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Forecasts of Atlantic and Gulf Menhaden Catches Based on the Historical Relation of Catch and Fishing Effort

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ABSTRACT—Forecasts of the annual purse seine catches in 1973 and 1974 of the Atlantic menhaden, Brevoortia tyrannus, *and Gulf menhaden,* B. patronus, *were made using multiple regression equations of catch in a given year on catch and effort in the previous year. Anticipated coefficients for the equations were estimated from effort for the given year, 16 years of data for the Atlantic fishery and 27 years for the Gulf. We applied this technique to all age classes combined. For the Atlantic fishery, the equation accounted for 85 percent of the variation in catches. The coefficient of determination for the Gulf fishery was 86 percent. Observed Atlantic catches deviated from the forecasts by 9 percent in 1973 and 22 percent in 1974. The errors for the Gulf were 2 percent in 1973 and 1 percent in 1974.*

When used to estimate historical catches, the equations were fairly accurate, but such empirical methods cannot substitute for an understanding of a causal mechanism determining population dynamics. Even though the average error may be quite small, the error for a specific year can be large.

INTRODUCTION

We prepared a method of forecasting seasonal purse seine catches of Atlantic menhaden, *Brevoortia tyrannus*, and Gulf menhaden, *B. patronus*, from catch and effort data. If a forecast of the annual catch were available, the fishing industry would be able to plan its operations for the coming year more efficiently. If the significance of the functional relations between catch and effort were determined, biologists would be able to build structural mathematical models (Graham, 1935, 1939; Schaefer, 1954, 1957; Schaaf and Huntsman, 1972). The success of man's continuing efforts to obtain greater harvests of marine organisms will depend on his ability to comprehend and predict the consequences of exploitation.

There are few published papers on forecasting of catches. Several papers that were presented recently at a symposium on forecasting in the USSR, discussed mainly the methods of determining the relative size of fish populations according to their rate of decrease (Dement'eva and Zemskaya, 1967). Instead of forecasting catches they established, for the most part, only trends in changes of the resource. Sette (1931, 1932, 1933, 1934) made forecasts of the Atlantic mackerel catches after examining age-class composition. Royce and Schuck (1954) made forecasts of haddock catches on Georges Bank by relating catch and effort of different age classes in a multiple regression equation. Schaefer (1954, 1957) and Shimada and Schaefer (1956) discussed the theoretical and future abundance of tuna in the Pacific, but attempted no actual forecasts of catches. Watt (1956) presented a summary of methods commonly used in prediction models. Forecasting sockeye salmon runs and their economic consequences to Bristol Bay, Alaska, was discussed by Mathews (1967). Frequent attempts, exemplified by Manthey (1972), were made to forecast Pacific salmon runs in certain rivers or river systems. Most of those forecasts were based on correlations between the index of escapement of juveniles and their estimated numbers when they returned to spawn.

Because menhaden processors have always been concerned about fluctuations in landings, development of methods to forecast seasonal abundance has been considered since studies began in the 1950's. Before forecasting could be attempted basic information about the fishery and the biology of menhaden has to be compiled. This information dealt with such problems as population structure and size, life cycles, distribution, movement, and age and size composition of the catches. By 1960 biologists had learned enough to make tentative statements about future seasonal abundance to members of the industry and their annual meetings, although they made no quantitative forecasts of catches. Such forecasts could not be made accurately until the relation between catch and effort was determined. We have explored that relation, and have established a basis for forecasting catches of Atlantic and Gulf menhaden.

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ATLANTIC MENHADEN FISHERY

Description of the Fishery

Federal biologists began studies in 1955 on the population dynamics of Atlantic menhaden that resulted in three findings pertinent to forecasting the catch: 1) the existence of a single population; 2) the gradual trends in catches rather than abrupt annual changes; and 3) the complex, stratified distribution along the coast by age and size. The first two simplify forecasting and the third complicates it.

As a single population, Atlantic menhaden occur from central Florida to the Gulf of Maine and are exploited throughout their entire range. Adults occur in inshore ocean waters and the larger bays and sounds and juveniles are found mainly in estuaries. Some fish live 10 years, but most do not live past seven. Although fish of all ages are subject to exploitation, most of those caught are from 1 to 3 years old.

Catches of Atlantic menhaden increased steadily through the mid-1950's, decreased in the mid-1960's, and then increased again in the early 1970's. As the fishery expanded following World War II, new plants and vessels were added, old vessels were modernized, and methods of locating, handling, and processing fish were improved. The catch rose from 296,000 metric tons in 1945 to 712,000 in 1956. A decline in catches began in the northern part of the fishery in the late 1950's and in the southern part in the early 1960's. By 1969 the catch had dropped to 161,000 metric tons. By 1972 it increased to 363,000 but decreased again in 1973 and 1974. Variations in the catches from one year to the next have been small relative to the historical range of catches.

From late spring until early autumn, adult Atlantic menhaden are distributed by age and size along the coast (Nicholson, 1971b, 1972). Age 1 fish are the most abundant age groups south of Cape Hatteras, although age 2 fish constitute up to 40 percent of the catch in some years. Age 1 and 2 fish are the most abundant age groups in Chesapeake Bay and coastal waters from Cape Charles, Va., to Delaware Bay. They are larger than fish of the same age south of Cape Hatteras. Age 2 fish are the most abundant age group in waters off New Jersey. Age 3 and 4 fish are most abundant in Long Island and Nantucket Sounds, while age 4 and older fish are dominant north of Cape Cod. Because of northward migrations in early spring, the slow northward movement during the summer, and southward migrations in autumn, the proportion of each age group in any area will change from time to time.

Estimation of Atlantic Catches in Previous Years

After examining the relation for past years between catch and effort, we found that a multiple regression equation employing these variables estimated annual catch more reliably than other methods we tried. As a unit of fishing effort we used the vessel week, which is one vessel fishing one calendar week (Nicholson, 1971a). Total effort is the sum of the number of weeks for all vessels.

Estimated catches for past years, or hindcasts, have been calculated by a multiple regression equation: $C_{n+1} = a + b_1 (E_n) + b_2 (C_n) + b_3 (E_{n+1})$,

where C_{n+1} = estimated catch in year $n+1$,

C_n = estimated catch in year n,

E_n = estimated fishing effort in year n, and

E_{n+1} = estimated fishing effort in year $n+1$.

The coefficients a, b_1, b_2, and b_3 are average values that are calculated mathematically from known values of catch and effort for the period 1955-72. They are not interpreted biologically. By substituting known values from our records for the independent variables, we estimated a catch for each year and compared it to the actual catch. The degree of association between the dependent and independent variables was measured by the multiple correlation coefficient (R). The percentage of variation in catches explained by the independent variables is measured by the square of the coefficient of determination (R^2).

The R^2 value showing variation in catch estimates associated with the

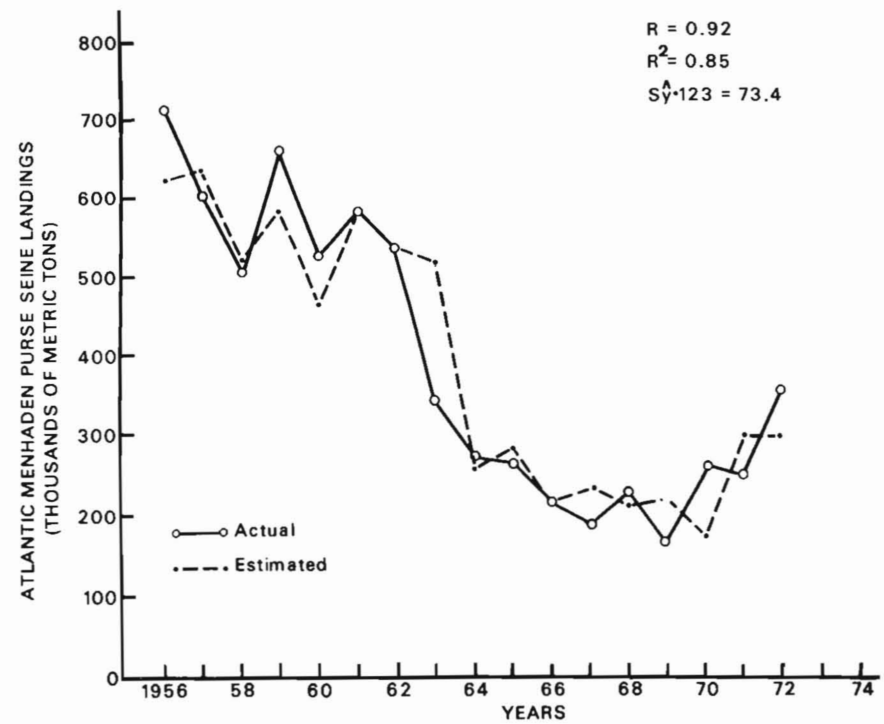

Figure 1.—Actual and predicted landings of Atlantic menhaden in thousands of metric tons by multiple regression, 1956-1972.

independent variables, was 85 percent. The agreement between actual and estimated catches was considered satisfactory for accomplishing our immediate forecasting needs (Fig. 1). The equation does not predict sudden and large changes in catch, however, such as in 1963, when the exceptionally large 1958 year class ceased to contribute substantially to the fishery. In that year the equation overestimated the catch by 50 percent. Since there is close agreement in most years between estimated and actual catches, the equation can be used to predict total catch on the Atlantic Coast.

Forecasts of 1973 and 1974 Atlantic Catches

Because we did not know exactly how much fishing effort there would be in the forecast year, we based our estimates on percentages of effort in the previous year. Estimates at various percentages of effort in the year prior to the forecast year are shown in Table 1. Advance information from industry provides a preliminary estimate of effort for the coming year. Our forecast of the Atlantic menhaden catch in the 1973 fishing season was 402,000 metric tons with a 10 percent increase over 1972 effort. Eighty percent confidence limits ranged from 308,000 to 496,000. The forecast for the 1974 fishing season was 352,000 metric tons with no change in effort. Eighty percent confidence limits ranged from 301,000 to 402,000.

Table 1.—Estimated catch of Atlantic menhaden and number of vessel weeks in the forecast years 1973 and 1974 based on varying percentages of fishing effort in 1972 and 1973.

Percent of effort	No. of vessel weeks	Forecast catch	Actual catch
		metric tons	*metric tons*
1972		1973	
+10	1,020	402,000	
[1]+ 8	**1,000**	**382,000**	347,000
No change	927	381,000	
−10	834	360,000	
1973		1974	
+10	1,100	357,000	
[1]+ 5	**1,050**	**360,000**	295,000
No change	1,000	352,000	
−10	900	329,000	

[1]Boldface numbers are estimates from actual percent of fishing effort in previous year.

The observed catch of 347,000 metric tons in 1973 was 14 percent less than predicted, but within the 80 percent confidence limits. Fishing effort however was 1,000 vessel weeks, 20 vessel weeks less than expected. If the correct amount of effort had been anticipated, the catch forecast would have been 382,000 metric tons, or 9 percent greater than observed.

The forecast issued for the 1974 fishing season anticipated a catch of 352,000 metric tons with unchanged effort (1,000 vessel weeks) and would have predicted a catch of 360,000 metric tons at a 5 percent increase in effort (1,050 vessel weeks). The observed catch in 1974 of 295,000 metric tons was 22 percent less than forecast and slightly outside the lower 80 percent confidence limit.

GULF MENHADEN FISHERY

Description of the Fishery

As a result of investigations begun on Gulf menhaden by the National Marine Fisheries Service in 1964, data on population structure and catch and effort statistics are available for that fishery. As in the Atlantic menhaden fishery, these data facilitated the development of methods for estimating catches.

One population ranging from southern Florida to Yucatan supports a fishery from Florida to Texas. Although Gulf menhaden may live to be 5 years old, the fishery is supported mainly by age 1 and 2 fish. Some fish are recruited in late summer at age 0 but most are recruited at age 1. There appears to be no extensive coastwise movement of fish by age and size throughout the fishing area. They move out of coastal waters in October and November to offshore areas in the Gulf and return to coastal areas in March and April. Fishing occurs from April to October.

The purse seine fishery began modernizing and expanding after the 1940's when demand for fish meal and oil increased. Expansion was rapid through the 1950's and continued until the mid-1960's. The catch, after increasing from 75,000 metric tons in 1948 to 479,000 tons in 1962, fluctuated between 316,000 and 728,000 from 1964 to 1972, the peak year. Fluctuations in yearly catches are greater than in the Atlantic fishery, as might be expected in a fishery with fewer age groups, although annual variations have been small relative to the historical range of catches.

Estimation of Gulf Catches in Previous Years

The multiple regression equation using catch and effort data is a reliable method of estimating catches in the Gulf fishery. The regression coefficients a, b_1, b_2, and b_3 were calculated from 27 years of records, 1946-72. Fishing effort is measured in vessel-ton weeks, the product of fishing time and the registered net tonnage of a vessel. Since on the average, large vessels catch more fish per week than small vessels, the vessel-ton week accounts for some of the differences in efficiency between different size vessels. Therefore, the vessel-ton week measures effort more accurately in the Gulf than a vessel week. The relation between estimated and actual catches is shown in Figure 2.

The agreement between actual and estimated catches for the 27-year period was good, but there was closer agreement in the early years of the fishery, from 1947 to 1956, than in later years (Fig. 2). As effort increased in later years and larger percentages of the available fish were caught, variations in year-class strength probably exerted more influence on the size of the catch. Since age 1 fish normally constitute over half of the weight of the catch, variations in their abundance and average weight have considerable effect on the catch. The greater the variability in the strength of the incoming year classes, the more difficult it is to predict catches accurately especially when using only historical catch/effort relationships.

Forecasts of 1973 and 1974 Gulf Catches

As with the Atlantic fishery, we did not know how much effort there would be in the forecast year so we based our forecasts on effort of the preceding year, plus or minus 10 percent of the earlier effort (Table 2). Our forecast of the Gulf menhaden catch in the 1973 fishing season was 466,000 metric tons with a 10 percent reduction from 1972 fishing effort. Eighty percent confidence

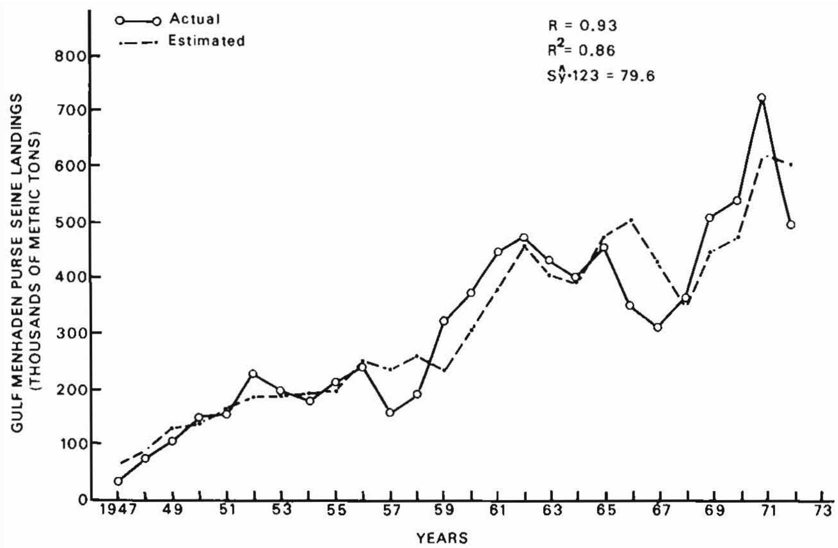

Figure 2.—Actual and predicted landings of Gulf menhaden in thousands of tons by multiple regression, 1947-1972.

limits on this forecast ranged from 404,000 to 528,000. The forecast for the 1974 fishing season was 557,000 metric tons with an increase in effort of 10 percent over observed effort in 1973. Eighty percent confidence limits ranged from 518,000 to 596,000.

The observed catch in 1973 was 486,000 metric tons with 426,000 vessel-ton weeks, a level of effort 5 percent less than in 1972. The catch predicted from only 426,000 vessel-ton weeks would have been 477,000 metric tons, 2 percent less than observed.

The catch forecast for 1974 was 557,000 metric tons at an increase in effort of 10 percent (469,000 vessel-ton weeks). Fishing effort actually increased 14 percent to 485,000 vessel-ton weeks and, if predicted accurately, our model would have estimated a catch of 584,000 metric tons, 1 percent less than the observed catch of 587,000 metric tons.

Table 2.—Estimated catch of Gulf menhaden and number of vessel-ton weeks in the forecast years 1973 and 1974 based on varying percentages of fishing effort in 1972 and 1973.

Percent of effort	No. of vessel-ton weeks	Forecast catch	Actual catch
		metric tons	*metric tons*
1972		1973	
+10	492,000	600,000	
No change	447,000	533,000	
[1]−5	**426,000**	**477,000**	486,000
−10	402,000	466,000	
1973		1974	
[1]+14	**485,000**	**584,000**	587,000
+10	469,000	557,000	
No change	426,000	492,000	
−10	384,000	426,000	

[1]Boldface numbers are estimates from actual percent of fishing effort in previous year.

SUMMARY

We have applied a method of predicting the total catch one year in the future for both the Atlantic and Gulf menhaden purse seine fisheries by considering an empirical relation between the total catch and the total effort. This method is usually applied to specific age classes in the fishery, where the logic of assuming that the catch depends on last year's catch and effort, as well as on current effort, is perhaps more reasonable. We used total catch, however, because 1) for the Atlantic fishery it is difficult to prorate effort on different ages, and 2) for the Gulf, aging is more uncertain; but there are fewer age classes in the fishery. In statistical studies of this sort many other models, of course, are conceivable and cannot be discarded a priori. It was not our intent to study the possibilities exhaustively, but to confine ourselves to fairly standard approaches that gave consistently reliable results for both fisheries. The multiple regression we used of C_{n+1} on C_n, E_n, and E_{n+1} accounted for 85 percent of the variance in Atlantic catches and 86 percent in Gulf catches. This model could be refined perhaps by the inclusion of more variables; gains in R^2 would have to be carefully evaluated against possible loss of precision with the fewer associated degrees of freedom. We present this work as a progress report and do not intend to stop considering alternative models. Forecasts might be more useful to the fishing industry, however, if they were more specific, perhaps by plant or port, even with less precision.

Useful as this type of forecast may be to industry, fishery biologists view it as a point in the continuum of understanding the dynamics of the resource under exploitation. Understanding and predicting deviations from average expected trends, presumably caused by variation in the number of young fish entering the fishery, requires more knowledge of the biology of recruitment. A measure of the incoming year class would permit development of short-term fishing strategies to take advantage of exceptional year classes or to prevent overexploitation of weak year classes. Forecasting recruitment is difficult and usually costly, but studies of this problem are in progress at the Atlantic Estuarine Fisheries Center, Beaufort, N.C. (Nelson et al.[1]). We will require structural mathematical models of the dynamics of a fish population in order to predict long-term consequences of various rates of exploitation and to achieve optimum yields. Our knowledge of the Atlantic menhaden fishery has progressed to the point where we have begun this type of modeling (Schaaf and Huntsman, 1972).

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