RELATIVE CONTRIBUTION OF HUDSON, CHESAPEAKE, AND ROANOKE STRIPED BASS, *MORONE SAXATILIS*, STOCKS TO THE ATLANTIC COAST FISHERY

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ABSTRACT

Morphological characters were used in discriminant analysis to quantitatively estimate the relative contribution of striped bass, *Morone saxatilis,* stocks from various estuaries to the striped bass fishery along the Atlantic coast. Representative samples of the spawning stocks of the Hudson River, Chesapeake Bay system, and Roanoke River were collected and counts and measurements were taken on each specimen. Discriminant functions based on five morphological characters correctly classified approximately 75% of the specimens. The effectiveness of three types of estimates based on these functions in accurately estimating stock proportions was investigated in a simulation study. Results of the simulation study indicated which type of estimate was least biased. A sampling design using geographical and temporal strata was then employed to sample the Atlantic coastal fishery from Cape Hatteras, N.C., to Maine. Observations for the morphological characters were taken on collected fish and the resulting data entered into discriminant functions obtained from spawning-stock collections. The specimens were classified by area of origin and the three types of estimates of relative contribution of the Hudson, Chesapeake, and Roanoke stocks were obtained. Results indicated that the Chesapeake stock was the major contributor to the Atlantic coastal striped bass fishery and the Hudson and Roanoke stocks were minor contributors.

The striped bass, *Morone saxatilis,* is an important sport and commercial fish in the estuaries and coastal waters of the Atlantic seaboard from Maine to North Carolina (Koo 1970). Recruitment to the striped bass fishery is from various stocks of striped bass spawned and developed in rivers and estuaries along the Atlantic coast. Recapture locations of tagged striped bass indicate that individuals from all spawning areas north of Cape Hatteras, N.C., utilize much of the Atlantic coast north of their respective spawning areas during a northward migration in the spring and a southward migration in the fall (Merriman 1941; Raney et al. 1954; Alperin 1966; Schaefer 1968; Florence[3]; Texas Instruments[4]). The major spawning areas which potentially contribute individuals to the fisheries operating during the northward and southward migrations are the tributaries of Chesapeake Bay and the Roanoke and Hudson Rivers.

Although tagging data have not led to quantitative estimates of relative contribution, they have led to conflicting ideas as to which major stock of striped bass predominates in the fishery: the Hudson stock or the Chesapeake stock. Most published works have generally concluded that the striped bass stock from the Chesapeake Bay system is the major contributor to the fisheries north of Chesapeake Bay (Merriman 1941; Vladykov and Wallace 1952; Alperin 1966; Schaefer 1968; Porter and Saila[5]; Raney[6]). However, Clark[7] and Goodyear[8] concluded that the striped bass stock

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[3]Florence, B. 1974. Tag returns from 1375 large striped bass tagged in two Maryland spawning rivers. Outdoor Message. Organized Sportsmen of Mass. Oct. 1974.

[4]Texas Instruments Inc. 1976. Report on relative contribution of Hudson River striped bass to the Atlantic coastal fishery. Prepared for Consolidated Edison Company of New York, Inc., 101 p.

[5]Porter, J., and S. B. Saila. 1969. Final report for the cooperative striped bass migration study. U.S. Fish. Wildl. Serv. Contract no. 14-16-005, 33 p.

[6]Raney, E. C. 1972. The striped bass, *Morone saxatilis,* of the Atlantic coast of the United States with particular reference to the population found in the Hudson River. Testimony before USAEC Safety and Licensing Board for Indian Point, Unit no. 2. Docket no. 50-247, Oct. 30, 105 p.

[7]Clark, J. 1972. Effects of Indian Point Units 1 and 2 on the Hudson River aquatic life. Testimony before USAEC Safety and Licensing Board for Indian Point, Unit no. 2. Docket no. 50-247, Oct. 30, 63 p.

[8]Goodyear, C. P. 1974. Origin of the striped bass of the middle Atlantic coast. Testimony presented to the Committee on Merchant Marine and Fisheries of the U.S. House of Representatives. Feb. 19, 40 p.

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from the Hudson River is the major contributor to the coastal fishery from New Jersey to Massachusetts because the number of striped bass tagged in Chesapeake Bay and recaptured outside the Bay was too low to indicate a large contribution of Chesapeake stock to that fishery.

Because of the controversy of which stock predominates, we conducted a study to obtain quantitative estimates of relative percentage of the major stocks in the coastal fishery. A previous study (Grove et al. 1976) demonstrated the feasibility of using discriminant analysis on morphological characters (counts and morphometric ratios) to distinguish among Hudson, Chesapeake, and Roanoke spawning stocks of striped bass. That study showed that adequate segregation of spawning stocks within the Chesapeake Bay system was not possible. Quantitative estimates of stock composition based on morphological characters and discriminant analysis have been obtained for sockeye salmon (Fukuhara et al. 1962; Anas and Murai 1969), pink salmon (Amos et al. 1963), and Atlantic herring (Messieh 1975). The present study establishes discriminant functions based on collections of spawning-stock specimens to classify striped bass collected in the Atlantic coastal fishery from southern Maine to Cape Hatteras. The percentage of specimens collected that were classified into each stock was used to estimate the relative contribution of that stock to the fishery.

METHODS AND MATERIALS

Collection of Spawning-Stock Specimens

During the spawning season of 1975, mature striped bass were collected from the natal rivers of major stocks along the Atlantic coast. These fish were assumed to have originated from the rivers (i.e., that striped bass, like salmon and other anadromous fishes, home to their natal stream to spawn). This assumption was supported by tagging studies in which striped bass tagged on spawning grounds were recaptured on the same spawning grounds in successive years (Mansueti 1961; Nichols and Miller 1967). Collections were composed of 232 mature striped bass from the Chesapeake Bay tributaries (70 from the Rappahannock River, 53 from the Potomac River, 52 from the Choptank River, and 57 from the Elk River and Chesapeake and Delaware Canal), 168 from the Hudson River, and 99 from the Roanoke River. Only 19 sexually ripe striped bass were collected from the Delaware River above the entrance to the Chesapeake and Delaware Canal, which confirms findings by Chittenden (1971) that spawning in the Delaware River is not substantial. Therefore specimens from the Delaware River were omitted from subsequent analyses. Collections were made primarily during April in the Chesapeake Bay tributaries, Delaware and Roanoke Rivers, and during May in the Hudson River. Most specimens were obtained fresh from commercial fishermen using pound nets, haul seines, and gill nets. Some were netted by study personnel.

To assure an adequate representation of the sexes and multiple year classes in spawning-stock collections, sampling was designed to obtain nearly equal numbers of male and female striped bass and a minimum of 10 individuals in each of the following length categories: ≤399, 400-549, 550-699, 700-849, and ≥850 mm. Discriminant functions based on male and female specimens from multiple year classes are needed to analyze an oceanic population which consists of a different sex ratio and broader age structure than that of the spawning stocks.

Processing of Spawning-Stock Specimens

Scale samples, counts, measurements, sex, and state of maturity were obtained from each specimen while in fresh condition. Scale samples from above the lateral line between the first and second dorsal fins were pressed on acetate cards. Ages were determined by the scale annulus method (Mansueti 1961). Measurements from the focus to the first and second annuli were made on magnified scale images. The following counts and measurements were taken: number of lateral line scales, left pectoral rays, right pectoral rays, second dorsal rays, anal rays, upper-arm gill rakers, fork length, snout length, head length, and internostril width. Methods used were those discussed by Hubbs and Lagler (1958) and Grove et al. (1976).

Counts, measurements, and age determinations were replicated by a second observer and a set of tolerances was established to reduce observation error. When differences between replicated observations exceeded tolerances, the observations were retaken. Means of the replicated counts and means of ratios of the replicated measurements were used in subsequent analysis.

Analysis of Spawning-Stock Specimens

Choice of morphological characters for segregation of Hudson, Chesapeake, and Roanoke spawning stocks followed three stages of statistical analysis: correlation analysis between each character and fork length (FL), analysis of the effects of sex and age on each character, and discriminant analysis. Analysis involved only specimens with observations on all counts and morphometric and scale-annulus measurements.

Since spawning stocks do not include immature specimens which occur in the coastal waters, we chose only those characters that were independent (i.e., not highly correlated) of fish size and could therefore be used to segregate specimens from the entire stock. Characters were considered to be independent of length when variations (r^2) attributable to length in any stock were ≤ 0.10. Characters not independent of length were used in further analysis when the distribution of character values had small overlap among spawning stocks since such characters help identify stock origin.

Multivariate statistical tests were made to determine the effect of sex and age on the characters used to determine the discriminant functions, since one assumption of discriminant analysis was that each stock was homogeneous. Differences in character values among ages for males or females and between sexes within each stock were tested with a procedure that combined tests of equality of means and equality of covariance matrices (Anderson 1958). Assuming equal covariance matrices, rejection of the null hypotheses of equal distributions indicated that one or more of the character means differed among ages or between sexes.

Multivariate discriminant analysis was used to gain maximum separation among stocks. Linear and quadratic discriminant functions (Anderson 1958; Kendall and Stuart 1968) for each spawning stock were determined from character values obtained from collections of that stock. A stepwise procedure on the linear function was used to indicate the subset of characters which best separated the stocks. The quadratic function based on this subset was formed if the assumption of a common covariance matrix among spawning stocks needed for the linear function was not met. The assumption in discriminant analysis that characters had a multivariate normal distribution was investigated with histograms.

Ability of the discriminant functions to separate stocks and accurately estimate stock proportions was assessed using functions based on total spawning-stock collections and functions obtained from a cross-validation procedure (Mosteller and Tukey 1968). In this procedure collections were randomly divided in half and discriminant functions were determined from one-half and applied to each half. Percentages of correct classification and estimates of stock proportion were obtained for each subset and compared with those from the total sample. Comparisons were also made between estimated and known spawning-stock percentages.

Although these estimates of stock percentages may accurately approximate true percentages in spawning-stock collections, they may deviate substantially from stock percentages in oceanic collections. Fukuhara et al. (1962) stated that the bias in these estimates increased as stock percentages became more disproportionate. Since stock percentages in oceanic collections may be more disproportionate than stock percentages in spawning-stock collections (i.e., 34% Hudson, 46% Chesapeake, and 20% Roanoke stocks), less biased estimates of stock percentages may be needed.

Adjusting Estimates of Stock Percentages

Two procedures were developed to obtain estimates of stock percentages that were less biased than the as-classified (i.e., classifications obtained directly from discriminant functions) estimates. The first procedure adjusted estimates using a technique described by Worlund and Fredin (1962) which generalized to the three population case methodology developed in Fukuhara et al. (1962). This procedure used percentages of specimens from each spawning stock that were misclassified into other stocks to correct as-classified estimates for bias due to misclassifications. When adjusted estimates were negative, as-classified estimates were modified by methodology developed by Schuermann and Curry.[9]

The second procedure iteratively reclassified specimens based on updated prior probabilities that specimens originated from each of the spawning stocks. The first stage of the procedure is the same as the as-classfied procedure; therefore as-

[9]Schuermann, A. C., and G. L. Curry. 1973. Notes on parametric programming. Unpubl. manuscr. Dep. Ind. Eng. Texas A&M Univ., College Station.

classified estimates of stock contribution are obtained at the end of this stage. However, these estimates are then used in the second stage as prior probabilities that specimens come from the three stocks. For example, the as-classified estimate of Hudson stock contribution obtained at the end of the first stage was used at the beginning of the second stage as our best guess of the proportion of specimens in the sample that originate from the Hudson. These prior probabilities are then used to weight the decision to classify each specimen into one of the stocks. Similarly, the proportion of specimens classified into each stock in the second stage were used as priors in the third stage. The procedure was carried out for nine stages.

The effectiveness of adjusted and iterative estimates in reducing bias in the as-classified estimate due to misclassification was investigated in a simulation study. Discriminant functions from the cross-validation study were used to classify a subset of specimens from the independent half of the spawning-stock collections, and each of the three types of estimates of relative percentage were obtained and compared with the known stock percentage. For percentages of Hudson stock ranging from 0 to 90%, the difference between each estimate of Hudson percentage and the known percentage of Hudson specimens in the subsample was obtained as a measure of bias in the estimate.

Collection, Processing, and Analysis of Atlantic and Hudson River Specimens

Assessment of the relative contribution of various stocks of striped bass to the Atlantic coastal fishery required a stratified sampling design that provided samples from the entire coastal fishery and considered the migratory nature of striped bass; therefore a geographically and temporally stratified sampling design was used. The geographical stratification consisted of 10 strata from southern Maine to Cape Hatteras, with 2 to 4 substrata within each stratum to compensate for variations in stock composition within the stratum (Figure 1). The Rhode Island stratum was not subdivided because of its small size. Temporally, the year was divided into six 2-mo periods to obtain estimates of stock composition by stratum throughout the year.

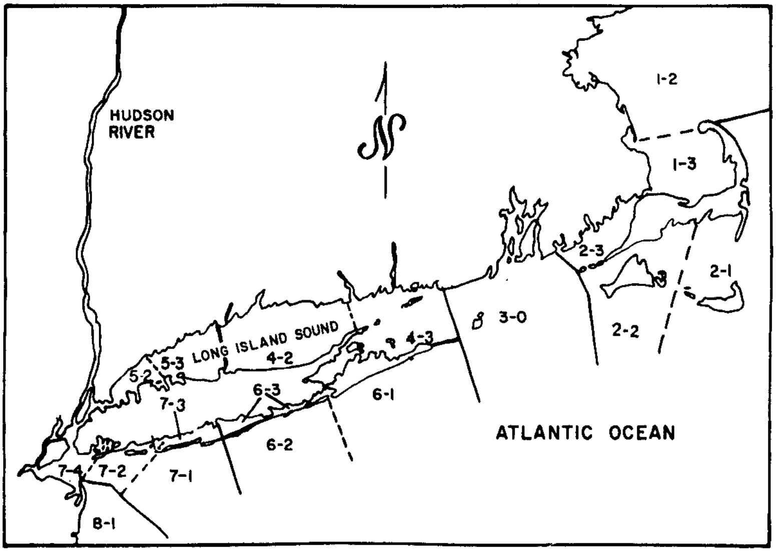
Collections of striped bass from the coastal fishery were obtained primarily from sport and commercial fishermen; however, in areas where adequate sport and commercial fisheries did not exist, study personnel used haul seines and gill nets to collect specimens. Collections were limited to striped bass caught during the same day (i.e., within 24 h) to assure freshness. In many instances the entire catch was used, but due to the size of some catches, a random sample proportional to the number of small (<550 mm), medium (550-850), and large (>850) striped bass caught was obtained.

Oceanic and overwintering specimens were processed in the same manner as spawning-stock specimens. Two replicates of 10 counts and measurements were taken from each specimen, and scale samples were obtained for subsequent age and growth rate determinations in the laboratory. A total of 2,737 oceanic specimens with a complete set of meristic, morphometric, and scale characters were processed (Table 1). Additionally, 79 striped bass overwintering in Croton Bay on the

TABLE 1.—Number of striped bass with complete character sets[1] collected by spatial stratum and period from Atlantic coastal fishery in 1975.

Spatial stratum	Locality	Legal/ sublegal[2]	Jan.-Feb.	Mar.-Apr.	May-June	July-Aug.	Sept.-Oct.	Nov.-Dec.	Total
1	S. Maine-N. Mass.	Legal			82	58	74		214
2	S. Mass.	Legal			91	90	82		263
3	Rhode Is.	Legal			60	43	56		159
4	E. Long Is. Sound	Legal			96		140	99	335
		Sublegal			5			1	6
5	W. Long Is. Sound	Legal	1	38	14	15	89		157
		Sublegal		2	42	85	10		139
6	E. Long Is. S. Shore	Legal		1	89	102	86	106	384
		Sublegal			8	17	19		44
7	W. Long Is. S. Shore	Legal		30	58	93	120	124	425
		Sublegal		4	11				15
8	N.J.	Legal		34	113	28	73	117	365
9	Del.-Md.-N. Va.	Legal		71	3		6	100	180
10	S. Va.-N.C.	Legal	27					24	51
Total			28	180	672	531	755	571	2,737

[1]Measurements and counts taken on all variables used in the character set.
[2]Sublegal-sized striped bass (<406.5 mm FL) from New York waters (strata 4 to 7) were analyzed separately.



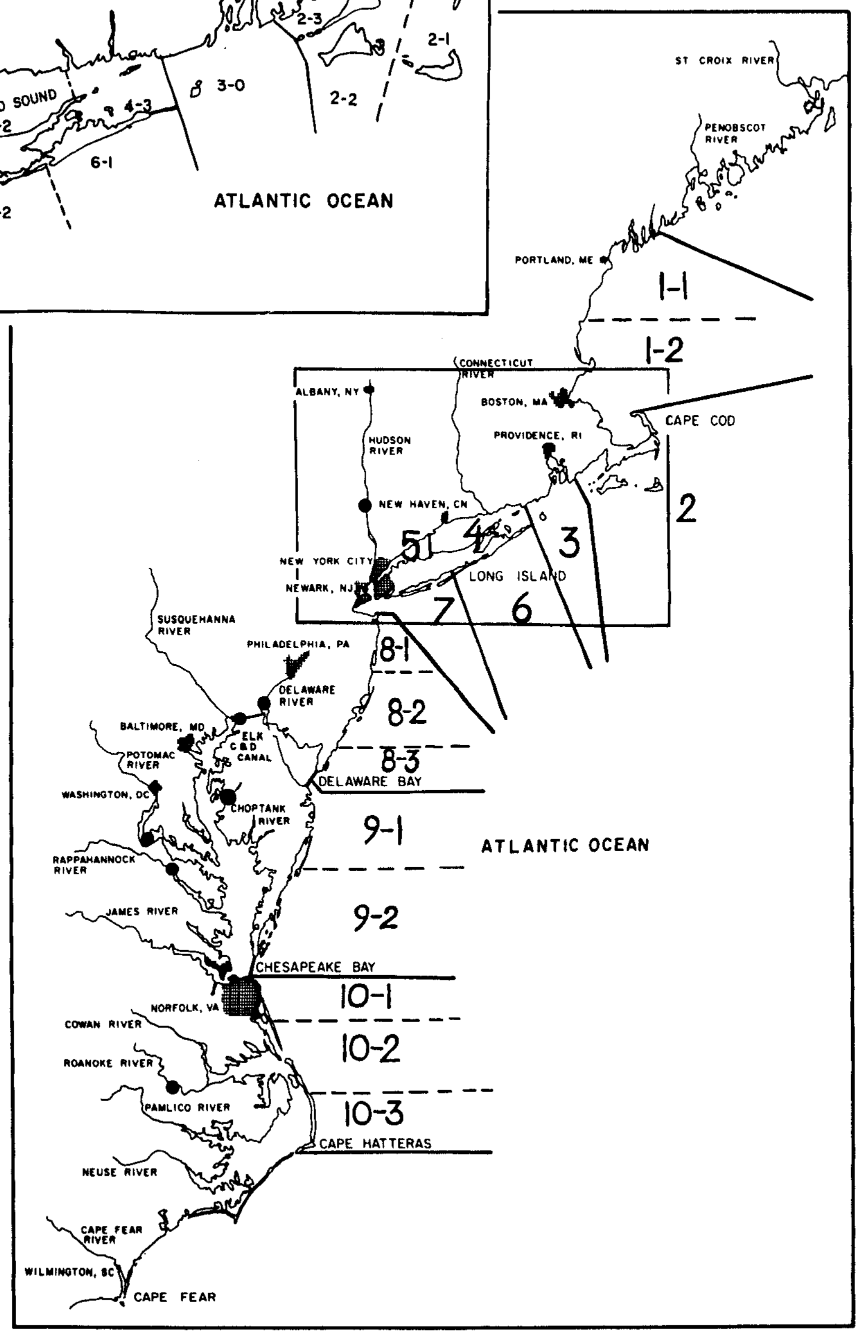


FIGURE 1.—Collection regions for the Atlantic coastal fishery for striped bass showing geographical stratification and substratification; collection sites for spawning-stock specimens indicated by dots on source rivers.

Hudson River from 6 December 1974 through 20 March 1975 were processed.

Three estimates of stock contribution, i.e., "as-classified," "adjusted," and "iterative" estimates, were calculated for collections of legal-sized, sublegal-sized, and overwintering striped bass by geographical and temporal strata. Sublegal-sized <406.5 mm or 16 in FL) and overwintering striped bass collected in New York waters were not considered to be a part of the coastal fishery and were analyzed separately. In each stratum, the percentage of striped bass allocated to a stock provided an estimate of that stock's relative contribution. Mean 1975 estimates of stock contribution of legal-sized striped bass were calculated by averaging strata estimates within periods then averaging across the six periods. Relative contribution estimates by age were also obtained.

The influence of the Hudson stock in coastal strata adjacent to the Hudson River was investigated by comparing the relative contribution of Hudson, Chesapeake, and Roanoke stocks within "inner" and "outer" zones designed by the U.S. Nuclear Regulatory Commission.[10] The inner zone encompassed western Long Island Sound (stratum 5), the New York Bight (stratum 7), and northern New Jersey (stratum 8-1), whereas the outer zone encompassed the remaining waters from Cape May, N.J., to Maine (strata 1 to 4, 6, 8-2, 8-3). Estimates of relative contribution for inner and outer zones were calculated for each period by summing the number of Hudson-, Chesapeake-, and Roanoke-classified fish within appropriate strata. Mean estimates of contribution within each zone were calculated for the year by averaging across temporal strata.

RESULTS AND DISCUSSION

Establishment of Discriminant Functions

Five characters were established as the character set best able to discriminate among Hudson, Chesapeake, and Roanoke stocks. They are, in order of importance (as established by stepwise linear discriminant analysis): 1) the ratio of snout length/internostril width, 2) the scale ratio of first to second annulus/focus to first annulus measure, 3) a character index (Raney and deSylva 1953), 4) the upper-arm gill raker count (which includes rudimentary rakers), and 5) the lateral line scale count. The character index, i.e., the sum of left and right pectoral, second dorsal, and anal fin rays, was used since Grove et al. (1976) demonstrated that individual fin ray characters did not add significant discriminatory ability.

The five characters satisfied the criterion for independence with fish length in each stock with only one exception. The snout length/internostril width ratio for the Roanoke stock has a coefficient of determination of nearly 0.20 but was retained because its distribution had the least overlap among spawning stocks of all characters, thus making it a potentially good discriminator.

Results of the test of homogeneity indicated that only the Hudson stock was homogeneous among ages and between males and females. Significant differences ($\alpha = 0.05$) were found among ages and between sexes in the Chesapeake spawning stock and among ages in the Roanoke spawning stock. Differences found in the Chesapeake spawning stock may have resulted from pooling collections from its four major tributaries.

Quadratic functions (Table 2) were used to discriminate among stocks as a result of the investigation of underlying assumptions of discriminant analysis. Significant differences ($\alpha = 0.05$) were found among covariance matrices of Hudson, Chesapeake, and Roanoke spawning stocks which suggested that quadratic functions would better discriminate among these stocks than linear functions. Histograms suggested that no radical departure of multivariate normality was evident, although normality of individual characters does not assure multivariate normality of the character set. Therefore multivariate normality of the character sets was assumed.

Percentage of spawning-stock specimens correctly classified by the quadratic functions and estimated stock percentages resulting from the use of these functions closely agreed with results obtained by the cross-validation procedure (Table 3). For the total set of collections, 76.8% of Hudson specimens, 67.7% of Chesapeake specimens, and 85.9% of Roanoke specimens were correctly classified, resulting in an overall correct classification of 74.4%. This was similar to overall percentages of 73.2 and 77.1 obtained for the cross-validation subsets. Estimated relative percentages for each stock varied <3 percentage points among the total set and cross-validated subsets, whereas varia-

[10]U.S. Nuclear Regulatory Commission. 1975. Final environmental statement related to operation of Indian Point Nuclear Generating Plant Unit no. 3 Consolidated Edison Company of New York, Inc. Office of Nuclear Reactor Regulation. Docket no. 50-286, Vol. 1:V-166-V-178.

TABLE 2.—Quadratic discriminant functions[1] based on Hudson, Chesapeake, and Roanoke spawning-stock specimens of striped bass and used to classify spawning-stock, oceanic, and overwintering specimens.[2]

Hudson:

$$F_{HUD} = -1{,}489.070559 - (0.077516\,U^2 + 0.256954\,W^2 + 1.171065\,X^2 + 2.536320\,Y^2 + 123.907000\,Z^2 - 0.019058\,UW + 0.015160\,UX - 0.007057\,UY + 0.090968\,UZ + 0.047441\,WX + 0.023246\,WY + 0.164200\,WZ + 0.457365\,XY - 2.799760\,XZ - 2.861250\,YZ) + 8.776221\,U + 28.127772\,W + 24.321052\,X + 7.985031\,Y + 381.695141\,Z.$$

Chesapeake:

$$F_{CHES} = -1{,}368.946420 - (0.089560\,U^2 + 0.242459\,W^2 + 1.122690\,X^2 + 2.155850\,Y^2 + 117.554000\,Z^2 - 0.007099\,UW + 0.005302\,UX + 0.015500\,UY + 0.321075\,UZ - 0.092151\,WX - 0.000861\,WY - 2.363980\,WZ + 0.381082\,XY + 3.623860\,XZ - 1.590090\,YZ) + 11.316822\,U + 21.749040\,W + 25.294896\,X + 7.014936\,Y + 323.469441\,Z.$$

Roanoke:

$$F_{ROAN} = -1{,}650.902863 - (0.107062\,U^2 + 0.316254\,W^2 + 2.063540\,X^2 + 0.842590\,Y^2 + 139.577500\,Z^2 - 0.062826\,UW + 0.015703\,UX + 0.043640\,UY + 0.228873\,UZ - 0.293615\,WX + 0.129292\,WY - 1.009790\,WZ + 0.106776\,XY - 0.606466\,XZ + 4.416000\,YZ) + 10.320202\,U + 27.000888\,W + 25.512087\,X + 22.351388\,Y + 469.422957\,Z.$$

[1]Except for an additive constant ($-2.5 \ln 2\pi$) common to each function.

[2]F = discriminant score, U = lateral line scale count, W = character index, X = upper-arm gill raker count, Y = first to second annulus/focus to first annulus measurement ratio, and Z = snout length/internostril width ratio.

TABLE 3.—Comparison of correct-classification percentages and estimated and known stock percentages among the total set of spawning-stock specimens of striped bass and cross-validation subsets.

	Random set[1]			Independent set[2]			Total set[3]		
Spawning stock	Correctly classified (%)	Known stock (%)	Estimated stock (%)	Correctly classified (%)	Known stock (%)	Estimated stock (%)	Correctly classified (%)	Known stock (%)	Estimated stock (%)
Hudson	81.0	33.7	36.5	72.6	33.6	35.2	76.8	33.7	36.9
Chesapeake	69.8	46.6	40.2	68.1	46.4	42.4	67.7	46.5	40.3
Roanoke	87.8	19.7	23.3	86.0	20.0	22.4	85.9	19.8	22.9
Overall	77.1			73.2			74.4		

[1]Randomly sampled half of total spawning-stock collections used to determine quadratic functions for cross-validation.
[2]Remaining half of spawning-stock specimens classified by quadratic functions based on the random set.
[3]All specimens from spawning-stock collections classified by quadratic functions based on the total set.

tions between estimated and known stock percentages within sets was as much as 9 percentage points. The quadratic functions thus provided slightly biased estimates of stock percentages when applied to collections composed of 34% Hudson, 46% Chesapeake, and 20% Roanoke stocks.

Best Estimator of Relative Contribution

The best estimate of the percentage of Hudson River specimens in subsamples from the simulation studies was the estimate from the third iteration of the reclassification procedure (Table 4). On the average, this iterative estimate was less biased than estimates from other iterations, the as-classified estimated (i.e., estimate from the first iteration), and the adjusted estimate for most percentages of Hudson stock considered. In addition, the variance of the bias of the iterative estimate was often less than that of the other estimates. For percentages of Hudson stock ≤ 50%, the iterative and adjusted estimates closely agreed and the bias in each estimate was small (≤5 percentage points). The iterative estimate will, therefore, be used to estimate Hudson stock contribution in oceanic collections, and the adjusted estimate will be used to substantiate estimates of Hudson contribution ≤ 50%. The iterative estimate will also be used to estimate Chesapeake and Roanoke stock contributions.

TABLE 4.—Mean and standard deviation of absolute bias[1] of estimated relative percentages of Hudson River stock of striped bass in replicated random samples from spawning-stock collections.[2]

	Estimates of absolute bias					
	As-classified		Iterative		Adjusted	
Known percent of Hudson River stock	Mean	SD	Mean	SD	Mean	SD
[3]90	23.0	2.40	4.3	2.97	14.4	5.73
80	20.2	5.14	7.4	8.82	14.3	7.78
75	17.6	3.47	8.4	3.82	12.8	5.00
70	13.0	3.32	4.7	4.52	7.3	4.80
65	10.8	3.11	3.3	2.98	7.5	4.07
60	9.0	3.21	5.3	2.84	6.8	5.00
55	7.5	2.95	4.8	3.52	7.4	4.02
50	5.5	1.99	4.2	2.66	4.7	3.44
45	2.2	2.17	3.5	1.85	4.7	2.14
40	1.2	1.04	3.2	3.44	4.3	4.21
35	2.2	1.45	[4]4.2	[4]2.09	4.4	2.87
30	5.9	3.18	3.3	2.43	3.4	1.79
25	7.8	3.07	4.0	2.25	4.2	3.27
20	9.5	2.26	2.8	1.72	1.8	0.99
15	12.1	4.19	3.5	3.24	3.3	2.62
10	15.1	3.80	4.5	3.36	5.0	3.61
5	17.4	4.03	4.5	3.72	4.3	3.85
0	18.1	2.53	2.5	1.73	1.5	1.69
Overall mean	11.0		4.4		6.2	

[1]Absolute value of the difference between the true relative percentage of Hudson River stock in the subsample and the estimated relative percentage based on nine replicates of varying Chesapeake and Roanoke proportions in the subsamples.

[2]Estimates were based on random samples from one-half of spawning-stock collections which were classified as to area of origin by quadratic functions obtained from the other half of the collections.

[3]Based on two replicates.

[4]Based on eight replicates.

Estimates of Stock Contribution for Oceanic and Overwintering Collections

Iterative estimates of relative contribution of Hudson, Chesapeake, and Roanoke stocks indicated that the Chesapeake stock was the major contributor to the striped bass fishery along the Atlantic coast while the Hudson and Roanoke stocks were minor contributors (Table 5). The Chesapeake stock predominated in 34 of 35 geographical and temporal strata while the Hudson stock predominated in the remaining stratum. Iterative estimates of Chesapeake contribution to the fishery exceeded 80% in all strata not adjacent to the Hudson River. Iterative estimates of the Hudson stock were largest in western Long Island Sound and the New York Bight with values exceeding 20% during some periods. Although iterative estimates of Roanoke stock contribution never exceeded 20%, they were highest in North Carolina waters (stratum 10) and in strata from Massachusetts to Maine (strata 1, 2).

The Hudson stock contribution in strata from Massachusetts north to Maine and from New Jersey south to North Carolina (strata 8 to 10) should be low as indicated by iterative estimates (Table 5) and results of tagging studies. Zero estimates in northern waters do not necessarily indicate an absence of Hudson River striped bass since the simulation study has shown that such estimates may be obtained in situations where true contribution is low. In fact, data on adult striped bass tagged in the Hudson River during spawning season and recaptured in waters as far north as Boston Harbor, Mass., have indicated a northern migration of a portion of the Hudson stock (Texas Instruments see footnote 4). However, these data support near-zero estimates of Hudson contribution in southern waters since tagged striped bass were not recaptured south of northern New Jersey. Data (Chapoton and Sykes 1961) on adult striped bass tagged along the outer coast of North Carolina and recaptured on the spawning grounds of Chesapeake Bay and Albemarle Sound

TABLE 5.—Estimates of relative contribution of Hudson, Chesapeake, and Roanoke stocks of legal-sized striped bass[1] to 1975 oceanic collections by period and spatial strata. As-cl. = As-classified, Iter. = Iterative, and Adj. = Adjusted estimates.

Period	Stratum	Sample size[2]	Hudson			Chesapeake			Roanoke		
			As-cl.	Iter.	Adj.	As-cl.	Iter.	Adj.	As-cl.	Iter.	Adj.
Jan.-Feb.	10	27	25.9	3.7	6.7	63.0	92.6	90.7	11.1	3.7	2.6
Mar.-Apr.	5	38	52.6	57.9	54.2	42.1	42.1	45.8	5.3	0.0	0.0
	7	30	23.3	3.3	0.0	73.3	96.7	100.0	3.3	0.0	0.0
	8	34	23.5	8.8	0.8	67.6	88.2	99.2	8.8	2.9	0.0
	9	71	8.5	0.0	0.0	77.5	97.2	98.9	14.1	2.8	1.1
May-June	1	82	11.0	0.0	0.0	68.3	90.2	88.5	20.7	9.8	11.5
	2	91	14.3	0.0	0.0	71.4	95.6	96.4	14.3	4.4	3.6
	3	60	30.0	3.3	13.9	60.0	96.7	84.5	10.0	0.0	1.6
	4	96	21.9	1.0	0.0	69.8	99.0	100.0	8.3	0.0	0.0
	5	14	35.7	28.6	23.0	57.1	71.4	77.0	7.1	0.0	0.0
	6	89	25.8	5.6	5.4	65.2	93.3	94.6	9.0	1.1	0.0
	7	58	41.4	25.9	33.7	51.7	70.7	66.3	6.9	3.4	0.0
	8	113	23.9	0.0	1.5	67.3	100.0	98.5	8.8	0.0	0.0
July-Aug.	1	58	19.0	0.0	0.0	67.2	94.8	95.4	13.8	5.2	4.6
	2	90	7.8	0.0	0.0	72.2	96.7	90.8	20.0	3.3	9.2
	3	43	30.2	2.3	10.3	65.1	97.7	89.7	4.7	0.0	0.0
	5	15	26.7	0.0	5.1	66.7	100.0	94.9	6.7	0.0	0.0
	6	102	22.5	7.8	1.6	63.7	88.2	92.7	13.7	3.9	5.7
	7	93	33.3	15.1	13.4	65.6	84.9	86.6	1.1	0.0	0.0
	8	28	21.4	0.0	0.0	71.4	100.0	100.0	7.1	0.0	0.0
Sept.-Oct.	1	74	13.5	0.0	0.0	77.0	98.6	100.0	9.5	1.4	0.0
	2	82	12.2	0.0	0.0	58.5	85.4	76.0	29.3	14.6	24.0
	3	56	25.0	3.6	7.5	58.9	94.6	83.3	16.1	1.8	9.2
	4	140	16.4	0.7	0.0	64.3	94.3	88.6	19.3	5.0	11.4
	5	89	41.6	40.4	37.2	46.1	57.3	56.5	12.4	2.2	6.4
	6	86	15.1	0.0	0.0	73.3	96.5	99.8	11.6	3.5	0.2
	7	120	23.3	1.7	2.9	63.3	95.0	91.8	13.3	3.3	5.2
	8	73	16.4	0.0	0.0	76.7	98.6	100.0	6.8	1.4	0.0
	9	6	16.7	0.0	0.0	66.7	100.0	92.2	16.7	0.0	7.8
Nov.-Dec.	4	99	21.2	0.0	0.0	66.7	98.0	96.9	12.1	2.0	3.1
	6	106	16.0	0.0	0.0	69.8	99.1	95.9	14.2	0.9	4.1
	7	124	21.0	4.8	0.0	76.6	95.2	100.0	2.4	0.0	0.0
	8	117	21.4	0.0	0.0	72.6	100.0	100.0	6.0	0.0	0.0
	9	100	8.0	0.0	0.0	80.0	99.0	100.0	12.0	1.0	0.0
	10	24	12.5	0.0	0.0	62.5	83.3	82.0	25.0	16.7	18.0
Overall mean			23.0	6.5	6.6	66.0	90.8	90.2	11.0	2.7	3.2

[1]Not included are striped bass <406.5 mm FL from New York waters.
[2]Sample sizes of five specimens or less in any stratum are not included.

tributaries also support near-zero estimates of Hudson River contribution in waters off North Carolina.

Comparison between iterative and adjusted estimates indicated close agreement for each stock within the 35 strata. The largest difference between estimates was 12.2 percentage points, but differences of <5 percentage points occurred in 80% of the strata for the Hudson stock, 71% of the strata for the Chesapeake stock, and 86% of the strata for the Roanoke stock. The adjusted estimates therefore substantiate low iterative estimates of contribution of Hudson and Roanoke stocks.

Comparison of mean iterative and adjusted estimates of relative contribution indicated that the two estimates differed by <1 percentage point for each stock. Mean iterative and adjusted estimates were, respectively, 6.5 and 6.6% Hudson, 90.8 and 90.2% Chesapeake, and 2.7 and 3.2% Roanoke contribution.

The contribution of the Hudson stock to the coastal fishery was greater in strata adjacent to the Hudson River than in the remaining strata. Mean iterative estimates of relative contribution of the Hudson River stock to inner and outer zones were 16.0% (15.0% adjusted) and 2.8% (0.0% adjusted), respectively, for the year (Table 6). Although the Chesapeake stock was the predominant contributor to both inner and outer zones, the contribution of the Hudson stock exceeded that of the Roanoke stock in the inner zone but was less in the outer zone.

TABLE 6.—Mean estimates[1] of relative contribution of Hudson, Chesapeake, and Roanoke stocks of legal-sized striped bass[2] to 1975 oceanic collections within USNRC zones.[3]

	Inner zone			Outer zone		
Estimate	Hudson	Chesapeake	Roanoke	Hudson	Chesapeake	Roanoke
As-classified	31.7	62.9	5.5	19.2	68.0	12.8
Iterative	16.0	83.1	0.9	2.8	94.2	3.0
Adjusted	15.0	84.2	0.8	0.0	96.4	3.6

[1]Average of five temporal strata since only one striped bass collected in inner zone during period 1 (Jan.-Feb.).
[2]Not included are striped bass <406.5 mm FL from New York waters.
[3]U.S. Nuclear Regulatory Commission inner zone corresponds to study strata 5, 7, and 8-1; the outer zone corresponds to study strata 1 to 4, 6, 8-2, and 8-3.

The Hudson stock predominated in collections of sublegal-sized striped bass in western Long Island Sound, the New York Bight, and in collections of specimens overwintering in Croton Bay on the Hudson River (Table 7). Iterative (and adjusted) estimates of the percentage of sublegal-sized fish classified into the Hudson stock in western Long Island Sound (primarily in Little Neck Bay) and the New York Bight were at least 80%, but were less than 40% along the southeastern shore of Long Island (stratum 6) from May through October. The iterative (and adjusted) estimated of contribution of the Hudson stock to the overwintering population in the Hudson River was greater than 95%.

This study has provided additional information in the importance of dominant year classes of striped bass. Approximately 52% of the specimens collected from the coastal fishery in 1975 were from the 1970 year class, and 77% of them were classified as Chesapeake fish. Schaefer (1972) stated that production of young-of-the-year striped bass in Chesapeake Bay during 1970 was the largest ever recorded and that this year class should provide excellent fishing in New York waters for 6 to 8 yr after recruitment. The presence of this dominant year class of Chesapeake fish confirms the rationale used by Merriman (1941) and Schaefer (1968) to conclude that the Chesapeake stock predominates in the coastal fishery. A summary of the occurrence of dominant year classes in the Atlantic coastal fishery has been given by Schaefer (1968).

TABLE 7.—Estimates of relative contribution of Hudson, Chesapeake, and Roanoke stocks of sublegal-sized striped bass[1] to New York waters by period and spatial stratum and of legal-sized striped bass to the overwintering population in the Hudson River. As-cl. = as-classified, Inter. = iterative, and Adj. = adjusted estimates.

				Hudson			Chesapeake			Roanoke		
Population	Period	Stratum	Sample size[2]	As-cl.	Iter.	Adj.	As-cl.	Iter.	Adj.	As-cl.	Iter.	Adj.
Overwintering			76	76.3	97.4	95.7	23.7	2.6	4.3	0.0	0.0	0.0
Sublegal	May-June	5	42	92.9	100.0	100.0	7.1	0.0	0.0	0.0	0.0	0.0
		6	8	12.5	0.0	0.0	50.0	62.5	64.3	37.5	37.5	35.7
		7	11	81.8	81.8	100.0	18.2	18.2	0.0	0.0	0.0	0.0
	July-Aug.	5	85	88.2	100.0	100.0	11.8	0.0	0.0	0.0	0.0	0.0
		6	17	41.2	35.3	39.2	41.2	58.8	47.4	17.6	5.9	13.4
	Sept.-Oct.	5	10	80.0	80.0	100.0	20.0	20.0	0.0	0.0	0.0	0.0
		6	19	26.3	15.8	20.8	36.8	47.4	41.9	36.8	36.8	37.3

[1]Striped bass <406.5 mm FL from New York waters.
[2]Sample sizes of five specimens or less in any stratum are not included. Three sublegal-sized specimens collected overwintering in the Hudson River were classified as Hudson fish.

SUMMARY AND CONCLUSIONS

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 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.

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