ABSTRACT

Milton Bennett Wynne, Jr. AN ANALYSIS OF RELATIONSHIPS BETWEEN SOME ENVIRONMENTAL VARIABLES AND RIVER HERRING ABUNDANCE IN THE CHOWAN RIVER, NORTH CAROLINA. (Under the direction of Charles W. O'Rear, Jr.) Department of Biology, April, 1987.

Multiple correlation analysis was used in an effort to identify major environmental factors that corresponded with abundance of river herring. Environmental variables temperature, precipitation, flow, harvested cropland acres, agricultural fertilizer sold, pulp mill effluent discharge and fishing effort were correlated with commercial catch data (estimates of abundance) over long term (annually for twenty years) and short term (monthly for five years) periods of time.

The strongest relationship found was the negative correlation between harvested cropland acres and river herring catch (R square = .724, total R square = .764). Increased agricultural fertilizer sales in counties bordering the Chowan appeared to be negatively correlated with the survival of young herring. Indications were that pulp mill effluent favored survival of young herring, although this apparent benefit did not correlate with unlagged total catch rates. Large departures from normal spring temperatures were also implicated with declines in abundance. Correlations of flow and precipitation with river herring abundance conflicted and remain unresolved.

AN ANALYSIS OF RELATIONSHIPS BETWEEN SOME ENVIRONMENTAL VARIABLES AND RIVER HERRING ABUNDANCE IN THE CHOWAN RIVER, NORTH CAROLINA

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by

Milton Bennett Wynne, Jr.

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INTRODUCTION

River herring is a collective term used in the south Atlantic states in reference to two very similar species of anadromous clupeid fishes, the alewife, *Alosa pseudoharengus*, and the blueback herring, *Alosa aestivalis*. North Carolina catch records indicate that river herring have higher biomass than any other commercial fish species in the Chowan River (Chestnut and Davis, 1975). The Chowan River has historically supported the most important river herring fishery in North Carolina, accounting for approximately 85 percent of all landings in recent years (Loesch *et al*., 1977; Fischer *et al*., 1981). This fishery has been an important regional industry since colonial times when salted herring were a valuable export commodity and even used as currency (Street, 1982). Modern utilization of river herring includes food for human consumption, bait and fish meal.

Landings of river herring have been declining in the Chowan River since 1970, from a 1969 catch of 19 million pounds to a 1981 catch of about 4 million pounds. Several observations have been made of factors which may have contributed to this decline. As early as the 1960's a conspicuous, darkly colored effluent downstream from the pulp producing facility on the Blackwater River in Franklin, Virginia was noted (Smith, 1963). This condition persisted for several miles downstream in the Chowan River despite dilution from the Nottoway River and had associated with it dissolved oxygen concentrations of 0.2 ppm and "hundreds of distressed fish." Channelization has been implicated in the deterioration of North Carolina's river herring fisheries because it reduces spawning and rearing habitat (Tyus, 1974 and 1975). The initial decline in landings has been attributed to oceanic overfishing by foreign nations, particularly during the late 1960's and early 1970's (Street, 1982). The Fishery Conservation and Management Act, instituted in 1976, restricted significantly the foreign offshore catch, but did not result in recovery of the stock. Since the strength of a year class is determined largely by the success of the early life history stages (Cushing, 1975 and 1982; Austin and Ingham, 1978), the thrust of most recent inquiry has been toward identification and protection of spawning and nursery areas (Fischer et al., 1981). Extensive and recurring blue-green algal blooms since the early 1970's in the lower Chowan River are suspected of creating oxygen-depleted conditions and altering trophic structure, which may in turn affect fish production (Paerl, 1982). The food consumption of young alewife has been found to be very size selective (Janssen, 1976), thereby implying that even subtle food web changes may profoundly affect larval survival. Blue green algal blooms are symptomatic of accelerated eutrophication and their occurrence or severity may be influenced by changes in land use within the drainage basin (Craig and Kuenzler, 1983) and climatological events (Klimek, 1982). Vagaries of climate alone have been shown to influence landings of some commercially important marine fish species

(Dow, 1977; Sutcliffe et al., 1977). Potential causes for decreased Chowan River landings, then, are quite numerous and varied.

The capacity of the Chowan River to support large numbers of river herring on a seasonal basis is due in part to the relatively low trophic position occupied by herring. Feeding on predominately herbivorous zooplankton throughout their life cycle, these fish are only twice removed from primary production. This short food chain allows greater conversion efficiency and production potential than that allowed many other predatory fish (i.e., striped bass, white perch, yellow perch, catfish, and sunfish) also inhabiting the Chowan. Also, evolution of an anadromous life cycle enables river herring to exploit the spring surge in lotic productivity for reproductive purposes, promoting successful recruitment by spawning at a time and place that provides larvae with abundant food items (Tyus, 1975). Since river herring are such a large part of the total fish community of the Chowan River and attain a relatively small size, their value as forage for sport and commercial fish species in both the river and Albemarle Sound is likely very great. Gross (1959) reported the utilization of alewife as forage by pumpkinseed and bluegill in a New Jersey lake. Juvenile river herring have been found to serve as food for crappie, white catfish, and channel catfish (Dickson, 1955). Striped bass have also been identified as an important predator on juvenile and adult river herring (Manooch, 1972).

Triggered by rising temperatures, the spawning migration usually begins in February and lasts well into May, with the earliest catches consisting primarily of alewife (Street and Pate, 1975). Later landings are dominated by blueback herring which comprise more than 80 percent of the total catch for most years (Street, 1982). Pound nets are the primary gear used to harvest herring in the Chowan River.

Although very plausible causes for the decline of the Chowan River's herring fishery have been presented during the last two decades, the need exists to examine the group of variables possibly affecting fish abundance simultaneously as a "package" in an effort to determine their relative importance. The objective of this study was to identify significant qualitative relationships that might exist between river herring abundance and selected environmental variables. This involved comparing Chowan River catch to environmental data over long term (1961-1980, annually) and short term (1977-1981, monthly) periods of time. Seven variables of climatological or land use origin; temperature, precipitation, flow, harvested cropland acres, fertilizer sold, pulp mill effluent and fishing effort; were chosen to compare with catch rates (estimates of abundance) for the following reasons:

1) intuitively perceived implications between these variables and river herring abundance, reproductive success, and larval survival.
2) documented instances of some of these variables influencing landings in other fisheries.
3) availability of continuous, uninterrupted data.

SITE DESCRIPTION

The Chowan River proper extends southeastward from the confluence of the Blackwater and Nottoway Rivers near the North Carolina-Virginia state line approximately 80 km to its mouth at the western end of Albemarle Sound (Figure 1). The Chowan River drainage basin comprises an area of 12,650 square km, approximately two-thirds of which lies in Virginia (Daniel, 1977). The Chowan River system includes several major tributaries. The Nottoway and Blackwater Rivers are located entirely within the state of Virginia, the Nottoway arising in the piedmont and the Blackwater arising from the northern coastal plain. The Meherrin River also has its headwaters in the piedmont of Virginia but joins the Chowan about 15 km south of the state line in North Carolina. The major tributary located entirely within North Carolina is the Wiccacon River.

The Chowan River is considered an estuary for hydrodynamic purposes although cloride concentrations are normally less than 50 mg/1 (Daniel, 1977). Wind and tributary inflow are the two primary factors affecting flow rates. Tributary inflow is the major influence on upper river flows while wind controls lower river flows (Daniel, 1977). Wind induced flows generally occur over a short time frame (hourly, daily), whereas tributary inflows affect river flow for longer periods (weekly or more) (Witherspoon et al., 1979). Astronomical tides influence flows and water levels negligibly due to the presence of barrier islands and distant inlets which limit the interchange of water between ocean and estuary.

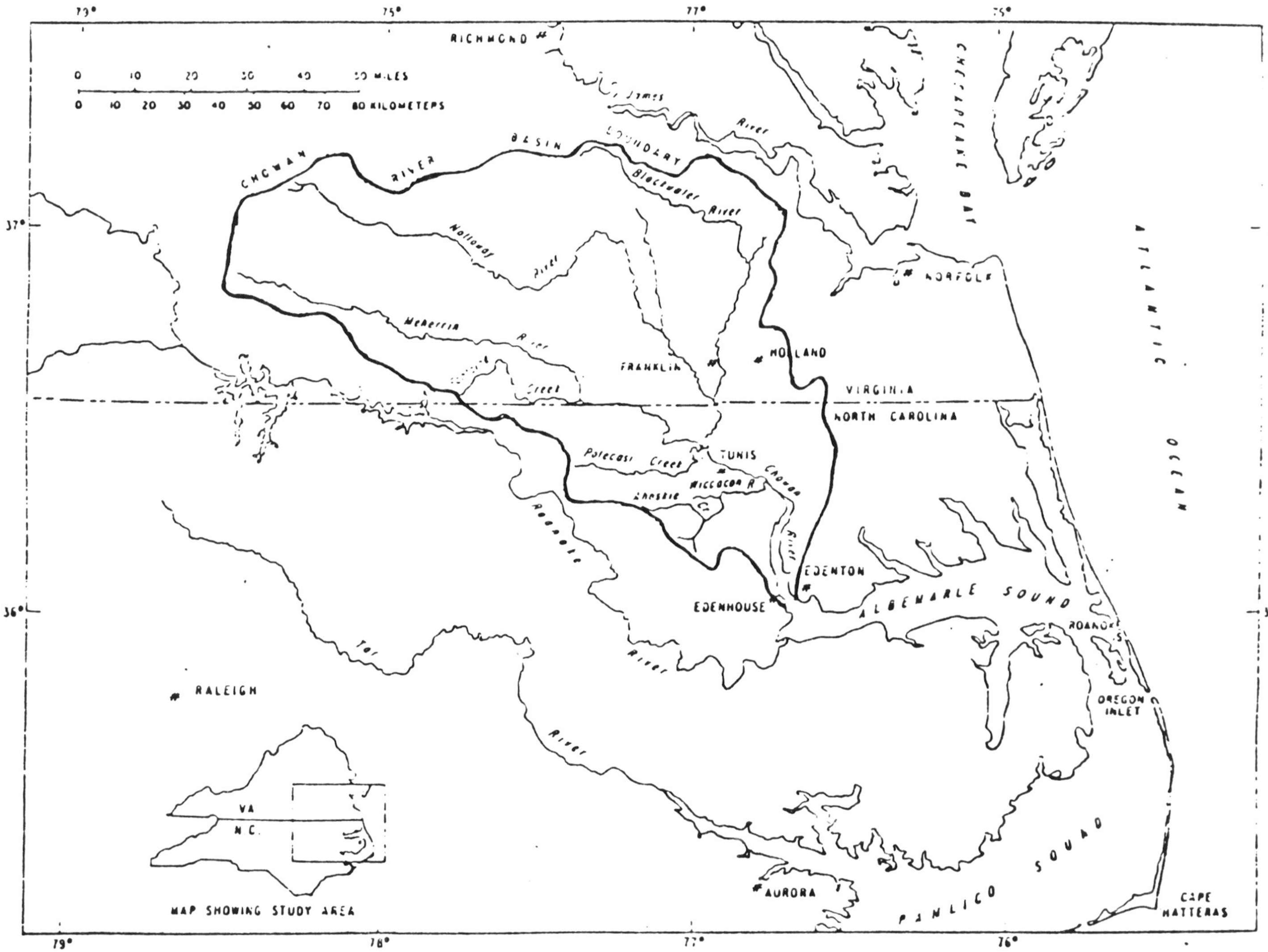


Figure 1.--The Chowan River drainage basin of northeastern North Carolina and southeastern Virginia.

LIFE HISTORY

Anadromous alewives and blueback herring are more alike than different for the purpose of this treatment; most aspects of their life histories, as much as they are known, being quite similar. Both species exhibit homing tendencies, returning to their natal streams to spawn (Tyus, 1975). Alewives initiate the spawning run in North Carolina, migrating slightly ahead of blueback herring (Johnson et al., 1981). Oceanic, adult river herring congregate near North Carolina inlets in February. By late March or early April, most of the fish have reached their destinations and spawning activity is at its peak (Johnson et al., 1981). River herring are not mainstream spawners, but prefer small tributary streams, low flooded areas, and irregular shoreline as spawning sites (Tyus, 1975).

River herring first spawn at age 3 or 4 years (Johnson et al., 1981) and may survive spawning to reproduce again, although mortality associated with this expenditure of energy can be high (Kissil, 1974). Studies in North Carolina indicate that the spawning population is generally comprised of fish in year classes III - VIII, 70 percent of this population being virgin fish (Johnson et al., 1981). Consequently, a substantial proportion of spawning fish are 3 or 4 years old.

Alewife eggs have been found to hatch 4 days after fertilization and larvae have been observed to begin feeding 2 days after hatching (Heinrich, 1981). Heinrich (1981) also noted the transformation of larvae to juveniles after 50 days. Upon transforming into juveniles, river herring move from littoral to pelagic habitats and, being more mobile, gradually move downstream through the main stems of creeks and rivers. Inlets leading to the ocean are usually reached by October or November (Davis and Cheek, 1966). Diets of young river herring have been found to consist primarily of copepods and cladocerans (Davis and Cheek, 1961; Burbridge, 1974).

MATERIALS AND METHODS

Data used in this investigation were obtained from existing sources. The variables studied, the years for which data were examined, and the sources from which the data were extracted are given in Table 1. The actual data and their descriptions appear in Table 2 and Table 3. Abbreviations used in these and later tables and figures are:

temp = temperature

prcp = precipitation

crop = harvested cropland acres

fert = agricultural fertilizer

effl = pulp mill effluent

mo = month

yr = year

cpue = catch per unit of effort

Data for some variables were adjusted for use in this analysis. Catch data were smoothed to the nearest thousand pounds in order to reduce statistical noise that might occur by using these relatively large numbers in their raw form. Since approximately 85 percent of total North Carolina river herring landings are from the Chowan River, a conversion factor of .85 was applied to total North Carolina landings to obtain the Chowan River catch. It should also be noted that for the variables "harvested cropland acres" and "fertilizer sold," data for each county were weighted according to

Table 1. List of variables studied, respective years examined and sources of data.

Variable	Years	Sources
Commercial catch data	1961-80	N.C. landings, Current Fisheries Statistical Series, U.S. Dept. of the Interior; Chestnut and Davis, 1975; Johnson *et al*., 1981; Fischer *et al*., 1981
Fishing Effort	1977-81	Johnson *et al*., 1981; Fischer *et al*., 1981
Departures from normal air temperature	1961-81	NOAA Climatological Data Annual Summaries for North Carolina
Depatures from normal precipitation	1961-81	NOAA Climatological Data Annual Summaries for North Carolina
Flow	1961-81	NSGA Surface Water Annual Reports for North Carolina Waters Years 1961-81
Harvested cropland acres	1961-80	R.L. Griffith, N.C. Crop and Livestock Reporting Service, pers. comm. 1983
Total mixed fertilizer and fertilizer material tonnage sold	1961-80	N.C. Cropland Livestock Reporting Service, Fertilizer Tonnage Reports, 1961-80
Pulp mill effluent	1961-80	John Eid, Union Camp Corporation, Franklin, Va., pers. comm. 1983

Table 2. Annual data and their descriptions.

Yr	a) Catch	b) Temp	c) Prcp	d) Flow	e) Crop	f) Fert	g) Effl
61	10158	01.9	5.2	63104	0	0	5500
62	12157	01.7	0.2	84553	-01.36	06.28	4400
63	12835	-01.5	-2.9	52146	00.38	11.17	5600
64	6427	03.5	-1.1	51849	-00.72	08.92	7410
65	10902	-00.3	-3.4	46322	-01.34	13.32	8670
66	10642	-05.2	4.5	44004	-04.82	18.08	----
67	15713	-00.5	-3.7	31763	-04.50	31.84	----
68	13196	-06.0	3.5	50981	-05.73	19.74	5400
69	16798	-05.6	0.3	54396	-06.28	00.19	5200
70	9793	-00.6	4.2	61365	-03.86	31.68	4200
71	10814	-01.4	3.7	63624	-01.01	23.54	3000
72	9551	-00.8	-0.4	45823	-03.25	20.06	5150
73	6737	02.5	2.9	61043	06.99	31.71	4440
74	5301	08.0	2.4	54680	23.33	55.80	3260
75	5059	-00.6	2.5	19130	10.91	35.63	2735
76	5441	16.1	-1.7	36486	12.82	54.27	6030
77	6816	09.0	3.9	48372	13.47	53.21	7315
78	4778	-12.5	3.2	74441	13.00	40.08	4740
79	4164	-02.6	8.7	114297	18.45	46.77	3050
80	4565	-03.6	0.5	54926	19.42	36.78	----

a) Values presented X 1000 are pounds of river herring landed in the Chowan River.

b) Cumulative February-May departures form normal air temperatures in degrees Farenheit at Edenton.

c) Cumulative February-May departures from normal precipitation in inches at Edenton.

d) Cumulative January-May discharge in cubic meters at Potecasi Creek.

e) Percent change in numbers of harvested cropland acres from the 1961 datum within the North Carolina portion of the Chowan River drainage basin.

f) Percent change in total mixed fertilizer and fertilizer material tonnage sold from the 1961 datum within the North Carolina portion of the drainage basin.

g) Total dissolved solids released in pounds per day by kraft pulp mill near Franklin, Va. into Chowan River system. Data for years 1966, 1967, and 1980 were not available.

Table 3. Monthly data and their descriptions.

Mo/Yr	a) Catch	b) Effort	c) Temp	d) Prcp	e) Flow
Mar 77	401	1848	5.5	0.54	18612
Apr 77	7351	2403	3.3	1.24	5909
May 77	266	603	0.7	4.23	4837
Mar 78	71	627	-2.6	2.03	19409
Apr 78	3431	1489	0.7	1.13	8858
May 78	2119	1529	-1.5	1.88	14652
Feb 79	32	140	-6.0	1.18	16838
Mar 79	564	1397	1.7	-0.19	27094
Apr 79	3540	1958	1.8	2.88	13086
May 79	761	1501	-0.1	4.82	28688
Mar 80	220	805	-1.0	2.17	19584
Apr 80	4486	1920	1.8	1.04	6464
May 80	214	365	0.5	-1.42	4480
Mar 81	265	1238	-2.2	-1.87	3123
Apr 81	2793	2100	4.4	-0.76	2066
May 81	165	782	-2.1	-0.87	602

a) Values presented X 1000 are pounds of river herring landed in the Chowan River.

b) Numbers of pound nets in use in the Chowan River based on weekly aerial counts.

c) Monthly departures from normal air temperature in degrees Farenheit at Edenton.

d) Monthly departures from normal precipitation in inches at Edenton.

e) Monthly discharge in cubic meters at Potecasi Creek.

the percentage of the county lying within the Chowan Basin (Craig and Kuenzler, 1983) before being added together to form a single yearly value.

Although approximately two-thirds of the Chowan drainage basin lies in Virginia, data presented by Craig and Kuenzler (1983) suggest that a majority of nutrient inputs into the system above background levels originate in North Carolina, based on the amount of fertilizer used and artificial drainage implemented by the two states. Therefore, with the exception of pulp mill effluent, all data used in this study were obtained from the North Carolina portion of the drainage basin.

Populations of herring-like fishes are considered to be very responsive to, and therefore vulnerable to, environmental change (Cushing, 1982). In this investigation, river herring landings were hypothesized to correlate with one or more climatological and/or land use variables. Preliminary examination of simple correlations and scatterplots between river herring catch and the various environmental variables revealed no single variable that could be identified as the controlling factor. Consequently, and in accordance with the potential complexity of the problem, multivariate analysis was selected as the most rational approach. Since the relative importance of the variables in question was a main concern, multiple correlation within a stepwise multiple regression computer program was used to analyze the data. The stepwise feature of this series of tests provided a means of estimating which environmental variables were significantly related to herring landings and also assessed their degree of association with landings, based largely on the relative strength of their coefficients of determination (R square values). Ulanowicz et al., (1980) similarly used multiple correlation within a stepwise multiple regression framework to identify environmental variables most related to oyster harvest in Chesapeake Bay. Zar (1974) provides a detailed discussion of stepwise multiple regression.

Yearly data were analyzed for indications of long term relationships between variables over the twenty year period 1961-1980. The initial stepwise multiple correlation examined catch and environmental data for corresponding years. Since 3 and 4 year old fish usually comprise a large proportion of the spawning population, environmental data were then lagged three and four years behind catch data in an effort to detect climatological and/or land use influences on larval and juvenile survival. The entire statistical run was repeated, omitting pulp mill effluent data due to missing values for this variable which caused concern for statistical validity. It should be noted that salinity and channelization were considered as variables but not included in this analysis due to the intermittent nature of the data available during the study period.

Monthly data were examined for short term intraseasonal relationships and to take advantage of fishing effort data. Fishing effort data have been collected in the Chowan Basin since 1977. Therefore, monthly data were examined for five years. Monthly data values for harvested cropland acres, fertilizer sold, and pulp mill effluent were not available, however, and were not included in the short term analysis.

Prior to the stepwise statistical analyses, yearly catch and environmental variable data for each variable were graphed in time series to visually improve and facilitate comparisons between trends depicted in Table 2. A separate straight multiple regression of river herring catch with all environmental variables was also performed ahead of the stepwise procedures in order to produce a matrix of correlation coefficients from which covariance between environmental variables might be addressed further. Graphical assessment of the data and residual plots indicated that normality and homoscedasticity requirements were satisfied. Therefore, no data transformations were made. Important to bear in mind throughout this investigation was the fact that even strong correlations between variables do not mean that cause and effect relationships exist.

RESULTS

Variable trends and covariance of environmental variables

The two most conspicuous trends in the data set were those of river herring catch and percent change in harvested cropland acres. The downward trend in herring catch, beginning the early 1970's (Figure 2), has already been presented as the reason for initiating this investigation. Figure 3 shows a positive percent increase (upward trend) in the number of harvested cropland acres within the Chowan Basin, also beginning in the early 1970's. A net upward trend existed over the entire study period for the percent change in fertilizer tonnage sold within the basin (Figure 4). Although no overall trend was evident for pulp mill effluent discharge into the Chowan River system, some periodicity of the data was observed in the form of 3 small, back to back trends of similar magnitude and duration (4 years each) from 1968 through 1979 (Figure 5).

The strongest climatological trend was that of annual departures from normal precipitation at Edenton (Figure 6), where a preponderance of wet years occurred during the 1970's decade. While departures from normal temperature at Edenton exhibited little of an overall trend during the study period, the greatest deviations from normal occurred during the years 1974-1978 (Figure 7). Annual flows at Potecasi Creek were cyclical over the study period, the cycles appearing to be roughly 8 years in duration (Figure 8).

Figure 2. Total annual herring catch.

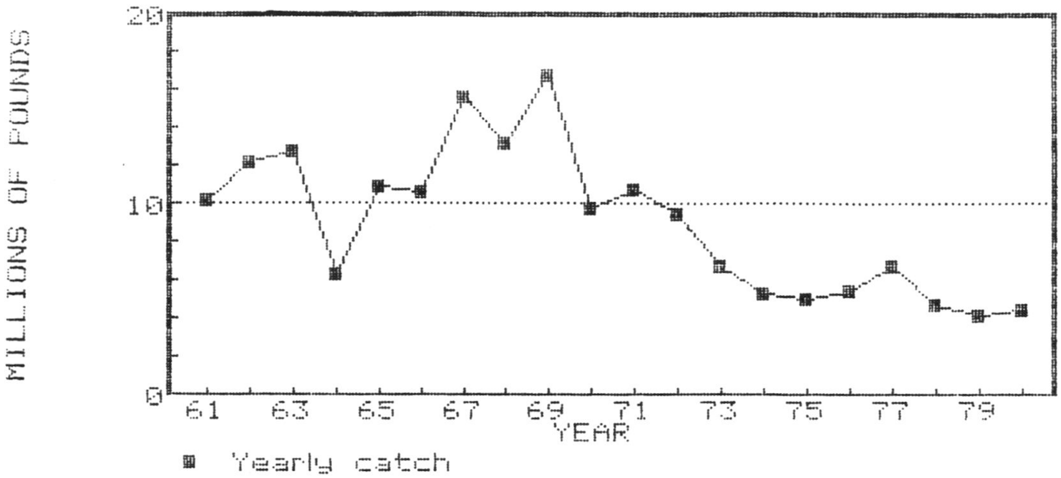


Figure 3. Harvested cropland acres.

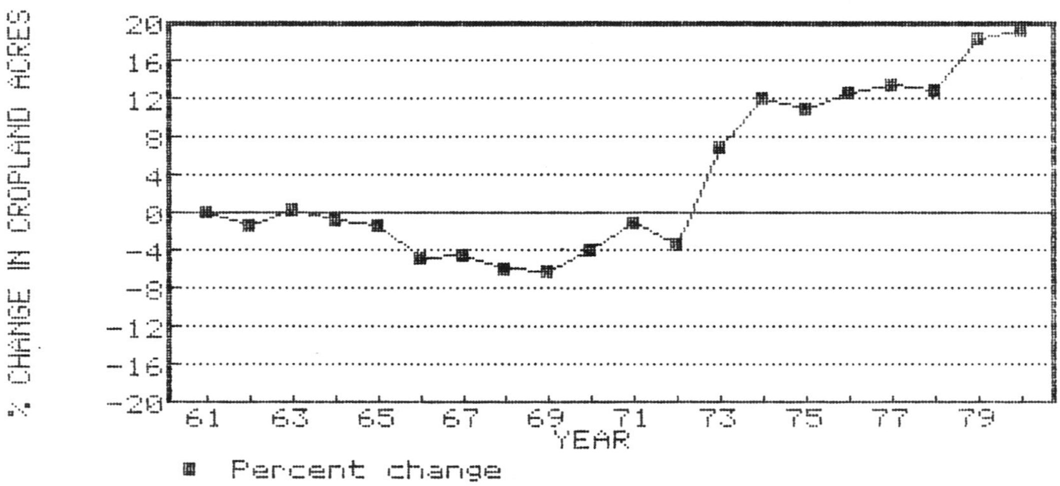


Figure 4. Total fertilizer sold.

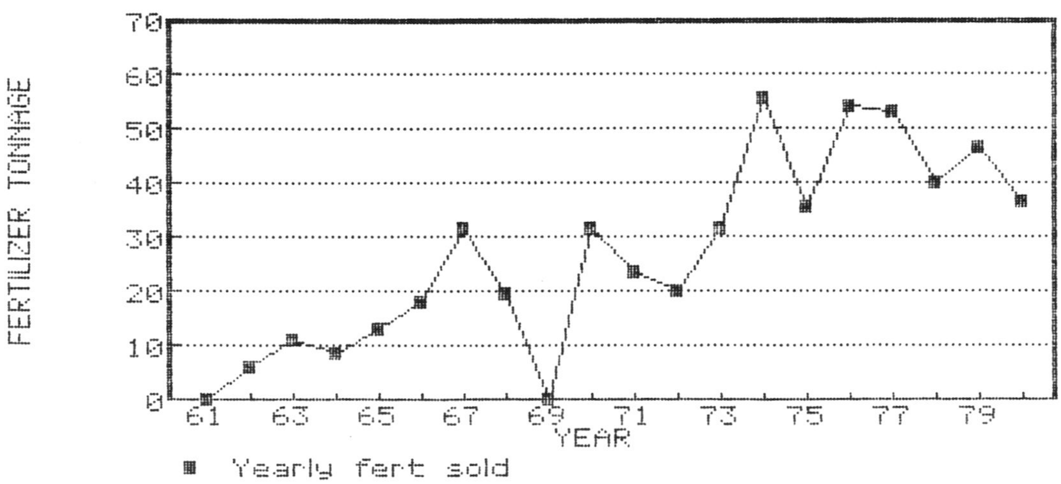


Figure 5. Pulp mill effluent discharge.

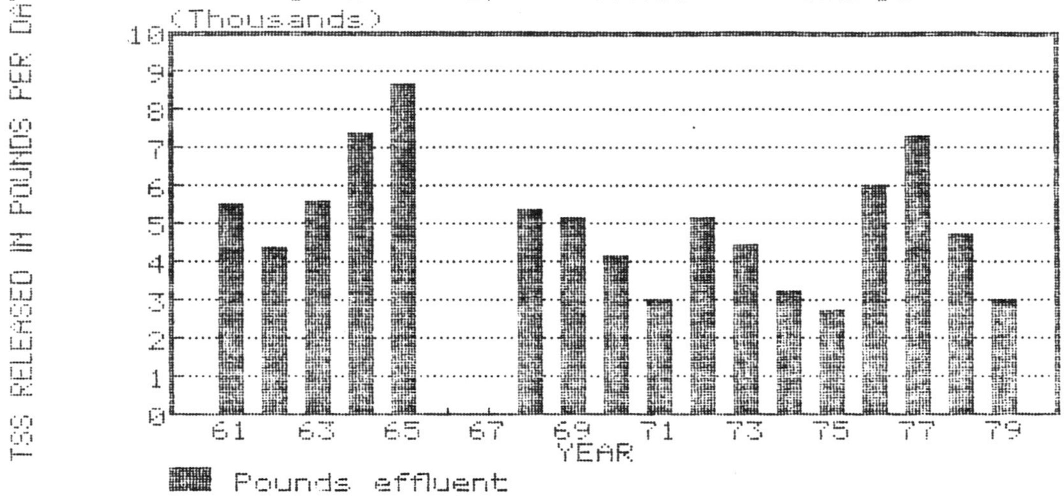


Figure 6. Departures from normal prcp.

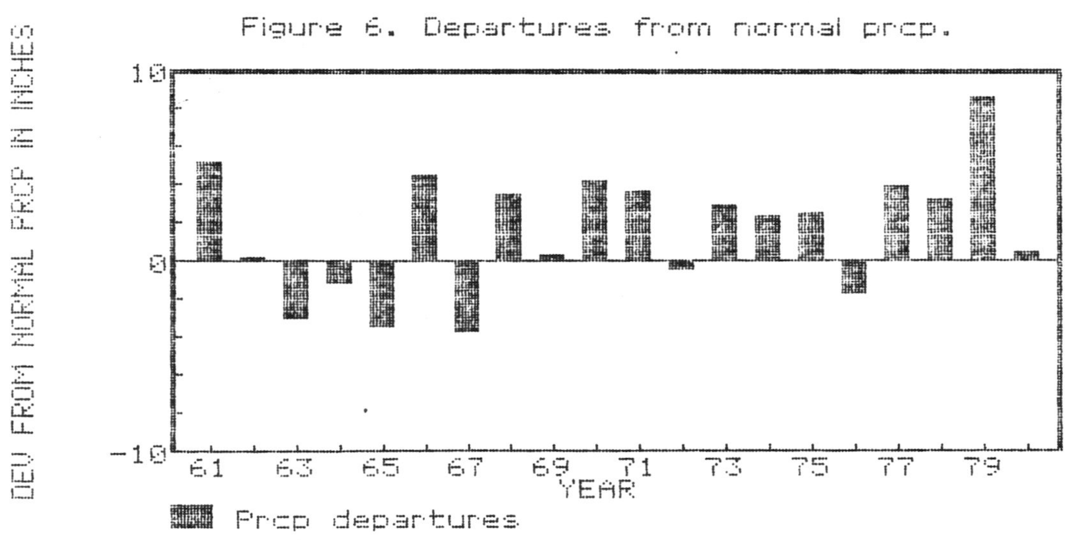


Figure 7. Departures from normal temp.

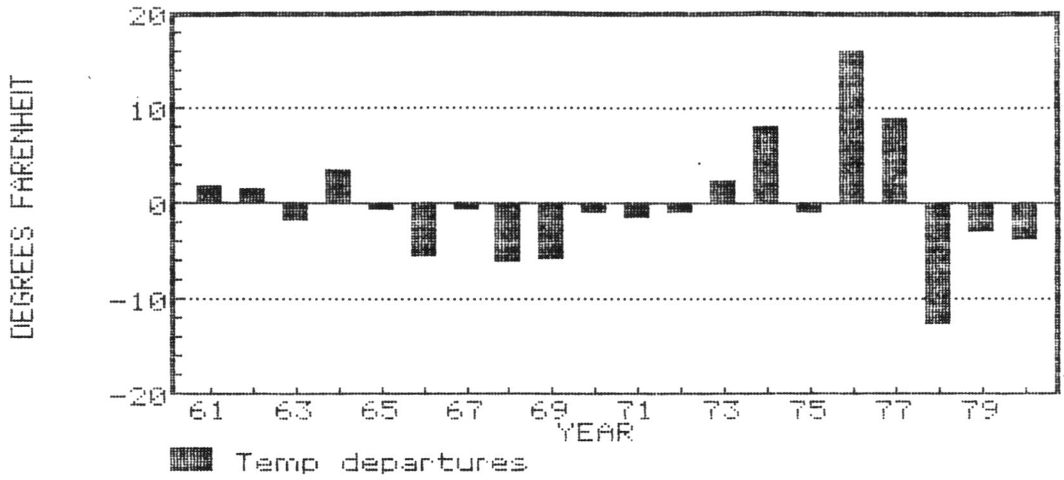
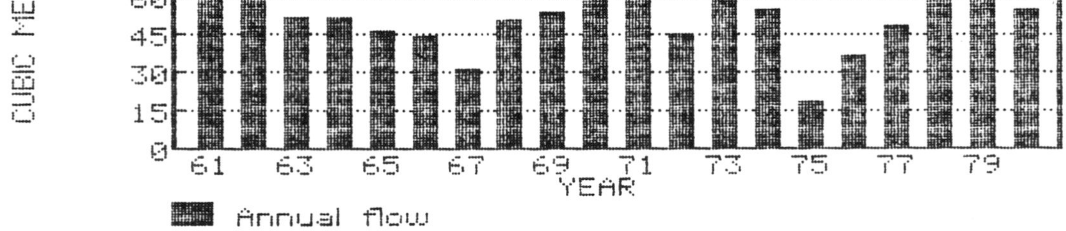


Figure 8. Annual Potecasi Creek flow.



Only 2 sets of environmental variables covaried to an appreciable degree based on correlation coefficients (R values) produced by the straight multiple regression of catch with the environmental variables (Table 4). The land use variables harvested cropland acres and fertilizer sold covaried most (r=-.460333).

Stepwise correlations of herring catch with environmental variables

In the first run of yearly stepwise correlations, all variables examined were significantly related to river herring catch for corresponding years (Table 5). However, although 74% of the variation in catch was explained by all 6 variables, 72% of that variation was explained solely by a negative correlation with percent change in harvested cropland.

Three environmental variables were significant contributions to the total 3 year lag stepwise correlation (Table 5). Negative and positive correlations with fertilizer and effluent, respectively, combined to explain 51% of the variation in lag 3 catch. A negative precipitation correlation added only 5% to the total stepwise correlation for a final R square of .560832.

All 6 environmental variables made significant contributions to the total 4 year lag stepwise correlation and together explained 84% of the variation in lag 4 catch (Table 5). The positive correlation with effluent alone accounted for 56% while effluent and fertilizer (negative) together explained 67% of the variation.

Table 4. Correlation matrix of environmental variables with river herring catch held constant. Nearness of correlation coefficients to 1.0 or -1.0 (perfect correlation) indicates strength of correlations.

	TEMP	PRCP	FLOW
TEMP	1.0	.165171	.155023
PRCP	.165171	1.0	- .460333
FLOW	.155023	- .460333	1.0
CROP	- .0648863	9.86668E-03	- .194684
FERT	- .273281	- .243183	.313826
EFFL	- .202952	.394876	-6.94214E-03

	CROP	FERT	EFFL
TEMP	- .0648863	- .273281	- .202952
PRCP	9.86668E-03	- .243183	.394876
FLOW	- .294684	.313826	-6.94214E-03
CROP	1.0	- .768323	- .0348754
FERT	- .768323	1.0	.147751
EFFL	- .0348754	.147751	1.0

Table 5. Results of 3 stepwise multiple correlations of yearly catch with environmental data. R squares are cumulative for each stepwise correlation. Positive (+) and negative (-) relationships are obtained from correlation coefficients. All correlations listed are significant at P < 0.05.

Catch variable	R^2	Lag 3 catch variable	R^2	Lag 4 catch variable	R^2
crop	.723142 -	fert	.350190 -	effl	.556455 +
temp	.732079 -	effl	.507802 +	fert	.673439 -
flow	.734919 +	prcp	.560832 -	crop	.699533 +
prcp	.741082 -			flow	.722622 +
fert	.743001 -			temp	.821480 -
effl	.743739 -			prcp	.836680 -

The second run of stepwise correlations was identical to the first except for the omission of the variable effluent. Results for corresponding years were very similar to those of the first run (Table 6). All variables contributed significantly to the total stepwise correlation, but again, the negative correlation between harvested cropland and herring catch emerged as by far the most important relationship (cropland alone explaining 72% of the variation in catch).

Both 3 and 4 lag stepwise correlation R squares decreased considerably when effluent was removed from consideration (Table 6). Harvested cropland was the only significant variable (again negatively related), accounting for 33% of the variation in lag 3 catch. Three environmental variables made significant contributions to the total lag 4 catch stepwise correlation, explaining 57% of the variation in 4 year lag catch. Negative correlations with both fertilizer and precipitation accounted for 56% of this variation.

In the final, monthly run of stepwise correlations, all variables examined were significantly related to monthly herring catch (Table 7). Together, these variables explained 73% of the variation in monthly catch. The most important of the variables, monthly fishing effort, alone accounted for 60% of this variation. A stepwise correlation of monthly catch per unit of fishing effort with the climatological variables flow, precipitation, and temperature produced no significant correlations (Table 7).

Table 6. Results of 3 stepwise multiple correlations of yearly catch with environmental data, omitting the variable effluent. R squares are cumulative for each stepwise correlation. Positive (+) and negative (-) relationships are obtained from correlation coefficients. All correlations listed are significant at $P < 0.05$.

Catch variable	R^2	Lag 3 catch variable	R^2	Lag 4 catch variable	R^2
crop	.724280 -	crop	.327835 -	fert	.340841 -
prcp	.740099 -			prcp	.564670 -
temp	.757936 -			flow	.566255 +
flow	.764036 +				
fert	.764036 +				

Table 7. Results of 2 stepwise multiple correlations of monthly catch and fishing effort with environmental data. R squares are cumulative for each stepwise correlation. Positive (+) and negative (-) relationships are obtained from correlation coefficients. All correlations listed are significant at $p < 0.05$.

Catch/month variable	R^2	CPUE/month variable	R^2
effort/mo	.592777 +	insignificant results	
flow/mo	.658330 -		
prcp/mo	.699005 +		
temp/mo	.727095 -		

In the yearly stepwise correlations, the more important relationships between herring catch and harvested cropland, fertilizer sold, precipitation departures, and temperature departures were consistently negative, while the more important relationships between catch and pulp mill effluent and flows were consistently positive (Table 5 and Table 6). For the monthly stepwise correlation, the relationship between catch and temperature departures was again negative, but contrary to the yearly results, relationships between catch and precipitation departures and catch and flows were positive and negative, respectively (Table 7).

DISCUSSION

River herring are generally filter feeding pelagic species, described by Austin and Ingham (1978) as undergoing wide fluctuations in abundance for other than environmental reasons. Density dependent factors, such as competition for food, influence abundance even when environmental conditions are favorable. Like most clupeidae, river herring are fecund fishes with individual female alewives spawning 48,000-360,000 eggs (Kissil, 1974). High fecundity can also lead to wide fluctuations in abundance if environmental variations increase egg or larval mortality (Austin and Ingham, 1978). Based on these assumptions, river herring populations have considerable natural variation from year to year and environmental influences may exaggerate variation further. This raises the question of whether there is indeed a problem with the Chowan River herring fishery. Catch data as depicted in Figure 2 indicate that there indeed is. Widely dispersed data for years 1961-1973 illustrate what might be interpreted as natural variation, but the low 1974-1980 values exhibit a peculiar homogeneity. The small 1977 peak represents all that remained of an unusually large 1973 year class (Fischer _et al._, 1980). This lack of variation at such a low level does not appear normal and supports reports of depressed herring abundance by Chowan River commercial pound net fishermen.

The environmental trends in Figures 3 through 8 of the Results were not well supported by the correlation matrix of environmental variables (Table 4). One would expect harvested cropland acres and fertilizer sold to covary positively, particularly after observing the graphed data in Figures 3 and 4. The correlation coefficient for these two land use variables, however, indicated a negative relationship. Similarly, the negative relationship between precipitation and flow as indicated by the matrix (Table 4) was not expected. This may be explained by the distance between the flow sampling station in Potecasi Creek and the precipitation sampling station at Edenton (approximately 55 km), and the resulting potential for varying levels of precipitation and/or flow between stations. Graphs of precipitation and flow did not show strong covariance (Figure 6 and Figure 8). The correlation matrix revealed no other strong correlations (Table 4). A more meaningful correlation matrix might have been obtained by using straight multiple correlation and deleting the river herring catch variable.

Trends in the environmental data were well supported by the yearly stepwise correlation results, however. The harvested cropland trend (Figure 3) and unlagged R square values (Table 5) identified this variable as the most important of those examined. The removal of pulp mill effluent from the correlation had little effect on cropland's high unlagged R square (Table 6). Failure of harvested cropland to appear as an important factor in lagged correlations (Table 5 and Table 6) may be due to the broad nature of the variable and resulting insensitivity to the finer interactions between herring larvae and their immediate environment. Overall, the increase in harvested cropland acreage within the North Carolina portion of the Chowan Basin appears to have been strongly related to the decline in river herring catch. Associated with harvested cropland is the amount of fertilizer applied to crops in the watershed. Modern, high yield agriculture requires elevated rates of fertilization. Comparing the fertilizer sold trend (Figure 4) with total catch (Figure 2) gives an indication that the variables are inversely related. Lagged correlation R square values agree that fertilizer and catch are negatively related (Table 5 and Table 6). Whereas harvested cropland appears to be the strongest covariant with total catch, the lagged correlation results suggest that fertilizer sold is more closely related to larval survival. The inference can be made, then, that the increase in fertilizer sold and assumed used within the basin has contributed significantly to the quantity and/or degree of stressors affecting herring larvae in the Chowan River. The amount of pulp mill effluent discharged into the Chowan, like fertilizer sold, correlates most strongly with lagged catch data, particularly the 4 year lag (Table 5). This may be due in part to the 4 year periodicity of the effluent data from 1968-1979 (Figure 5). Of notable interest is the possibility that a preponderance of Chowan herring spawners are age IV fish. The most intriguing aspect of the relationship between effluent discharged and lagged catch, however, is that it is positive. Hinshaw (1981) documented a positive correlation between young-of-year alewife stomach fullness and kraft paper mill effluent in the Neuse River near New Bern, North Carolina.

The effluent enhanced the production of copepods, a favored food item of both _A. pseudoharengus_ and _A. aestivalis_, in a somewhat localized area immediately downstream from the discharge outfall. A similar situation may exist in the Chowan River downstream from Franklin, Virginia, where river herring are actually benefiting from some component of pulp mill effluent. Removing effluent from the stepwise correlations resulted in considerably lower lagged R square values (Table 6), indicating that it is indeed related to lagged catch. The inclusion of missing effluent data values may have strengthened or weakened this argument, however.

Weather related events are often responsible for controlling the timing of interactions that lead to recruitment of young fish to a fishery (Cushing, 1975 and 1982). A mismatch in time of crucial events, such as yolk sac absorption and food production, can result in the decimation of a year class. Despite the potential importance of climatological factors in determining fish abundance, the correlations obtained in this investigation between climate variables and Chowan herring catch were decidely weaker with both lagged and unlagged data than were the correlations obtained between land use variables and herring catch (Table 5 and Table 6). For the Chowan River herring fishery, effects of land use practices within the basin may override influences exerted by climatological variables upon abundance, as has been noted elsewhere in general terms by Bardach and Santerre (1981). Nonetheless, one or more climatological variables were significantly related to herring catch for all yearly stepwise correlations except lag 3 without effluent (Table 5 and Table 6) so their potential contributions to herring abundance cannot be dismissed as unimportant.

No yearly climatological variable clearly dominated the rest with regard to its correlation with river herring catch. Departures from normal precipitation, however, exhibited the strongest trend (Figure 6). Correlation results showed precipitation departures to be negatively related to catch (Table 5 and Table 6), indicating that large departures from normal precipitation levels are accompanied by low catch rates. A series of predominantly wet springs during the 1970's (Figure 6) may have contributed to the decline in catch during the decade (Figure 2). Wet springs and associated runoff from nutrient-laden, cultivated soils would combine to magnify eutrophic conditions in the Chowan River. Subsequent alteration of trophic structure may have reduced the availability of required food items, resulting in lowered larval survival. Changes in water quality associated with advanced eutrophication, such as periodic low levels of dissolved oxygen, may also have increased mortality of young herring. Contrary to this finding, Ulanowicz et al., (1982) found precipitation to correlate positively to anadromous river herring abundance in Maryland. This may represent the naturally-existing relationship in a coastal river system before eutrophication becomes advanced, whereby herring exploit spring blooms of desirable zooplankton.

Flows have been shown to affect abundance of another anadromous species, striped bass Morone saxatilis (Turner and Chadwick, 1972); Stevens, 1977; Hassler et al., 1981), and have been positively correlated to the initiation of alewife spawning migrations (Richkus, 1974). Sutcliffe et al., (1977) found fresh water flow into an estuarine embayment to be a good indicator of fish production. High flows expand spawning and rearing habitat by inundating floodplains and associated structural substrate suitable for attachment of the demersal, adhesive eggs of river herring. Flood conditions may facilitate the spawning migration by enhancing the olfactory recognition of natal streams. Comparison of Chowan catch and flow trends in Figure 2 and 8 discloses no obvious relationship, but stepwise correlation results show a significant positive correlation between these two variables (Table 5 and Table 6). High flows, therefore, appear to be associated with increased catch based on the long term, yearly data. Of notable interest is the possibility that flow is cyclic over time in the impoundment-free Chowan, as shown by Figure 8. The existence of such a pattern could benefit any future attempts at abundance prediction.

The opposing relationships between flow and catch and between precipitation and catch, though puzzling, may be partially explained by the periodicity of precipitation as it relates to soil moisture content. Frequent, low level precipitation events likely produce less runoff and thus, less river flow than infrequent deluges that rapidly exceed the capability of soil and vegetation to absorb water. Conceivably, an otherwise dry year with a few, heavy rainfall events could produce higher mean river flows than a relatively wet year during which rainfall events occurred at low levels but regular intervals. Flow, therefore, may not be required to correlate positively with precipitation.

Years having large seasonal departures from normal temperatures (Figure 7) correspond to years of reduced herring catch (Figure 2). Abnormally warm springs (1974, 1976, and 1977) as well as an abnormally cool spring (1978) were associated with a decline in herring catch. Some spring temperatures corresponding to the decline in catch, however, approached normal (Figure 7 and Figure 2). Stepwise correlation results further indicate that Chowan River herring catch correlates negatively with departures from normal temperatures (Table 5 and Table 6). The use of water temperature data, had it been available, might have produced a tighter correlation. Abnormal spring temperatures could adversely impact a number of life history stages, including gonadal development, migration initiation, time of spawning, egg and larval development, as well as influence food availability.

Analysis of the smaller, monthly data set yielded some additional information. Of the variables examined, monthly fishing effort showed the highest correlation with monthly herring catch (Table 7). This positive relationship indicates that total catch is an acceptable substitute for catch-per-unit-of-effort at this level of inquiry. The monthly climatological variables flow, precipitation, and temperature each made significant, although smaller, contributions to the total stepwise correlation. Monthly departures from normal temperature, in agreement with the yearly temperature-catch relationship, correlated negatively with monthly catch. The correlation between monthly flow and monthly catch, however, disagreed with its yearly counterpart and showed a negative relationship. High flows on a short term basis may disperse the fish, altering their movements and decreasing their concentration, or increase the problem of debris-fouled nets, both of which tend to decrease fishing effectiveness. The negative correlation between monthly catch and flow may therefore be due to decreased fishing effectiveness associated with high flows, rather than an actual decrease in river herring abundance. The correlation between monthly precipitation departures and monthly catch also disagreed with its yearly counterpart, showing a positive relationship. Dry (or less conceivably, wet) conditions may in some way make fishing more productive.

The conflicting results throughout this study concerning the variables catch, flow, and precipitation may simply underscore the fact that positive and negative dynamic factors influencing river herring abundance are at work simultaneously, and that these factors are likely affected by still other variables. Alternatively, and as alluded to earlier, the flow and precipitation sample stations used may not have been representative of the Chowan system as a whole and as such produced conflicting data. Still another possibility is that the use of herring catch as an estimate of herring abundance for the correlation analyses, while useful in identifying major relationships, produced some fortuitous R squares at the bottom (less important) end of the stepwise correlations where flow and precipitation were located. This possibility is supported by the second monthly stepwise correlation, in which catch-per-unit-of-effort was correlated with flow, precipitation, and temperature (Table 7). Catch-per-unit-of-effort is preferred over catch alone as an estimate of abundance since it dampens some of the variation in catch that is of social origin, and thus provides a more accurate estimate. This final stepwise correlation failed to produce significant results. The use of catch-per-unit-of-effort instead of catch throughout this investigation, had 20 years of fishing effort data been available, may have resulted in fewer significant correlations.

While it is far from certain that the best set of environmental variables were chosen to correlate with estimates of river herring abundance, those qualitative relationships identified as most important in this study deserve the attention of those seeking to use, manage, or further research this commercial fishery. The Chowan River herring resource could benefit from future investigations addressing food and feeding of larval and juvenile river herring, response of young and adult herring to varying levels of salinity and dissolved oxygen, and extent and importance of fishing mortality at low levels of abundance.

CONCLUSIONS

1. Indications are that the decreases in the Chowan River's total herring catch are most strongly tied to increases in the number of harvested cropland acres in North Carolina counties within the drainage basin.
2. Increases in agricultural fertilizer sales within the North Carolina section of the Chowan Basin appear to have contributed significantly in a negative fashion to larval herring survival.
3. While pulp mill effluent discharge level is shown to have little, if any, impact on total herring catch, it may favor larval survival.
4. Large departures from normal spring temperatures during the 1970's may have contributed to declines in river herring abundance.
5. Effects of flows and departures from normal precipitation upon river herring abundance conflict and remain unresolved.

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