Fisheries Research, 1 (1981/1982) 289—298
Elsevier Scientific Publishing Company, Amsterdam — Printed in The Netherlands

A STATISTICAL MODEL OF WHITE PERCH (*MORONE AMERICANA*) HARVEST ASSESSMENT IN RELATION TO ENVIRONMENTAL VARIATION

J. KEVIN SUMMERS, WILLIAM A. RICHKUS, RICHARD N. ROSS and ROBERT E. ULANOWICZ[1]

Martin Marietta Environmental Center, 1450 South Rolling Road, Baltimore, MD 21227 (U.S.A.)
[1] *University of Maryland, Chesapeake Biological Laboratory, P.O. Box 38, Solomons, MD 20688 (U.S.A.)*

(Accepted 5 August 1982)

ABSTRACT

Summers, J.K., Richkus, W.A., Ross, R.N. and Ulanowicz, R.E., 1982. A statistical model of white perch (*Morone americana*) harvest assessment in relation to environmental variation. *Fish. Res.*, 1: 289—298.

Multivariate regression models of annual white perch landings from the Maryland Chesapeake Bay and tributaries are developed by step-wise regression procedures. The models employ several environmental parameters and concurrent annual striped bass catch as predictor variables. Models using environmental conditions alone and environmental conditions in combination with annual striped bass landings explain 88% and 92% of the variation in annual perch harvest, respectively. Possible causal relationships between the significant environmental parameters and stock size are discussed.

INTRODUCTION

Correlative or regression models relating commercial landings and environmental variables have been developed for several fisheries. Ulanowicz et al. (1980) showed that 53% of the annual variation in oyster spat set (an indicator of oyster yearclass strength) could be explained by three environmental variables and concurrent oyster harvests in Maryland. Ulanowicz et al. (in press) demonstrated that certain environmental variables could explain a significant portion of the variability in commercial landings of four finfish and three shellfish stocks in the Maryland Chesapeake Bay. Using temperature and salinity as predictive variables, Hunt et al. (1979) developed a regression model for brown shrimp landings off North Carolina. Correlative relationships between temperature and commercial landings in Maine (Dow, 1977) and freshwater discharge and fisheries production in St. Margaret's Bay (Sutcliffe, 1972) have also been demonstrated.

0165-7836/82/0000—0000/$02.75

Regression models cannot establish the causes of variation in annual landings in any stock since they measure correlations only. Also, one of the assumptions in their use is that the relationship between factors influencing landings and the landings over the period of the data record remain stationary or constant. Despite these limitations, they can be a useful management tool for forecasting harvests when sufficient information is unavailable for constructing more detailed deterministic models. They can also indicate potentially important causes of harvest variations, thus providing direction for fisheries management research. In a recent review and evaluation of fisheries management models, Richkus et al. (1980a) assessed the applicability of various model types to the development of management programs for Maryland's tidewater fisheries. A concurrent survey of existing data revealed that data required for various "classical" fisheries models were generally unavailable. Sufficient data were available, however, to develop multivariate regression models using environmental variables as predictors. The white perch (*Morone americana*), a major commercial and recreational resource in Maryland, was one species for which such models were constructed. The resultant models and a discussion of their relevance to the biology and management of white perch are presented here.

MARYLAND WHITE PERCH FISHERY

The semi-anadromous white perch (*Morone americana*) is indigenous to the Chesapeake Bay and those in Maryland that spend their entire life cycle in the upper Bay remain within Maryland waters. The white perch fishery in the Bay has historically been dynamic, with annual landings varying from 0.5 to 2 million pounds/year from 1944 to 1979 (Fig. 1). Landings from 1974 to 1976 were the lowest recorded over the 36-year period, but those in 1978 were approximately equal to the mean for the entire period. Annual white perch landings show no obvious periodicity over time.

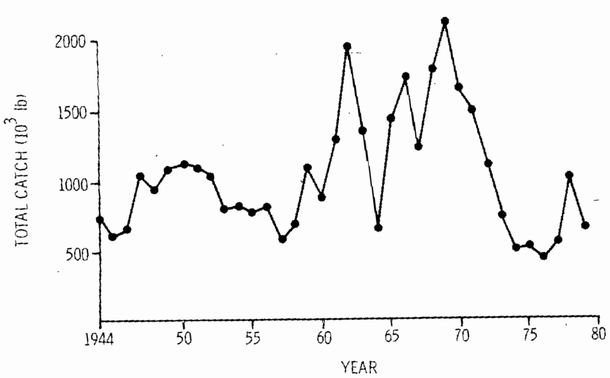

Fig. 1. Total annual white perch landings (pounds) in Maryland Chesapeake Bay, 1944—1979.

White perch are commercially fished in the Chesapeake Bay using gill nets, fyke nets, haul seines, and pound nets. In recent years the gill net fishery has accounted for approximately 70% of total white perch landings, while in the 1940's and 50's, pound nets and haul seines contributed 34% and 26%, respectively, of the total white perch catch.

Gear types can be important in controlling the age class (or size class) distribution of the stock being harvested. Inspection of individual landings records suggests that white perch are often a by-catch in a gill net fishery directed at striped bass (*Morone saxatilis*), but are the target species in the fyke net fishery (Mansueti, 1961; Richkus et al., 1980 b). Thus, age of recruitment varies with gear type and cannot be documented with present data. Generally, annual variability in the white perch harvest, like most other fisheries, is due to a combination of intrinsic population dynamics, external factors (Driver, 1976; Nelson et al., 1976; Ulanowicz et al., in press), and level of fishing effort. Stocks in some Chesapeake tributaries appear to display dominant yearclasses (see, for example, St. Pierre and Davis, 1972), but no stock recruitment relationships are documented in the literature for this species (Richkus et al., 1980a). Thus a modelling effort was undertaken to determine if the variability in the 36-year record of landings could be explained by the effect of environmental variables which might influence spawning success and/or growth and mortality of all life stages.

CHARACTERIZATIONS OF ANNUAL ENVIRONMENTAL DATA

Daily recordings of water temperature, salinity, air temperature, and precipitation have been taken for 40 years from the Chesapeake Biological Laboratory pier near the mouth of the Patuxent estuary in Solomons, Maryland. Since Solomons is located in the central region of the Maryland Chesapeake Bay, these data are considered representative of mean conditions for the Maryland portion of the Bay. All four of these environmental variables could potentially affect white perch spawning success, growth, or mortality and, therefore, landings. The annual average of each variable alone is not a suitable indicator because it is not representative of the behavior of the variable during the course of a single year. Thus, the annual record of each variable was characterized in seven different manners: mean values, cumulative number of days above and below arbitrarily chosen high or low values, number of episodes of greater than 3 days length above arbitrary high or low values, and extreme high and low values (Ulanowicz et al., 1980). The goal of this procedure was to pair each annual catch figure with a characteristic of an environmental variable that might have affected the stock during that year. These seven treatments of the original four time series, yielded 28 annual series of environmental data.

Cumulative effects of deviations from annual means were characterized by defining variables analogous to the degree-days of agricultural science. For each of the four environmental variables recorded, we chose a high and a low bias level (Table I) that represented relatively large excursions from the norm and

TABLE I

Parameters used in calculating cumulative variables and episodes

Variable	High bias	Low bias
Salinity ($^0/_{00}$)	16.2	10.5
Water temperature (°C)	26.5	4
Air temperature (°C)	30	0
Precipitation (cm/day*)	3	0

*This value is used in determining the cumulative number of high rain days. The value is changed to 0.01 cm/day to calculate episodes of rain (i.e., any day rain occurs is included).

presumably could influence a species' physiological condition. Durations of the longest episodes beyond the high and low bias values represented two additional data characteristics tabulated for each variable. To avoid contamination of these values from high frequency events, we chose a "gap-interval" for each variable ranging from 3 to 5 days (e.g., excursions beyond the bias level that did not exceed the gap interval were not terminated, although the days on which the lapse occurred were not tallied in the episode length). Annual extremes and the means of each variable were also included as data characteristics since the stocks might be acutely affected by short-term, intense stresses. Cumulative and extreme low precipitations are uniformly zero by definition and provide no information concerning the variability of these events among years. Therefore, they were removed from the data set, leaving 26 annual time series. These series constituted the possible "predictor vectors" from which those yielding the best multiple regressions would be chosen. The values for the 26 variables calculated for the years 1938—1976 are tabulated in Ulanowicz et al. (1980).

ANALYTICAL RATIONALE

Yearclass size is generally based on juvenile abundance in most fish stocks (Cushing, 1975). Therefore, magnitude of recruitment into the fishery and, consequently, size of harvest are often correlated with the previous specific environmental conditions that influenced spawning success as well as growth and mortality rates prior to recruitment.

In populations where most individuals from a given yearclass are recruited into a fishery in a single year, significant correlations are obtained when environmental variables are lagged a length of time equivalent to age at recruitment. However, landings of white perch in Maryland generally consist of members of several yearclasses. This result may be due in part to the occasional stunting of several Maryland white perch stocks (i.e., high-density populations exhibiting lower than average growth rates), as has been documented for the Potomac and Susquehanna Rivers (Lippson et al., 1979; Foerster, 1976).

Another factor influencing age composition of catch may be the variable growth rates within individual age classes (Mansueti, 1961). A third contributing factor is gear selectivity. Many gears employed in the white perch fishery in Maryland are relatively non-selective for size (e.g., fyke nets).

Because an extended partial recruitment is generally assumed for the white perch fishery, environmental conditions important in determining yearclass strength may be partially correlated with landings over several years. To account for such partial correlation, stepwise regression techniques were used to successively introduce the contributions to the landings of individual lagged environmental variables chosen from the estimated period of recruitment. Landings may also be influenced by the availability of fish during a given fishing season or the nature of the fishing effort, both of which could also be influenced by environmental conditions. Thus, lags incorporated in the regression procedure ranged from 0, representing effects on effort and fish availability during the year of catch, to 10, representing the oldest age class appearing in catches. This approach does not take into account changes in age-specific growth rates, but the regression coefficients do intrinsically incorporate potential differences in age-specific growth.

REGRESSION METHODOLOGY

A stepwise multiple regression routine, BMDP2R (Dixon et al., 1977), was used in the search for key environmental factors influencing white perch harvest. The stepwise regressions of annual landings were conducted on 286 possible predictor variables (consisting of 26 environmental variables lagged from 0 to 10 years); variables were entered into or removed from the regression equation by computing a partial F-statistic for each variable at each step and comparing it to a preselected F-value based on the number of observations (e.g., 33 cases for 0 lag and 23 cases for 10-year lag). Variables with a partial F-statistic greater than the criterion value (i.e., those that provide a significant contribution) were entered into the regression equation.

Since it was impractical to attempt to determine the best multiple regression in one pass through the program, a step-wise regression on the 26 environmental parameters was performed initially using all variables lagged a similar amount. Then, as successive multiple regressions were completed, the 20 most significant variables were aggregated into one run to determine the final set of predictor parameters and the multiple regression equation. Each run in the initial regression series was terminated when the F-to-enter value of the next variable to be added to the regression dropped below 4.0 at 0 lag and 3.9 at 10-year lag ($\alpha < 0.01$). In this final stage of the procedure, predetermined F-to-enter values were higher than in previous regressions (8.53 to enter and 8.43 to remove) to reduce the number of variables that could enter the regression due to chance alone.

Since white perch are often taken as by-catch in the striped bass gill net fishery, a second series of regressions was run with concurrent striped bass landings as an additional variable for each year of white perch catch. All regression procedures used were identical to those already described.

In order to ensure that regression results were not spurious due to the large number of independent variables (approximately 26 parameters in each year), regressions were run using randomly generated records for the white perch fishery. These randomly generated time series encompassed the same time period as the observed record and were constrained between the values of 500 000 and 2 500 000 pounds. A total of ten random time series was used and both the number of significant variables entering the final multiple regression and the R^2 value of the final analysis were compared with the results of the white perch regressions.

RESULTS

The stepwise regression of the environmental parameters on white perch landing yielded a significant relationship ($\alpha < 0.01$) which accounted for 88% of the annual variability by four variables: extreme high salinity lagged 4 years and 10 years, extreme low air temperature lagged 5 years, and the longest episode of high air temperature lagged 10 years (Fig. 2). Because variables with 10-year lags are included in the regression, statistically modeled harvest estimates can only be determined for the years 1954—present. The regression equation is:

$$Y_i = 2823.549 + 1096.011\ XS4 - 2828.112\ XS10 - 79.935\ Xt5 + 36.046\ ET10$$

where Y_i = white perch annual landings in year i (10^3 pounds), XS4 = maximum daily salinity for the entire year 4 years preceding harvest, XS10 = maximum daily salinity for entire year 10 years preceding harvest, Xt5 = minimum air temperature for the entire year 5 years preceding harvest, and ET10 = maximum length in consecutive days of air temperature above 30°C in the year 10 years previous to harvest.

Extreme high salinity, lagged 10 years (XS10), accounted for 47% of the annual variability in white perch harvest, while episodes of high air temperature lagged 10 years (ET10), extreme high salinities lagged 4 years (XS4), and extreme low air temperature lagged 5 years (Xt5) accounted for an additional 18, 14, and 9% of the variability, respectively. Fig. 2 shows the predictive power of this regression model for annual, Maryland white perch landings in 1977, 1978, and 1979 (data not used in model derivation). While this correspondence is clearly not a true validation of the formulation, the agreement between predicted and recorded landings over the 3 years suggests that the model reflects possible causes of annual variability in white perch landings.

The stepwise multiple regression of white perch catch on environmental variables and concurrent striped bass harvest accounted for 92% of the annual variation ($\alpha < 0.05$) in white perch landings with seven variables: concurrent striped bass catch (BASS), extreme high salinities lagged 4 and 10 years (XS4, XS10), extreme low air temperature lagged 4 and 5 years (Xt4, Xt5), length

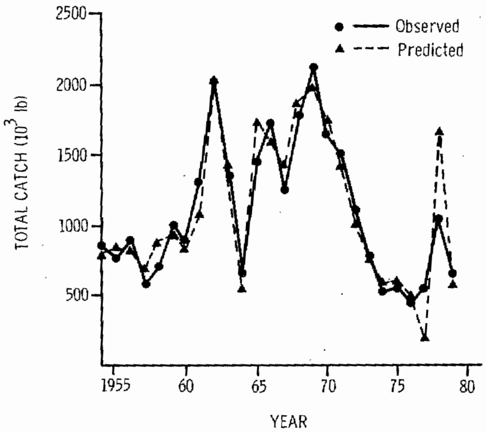

Fig. 2. Recorded Bay-wide white perch landings and predicted landings using four environmental variables (observed values from 1977—1979 were not used in model formulation).

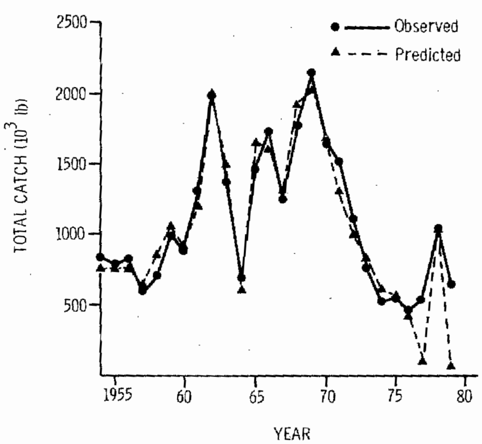

Fig. 3. Recorded Bay-wide white perch landings and predicted landings using six environmental variables and concurrent striped bass landings (observed values from 1977—1979 were not used in model formulation).

in consecutive days of salinity $< 10.5‰$ lagged 9 years (Es9), and length in consecutive days of air temperature $> 30°C$ lagged 10 years (ET10). The regression equation is:

$$Y_i = 2971.915 + 0.0\,877\ \text{BASS} + 637.572\ \text{XS4} - 2755.483\ \text{XS10} - 46.315\ \text{Xt4} - 57.023\ \text{Xt5} + 1.844\ \text{Es9} + 29.905\ \text{ET10}$$

A plot of the recorded and predicted annual white perch landings is shown in Fig. 3.

The addition of concurrent striped bass landings accounted for an additional 4% of the variability. The predicted values of this regression for total white perch catches in 1977, 1978, and 1979 (Fig. 3) were much less exact than those of the initial regression.

Regressions were done using ten random time series for white perch landings. The results of these randomized regressions were somewhat mixed, as would be expected, but in no instance did more than two independent variables enter as a result of the regressions for individual years. Seven variables entered when using the observed white perch data. Regression parameters accounted for a mean of 24% ± 6% of the variability in the random series generally by using a single environmental parameter. This proportion of explained variation for the random series is much less than the 88—92% of the variation accounted for in the observed white perch landing data. As a result, we feel that the white perch regression results are not due simply to chance correlations (although some portion of the explained variation may be).

DISCUSSION

An analysis of white perch growth rates and gill net mesh sizes used in the fishery suggests that the perch up to age 10 could contribute substantially to the gill net fishery for this species although no long-term catch/age composition data for this fishery exist for corroboration (Richkus et al., 1980b). The significance of the salinity variable, lagged 10 years, in accounting for 47% of the catch variability in the first regression points to some mechanism involving salinity effects on juvenile survival or growth. The negative coefficient of this variable may relate to encroachment of saline waters on the freshwater and estuarine spawning habitats of the species. Incidences of extreme high salinity could potentially reduce the effective spawning area for this stock. More likely, extreme salinity is probably cross-correlated with a suite of favorable environmental conditions which the regressions cannot identify. The predictive power of the regression model may have decreased when striped bass landings were included as an independent variable because the striped bass fishery in the predicted years (1977—1979) was generally at the lower extreme of the range for the data set of striped bass landings used in developing the regression model (1944—1976). Thus, the regression was predicting at the limits (or possibly beyond the limits) of its range.

There are several limitations to using statistical models such as these in the management of fisheries. Foremost, since the relationships are correlative rather than causal, the regression model is of limited use in making management decisions. The explanation of substantial portions of the annual variability in white perch landings by combinations of environmental conditions only suggests that these conditions or some related environmental phenomena play a role in determining size of landings. Because fishing effort is implicitly rather than explicitly represented in these regressions, changes in certain environmental parameters may affect changes in directed effort or fish availability rather than stock abundances.

These regression relationships cannot be interpreted causally because of our inability to partition the influence of these various effects. However, the suggestion that a large degree of variation in white perch landings can be accounted for by environmental variability can be interpreted as an indication of stock-independent recruitment for Chesapeake Bay white perch (cf., Ulanowicz and Polgar, 1980).

ACKNOWLEDGEMENTS

This work is the result of research sponsored by the Coastal Resources Division of the Maryland Department of Natural Resources and the Maryland Tidewater Administration.

REFERENCES

Cushing, D.H., 1975. Marine Ecology and Fisheries. Cambridge University Press, New York, NY, 183 pp.

Dixon, W.J., Brown, M.B., Engelman, L., Frane, J.W. and Jennrich, R.I., 1977. BMDP-77: Biomedical Computer Programs P-Series. University of California Press, Berkeley, CA, 690 pp.

Dow, R.L., 1977. Effects of climatic cycles on the relative abundance and availability of commercial marine and estuarine species. J.Cons., Cons. Int. Explor. Mer, 37: 274—280.

Driver, P.A., 1976. Prediction of fluctuations in the landings of brown shrimp (*Crangon crangon*) in the Lancashire and Western Sea Fisheries District. Estuarine Coastal Mar. Sci., 4: 536—567.

Foerster, J.W., 1976. Assessment of the effect of hydroelectric water discharged from Conowingo Dam on the spawning fish in the lower Susquehanna River. Prepared for the Power Plant Siting Program, Maryland Department of Natural Resources. Publ. Goucher College, Baltimore, MD, 223 pp.

Hunt, J.H., Carroll, R.J., Chinchilli, V. and Frankenburg, D., 1979. Relationship between environmental factors and brown shrimp production in Pamlico Sound, North Carolina. Completion Report for Project 2-315-R, North Carolina Department of Natural Resources, Moorehead City, NC.

Lippson, A.J., Haire, M.S., Holland, A.F., Jacobs, F., Jensen, J., Moran-Johnson, R.L., Polgar, T.T. and Richkus, W.A., 1979. Environmental Atlas of the Potomac Estuary. Prepared for Maryland Department of Natural Resources by the Martin Marietta Environmental Center, Baltimore, MD, 291 pp.

Mansueti, R.J., 1961. Movements, reproduction, and mortality of the white perch, *Roccus americanus*, in the Patuxent estuary, Maryland. Chesapeake Sci., 2: 142—205.

Nelson, W.R., Ingham, M.C. and Schaaf, W.E., 1976. Larval transport and year-class strength of Atlantic menhaden, *Brevoortia tyrannus*. Fish. Bull., 75: 23—41.

Richkus, W.A., Summers, J.K., Polgar, T.T. and Holland, A.F., 1980a. A review and evaluation of fisheries stock management models. Prepared for Coastal Resources Division, Maryland Department of Natural Resources, by Martin Marietta Environmental Center, Baltimore, MD, 240 pp.

Richkus, W.A., Summers, J.K., Polgar, T.T., Holland, A.F., Ross, R., Johnson, G.F. and Souza, P., 1980b. A review and evaluation of fisheries stock management models. Phase II: Applicability to Maryland tidewater fisheries. Prepared for Coastal Resources Division, Maryland Department of Natural Resources by Martin Marietta Environmental Center, Baltimore, MD, 197 pp.

St. Pierre, R.A. and Davis, J., 1972. Age, growth, and mortality of the white perch, *Morone americana*, in the James and York Rivers, Virginia. Chesapeake Sci., 13: 272—281.

Sutcliffe, W.H., Jr., 1972. Some relations of land drainage, nutrients, particulate material, and fish catch in two eastern Canadian bays. J. Fish Res. Board Can., 29: 357—362.

Ulanowicz, R.E. and Polgar, T.T., 1980. The influences of anadromous spawning behavior and optimal environmental conditions upon yearclass strength. Can. J. Fish. Aquat. Sci., 37: 143–154.
Ulanowicz, R.E., Caplins, W.C. and Dunnington, E.A., 1980. The forecasting of oyster harvest in central Chesapeake Bay. Estuarine Coastal Mar. Sci., 11: 101–106.
Ulanowicz, R.E., Ali, M.L., Vivian, A., Heinle, D.R., Richkus, W.A. and Summers, J.K., in press. Climactic factors influencing commercial seafood landings in Maryland. Fish. Bull.