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DISCRIMINANT FUNCTION ANALYSIS OF MORPHOMETRIC CHARACTERS FROM SILVER HAKE IN THE NEW ENGLAND - MIDDLE ATLANTIC AREA

by

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INTRODUCTION

The silver hake (Merluccius bilinearis) is a widely distributed, slender, swiftly swimming gadid species which is found in continental shelf waters between Newfoundland and South Carolina, but is most abundant from Nova Scotia to New Jersey. The abundance and availability of silver hake have made it important to domestic commercial and recreational fisheries as well as to distant-water-fleet fisheries.

Silver hake in US waters from the Gulf of Maine to Cape Hatteras have, since the early 1970's, been grouped into three stocks using as boundaries the divisions and subdivisions of the International Commission for the Northwest Atlantic Fisheries (ICNAF) (replaced in 1980 by the Northwest Atlantic Fisheries Organization): (1) the Gulf of Maine (Div. 5Y), (2) Georges Bank (Subdiv. 5Ze), and (3) Southern New England - Middle Atlantic (Subdiv. 5Zw and Statistical Area 6) (Figure 1). These stock definitions were established based on scientific information available when management of this species through ICNAF catch quotas began in 1973.

Various studies, reviewed by Anderson et al. (1980), suggest that at least two discrete stocks of silver hake exist in the area between the Gulf of Maine and Cape Hatteras. None of these studies, however, have provided a comprehensive examination of fish from the entire area nor conclusive evidence to define the stock structure.

An attempt was made, as described herein, to obtain new information on the silver hake stock structure through an analysis of morphometric

characters from fish collected throughout the area of concern at various times of the year. The present study essentially repeated an earlier comparison of morphometric characters conducted by Conover et al. (1961), but was based on a much larger and more widespread collection of samples and more recently developed statistical techniques. The morphometric data were subjected to discriminant function analysis, a multivariate statistical technique developed by Fisher (1936) for distinguishing among individuals and classifying them into groups. This technique has been applied in defining the stock structure of various species such as American shad (*Alosa sapidissima*) (Hill 1959), sockeye salmon (*Oncorhynchus nerka*) (Fukuhara et al. 1962; Anas and Murai 1969), pink salmon (*O. gorbuscha*) (Amos et al. 1963; Pearson 1964), Atlantic herring (*Clupea harengus harengus*) (Parsons 1972; Messieh 1975), capelin (*Mallotus villosus*) (Sharp et al. 1978), and summer flounder (*Paralichthys dentatus*) (Wilk et al. 1980).

METHODS

During the summer and autumn of 1978 and the spring of 1979, a total of 3,015 silver hake were collected from research vessel bottom trawl survey catches (Figures 2 and 3). Specimens were frozen and returned to the laboratory for analysis. Fork length was measured to the nearest millimeter, and sex and maturity stage was determined. A total of 13 morphometric characters (Table 1) were measured to the nearest 0.1 mm using vernier calipers. All data were transferred to computer file for retrieval

and analysis. Of the original number of specimens collected and measured, data from 1,132 males and 1,420 females were used in the subsequent analysis; data from the remaining immature fish were not used.

Examination of composite plots of adult silver hake catches from spring trawl surveys (Figures 4 and 5) indicated a clear separation of fish at that time of year into components north and south of Georges Bank, with the shoal portions of the Bank and Nantucket Shoals generally devoid of fish. Hypothesizing that fish from these two components may constitute different stocks by virtue of being separated during overwintering, two groups of spring-caught fish were selected for testing as possible separate stocks: (1) north of Cape Cod (Gulf of Maine), and (2) south and west of Long Island (Southern New England - Middle Atlantic) (Figure 2). Remaining spring-caught fish were divided into northern Georges Bank and southern Georges Bank (including south of Nantucket Shoals) groups. Fish collected during the summer and autumn were similarly categorized into the above four groups.

It was also decided to investigate whether fish separated at the time of spawning may represent separate stocks. Silver hake spawn from May to November (Bigelow and Schroeder 1953; Marak and Colton 1961; Sauskan and Serebryakov 1968; Colton and St. Onge 1974; Fahay 1974) with peak spawning occurring in June-July along the continental shelf and in July-August in the Gulf of Maine. Spawning apparently occurs throughout the entire area from the Gulf of Maine to Cape Hatteras generally at depths less than 90 m, with the area between Cape Cod and Cape Ann in the

Gulf of Maine and the area between Nantucket Shoals and Hudson Canyon identified as major spawning sites. Fish from summer and autumn samples determined to be in spawning or post-spawning condition were assigned to two groups corresponding to the above areas for testing as possible separate stocks.

Since silver hake have been shown to be sexually dimorphic with respect to growth (Schaefer 1960; Nichy 1969), analysis of covariance was done on the morphometric measurements for males and females (all samples combined) to test for differences in characters between sex. Significant differences ($p = 0.01$) were evident for 9 of 13 characters (Table 1); therefore, data were treated separately by sex throughout the discriminant analysis. Strong linear relationships were found between each morphometric character and fork length, with correlation coefficients (r) averaging 0.943 for females (range = 0.858 to 0.979) and 0.906 for males (range = 0.842 to 0.957). Examination of residuals indicated the absence of any non-linear trends. To remove the linear effect, all characters were expressed as percentages of body length. Data representing the possible separate stocks mentioned above were used in the stepwise linear discriminant analysis program BMDP7M (Dixon 1977) to select characters which would best distinguish between groups. Data for these characters were then used in a two-group linear discriminant analysis program BMD04M (Dixon 1977) to construct linear functions for each sex to compare fish from the hypothesized stocks. Details of the statistical procedures used are described by Fisher (1936), Mahalanobis

(1936), Rao (1952), Fukuhara et al. (1962), and Amos et al. (1963).

The previous analysis of morphometric characters (Conover et al. 1961) indicated highly significant differences between silver hake from the Gulf of Maine - northern Georges Bank area and the Southern New England - Middle Atlantic area but non-significant differences within each area. This analysis was done with sexes combined. Since the present study found significant differences in morphometric characters between sex, it was decided to analyze the present data in the same manner as done by Conover et al. (1961), except with sexes separate. This was done with the analysis of coveriance program BMDP1V (Dixon 1977) on the appropriate groups of fish with fork length treated as the covariate.

RESULTS

Stepwise discriminant analysis applied to the data representing the two hypothesized stocks from spring samples (Gulf of Maine and Southern New England - Middle Atlantic) indicated that four characters contributed significantly to the separation of the two groups for males and five characters for females. Results of the two-group linear discriminant analysis based on these characters produced the following linear function for males:

$$Z_m = 0.10395X_1 - 0.13497X_2 + 0.06046X_3 + 0.08583X_4$$

and for females:

$$Z_f = 0.12357X_1 - 0.31752X_2 - 0.21662X_3 + 0.15867X_4 + 0.06695X_5.$$

For males, X_1, X_2, X_3, and X_4 represent pelvic fin length, length from snout to insertion of pelvic fin, first ventral fin length, and first dorsal fin length, respectively. For females, X_1, X_2, X_3, X_4, and X_5 represent head length, eye diameter, length from snout to insertion of pelvic fin, length from snout to insertion of pectoral fin, and second ventral fin length, respectively. It is unclear why the significant characters differed between sex. Means and differences between means for discriminating characters from the two groups are given in Table 2. The estimated mean Z-values for each sex from the two areas were determined by substituting the respective mean X-values into the appropriate function. The Z_m-values were 0.00880 for the Gulf of Maine group and 0.01012 for the Southern New England - Middle Atlantic group, with a mean of 0.00946. The Z_f-values were 0.01698 for the Gulf of Maine and 0.01350 for Southern New England - Middle Atlantic, with a mean of 0.01524. In discriminating between the two groups, males with a Z_m-value less than 0.00946 and females with a Z_f-value greater than 0.01524 were classified as Gulf of Maine fish, and males with a Z_m-value greater than 0.00946 and females with a Z_f-value less than 0.01524 were classified as Southern New England - Middle Atlantic fish. Analysis of variance indicated that differences between the two groups were significant at the 0.035 probability level ($F_{4,343} = 6.83$) for males and at the 0.002 level ($F_{5,358} = 17.13$) for females. The probability of correctly classifying fish was found to be 63.3% for males and 71.2% for females.

Stepwise discriminant analysis applied to data from Gulf of Maine and Southern New England - Middle Atlantic fish in spawning or post-spawning condition from summer and autumn samples hypothesized to represent discrete stocks indicated only one character for males and two characters for females which contributed significantly to the separation of the two groups. Analysis of variance indicated that differences between the two groups were significant at the 0.216 probability level ($F_{1,248} = 13.30$) for males and at the 0.121 level ($F_{2,410} = 7.78$) for females. The probability of correct classification was determined to be less than 60% for both males and females. These percentages, as well as the significance levels, were considered insufficient to provide a basis for defining the two groups as separate stocks.

The discriminant functions calculated for males and females from the spring samples were used to classify individual fish not used to derive the functions. Results indicated that, of the remaining fish collected during the spring of 1979, 86.7% (sexes combined) of those from the northern part of Georges Bank (Figure 3) were classified as belonging to the Gulf of Maine group (Table 3), whereas only 52.9% of those from the southern part of Georges Bank were classified as belonging to the Southern New England - Middle Atlantic group. Approximately 60-75% of the fish collected during the summer and autumn of 1978 (Figure 3), regardless of the area, were classified as belonging to the Gulf of Maine group, with only 25-40% assigned to the Southern New England - Middle Atlantic group. There was no north-south trend evident.

Results of the analysis of covariance of the various morphometric characters with respect to fish length for each sex between areas are given in Table 4. Significant differences were found between fish from the Gulf of Maine and Georges Bank based on autumn samples but not on spring samples. From autumn samples, four characters exhibited significant differences among males and seven characters among females. Significant differences were also found between fish from Southern New England and the Middle Atlantic area based on both autumn and spring samples, although more characters showed differences in the autumn (three for males and five for females) than in the spring (one for males and four for females). When comparing Gulf of Maine - Georges Bank fish with Southern New England - Middle Atlantic fish, significant differences were found and were more prevalent in spring samples (six characters for males and eight for females) than in autumn samples (two characters for males and four for females).

DISCUSSION

Analysis of morphometric characters of silver hake collected in 1978-79 in the area from the Gulf of Maine to Cape Hatteras provided no clear-cut delineation of separate stocks within this area. Although discriminant analysis was able to define significantly different groups of fish in the spring in the Gulf of Maine and in the Southern New England - Middle Atlantic area, the probability of correct classification (63-71%) was lower than that generally found in discriminant analysis of other species (in excess of 80-90%, e.g. Parsons 1972; Wilk et al. 1980).

Classification of fish not used in calculating the discriminant functions resulted in 60-75% being assigned to the Gulf of Maine group regardless of the area and season of capture. The classification of approximately 70% of the fish sampled in the summer and autumn in Southern New England - Middle Atlantic waters to the Gulf of Maine group suggests a southerly movement of northern fish during that time. This, however, does not appear to be consistent with what is known about the seasonal movements of silver hake (Anderson et al. 1980). Fish generally undergo a shoreward and northerly movement as waters warm and a southerly or offshore movement in the autumn. Knowledge concerning seasonal shifts in abundance is based generally on research vessel survey catches (Bowman 1972; Anderson 1974); specific migration patterns, if they exist, have not been verified. Results from tagging studies conducted in 1957-58 (Fritz 1959, 1963) and in 1964 (Noskov 1970) are insufficient to define the extent of movements of silver hake within the area.

Discriminant analysis was unable to satisfactorily define separate spawning groups in the Gulf of Maine and the Southern New England - Middle Atlantic area based on summer and autumn samples. However, a recent study sponsored by the Northeast Fisheries Center (Schenk, MS in preparation[1]), which examined enzyme systems from tissue samples collected in the summer of 1979 from spawning fish from these two areas, found significant genetic differences between the two areas. Since samples were not examined from other areas or seasons, results from this study do not resolve the overall stock question.

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Analysis of morphometric characters indicated significant differences between Gulf of Maine - Georges Bank fish and Southern New England - Middle Atlantic fish. These results are in agreement with the work done previously by Conover et al. (1961). However, the current analysis also found differences between Gulf of Maine and Georges Bank fish and between Southern New England and Middle Atlantic fish, whereas Conover et al. (1961) reported no differences. This lack of agreement may be due to the fact that the current analysis treated sexes separately, while Conover et al. (1961) did not distinguish between sexes. Current analysis found significant differences in characters between sexes.

Overall results from the study reported herein suggest, based on analysis of spring-caught fish, the existence of at least two separate groups of silver hake, defined herein as the Gulf of Maine group and the Southern New England - Middle Atlantic group. If the observed differences between morphometric characters reflect genetic separation, these two groups may represent separate stocks. The definition of these two groups agrees with conclusions reached by Conover et al. (1961) and Schenk (MS in preparation, see footnote 1). Results from the current study are insufficient to identify other possible stocks (e.g. a Georges Bank stock), or to establish any clearly-defined distribution of stocks by season. The results appear to reflect either a substantial amount of intermixture throughout the area or a pronounced inability of the morphometric characters examined to adequately represent separate stocks.

The results from the study reported herein do not provide a clear delineation of the Gulf of Maine - Cape Hatteras silver hake resource

into stocks identifiable by area and season. Further attempts to utilize morphometric characters to define silver hake stocks will probably be unproductive. It is felt, however, that the greatest potential for obtaining additional information concerning stock identity and delineation lies with biochemical analysis of enzyme systems to detect genetic differences between fish.

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Table 1. Results of analysis of covariance of males versus females with all areas and all seasons combined. Values listed are the results of F-test for equality of adjusted group means.

Character	F-value
Head length	30.8204**
Eye diameter	78.3902**
Snout length	76.3027**
Snout to anal opening	17.2411**
Snout to insertion of pelvic fin	53.1674**
Snout to insertion of pectoral fin	71.1146**
Pelvic fin length	15.0922**
Pectoral fin length	26.0644**
First dorsal fin length	0.2524
Second dorsal fin length	1.8875
Third dorsal fin length	2.5637
First ventral fin length	10.7971**
Second ventral fin length	4.6207
Degrees of freedom	2555

**Significant at the 1% level.

Table 2. Means and differences between means of morphometric characters (expressed as percentages of fork length) of silver hake in the spring of 1979 from the Gulf of Maine and Southern New England - Middle Atlantic.

Character	Mean		Difference between means
	Gulf of Maine	Southern New England-Middle Atlantic	
	Males		
Pelvic fin length (X_1)	14.488	14.870	0.382
Snout to insertion of pelvic fin (X_2)	22.315	22.086	0.229
First ventral fin length (X_3)	24.539	25.096	0.557
First dorsal fin length (X_4)	10.512	10.831	0.319
	Females		
Head length (X_1)	22.668	23.547	0.879
Eye diameter (X_2)	4.491	4.283	0.208
Snout to insertion of pelvic fin (X_3)	22.605	22.327	0.277
Snout to insertion of pectoral fin (X_4)	23.634	24.065	0.431
Second ventral fin length (X_5)	16.750	17.423	0.673

Table 3. Summary results of discriminating capabilities of discriminant functions on samples not used in the construction of functions.

Time and location of sample	Percentage of fish classified as belonging to the Gulf of Maine group	Southern New England-Mid. Atlant. group	Sample size
Spring 1979			
Northern Georges Bank	86.7	13.3	30
Southern Georges Bank	47.1	52.9	208
Summer 1978			
Gulf of Maine	75.2	24.8	101
Northern Georges Bank	61.8	38.2	123
Southern Georges Bank	74.3	25.7	105
Southern New England - Middle Atlantic	70.0	30.0	203
Autumn 1978			
Gulf of Maine	59.2	40.8	470
Northern Georges Bank	60.5	39.5	195
Southern Georges Bank	70.3	29.7	118
Southern New England - Middle Atlantic	64.5	35.5	287
Combined Summer and Autumn 1978			
Gulf of Maine and northern Georges Bank	61.7	38.3	889
Southern New England - Middle Atlantic and southern Georges Bank	68.5	31.5	713

Table 4. Results of analysis of covariance tests on each characteristic used in both the discriminant analysis and in the previous morphometric study by Conover et al (1961). The values listed are F values for each characteristic with fork length used as the covariate in each case. Fall results include those from summer samples.

Character	Gulf of Maine vs. Georges Bank				Southern New England vs. Middle Atlantic				Gulf of Maine-Georges Bank vs. Southern New England-Middle Atlantic			
	Males		Females		Males		Females		Males		Females	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Head length	.4272	4.0083*	.4203	9.8431**	.1129	.1634	.9904	6.7994**	8.1864**	.7974	25.5347**	3.4362
Eye diameter	1.0899	24.3621**	.5998	56.8464**	3.9003*	.0047	8.4556**	.6720	.0121	.0147	2.1283	.0936
Snout length	.4939	.9471	.0335	13.4571**	.1746	2.2281	9.5509**	8.8671**	14.2253**	2.0239	18.9685**	4.3837*
Snout to anal opening	1.2587	6.4584*	.3267	5.3742*	.0054	.0231	1.7719	3.1837	.3075	3.1117	.2584	5.3277*
Snout to insertion of pelvic fin	.0818	3.1745	.0216	1.2928	1.2491	3.8017	4.2168*	3.8742	1.4842	.5081	.0722	.0725
Snout to insertion of pectoral fin	.4363	.4878	.0219	.0100	.1463	.0457	2.9290	.9729	4.1266*	4.4794*	24.7564**	4.4192*
Pelvic fin length	.1946	2.9042	.2692	10.0579**	.1074	.1003	1.9810	.7971	20.7565**	.3194	36.3897**	2.3348
Pectoral fin length	.7710	1.8770	.0278	1.9761	1.7387	.0611	.0000	.4416	.8814	9.6251**	7.8573**	1.1003
First dorsal fin length	2.9878	.1485	3.6647	3.4151	.0324	6.4989*	7.4474**	1.6421	.0939	.9274	.6015	.4189
Second dorsal fin length	1.0722	3.6606	.2597	8.0348**	.7219	24.5171**	.0438	19.9839**	.2431	2.4767	1.4632	.1830
Third dorsal fin length	1.1623	2.0937	.0013	.0754	.0002	1.1944	.0038	.0598	6.8619**	.5753	28.0525**	1.4680
First ventral fin length	1.4916	13.6633**	.0275	6.8000**	.8127	6.3939*	.0186	4.7957*	2.0222	2.6967	9.7614**	.9227
Second ventral fin length	3.3293	.5314	.0220	3.1026	.0061	1.1476	.0136	4.2729*	14.1105**	1.4217	30.7202**	6.7594**
Degrees of freedom	161	340	206	517	271	240	275	236	435	583	484	756

* - significant at the 5% level.

** - significant at the 1% level.

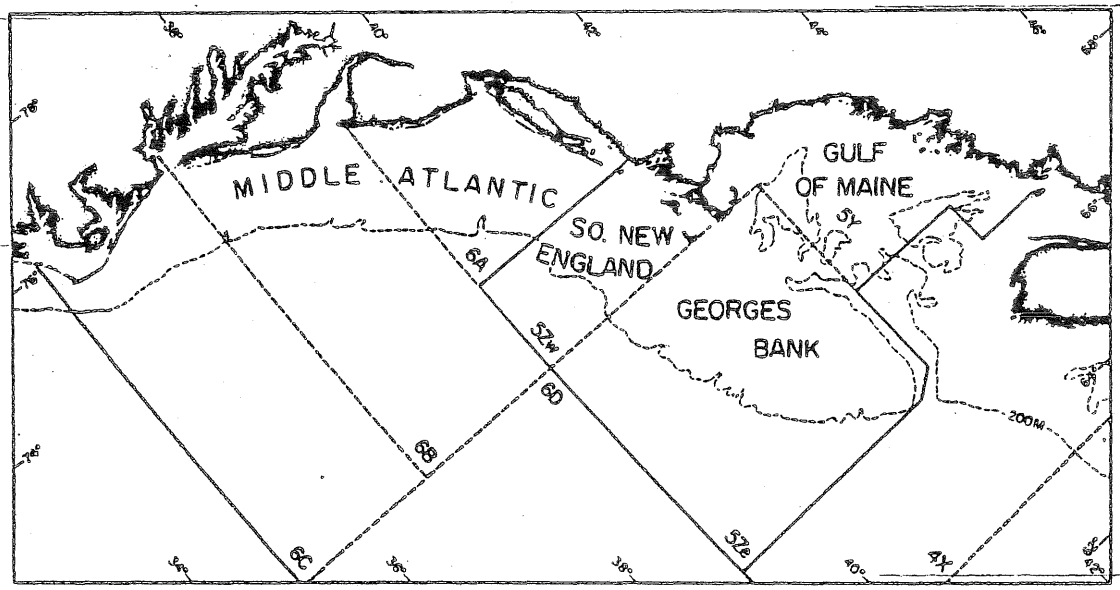

Figure 1. Fishing grounds off the northeastern United States and divisions and subdivisions of ICNAF/NAFO Subarea 5 and Statistical Area 6.

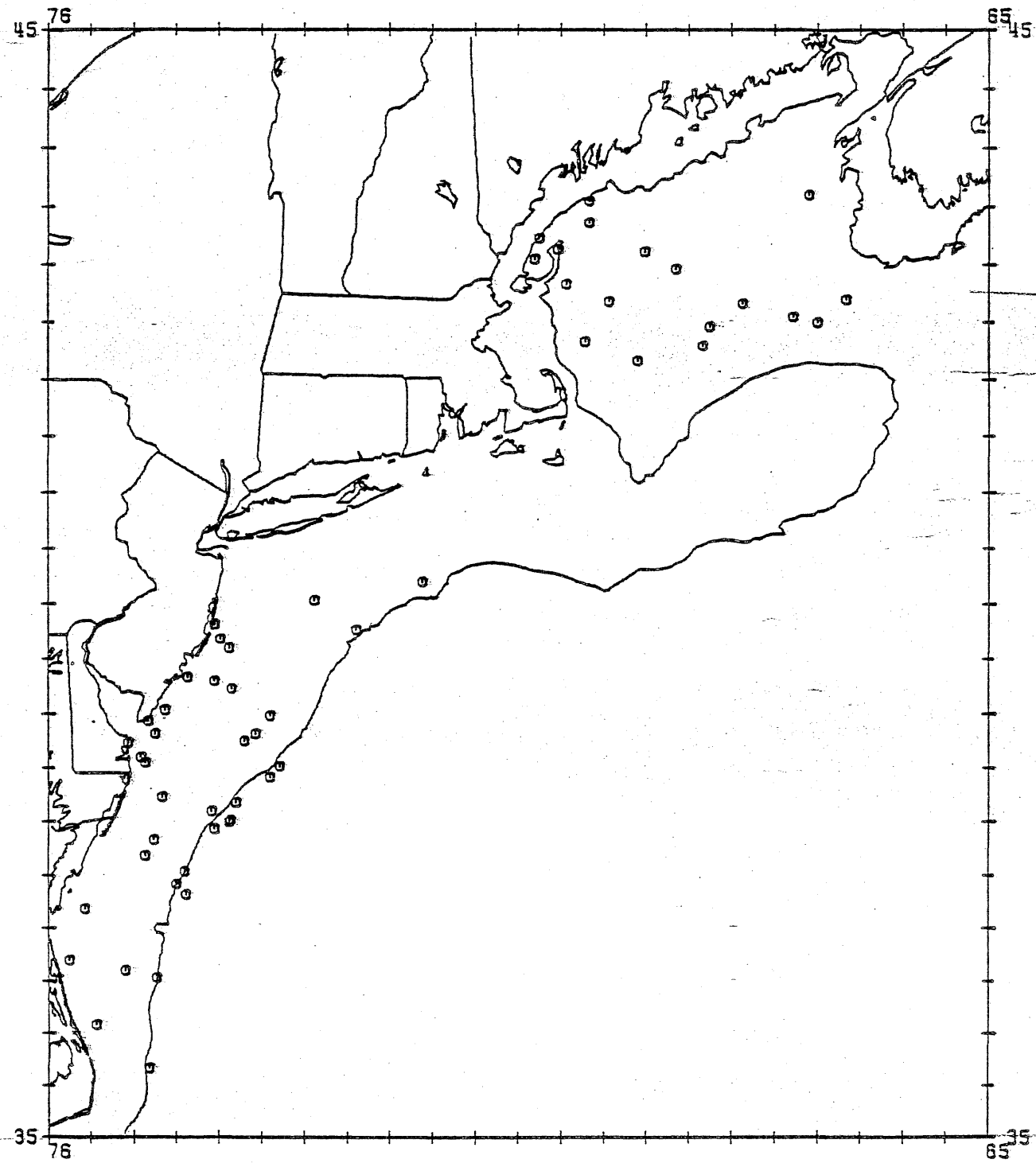

Figure 2. Location of silver hake samples collected from the NMFS spring 1979 bottom trawl survey used in calculating discriminant functions.

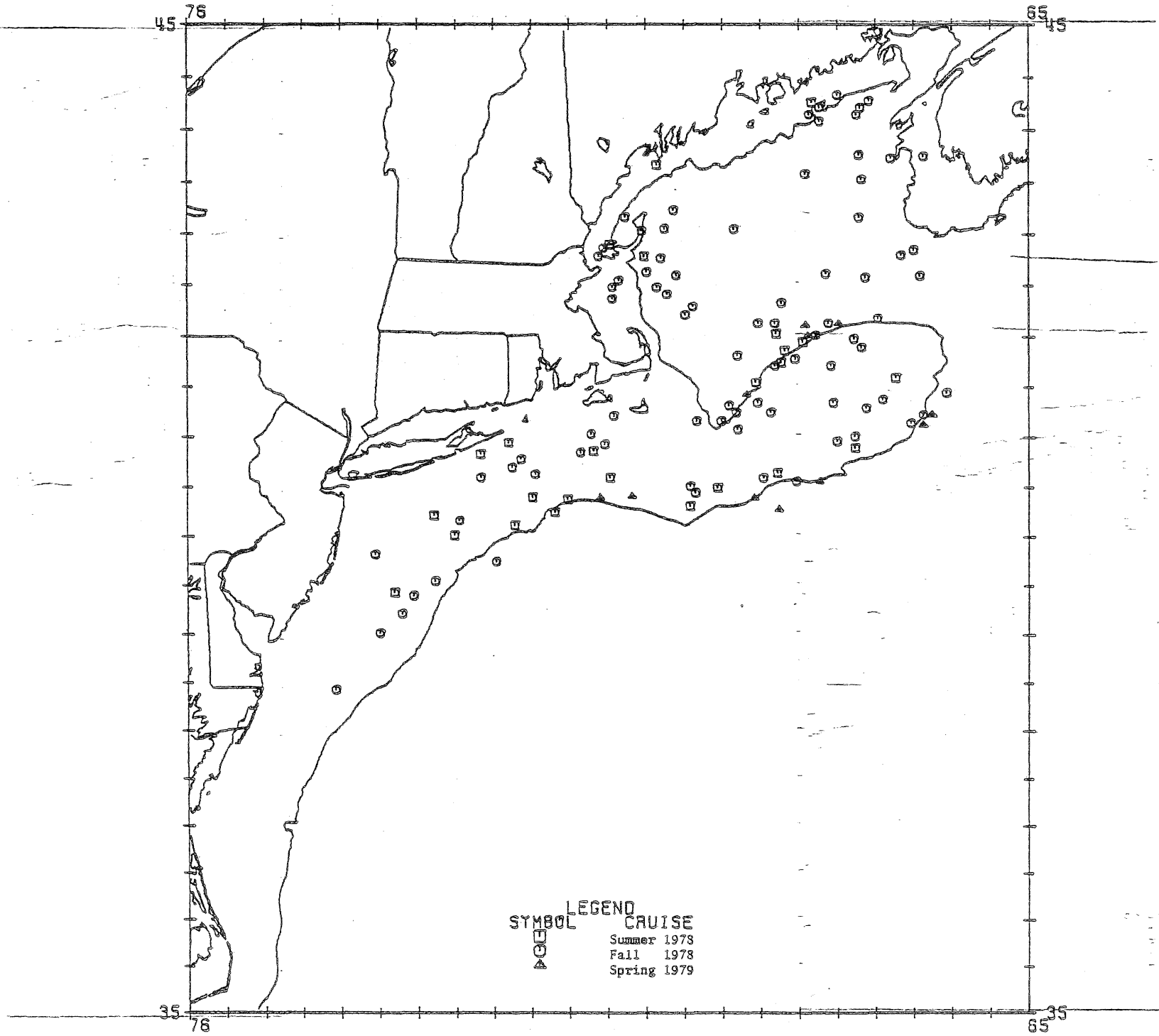

Figure 3. Location of silver hake samples collected from NMFS summer and autumn 1978 and spring 1979 bottom trawl surveys (not including those shown in Figure 2) used in the analysis of morphometric characters.

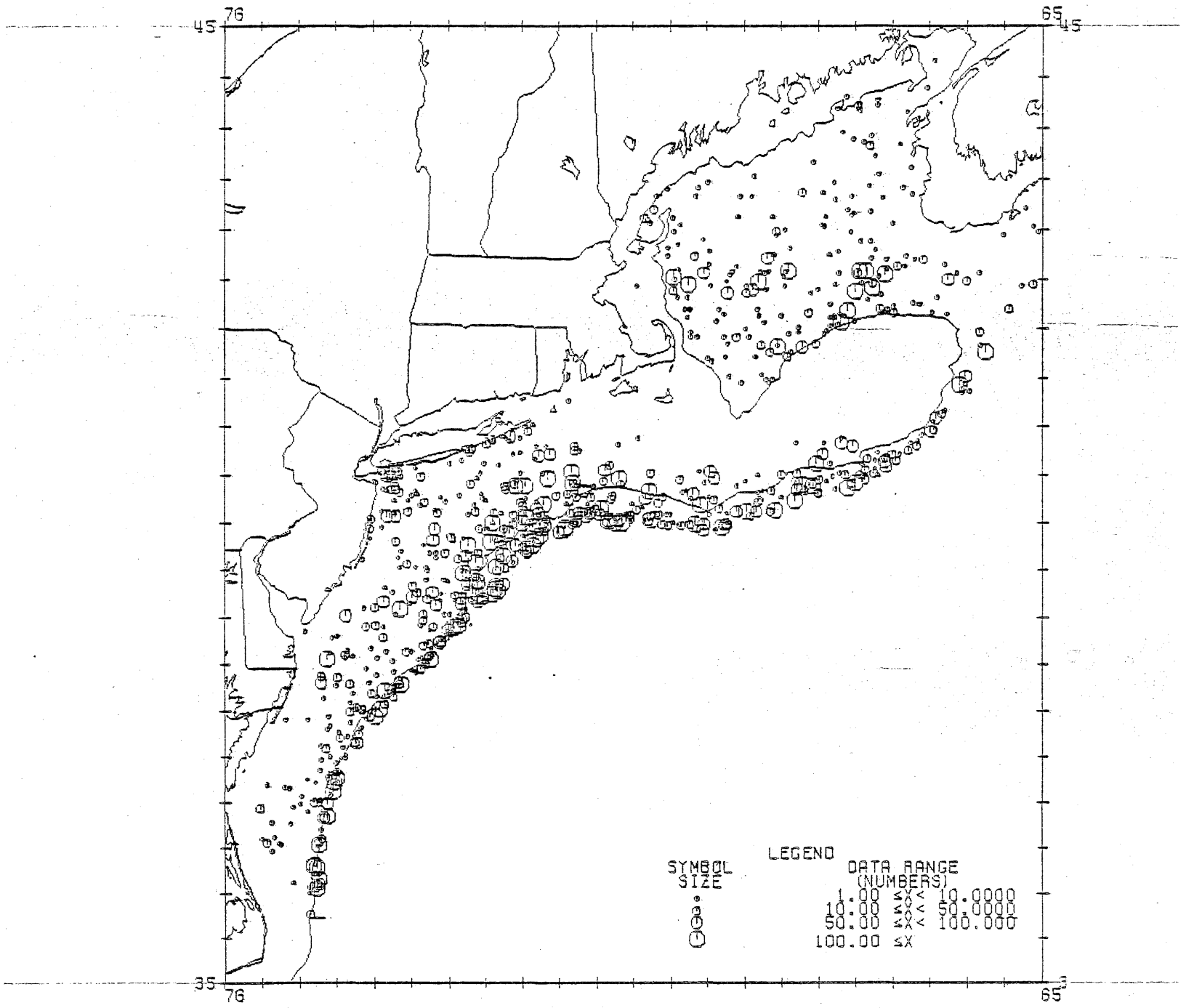

Figure 4. Distribution of catches of adult silver hake from NMFS spring 1968-73 bottom trawl surveys (inshore and offshore).

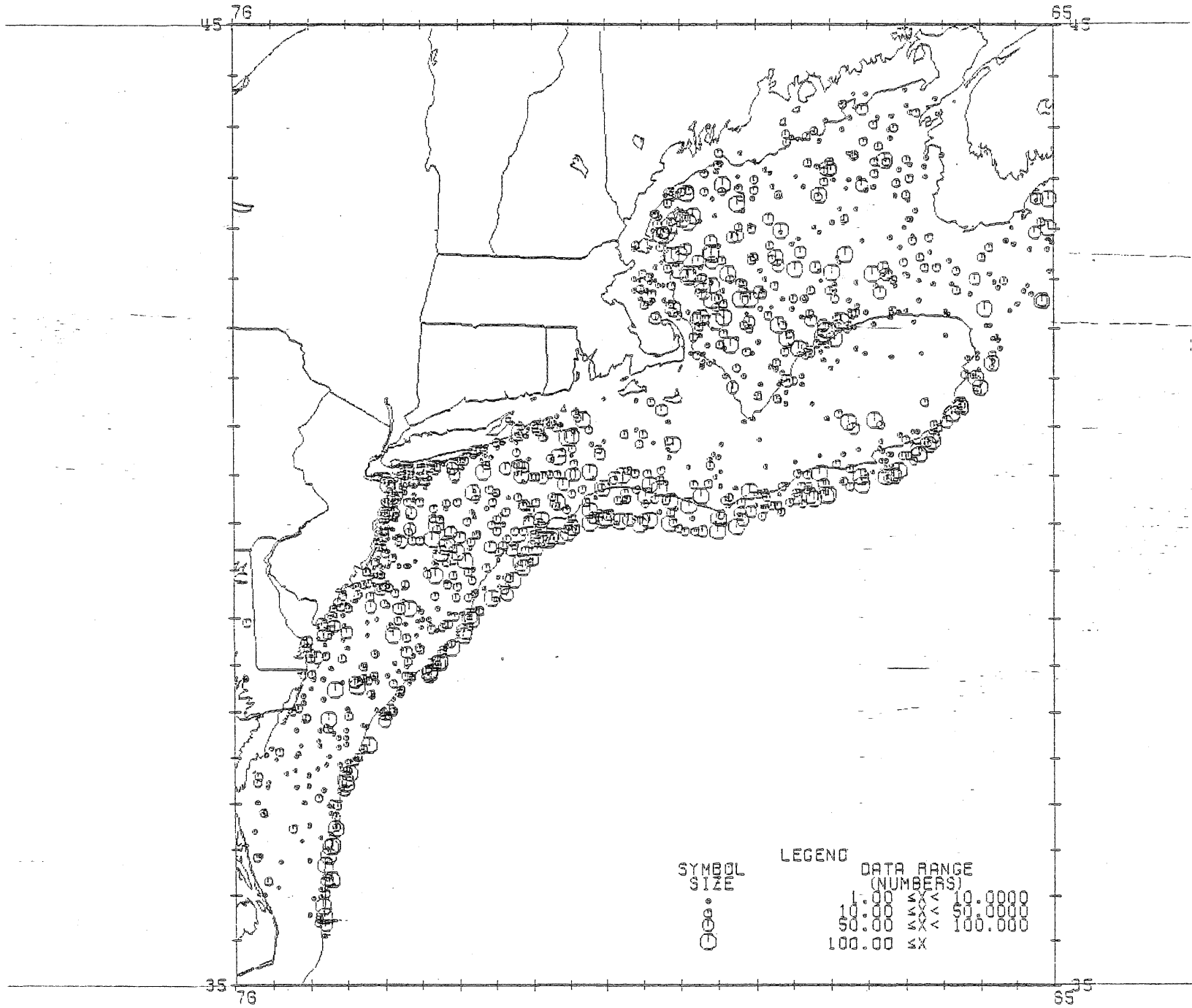

Figure 5. Distribution of catches of adult silver hake from NMFS spring 1974-79 bottom trawl surveys (inshore and offshore).