., and M. P. Fahay. 1969. Studies of Estuarine Dependence of Atlantic Coastal Fishes. Bur. Sport Fish. Wildl. Tech. Paper No. 28. 132 p.

Clark, J., W. G. Smith, A. W. Kendall, Jr., and M. P. Fahay. 1970. Studies of Estuarine Dependence of Atlantic Coastal Fishes. Data Report II: Southern Section, New River Inlet, N.C., to Palm Beach, Fla. R/V Dolphin Cruises 1967-68: Zooplankton volumes, surface-meter net collections, temperatures, and salinities. Bur. Sport Fish. Wildl. Tech. Paper No. 59, 97 p.

Coston-Clements, L. 1980. Preliminary studies on the role of chaetognaths as planktonic predators of marine fish larvae. The ASB Bulletin, 27(2):29, Abstr.

Cushing, D. H. 1971. The dependence of recruitment on parent stock in different groups of fishes. J. Cons. Perm. Int. Explor. Mer. 33(3):340-362.

Cushing, D. H. 1975. Marine Ecology and Fisheries. Cambridge, UK. 278 pp.

Cushing, D. H. 1978. Biological effects of climatic change. Rapp. P-v. Reun. Cons. Int. Explor. Mer. 173:107-116.

Cushing, D. H. and R. R. Dickson. 1976. The biological response in the sea to climatic changes. Adv. Mar. Biol. 14:1-122.

Daniel, C. and F. S. Wood. 1971. Fitting Equations to Data: Computer Analysis of Multifactor Data for Scientists and Engineers. Wiley InterScience, New York, pp. 19-25.

Dovel, W. L. 1968. Predation by striped bass as a possible influence on population size of Atlantic croaker. Trans. Amer. Fish. Soc. 97(4):313-319.

Harris, R. E. and W. A. Van Engel. 1981. Relationship between the Chesapeake Bay blue crab and its climatological environment: Oceanographic and atmospheric data. VIMS, Data Rept. No. 15, 41 p.

Haven, D. S. 1957. Distribution, growth, and availability of juvenile croaker, <u>Micropogon undulatus</u>, in Virginia. Ecology 38(1):88-97.

Hildebrand, S. F. and L. E. Cable. 1930. Development and life history of fourteen teleostean fishes at Beaufort, North Carolina. Bull. U.S. Bur. Fish. 46:383-488.

Hunter, J. R., ed. 1976. Report of a colloquium on larval fish motrality studies and their relation to fishery research, January 1975. NOAA Tech. Rep., NMFS Circ. #395. 5 p.

Intergovernmental Oceanographic Commission (of UNESCO). 1980. <u>Meeting of Experts on Ocean Sciences in Relation to Living Resources (OSLR), FAO Headquarters, Rome, 14-17 October 1980</u>. IOC/INF-438, Paris, 25 November 1980, 26 p.

Joseph, E. B. 1972. The status of the sciaenid stocks of the middle Atlantic Coast. Ches. Sci. 14:87-100.

Lasker, R. 1978. The relation between oceanographic conditions and larval anchovy food in the California Current: Identification of factors contributing to recruitment failure. Rapp. P-v. Reun. Cons. Int. Explor. Mer. 173:212-230.

Lasker, R. 1979. Factors contributing to variable recruitment of the Northern anchovy (*Engraulis mordax*) in the California Current: Contrasting years, 1975 through 1978. ICES Early Life History Symposium, Woods Hole, Mass., April. MS.

Lettau, B., W. A. Brower, Jr., and R. G. Quayle. 1976. *Marine Climatology*. MESA New York Bight Atlas, Monograph 7. New York Sea Grant Institute, Albany, New York, December. 239 p.

Lough, R. G., G. R. Bolz, M. D. Grosslein, and D. C. Potter. 1979. Abundance and survival of Sea Herring (*Clupea harengus* L.) larvae in relation to environmental factors, spawning stock size, and recruitment for the Georges Bank area, 1968-1977 seasons. ICES Early Life History Symposium, Woods Hole, Mass., April.

McHugh, J. L. and J. J. Ginter. 1978. *Fisheries*. MESA New York Bight Atlas, Monograph 16, New York Sea Grant Institute, Albany, New York, January, p. 40.

Massmann, W. H. and A. L. Pacheco. 1960. Disappearance of young Atlantic croakers from the York River, Virginia. Trans. Am. Fish. Soc. 89(2):154-159.

Mid-Atlantic Fishery Management Council. 1978. Final environmental impact statement and fishery management plan for the Atlantic mackerel fishery, May, 133 p.

Morse, W. W. 1980. Maturity, spawning, and fecundity of Atlantic croaker, Micropogonias undulatus, occurring north of Cape Hatteras, North Carolina. Fish. Bull. 78(1):190-195.

Nelson, W. R., M. C. Ingham and W. E. Schaaf. 1977. Larval transport and year-class strength of Atlantic menhaden, Brevoortia tyrannus. Fish. Bull., U.S. 75(1):23-41.

Parrish, R. H. and A. D. MacCall. 1978. Climatic variation and exploitation in the Pacific mackerel fishery. St. of Calif. Res. Agency. Dept. of Fish & Game, Fish. Bull. #167, 110 p.

Richards, C. E. 1965. Availability patterns of marine fishes caught by charter boats operating off Virginia's Eastern Shore, 1955-1962. Ches. Sci. 6(2):96-108.

SAS Institute, Inc., The SAS User's Guide, 1979 Edition. P.O. Box 10066, Raleigh, N.C. 27605, 494 p.

SAS Institute Inc., SAS/GRAPH USER'S GUIDE, 1980 Edition. P.O. Box 10066, Raleigh, N.C. 27605, 66 p.

Sissenwine, M. P., B. E. Brown and J. Brennan-Hoskins. 1978. Brief history and state of the art of fish production models and some applicaions to fisheries off the Northeastern United States. IN: Climate and Fisheries--Proc. 1978. Cent. Ocean Mgmt. Stud., URI, pp. 25-48.

Steyeart, L. T. 1980. Early warning of drought-related food shortages in developing countries. EDIS 11(6):3-11.

Wojcik, F. J. 1978. Temperature-induced croaker mortality. Coast. Ocean. Climat. News. 1(1):5.