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Relative Stock Composition of the Atlantic Coast Striped Bass Population: Further Analysis

W. Van Winkle
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ENVIRONMENTAL SCIENCES DIVISION
Publication No. 1988

Prepared for Dr. P. Hayes, Project Representative
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Under Interagency Agreement No. DOE 40-550-75

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

Available from
GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

NUREG/CR-2563
ORNL/TM-8217
Distribution Category-RE

Contract No. W-7405-eng-26

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Manuscripted Completed - May 1982
Date Published - June 1982

Prepared for the
Division of Health, Siting, and Waste Management
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555
Under Interagency Agreement No. DOE 40-550-75

NRC FIN B0165

Task: Methods to Assess Impacts on Hudson River Striped Bass

NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

ACKNOWLEDGMENTS

The authors thank L. W. Barnthouse, J. J. Beauchamp, S. W. Christensen, C. P. Goodyear, and V. E. Kane for their critical review of this report. The data analyzed were made available to us by Texas Instruments, Inc., through Consolidated Edison Company of New York, Inc., as part of the operating license proceedings for Consolidated Edison's Indian Point Nuclear Generating Plant, Unit 3, before the U.S. Nuclear Regulatory Commission.

ABSTRACT

VAN WINKLE, W., and K. D. KUMAR. 1982. Relative stock composition of the Atlantic Coast striped bass population: Further analysis. NUREG/CR-2563; ORNL/TM-8217. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 38 pp.

Fourteen variables derived from thirteen morphological characters were used in a stepwise discriminant analysis and a maximum likelihood analysis to estimate the relative contribution of striped bass (Morone saxatilis) stocks from the Hudson River and Chesapeake Bay to the coastal striped bass population. The analyses made use of the spawning-stock data and ocean data collected by Texas Instruments in 1975, although deletions were made to simplify the data to focus on relative contribution north of Chesapeake Bay and on sex and year-class differences. The discriminant function method misclassified approximately 20% of the spawning-stock fish. Errors in estimates of relative contribution for the spawning stock data were similar for the two methods of analysis. Estimates of relative contribution of the Hudson stock to the coastal population varied considerably among year classes. In particular, the estimated relative contribution for the 1965 year class was between 40 and 50%, while the relative contributions for the 1966, 1968, and 1969 year classes were approximately 10% or less. The relative contribution of males was greater than that of females. The two methods of analysis gave similar estimates of relative contribution of the Hudson stock to the coastal population.

SUMMARY

This report presents an analysis of the Texas Instruments 1975 spawning-stock and ocean data collected as part of a study to identify the origin of striped bass collected in the Atlantic coastal population and to estimate the relative contribution of major stocks to the coastal population. The specific purposes of this report are to analyze this large and valuable data set by developing and applying alternative methods of analysis and by focusing on estimating relative contribution by sex and year class, and to argue that the time is propitious to have this study repeated.

Roanoke fish were deleted from the spawning-stock data and stratum 10 was deleted from the ocean data in an effort to simplify the data set to focus on the primary area of controversy, namely, the relative contribution of the Chesapeake and Hudson stocks to the ocean population north of Chesapeake Bay. We further simplified the data by deleting from the spawning-stock data (and then from the ocean data) any sex and year-class combination for which there were fewer than two fish for either spawning stock. The relative contribution of the Hudson stock was estimated using both a stepwise discriminant function method and a maximum likelihood method. Prior to statistical analysis, we attempted to correct for sex and year-class effects in an effort to obtain a clearer picture of the pattern of relative contribution between sexes and among year classes. The data were not transformed because it was not possible to test the statistical validity of such transformations in terms of a better or poorer fit to a multivariate normal distribution. In selecting characters to be used in the discriminant function, we allowed not only the observed characters but also their squares and cross products to be candidates for inclusion.

The final discriminant function included 14 characters. Although there was no direct correspondence between our 14 characters and the five characters selected by Texas Instruments, it was apparent that snout length, internostril width, distance between focus and first annulus, distance between first annulus and second annulus, and number of rays in the various fins were the most discriminating characters in both analyses. The confusion matrix indicated that 21% of the Hudson spawning stock was misclassified as Chesapeake and 20% of the Chesapeake spawning stock was misclassified as Hudson. Error, defined as the absolute difference between the estimated and true relative contribution from the Hudson for the spawning-stock data, was similar for the discriminant function method and the maximum likelihood method. Error increased as sample size decreased.

Estimates of relative contribution of the Hudson spawning stock to the Atlantic coastal population of striped bass north of Chesapeake Bay differed considerably among year classes. In particular, the estimated relative contribution for the 1965 year class was between 40 and 50%, while the relative contributions for the 1966, 1968, and 1969 year

classes were approximately 10% or less. The relative contribution of males was significantly greater than that of females. This difference is thought to be due to (1) the geographic boundaries used by Texas Instruments to define the ocean data set and (2) the greater tendency for Chesapeake females, as compared to males, to migrate outside of Chesapeake Bay. The discriminant function method and the maximum likelihood method did not give appreciably different estimates of relative contribution for the ocean data.

We recommend that the study be repeated as soon as possible, perhaps funded by the Emergency Striped Bass Study (i.e., the Chafee Amendment), now that the dominant 1970 year class from the Chesapeake is no longer evident and given that all year classes from the Chesapeake since 1974 have been weaker than average. Furthermore, we recommend that the sampling design for the spawning stocks for the follow-up study be modified to include more length categories and/or more fish per length category for each sex, and that measurements be made of only those morphological variables that are the best discriminators between stocks.

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INTRODUCTION

One of the major issues in the Nuclear Regulatory Commission (NRC) licensing hearings for operation of both Indian Point Units 2 and 3 was the relative stock composition of the Atlantic Coast striped bass population (USAEC 1972, USNRC 1975). In particular, the concern was that if the Hudson River were a major contributor and if entrainment and impingement mortality of young-of-the-year striped bass at power plants along the Hudson were high, then there was a risk that the Indian Point facility might contribute substantially to a reduction in the commercial and sport fishery for striped bass along the Atlantic Coast. In response to this concern, Consolidated Edison Company of New York funded a study by Texas Instruments. The results of this study were presented in reports (McFadden et al. 1978, Texas Instruments 1976) and in the open literature (Berggren and Lieberman 1978, Grove et al. 1976). The summary and conclusions from this study were as follows:

> "A study was conducted to identify the origin of striped bass collected in the Atlantic coastal fishery and estimate the relative contribution of major stocks to the fishery. Quadratic discriminant analysis was applied to values of five morphological characters obtained from Hudson, Chesapeake, and Roanoke spawning-stock specimens to determine functions which best separated the stocks. Correct-classification percentages of 76.8, 67.7, 85.9% were obtained for the Hudson, Chesapeake, and Roanoke spawning stocks, respectively, resulting in an overall correct classification of 74.4% of the specimens.
>
> "A simulation study was conducted to investigate the bias in as-classified, iterative, and adjusted estimates of relative contribution due to misclassification error inherent in the discriminant functions. Results indicated that iterative estimates may best approximate the true contribution of the Hudson stock in oceanic collections.[a]

---

[a] Robson (1979, p. 39) commented that "the [iterative] method appears to be an innovation and is presented without reference citations or theoretical justification. Available empirical evidence is sufficiently compelling to justify a theoretical study of the procedure, but until the mathematical properties are investigated there is no firm basis for its application." In light of Robson's evaluation, we used Berggren and Lieberman's (1978) adjusted estimates rather than their iterative estimates in making comparisons with our own results.

> "A stratified sampling design was used during six 2-mo periods in 1975 to collect representative samples of striped bass in the Atlantic coastal fishery from southern Maine to Cape Hatteras. This provided estimates of stock composition by stratum throughout the year.
>
> "Oceanic samples were classified by discriminant functions and as-classified, iterative, and revised estimates of relative contribution of the major stocks were obtained. Mean iterative estimates of relative contribution for 1975 are 6.5% Hudson, 90.8% Chesapeake, and 2.7% Roanoke stocks. Iterative estimates of Hudson contribution for legal-sized striped bass exceeded 20% only in western Long Island Sound and the New York Bight, during certain months. In collections from Western Long Island Sound and the New York Bight, iterative estimates of the percentage of sublegal-sized fish classified into the Hudson stock were at least 80% during the May through October periods. For Hudson River collections of overwintering striped bass, an iterative estimate of 97.4% Hudson stock was obtained.
>
> "The occurrence of a dominant year class was noted. Approximately 52% of the legal-sized specimens collected in the 1975 oceanic sampling program were from the 1970 year class, and 77% of these were classified as Chesapeake in origin.
>
> "Major conclusions drawn from the study are (1) the Chesapeake stock is the major contributor to the Atlantic coastal striped bass fishery from southern Maine to Cape Hatteras; (2) the Chesapeake stock is also the major contributor of legal-sized striped bass in the vicinity of the Hudson River (western Long Island Sound and the New York Bight); (3) sublegal-sized striped bass collected in the vicinity of western Long Island Sound and the New York Bight are predominantly of Hudson origin; and (4) striped bass overwintering in the Hudson River are predominantly of Hudson origin (Berggren and Lieberman 1978, p. 344)."

In 1977 we obtained on tape the complete data set for this Texas Instruments study. We repeated their as-classified analysis and obtained identical results, and then we performed our own independent analysis. Our initial results were presented at the Northeast Fish and Wildlife Conference in 1978 (Kumar and Van Winkle, unpublished ms). Our conclusions at that time, on the relative contribution of the Hudson stock to the Atlantic Coast population based on the 1975 ocean sample of 4- to 12-year-old striped bass, were as follows:

(1) Relative contribution varies considerably from year class to year class, but it does not appear to have exceeded 30% for any year class between 1963 and 1971.
(2) Both Texas Instruments and our preliminary estimates of relative contribution of the Hudson stock averaged over age, sex, and temporal and spatial strata were less than 5%.
(3) These estimates of less than 5% are probably lower than the long-term average relative contribution due to the dominant effect of the 1970 year class from the Chesapeake.

We then discussed the need to more carefully examine the pattern of the estimates of relative contribution by sex within year class, although we recognized the problem of small sample size for some of these sex and year-class combinations. We concluded that the study needed to be repeated in the 1980s, after the 1970 year class was a minor component of the ocean population.

The purpose of this report is to further analyze this large and valuable data set. In particular we (1) developed and applied alternative methods of analysis, (2) focused on estimating relative contribution by sex and year class, and (3) argued that the time is propitious to have this study repeated.

METHODS

Spawning-Stock Data

The collection and processing of spawning-stock specimens is described in Berggren and Lieberman (1978). For our analysis we deleted the Roanoke fish from the spawning-stock data set. Our reasoning was as follows. Tag-recapture studies do not indicate appreciable migration of Roanoke fish north of the entrance to Chesapeake Bay (Hassler et al. 1981) or appreciable migration of Hudson fish south of the entrance to Chesapeake Bay (Texas Instruments 1976, Appendix A). The controversy concerning the relative stock composition of the ocean population concerns primarily the area north of Chesapeake Bay. By deleting the Roanoke fish, we assume that we are simplifying the data set in a manner that will more accurately allow us to estimate what we are primarily interested in, without the complicating and confounding effects of including a third stock with its own differences among ages and between sexes. Consistent with our deletion of Roanoke fish from the spawning-stock data set is our deletion of all fish from stratum 10 (south of the entrance to Chesapeake Bay) from the ocean data set.

Berggren and Lieberman (1978, Table 5, their adjusted estimates) report that the relative contribution of the Roanoke stock to stratum 1 (Pemaquid Neck Light on the coast of Maine south to Race Point Light at the tip of Cape Cod and including all of Cape Cod Bay) was 11.5% (9 of

82 fish) during May-June and 4.6% (3 of 58 fish) during July-August. The relative contribution of Roanoke stock to stratum 2 (Race Point Light south along the outer coast of Cape Cod to the Massachusetts-Rhode Island border) was 24.0% (20 of 82 fish) in September-October 1975. While these results may reflect extensive migrations by the Roanoke stock, they are at odds with the extensive tag-recapture data (Hassler et al. 1981) currently available for the Roanoke stock. An alternative, and we feel more likely, interpretation is that these results are artifacts of the discriminant analysis procedure, and to avoid this problem we deleted the Roanoke spawning stock from the analysis.

The sex and year-class composition of the spawning stocks from the Hudson and Chesapeake are given in Table 1. To minimize bias due to sex and year-class differences in the characters, we deleted all sex and year-class combinations if there were fewer than two fish for either stock. Our reasoning was that at least some measure of variability was desirable, which is possible with two fish but not one. The analysis is being repeated with a criterion for deleting a sex and year-class combination of fewer than one fish for either spawning stock, but results are not available at this time. The resulting data set includes 4-, 5-, 6-, 7-, 8-, 10-, and 11-year-old males; and 6-, 7-, 9-, 10-, and 11-year-old females; a total of 28 of 164 fish were deleted from the Hudson stock and 78 of 231 fish from the Chesapeake stock.

Ocean Data

The collection and processing of the ocean specimens are described in Berggren and Lieberman (1978). Figure 1 illustrates the geographical stratification used by Texas Instruments; temporal stratification consisted of dividing the calendar year into six 2-month periods. As indicated above, we deleted from the ocean data set all fish caught in stratum 10. We also deleted from the ocean data set (Table 2) all fish that did not belong to one of the sex and year-class combinations retained in the spawning-stock data set (Table 1). The final data set that we used in our analysis consisted of data from 798 striped bass.

Simplifying the two data sets to focus our analysis on how relative contribution varies by sex and year class highlighted an unfortunate problem. Only one 5-year-old female is in the Hudson spawning-stock (Table 1). Consequently, the sex-age combination of female, 5-year-old striped bass was not retained in the ocean data set, resulting in the deletion of 1123 fish or 44% of the total number of fish in the ocean sample. This is the primary reason the analysis is being repeated with the alternative criterion for deleting a sex and year-class combination of fewer than one fish for either spawning stock. The low abundance of 5-year-old females in the Hudson spawning stock is not unexpected because Hudson striped bass become sexually mature at a later age than do Chesapeake striped bass (McFadden et al. 1978). The

Table 1. Sex and year-class composition of the 1975 spawning stock data from the Hudson River and Chesapeake Bay

Sex	Year class	Age[a] (year)	Number of legal-sized fish	
			Hudson	Chesapeake
Male	1973	(2)	0	3
	1972	(3)	0	26
	1971	4	11	20
	1970	5	17	64
	1969	6	13	5
	1968	7	2	2
	1967	8	5	3
	1966	(9)	8	0
	1965	10	13	2
	1964	11	7	3
	1963	(12)	2	0
	1962	(13)	2	0
	Total:	Without deletions	80	128
		With deletions	68	99
Female	1971	(4)	0	4
	1970	(5)	1	29
	1969	6	9	10
	1968	7	7	6
	1967	(8)	1	11
	1966	9	18	24
	1965	10	17	5
	1964	11	17	9
	1963	(12)	11	1
	1962	(13)	1	1
	1961	(14)	0	0
	1960	(15)	1	0
	1959	(16)	0	0
	1958	(17)	1	3
	Total:	Without deletions	84	103
		With deletions	58	54
	Total for both sexes:			
		Without deletions[b]	164	231
		With deletions	136	153

[a] Age in parentheses means that fish in that sex and year-class combination were deleted from the spawning-stock data set for our analysis. Criterion for deletion was fewer than two fish from either the Hudson or the Chesapeake.

[b] These totals do not include four fish from the Hudson and one from the Chesapeake, which accounts for the discrepancy with the 168 Hudson fish and 232 Chesapeake fish reported by Berggren and Lieberman (1978). We did not include these five fish because they were not assigned an age by Texas Instruments due to conflicting age estimates based on scale annulus readings (J. T. Lieberman, personal communication).

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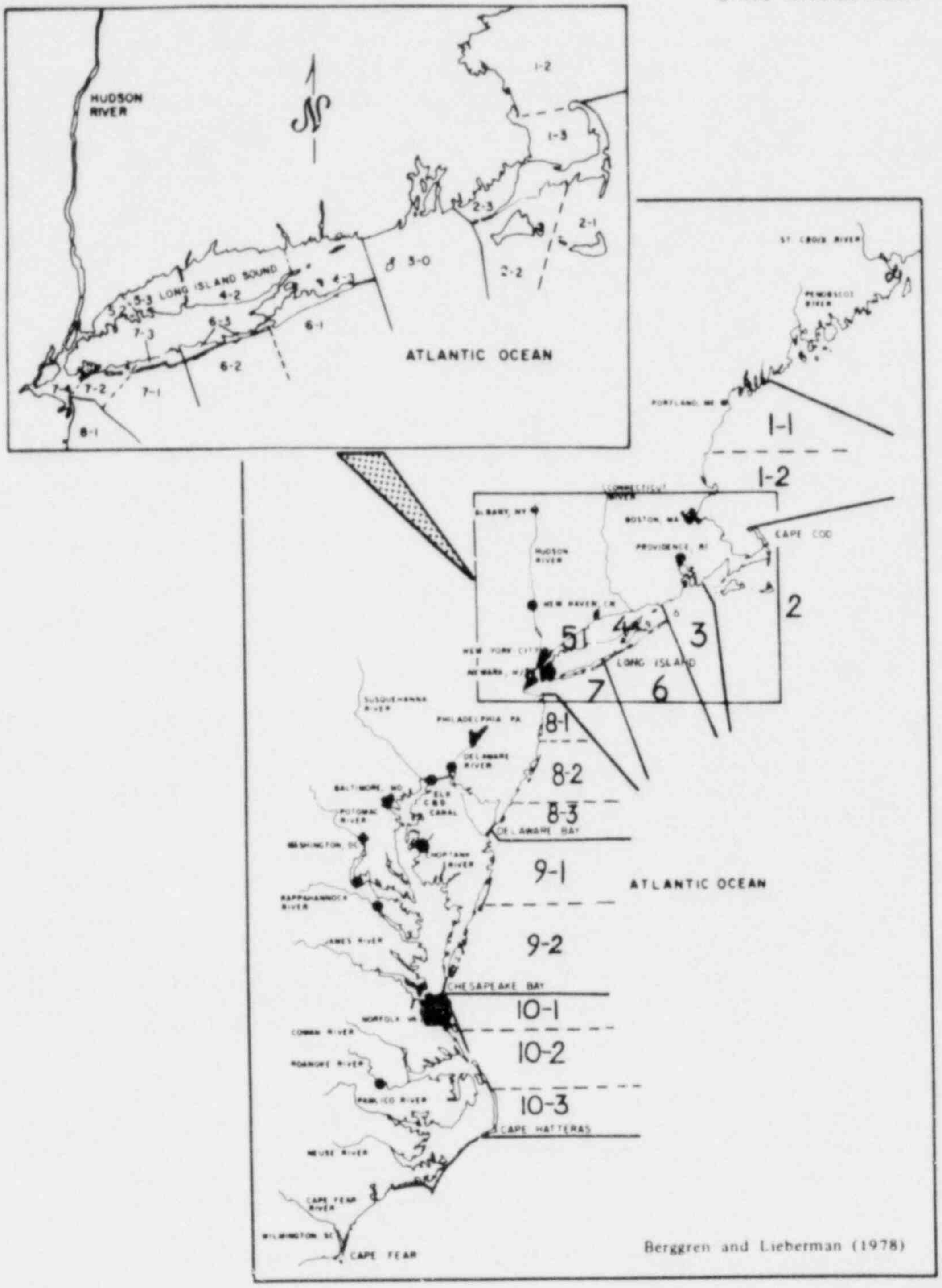

Berggren and Lieberman (1978)

Fig. 1. Collection regions for the Atlantic coastal population of striped bass showing geographical stratification and substratification; collection sites for spawning-stock specimens indicated by dots on source rivers (modified from Berggren and Lieberman 1978).

Table 2. Sex and year-class composition of the 1975 ocean data[a]

Sex	Year class	Age[b] (year)	N
Male	1973	(2)	4
	1972	(3)	16
	1971	4	87
	1970	5	196
	1969	6	25
	1968	7	6
	1967	8	7
	1966	(9)	13
	1965	10	3
	1964	11	5
	1963	(12)	1
	1962	(13)	1
	Total:	Without deletions	364
		With deletions	329
Female	1973	(2)	4
	1972	(3)	100
	1971	(4)	234
	1970	(5)	1123
	1969	6	166
	1968	7	48
	1967	(8)	78
	1966	9	151
	1965	10	38
	1964	11	66
	1963	(12)	76
	1962	(13)	7
	1961	(14)	6
	1960	(15)	2
	1959	(16)	4
	1958	(17)	3
	1955	(20)	1
	Total:	Without deletions	2107
		With deletions	469
	Total for both sexes:		
		Without deletions	2471
		With deletions	798

---

[a] All fish in stratum 10 (south of the entrance to Chesapeake Bay) were deleted (= 51 fish). Five fish in strata other than stratum 10 were deleted because sex was undetermined. One fish in stratum 9 was deleted because it was collected in Chesapeake Bay rather than the ocean. The 2471 fish without deletions in this table + 51 fish in stratum 10 + 5 fish of undetermined sex + 1 fish in stratum 9 but in Chesapeake Bay = 2528 fish, which is the total sample size in Table 5 of Berggren and Lieberman (1978).

[b] Age in parentheses means that fish in that sex and year-class combination were deleted from the ocean data set for our analysis. Criterion for deletion was fewer than two fish from the Hudson or the Chesapeake spawning-stock data set (see Table 1).

dominance in the ocean sample of 5-year-old bass, both female and male (Table 2), reflects the 1970 dominant year class produced in the Chesapeake.

Statistical Methods

The primary goal of the statistical analysis is to estimate the contribution of the Hudson River striped bass stock to the Atlantic Ocean striped bass population. We estimated the contribution (p_1) by two independent methods, the discriminant function method and the maximum likelihood method.

Discriminant Function Method

Given a spawning-stock data set where the striped bass are of known origin, namely, the Hudson and Chesapeake, the discriminant function method attempts to classify each of the ocean fish of unknown origin as belonging to one group or the other. Hence, given a sample of size N of striped bass collected in the ocean, the discriminant function will classify $\hat{N}_1$ (the '^' denotes an estimate as opposed to the 'true' value) as belonging to the Hudson stock. The relative contribution of the Hudson stock (p_1) is given by

$$p_1 = \alpha\left(\frac{\hat{N}_1}{N}\right) + \beta \quad , \tag{1}$$

where α and β are constants that can be estimated from the spawning-stock data set. In this section we discuss (1) the method of estimating the discriminant function, (2) the method for estimating the "confusion matrix," and (3) the derivation of Eq. (1) from the confusion matrix.

Estimation of Linear Discriminant Function

Let $y_1 = (y_{11}, y_{12} \ldots, y_{1K})$ and $y_2 = (y_{21}, y_{22}, \ldots, y_{2K})$ be the vectors of K character variables for each fish (both sexes and all ages) sampled from the Hudson and Chesapeake, respectively. Let n_1 and n_2 be the number of fish sampled in each of the spawning stocks. We further define the following terms:

$\overline{y}_i$ = mean sample vector of character variables for spawning stock i (i = 1,2),

S_i = variance-covariance sample matrix for spawning stock i (i = 1,2),

$n = n_1 + n_2$ = total sample size from the spawning stocks,

$\overline{y} = \dfrac{n_1\overline{y}_1 + n_2\overline{y}_2}{n}$ = overall mean sample vector of character variables,

$W = \dfrac{1}{n-2}\left[(n_1-1)\ S_1 + (n_2-1)\ S_2\right]$ = within-group, variance-covariance sample matrix,

and

$B = n_1\ (\overline{y}_1 - \overline{y})(\overline{y}_1 - \overline{y})' + n_2(\overline{y}_2 - \overline{y})(\overline{y}_2 - \overline{y})'$ = between-group, variance-covariance sample matrix, where the prime denotes the transpose of the vectors of differences $(\overline{y}_i - \overline{y})$.

It is assumed that the y_i are samples from multivariate normal distributions and that the S_i are estimates of a common variance-covariance matrix. If the vector $z = a'y$ denotes a linear combination of the original character variables, a one-way analysis of variance for the derived variable z will lead to the following F-ratio of the between-groups mean square to the within-group mean square:

$$F = \frac{a'Ba}{a'Wa} \quad . \tag{2}$$

If we choose the elements of the coefficient vector $\underline{a}$, such that this F-ratio is maximized, we are in fact selecting the linear combination of the original character variables which best "discriminates" between the two stocks. The value of $\underline{a}$ is given by the eigenvector corresponding to the largest eigenvalue of $W^{-1}B$ (see Gnanadesikan 1977, Chapter 4). Once the coefficient vector $\underline{a}$ has been determined, we can then classify the i^{th} fish in the ocean sample as belonging to the Hudson stock if

$$a'x_i > a'\ (\overline{y}_1 + \overline{y}_2)/2 \quad , \tag{3}$$

where x_i is the vector of K character variables for the i^{th} fish in the ocean sample. Otherwise, the i^{th} fish is classified as belonging to the Chesapeake stock. The reader should refer to Rao (1952) and Gnanadesikan (1977) for more details.

The Confusion Matrix

Once the discriminant function has been estimated, we can evaluate the effectiveness of the discriminant function by estimating the "confusion matrix." Let ϕ_{ij} represent the proportion of the i^{th} spawning stock that was classified as belonging to the j^{th} spawning stock. Hence, ϕ_{11} and ϕ_{22} represent the proportions correctly classified as Hudson and Chesapeake, respectively, while ϕ_{12} and ϕ_{21} represent the proportions misclassified (e.g., ϕ_{21} represents the proportion of the Hudson spawning stock misclassified as Chesapeake spawning stock). The confusion matrix can be estimated using the jack-knife method (also called the U-method) (Kshirsagar 1978). The confusion matrix is estimated as follows:

Step 1: Compute the discriminant function using the two spawning-stock data sets combined, except for the i^{th} fish.

Step 2: Classify the i^{th} fish using the discriminant function computed in Step 1.

We repeat the two steps for all the fish in the combined spawning-stock data set. The reader is referred to Kshirsagar (1978, Chapter 6) for a general discussion of different methods of estimating the confusion matrix. The overall effectiveness of the discriminant function is then given by the ratio of the total number of fish misclassified to the total number of fish in the spawning stock data set. The lower this number, the better the discriminant function.

Estimation of Relative Contribution (p_1)

The number of ocean fish classified as Hudson, $\hat{N}_1$, may be expressed as

$$\hat{N}_1 = \text{Prob}(1,1)N_1 + \text{Prob}(2,1)N_2 \quad , \tag{4}$$

where N_1 and N_2 are the true number of Hudson and Chesapeake fish in the ocean sample, respectively, Prob(1,1) is the probability a Hudson fish is classified as Hudson, and Prob(2,1) is the probability a Chesapeake fish is classified as Hudson. Dividing both sides by $N = N_1 + N_2$ gives

$$\hat{p}_1 = \text{Prob}(1,1)p_1 + \text{Prob}(2,1)(1 - p_1) \quad , \tag{5}$$

where $\hat{p}_1$ is the proportion of the ocean sample classified as Hudson, and p_1 is the 'true' proportion of the ocean sample from the Hudson. Assuming $\phi_{1,1}$ equal to Prob(1,1) and $\phi_{2,1}$ equal to Prob (2,1) and solving for p_1, we get

$$p_1 = \frac{\hat{p}_1 - \phi_{21}}{\phi_{11} - \phi_{21}} \quad . \tag{6}$$

Then

$$p_1 = \alpha\, \hat{p}_1 + \beta \text{ (i.e., Eq. 1)} \quad , \tag{7}$$

where

$$\alpha = 1/(\phi_{11} - \phi_{21}) \text{ and } \beta = -\phi_{21}/(\phi_{11} - \phi_{21}) \quad . \tag{8}$$

This method of adjusting the estimates of contribution obtained directly from the discriminant analysis to correct for bias due to misclassification is akin to moment estimation (Kendall and Stuart 1973). It is the same procedure used by Berggren and Lieberman (1978; their adjusted estimates); see also Fukuhara et al. (1962) and Anas and Murai (1969) who used this procedure to adjust estimates of stock contribution for salmon. If $p_1 < \phi_{21}$ or $\phi_{11} < \phi_{21}$ (but not both), the estimate of p_1 will be negative, indicating that the method is unable to estimate the contribution because it is very small or because the sample size is small. Whenever a negative p_1 was obtained, we set it equal to zero, unlike the procedure used by Berggren and Lieberman (1978).

Maximum Likelihood Method

The maximum likelihood method treats the task of estimating p_1 as a "mixture-of-normals" problem, and p_1 is estimated directly without classifying individual fish (Odell and Basu 1976, Robson 1979, Peters and Coberly 1976, and Tubbs and Coberly 1976). As a result, there is no equivalent of the bias problem encountered with the discriminant function method, and thus there is no need to adjust maximum likelihood estimates of p_1 as in Eq. (7).

Let $f_1(y_1)$ and $f_2(y_2)$ be the K-dimensional probability density functions of the character variables for the Hudson stock and Chesapeake stock, respectively; then the density function of the character variables for the ocean stock is a mixture of these two spawning-stock density functions. In our case, we define for the ocean sample (denoted by x) a binomial distribution leading to the density function

$$f(x) = \hat{p}_1\, f_1(x) + (1 - \hat{p}_1) f_2(x) \quad , \tag{9}$$

where $\hat{p}_1$ = estimated contribution of Hudson stock to the Atlantic Ocean population. We further assume that $f_i(x)$ is a K-dimensional, multinormal distribution with mean vector, Θ_i, and variance-covariance matrix, Σ_i. Furthermore, to remain consistent with the linear discriminant function method, let $\Sigma_1 = \Sigma_2 = \Sigma$.

Given the spawning-stock data, we can readily obtain the usual estimates of Θ_1, Θ_2, and Σ. Hence, f(x) can be re-written as

$$\widehat{f(x)} = \hat{p}_1 \widehat{f_1(x)} + (1 - \hat{p}_1) \widehat{f_2(x)} \quad . \tag{10}$$

One can then obtain the maximum likelihood estimate of p_1 by forming the likelihood function of $\widehat{f(x)}$, differentiating the function with respect to $\hat{p}_1$, and setting this derivative equal to zero. After some algebraic manipulations we obtain the equation

$$\hat{p}_1 = \frac{\hat{p}_1}{N} \sum_{i=1}^{N} \frac{\widehat{f_1(x_i)}}{\hat{p}_1 \widehat{f_1(x_i)} + (1 - \hat{p}_1) \widehat{f_2(x_i)}} , \tag{11}$$

where N is again the number of fish in the ocean sample. Since $\hat{p}_1$ occurs on both sides of the equation, a fixed-point solution method is used to estimate p_1. The above equation is re-written as

$$\hat{p}_1^{(r)} = \frac{\hat{p}_1^{(r-1)}}{N} \sum_{i=1}^{N} \frac{\widehat{f_1(x_i)}}{\hat{p}_1^{(r-1)} \widehat{f_1(x_i)} + (1 - \hat{p}_1^{(r-1)}) \widehat{f_2(x_i)}} \tag{12}$$

where $\hat{p}_1^{(r)}$ = estimate of p_1 at the r^{th} iteration.

The estimation algorithm is

Step 0: Let $\hat{p}_1^{(0)} = 0.5$. This is the initial estimate of p_1.
Step r: Substitute the estimate of p_1 at the $(r-1)^{\text{th}}$ iteration $\left(\hat{p}_1^{(r-1)}\right)$ in Eq. (12) to obtain $\hat{p}_1^{(r)}$. If $|\hat{p}_1^{(r)} - \hat{p}_1^{(r-1)}|$ is less than some small number ϵ (0.00001 in our case), the algorithm has converged and $\hat{p}_1^{(r)}$ is our best estimate of p_1. Otherwise we repeat Step r.

It can be readily shown that given $\widehat{f_1(x)}$ and $\widehat{f_2(x)}$, the algorithm will converge. When $\hat{p}_1^{(r)}$ is close to zero or one, the algorithm is stopped, and $\hat{p}_1^{(r)}$ is set equal to zero or one, respectively.

One of the potential advantages of this maximum likelihood method is that it is theoretically possible to calculate a confidence interval about $\hat{p}_1$, whereas this is not possible with the discriminant function method. The procedure for doing this, however, would not be straightforward and would require developing additional computer programs. This is an area that could profit from further research.

In the preceding two subsections we discussed two methods for estimating the contribution of the Hudson spawning stock to the ocean population. In the next two subsections we discuss some of the problems that exist in dealing with the type of data this study involves and our approach to resolving these problems.

Transformations and Sex and Year-Class Effects

Before an analysis can be carried out, two important issues must be addressed. These are

(1) Should the data be transformed (examples: logarithmic or square-root transformation)? A decision was made a priori that given the high dimensionality of the data set (13 morphological characters) and a lack of knowledge concerning the true multivariate distribution, it is not wise to attempt such transformations because it is not possible to empirically test the statistical validity of these transformations in terms of a better or poorer fit to a multivariate normal distribution. Berggren and Lieberman (1978) did not use transformations either.

(2) How does one account for sex and year-class effects? Under ideal circumstances one would like to conduct the analysis for each sex and year-class combination, so that one could obtain a clearer picture of the contribution pattern. However, because the sample sizes were not sufficiently large to allow such an analysis, we took the alternate route of attempting to "correct" the data for these effects, as follows: Consider a specific sex (S) and year class (Y). For this sex and year-class combination (SY), we obtain the mean of the j^th^ morphological character, $\bar{v}_j^{(SY)}$, over both spawning stock samples. Then for each fish in this sex and year-class combination in either spawning-stock sample, we define the new character

$$y_{ijk}^{(SY)} = v_{ijk}^{(SY)} - \bar{v}_j^{(SY)} \quad , \tag{13}$$

where $v_{ijk}^{(SY)}$ is the original value of the j^{th} character for the k^{th} fish from the i^{th} spawning stock in sex and year-class combination SY. This mode of correction is based on a linear model for the effect of sex and year class on each morphological character. Because the averaging is done over both spawning stocks, it is essential that one must have data from both sources for a given sex and year class. As a consequence, several sex and year-class combinations were dropped from the analysis due to lack of data for both spawning stocks. Table 1 shows the sex and year-class combinations used in this study.

Alternative methods of accounting for sex and year-class effects were explored, involving regression of each morphological character on age or fork length for males and females separately. We preferred Eq. (13) because it was the simplest method and involved the fewest assumptions.

Selection of Characters to Be Used in the Discriminant Function

The Texas Instruments data collection program involved measuring 13 characters for each fish. The utility of the discriminant function is maximized when only the most "discriminating" characters are used in the function. It is our hypothesis that the relationship between the 13 measured characters is complex and not fully understood or known. Based on this hypothesis, we decided that not only the measured characters but also their squares and cross-products for a total of 104 character variables should be candidates for inclusion in the discriminant function. Note that this procedure is analogous to the second-degree polynomial approach used in response surface methods (Cochran and Cox 1957). The variables included in the function were determined using the stepwise discriminant function method (Rao 1952). We allow the possibility of a square of a measured character or a cross product of two characters to be in the model, without the measured characters appearing by themselves. This allows the discriminant function to be more general in nature than the one permitted by the usual quadratic-discriminant-function method (Kshirsagar 1978), used by Berggren and Lieberman (1978). The quadratic-discriminant-function method requires that the measured character itself be selected for the model before the square of this character or a cross product involving this character is considered.

The same character variables selected for the discriminant function method were used for the maximum likelihood method. It would have been possible to have this method select its own set of variables in a stepwise fashion, but only with considerable work and the development of a new computer program. We decided this was not a worthwhile investment of time and money because the stepwise-discriminant-function method of selecting variables is well established in the field as being sound.

RESULTS AND DISCUSSION

Discriminant Function

The stepwise linear discriminant function procedure resulted in selection of 14 of the 104 character variables (Table 3). Before a variable could be selected, two criteria had to be established. First, for the i^{th} variable to be selected in the discriminant function already having the (i-1) most descriptive variables, the probablity of obtaining the calculated F value for the i^{th} variable needed to be greater than the 90th percentile of the theoretical F distribution with the corresponding degrees of freedom. Then, each of the (i-1) previously included variables was tested for inclusion, assuming that the i^{th} included variable was in the equation. This F value also had to be greater than the 90th percentile.

Our choice of the 90th percentile is somewhat arbitrary. The procedure was evaluated using the 75th, 80th, 90th, and 95th percentiles, which of course resulted in progressively fewer variables being selected. There was not a pronounced pattern, however, in which variables were selected at the various probability levels, nor was there an appreciable change in the misclassification proportions.

The five character variables established by Berggren and Lieberman (1978) as the best set to discriminate among Hudson, Chesapeake, and Roanoke stocks were (in order of importance as established by stepwise linear discriminant analysis): (1) the ratio of snout length to internostril width; (2) the ratio of the distance between the first annulus and second annulus to the distance between the focus and the first annulus; (3) a character index, defined as the sum of the number of rays in the left and right pectoral, second dorsal, and anal fins; (4) the number of upper-arm gill rakers (including rudimentary rakers); and (5) the number of scales along the lateral line. Although there is not any direct correspondence between our 14 variables and the five variables selected by Texas Instruments, it is apparent that snout length, internostril width, distance between focus and first annulus, distance between first annulus and second annulus, and number of rays in the various fins are the most discriminating morphological characters in both analyses.

Confusion Matrix

The confusion matrix for the spawning-stock data is given in Table 4. Of the 136 striped bass from the Hudson River, 28 (21%) were misclassified to the Chesapeake. Of the 153 striped bass from the Chesapeake, 30 (20%) were misclassified to the Hudson. These misclassification percentages are higher than might be desired, but they are somewhat lower than those obtained by Berggren and Lieberman (1978).

Table 3. Variables included in the discriminant function as determined using stepwise discriminant analysis

Variable number	Description	F[a]
1	Snout length	55.0
2	Fork length	49.3
3	Number of rays on left pectoral fin	12.3
4	Distance from focus to first annulus of scale	10.2
5	Distance from first annulus to second annulus of scale	10.5
6	Product of number of soft rays on second dorsal fin and number of scales along lateral line	5.88
7	Product of number of rays on left pectoral fin and number of scales along lateral line	4.98
8	Internostril width	4.86
9	Product of number of rays on right pectoral fin and number of upper arm gill rakers including rudimentary rakers	3.61
10	Product of internostril width and number of upper arm gill rakers including rudimentary rakers	3.53
11	Product of number of soft rays on anal fin and head length	3.78
12	Square of number of soft rays on anal fin	5.12
13	Square of number of soft rays on second dorsal fin	3.12
14	Product of number of soft rays on anal fin and internostril width	3.87

[a] F = value of the F statistic to remove a character from the discriminant function. The larger the F value, the more important that character is as a discriminator between the two stocks.

Table 4. Confusion matrix for the spawning-stock data

Actual	Classified[a] Hudson	Chesapeake	Total
Hudson	108 $\phi_{11} = 0.79$	28 $\phi_{12} = 0.21$	136
Chesapeake	30 $\phi_{21} = 0.20$	123 $\phi_{22} = 0.80$	153

[a] ϕij = number in row i and column j divided by the total for row i.

Their values were 23% (39 of 168 fish) of the Hudson fish misclassified to the Chesapeake or Roanoke, and 32% (74 of 232 fish) of the Chesapeake fish misclassified to the Hudson or Roanoke.

Some of this misclassification is undoubtedly due to real differences in characteristics between stocks being confounded with differences in characteristics due to sex and age. For example, when we repeated the analysis using only five-year-old males from the Hudson and Chesapeake spawning stocks, only one of 17 Hudson fish was misclassified to the Chesapeake (6%) and only two of 64 Chesapeake fish were misclassified to the Hudson (3%). The reason for selecting 5-year-old males for this example is that sample size was largest for this sex-age combination (Table 1).

Estimates of Relative Contribution

Spawning-Stock Data

The error in the discriminant function method and the maximum likelihood method in estimating the relative contribution of the Hudson stock was evaluated by examining the absolute value of the difference between the estimated and true fractional contribution in the spawning-stock data by sex-age combination, by age, by sex, and overall (Table 5). Neither method results in a consistently smaller error than the other. Error varies with sample size as expected; the larger the sample, the smaller the error tends to be. Except for 10- and 11-year-old males (sample sizes of 15 and 10 fish, respectively), the error is less than 10%, and for one-half of the twelve sex-age combinations it is less than 5%. If this study is repeated, we recommend that

Table 5. Absolute error in the estimated relative contribution of the Hudson in the 1975 spawning-stock data set. Estimates are given by sex and year-class combination, by year class, by sex, and overall, using two methods of analysis.

				Discriminant function method			Maximum likelihood method		
				p_1			p_1		
Sex	Year class	Age (year)	Sample size[a]	Estimate	True	Bias[b]	Estimate	True	Bias[b]
				By sex and year-class combination					
Male	1971	4	31	0.433	0.355	0.078	0.375	0.355	0.020
	1970	5	81	0.217	0.210	0.007	0.202	0.210	0.008
	1969	6	18	0.789	0.722	0.067	0.808	0.722	0.086
	1968	7	4	0.513	0.500	0.013	0.326	0.500	0.174
	1967	8	8	0.720	0.625	0.095	0.593	0.625	0.032
	1965	10	15	0.679	0.867	0.188	0.872	0.867	0.005
	1964	11	10	0.844	0.700	0.144	0.858	0.700	0.158
Female	1969	6	19	0.470	0.474	0.004	0.410	0.474	0.064
	1968	7	13	0.450	0.538	0.089	0.500	0.538	0.038
	1966	9	42	0.395	0.429	0.034	0.460	0.429	0.031
	1965	10	22	0.814	0.773	0.041	0.767	0.773	0.006
	1964	11	26	0.641	0.654	0.013	0.661	0.654	0.007
				By year class					
	1971	4	31	0.427	0.355	0.072	0.374	0.355	0.019
	1970	5	81	0.209	0.210	0.001	0.202	0.210	0.008
	1969	6	37	0.621	0.595	0.027	0.593	0.595	0.002
	1968	7	17	0.459	0.529	0.070	0.466	0.529	0.063
	1967	8	8	0.717	0.625	0.092	0.593	0.625	0.032
	1966	9	42	0.389	0.429	0.040	0.460	0.429	0.031
	1965	10	37	0.757	0.811	0.054	0.801	0.811	0.010
	1964	11	36	0.694	0.667	0.027	0.735	0.667	0.068
				By sex					
Male		167	0.423	0.407	0.016		0.426	0.407	0.019
Female		122	0.536	0.557	0.022		0.537	0.557	0.020
				Overall					
		289	0.478	0.471	0.007		0.474	0.471	0.003

---

[a] Calculated from Table 1.

[b] Error = |Estimate - True.|

length categories and minimum sample sizes for each sex be selected to minimize the chance of errors greater than 10% for the spawning stock data.

Ocean Data

Estimates of relative contribution of the Hudson stock to the Atlantic coastal population of striped bass north of Chesapeake Bay range from 0 to 79%, depending on year class, sex, and method of estimation (Table 6, Fig. 2). The results indicate that (1) there are marked differences among year classes, (2) the relative contribution of males may be higher than that of females, and (3) the two methods of estimating relative contribution give similar results.

Because 85% of the striped bass in the ocean sample were female (Table 2), it is appropriate to pay particular attention to the $\hat{p}_1$ values in Table 6 for females. The two estimates for 10-year-old females are between 40 and 50%, suggesting that the 1965 year class from the Hudson was relatively strong. The two estimates for 10-year-old males support this conclusion, although the estimates are based on a sample size of only three fish. The estimates for 6-, 7-, and 9-year-old females are all less than 10%, and these estimates are based on reasonably large sample sizes. The estimates for 7-year-old males are also low, consistent with the estimates for females. The estimates for 6-year-old males, however, based on a sample size of 25 fish, are approximately 30%. This result suggests that the relative contribution of males from the Hudson may be higher than that of females, a finding which is supported by a $\hat{p}_1$ value for males (averaged over year classes) of approximately 20% versus 10% or less for females (Table 6). The two estimates for 5-year-old males are relatively low as expected, due to the dominant 1970 year class in the Chesapeake. The contribution for 5-year-old females was undoubtedly lower than 10%, since this sex-age combination dominated in the Texas Instruments ocean data, which in their analysis yielded a relative contribution for the Hudson of 6.6% (Berggren and Lieberman 1978, Table 5, adjusted estimate). The finding that the two methods give similar results is reassuring, but not unexpected, in light of the estimates in Table 5 for the spawning stock data indicating that the two methods give comparable results.

That the relative contribution from the Hudson varies is to be expected, since the historical record does not indicate a marked tendency for dominant or weak year classes to occur in the Hudson and Chesapeake simultaneously (Florence 1980, Klauda et al. 1980). What our analysis contributes is an indication of the range of variation, which appears to be from less than 5% to as high as 40 to 50%. The upper bound is less certain than the lower bound because sample sizes were small for most year classes for which the relative contribution from the Hudson appears to be high.

Table 6. Estimates from the 1975 ocean data of the relative contribution of the Hudson stock to the coastal striped bass population north of Chesapeake Bay. Estimates are given by sex and year-class combination, by year class, by sex, and overall, using two methods of analysis.

				$\hat{p}_1$	
Sex	Year class	Age (year)	Sample size[a]	DFM[b]	MLM[c]
By sex and year-class combination					
Male	1971	4	87	0.441	0.369
	1970	5	196	0.082	0.142
	1969	6	25	0.274	0.327
	1968	7	6	0.000[d]	0.028
	1967	8	7	0.389	0.408
	1965	10	3	0.787	0.667
	1964	11	5	0.000[d]	0.000
Female	1969	6	166	0.005	0.086
	1968	7	48	0.000[d]	0.045
	1966	9	151	0.000[d]	0.041
	1965	10	38	0.464	0.488
	1964	11	66	0.179	0.173
By year class					
	1971	4	87	0.441	0.369
	1970	5	196	0.082	0.142
	1969	6	191	0.040	0.118
	1968	7	54	0.049	0.044
	1967	8	7	0.389	0.408
	1966	9	151	0.073	0.041
	1965	10	41	0.488	0.501
	1964	11	71	0.143	0.148
By sex					
Male			329	0.196	0.217
Female			469	0.036	0.109
Overall					
			798	0.102	0.152

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[a] From Table 2.

[b] DFM = discriminant function method.

[c] MLM = maximum likelihood method.

[d] Negative values of $\hat{p}_1$ were set equal to zero; see text for description of discriminant function method.

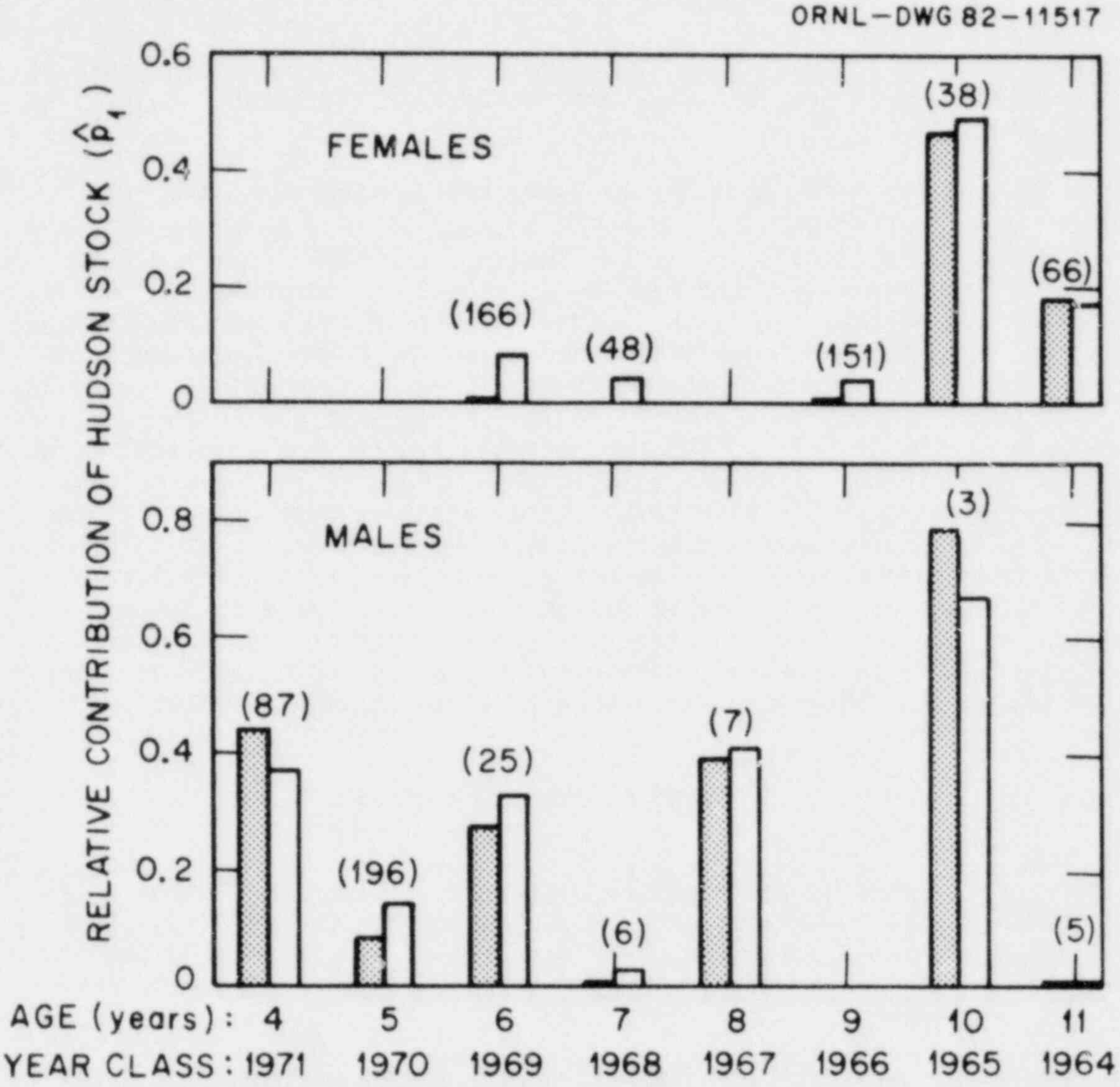

Fig. 2. Estimates from the 1975 ocean data of the relative contribution of the Hudson stock to the coastal striped bass population north of Chesapeake Bay. Estimates are from Table 6 for seven year classes of males and five year classes of females (sample sizes in parentheses) for the discriminant function method (solid line) and the maximum likelihood method (dashed line).

The finding that the relative contribution of males tends to be greater than that of females may reflect (a) that males are less migratory than females and (b) that the geographic bounds used in defining the ocean data set incorporate this sexual difference in one way for Chesapeake Bay and in a different way for the Hudson. Chesapeake males appear to migrate throughout Chesapeake Bay, but proportionately few leave Chesapeake Bay, which is not included in the geographic bounds for the ocean population. On the other hand, Hudson males migrating anywhere in Long Island Sound, along the south shore of Long Island, or in New York Bay were included in the ocean data set (Fig. 1).

Now that the 1970 dominant year class from the Chesapeake is no longer prominent in the ocean population, and because there have been no dominant year classes in the Chesapeake since 1970 (Florence 1980, State of Maryland 1981), the time seems propitious to repeat the study. Such a study might logically be funded as part of the Emergency Striped Bass Research Study (commonly referred to as the Chafee Amendment), as authorized by the amended Anadromous Fish Conservation Act, P.L. 96-118. If the study is repeated, one of the implications of our further analysis of the 1975 Texas Instruments data is that the sampling design should be modified to include more length categories and/or more fish per length category for each sex, so that adequate numbers of striped bass are available to permit estimation of relative contribution for as many sex and year-class combinations as possible. Another implication is that only those character variables found to be the most discriminating in both Berggren and Lieberman's (1978) and our discriminant analysis should be measured. This simplification would save some money with little sacrifice in ability to estimate relative contribution.

CONCLUSIONS AND RECOMMENDATIONS

1. Error, defined as the absolute difference between the estimated and true relative contribution from the Hudson for the spawning-stock data, was similar for the discriminant function method and the maximum likelihood method. Error increased as sample size decreased, as expected.

2. Estimates of relative contribution of the Hudson spawning stock to the Atlantic coastal population of striped bass north of Chesapeake Bay differed appreciably among year classes. In particular, the estimated relative contribution for the 1965 year class was between 40 and 50%, while the relative contributions for the 1966, 1968, and 1969 year classes were approximately 10% or less.

3. The relative contribution of males was greater than that of females. This difference is thought to be due to the geographic boundaries used to define the ocean data set and to the greater tendency for Chesapeake females, as compared to males, to migrate outside of Chesapeake Bay.

4. The discriminant function method and the maximum likelihood method gave similar estimates of relative contribution.

5. We recommend that the study be repeated as soon as possible now that the dominant 1970 year class from the Chesapeake is no longer prominent and given that all year classes from the Chesapeake since 1974 have been weaker than average.

6. We recommend for the next study that the sampling design for the spawning stocks be modified to include more length categories and/or more fish per length category for each sex.

7. We recommend for the next study that measurements be made on only the morphological characters that are the best discriminators.

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