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Discrimination of Possible Silver Hake (*Merluccius bilinearis*) Stocks on the Scotian Shelf

by

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Abstract

Silver hake on the Scotian Shelf have been traditionally managed as a unit stock, separate from those found off the eastern seaboard of the United States. Recently available data from the Scotian Shelf Ichthyoplankton and Observer Programs coupled with bottom trawl random stratified surveys suggest at least two stocks on the Scotian Shelf (an Emerald Basin and a Shelf Slope stock). Discriminant analysis of morphometric variables from these two areas on the Scotian Shelf gives an overall classification capability of 75%. Similar discriminant analysis for female silver hake gives as high as 87% classification between the stocks. Silver hake collected from the La Have Basin area were successfully classified as belonging to the adjacent Emerald Basin Group. Morphometric variables collected from silver hake on the Scotian Shelf were classified to the Southern Georges Bank-mid Atlantic stock. This could suggest that there are two main silver hake stocks with the probability of a third in the north west Atlantic. These could be delineated as a northern Georges Bank-Gulf of Maine; southern Georges Bank-mid-Atlantic-Scotian Shelf; and an Emerald Basin complex.

Introduction

Members of the Merlucciidae (hakes) gave a worldwide distribution generally in temperate waters (Fig. 1). In tropical waters they are present in active upwelling zones. On the eastern Atlantic there are seven varieties either

classified as seven subspecies of Merluccius merluccius (Franca, 1960 and Jones, 1974) or as separate species. These seven family members demonstrate a high degree of mixing and are found from Norway to South Africa.

The western Atlantic coasts have five species of which only two, Merluccius bilinearis (silver hake) and M. Albidus (offshore hake) are found exclusively in the Atlantic. All other species range from both the western Atlantic to the eastern Pacific Oceans (Bullock, 1980).

The distribution of M. bilinearis extends from the Gulf of St. Lawrence and southern Newfoundland to South Carolina (Bigelow and Schroeder, 1965; Liem and Scott, 1966). Two stocks were hypothesized in waters off the United States. A resident Georges Bank-Gulf of Maine stock and a Long Island Sound-South Carolina stock were suggested by Bigelow and Schroeder, 1955. Tagging studies by Fritz (1959) and Noskov (1970) provided inconclusive evidence for separate stocks.

Conover et al. (1961) examined morphometric characteristics of silver hake which were used to define two broad geographical areas, the Gulf of Maine and mid-Atlantic (Southern New England to New Jersey). Nichy (1969) detected differences in otolith zonal formation and lengths-at-age between silver hake from the Gulf of Maine and southern New England. Anderson (1974) using seasonal distribution patterns of silver hake from various research vessel surveys suggests that there are two stocks, a northern Georges Bank - Gulf of Maine and a southern Georges Bank-Cape Hatteras stock.

Almeida and Anderson (1980) and Almeida (1982) measured 13 morphometric characters earlier defined by Conover (1961). Using a discriminant function analysis, Almeida was able to substantiate Anderson's (1974) earlier contentions.

The movements of silver hake on the Scotian Shelf were described by Sauskan (1974) as commencing along the Shelf Slope in a north east direction during the spring and early summer. Later, as the Shelf waters warm, both immature and spawning fish move landward. Of particular interest was his observation that no sizeable concentrations of mature post spawning silver hake were found in NAFO

Division 4W during the winter. Sarnits and Sauskan (1967) present results which coroborate Sauskan's (1964) observations (Fig. 2). Clay (1979) summarized 8 years (1961-1968) of Soviet commercial trawl data (Fig. 3). These show a limited winter fishery existed on the Scotian Shelf in the vicinity of Emerald Basin. During the spring and summer months, silver hake, which the fishery concentrated on, appear to migrate from the 4X area and progress to the north-eastern edge of Sable Island by September. Clay (1979) also suggests the northern Browns Bank to Banquereau Bank population of silver hake is a unit stock separate from those found off the eastern seaboard of the United States. He further suggests that mixing between these areas may occur in the fall-winter periods.

It is the intention of this paper to investigate the concept of a distinct silver hake stock unit on the Scotian Shelf.

Materials and Methods

In May 1982 a bottom trawl random stratified survey research cruise collected silver hake from the Shelf Slope and Emerald Basin (Fig. 4). The fish were frozen at sea and returned to BIO for detailed morphometric sampling. Of the fish collected, 546 fish were in the subsequent analyses; 263 were sampled for the Emerald Basin area (area 1) and the remaining 283 from the Slope of the Scotian Shelf (area 2). Both mature and immature fish were included in the analysis.

The eleven morphometric characters measured for this analysis were earlier derived by Conover et al. (1961) and presented in Almeida and Anderson (1980) (Table 1, Fig. 5). These methods were followed such that possible silver hake stock(s) from the north west Atlantic could be separated. However, in contrast to Almeida and Anderson's (1980) analysis, the second dorsal fin and third dorsal fin of each fish were combined because of an inability to distinguish clearly between them. Similarly for the first and second ventral fin length measurements. Fork length was measured to the nearest millimeter while all other measurements were taken to the nearest 0.1 mm using vernier calipers on the left side of each fish. The influence of growth on the relationship of these variables was tested using a multiple regression analysis package (SPSS version

8) which regressed all variables against length. This analysis showed that each variable measured is correlated to length, therefore, in subsequent analyses all variables were standardized to length. However, there existed the possibility that transformations of the ratios derived would be necessary. Frequency histograms were plotted and showed there was no reason to transform the ratios.

Following this, a 2-way analysis of variance (Anova) program was run on the length standardized variables testing for differences between the sexes, areas and any 2 way interactions between them. One way analyses were employed to define differences between sex, regardless of area, and area, regardless of sex.

A discriminant analysis of the 546 cases (SPSS, Version 8, Discriminant) was used to show which variables measured best discriminated between the two hypothesized stocks (Emerald Basin-Shelf Slope). Based on the results of the analysis of variance the discriminant analysis was executed on male and female silver hake separately. Discrimination between the two areas was performed in a stepwise analysis utilizing Mahalanobis D as the method by which each variable was considered and entered. This particular method is effective in that it measures the largest distance between the closest groups based on specific Mahalanobis' calculations.

$$D^2 = (\overline{X}_1 - \overline{X}_2)\, S^{-1}\, (\overline{X}_1 - \overline{X}_2)$$

where $\overline{X}_1$ and $\overline{X}_2$ represent the means of the first and second groups, the prime indicates a transposition of the square matrices representing the pooled within-groups covariance matrix for the two groups being compared.

Mahalanobis D^2 can be converted to an F statistic by first calculating a Hotelling's T^2

$$T^2 = D^2 / \left(\frac{1}{N_1} + \frac{1}{N_2}\right)$$

and then calculating

$$F = \frac{T^2(N_1 + N_2 - V - 1)}{V(N_1 + N_2 - 2)}$$

where V is the number of variables and N is the number of cases for each group used in the analysis. In the analysis where unequal group sizes are encountered both T^2 and F increase as N increases. D^2 is independent of the samples sizes and therefore is a better description of the distance between groups. The F-to-remove and F-to-enter for each variable were referenced from a table of F values and assigned the values of 3.91 and 4.00 respectively.

Classification coeffieicnts were derived from the pooled-within groups covarince matrix and the group centroids from the discriminating variables.

Distributional plots for silver hake eggs, larvae and juveniles were obtained from data supplied through the Scotian Shelf Ichthyoplaknton Program. Plots of adult commercial catches were summarized from set by set observations collected from the Canadian Dept. of Fisheries and Oceans, Observer Program.

Results

New Scotian Shelf silver hake distributional data has been collected since 1977 by the Canadian Department of Fisheries and Oceans' Scotian Shelf Ichthyoplankton Program (SSIP). Surveys were done on prescribed transects at least every other month (O'Boyle, pers. comm.). Composite plots of silver hake egg, larvae and juvenile catch (nos.)/tow show for eggs the densest concentrations are localized to the Sable Island Bank area (Fig. 6). Less dense concentrations of eggs are found on the Banquereau and Browns Bank. Larvae retain a similar distribution pattern relative to that of eggs (Fig. 7) while juveniles are densest in the deeper waters of the Shelf Slope and Emerald and La Have Basins (Fig. 8).

Adult distributions collected during the Canadian summer random stratified research surveys were obtained from Scott (1975) and unpublished data (Figs. 9 and 10). Both plots indicate dense concentrations in the Emerald-La Have Basin area, Shelf Slope and Browns Bank. This is particularly evident for the composite plot of 1975-1979 data (Fig. 10).

Plots of silver hake catches observed during the 1977 - 1979 foreign fishery on the Scotian Shelf emphasize the concentrations of fish in the Emerald-La Have Basin and Shelf Slope areas (Fig. 11, 12 and 13).

Results of discriminant analysis

A 2-way Anova on each variable against sex and area showed that snout to pectoral fin insertion and first dorsal fin length were the only variables with non-significant variation (Table 1). All other variables showed either a significant variation between sex, area or both. No significant 2-way interactions were calculated.

Investigation of these sources of variation by one way ANOVA on each sex for all areas combined are reported in table 3. Since 60% of the observations demonstrated significant variation within sexes between the two areas investigated, the discriminant analysis was done for males separate from females.

Discriminant function analysis results are reported in table 4. The ability to correctly classify either to Basin or Shelf for females (79%) is higher than males (72%). Overall classification regardless of sex is 75%. Classification coefficients for males, females and overall categories are presented in tables 5, 6 and 7.

Testing the ability of these classification equations to correctly classify fish not included in the discriminant function analysis is limited to 102 fish taken in the La Have Basin during a July, 1982 research vessel cruise (Fig. 4). Both male and female silver hake from this area were classified 67.0% and 81% respectively to the Emerald Basin group (Table 8).

In Almeida's (1982) discriminant analysis 6 classification equations, 3 for each sex, were derived based on 3 saesonal time periods. The mean calculated for each equation was the parameter by which the area, either north Georges Bank or south Georges Bank was specified.

Using these classification equations , the data used in this analysis were classified for males and females separately (Tables 9 and 10). Ninety-seven percent of the males from both the Basin and Shelf areas were classified as belonging to the southern Georges Bank-mid-Atlantic stock (SGB). There is no significant difference between the distribution of Basin and Shelf classifications to the areas designated by Almeida (1982). All males

can be successfully classified as belonging to SGB from the Autumn 1978 collection.

Female silver hake caught on the Scotian Shelf are more diverse in their classification against Almeida's (1982) areas (Table 10). There is a much wider distribution of classification for both Basin and Shelf female silver hake over the two areas off the United States. Chi-squared analysis suggests that there is a significant difference between the classification into the United States areas for female silver hake from the Scotian Shelf. As with the males, the female silver hake are most frequently classified to the southern areas (SGB) and in particular when using the summer 1978 classification function (Table 10).

Discussion

Although the silver hake caught on the Scotian Shelf (NAFO Divisions 4VWX) are assessed and managed as a unit stock, the historical Soviet (Sarsits and Serebryakov, 1968) and Canadian research vessel data (Scott 1975 and unpublished) suggest the presence of at least two stocks. A third group of fish, those found on the tip of Browns Bank may belong to the northern Georges Bank-Gulf of Maine stock identified by Almeida (1982). Specimens have been collected from this area but not analysed at the time of writing.

Recently available data from the Canadian SSIP and Observer Programs suggest one prime spawning area on Sable Island Bank which is heavily prosecuted by the commercial fishery (Figs. 6, 11, 12, 13). Larvae are distributed to a much wider degree than eggs possibly as a result of drifting with water currents (Fig. 7). Juvenile silver hake are more narrowly distributed along the Shelf Slope and in or adjacent to the Emerald Basin (Fig. 8). The juvenile as well as adult distributions from commercial fisheries strongly suggest at least two stocks, Emerald Basin and Shelf Slope.

Discriminant analysis of samples collected from the Emerald Basin and Shelf Slope gave an overall classification of 74% with more distinct classification by females at 80% (Table 4.) These results also suggest the hypothesis of at least two silver hake stocks in the NAFO Division 4VWX area. The successful classifications of a La Have Basin sample collected during a later cruise (July, 1982) into the Emerald Basin complex reinforces the concept of a separate Basin and a Shelf stock.

The use of classification equations derived from discriminant functions for silver hake located in waters off the eastern coast of the United States (Almeida, 1982) to classify Scotian Shelf silver hake present some interesting results as to the associations of these stocks (Fig. 14). Both Basin and Shelf silver hake are strongly classified to the SGB stock. Males are classified with Autumn 1978 SGB silver hake (97%) while females have a much more diverse classification. Seventy-four percent of the female and 98% of the male silver hake from the Emerald Basin area are classified as belonging to the SGB stock. The classification of males (95%) and females (60%) Shelf Slope silver hake to the SGB stock is less than those silver hake from the Emerald Basin. In particular, the inability to successfully classify female silver hake from the Shelf area to SGB on the northern Georges Bank-Gulf of Maine (NGB) stocks may suggest that females from the SGB and NGB stock mix in the Scotian Shelf slope waters. However, the low sample sizes for female silver hake from the Shelf Slope ($n = 52$) used in the above classification analysis may contribute to the inability of successfully classifying the Shelf Slope females into either the SGB or NGB stock.

It can be hypothesized that, in general, silver hake found on the Scotian Shelf are associated with silver hake from the southern Georges Bank-mid-Atlantic area. Further, silver hake from the Emerald Basin area have been isolated from those on the Shelf Slope due to hydrological conditions during the late fall and winter months. Since silver hake are sequential spawners (Sauskan and Serebryakov, 1968), it is possible that both the Basin and Shelf stocks occupy the same spawning areas (i.e. Sable Island Bank) but at different times.

Continuing studies into stock discrimination along the north west Atlantic are recommended. Emphasis should be placed on distinguishing between a northern Georges Bank-Gulf of Maine and a southern Georges Bank-mid-Atlantic Scotian Shelf stock.

Acknowledgement

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Table 1. Body measurements used in the various studies for separating groups of silver hake.

Measurements	Conover	Almeida	This Study
Fork length (indep)	x	x	x
Head length	x	x	x
Snout length	x	x	x
Snout to anal opening	x	x	x
Snout to insertion of pelvic fin	x	x	x
Snout to insertion of pectoral fin	x	x	x
Fin, first dorsal, length	x	x	x
Fin, second dorsal, height	x		
Fin, second dorsal, length	x	x	x
Fin, third dorsal, length	x	x	x
Fin, third dorsal, height	x		
Fin, pectoral, length	x	x	x
Fin, pelvic, length	x	x	x
Fin, first ventral, length	x	x	
Fin, first ventral, height	x		x
Fin, second ventral, length	x	x	
Fin, second ventral, height	x		
Eye diameter	x	x	x

Table 2. F values and significance levels for a 2-way ANOVA of standardized discriminant variables to length for Merluccius bilinearis (n = 546)

Variable	Source of Variation		
	Sex	Area	2-Way Interactions
Eye diameter	12.348 (.001)*	2.199 (.139)	.268 (.605)
Eye-Snout	26.723 (.001)	6.904 (.009)	.730 (.393)
Head length	.687 (.407)	82.606 (.001)	1.566 (.211)
Snout-Anus	2.709 (.100)	7.404 (.007)	3.040 (.082)
Snout-Pelvic fin	6.568 (.011)	2.446 (.118)	1.993 (.159)
Snout-Pectoral fin	2.857 (.092)	1.600 (.206)	3.621 (.058)
Pelvic fin length	15.139 (.001)	18.368 (.001)	.439 (.508)
Pectoral fin length	.482 (.488)	9.593 (.002)	2.486 (.115)
First dorsal fin length	1.034 (.310)	1.129 (.288)	1.047 (.307)
Second dorsal fin length	.003 (.955)	8.298 (.004)	1.100 (.295)
Ventral fin length	4.349 (.038)	.032 (.858)	.169 (.681)

* ( ) - Significance Levels

Table 3. F values and significance levels for a 1-way ANOVA of standardized discriminant variables to length for Merluccius bilinearis (n = 546).

Variable	MALE	FEMALE
Eye diameter	3.954 (.048)*	9.253 (.003)
Eye-Snout	21.643 (.001)	8.250 (.004)
Head length	2.947 (.087)	0.073 (.787)
Snout-Anus	0.003 (.958)	14.338 (.001)
Snout-Pelvic fin	6.986 (.009)	0.751 (.387)
Snout-Pectoral fin	7.389 (.007)	0.021 (.886)
Pelvic fin length	4.056 (.045)	13.780 (.001)
Pectoral fin length	0.311 (.577)	3.304 (.070)
First dorsal fin length	0.000 (.997)	2.401 (.122)
Second dorsal fin length	0.421 (.517)	0.719 (.397)
Ventral fin length	2.833 (.094)	1.543 (.215)

* ( ) - Significance Levels

Table 4. Percent classified of silver hake (males, females, and sexes combined).

Group	No. of Cases	Predicted Group Membership Basin	Shelf
MALE			
Basin	111	73.9%	26.1%
Shelf	139	29.5%	70.5%
Percent correctly classified 72.00%			
FEMALE			
Basin	151	86.8%	13.2%
Shelf	141	28.5%	71.5%
Percent correctly classified 79.32%			
SEXES COMBINED			
Basin	262	79.0%	21.0%
Shelf	283	29.7%	70.3%
Percent correctly classified 74.50%			

Table 5. Female silver hake classification coefficients by area.

VARIABLE	BASIN	SHELF
Eye-Snout	-16.47564	97.24125
Head length	1433.246	1308.026
Snout-Anus	1450.016	1491.331
Snout-Pectoral fin	1170.811	1134.999
Pectoral fin length	1936.5219	1892.626
Constant	-735.7169	-719.5617

Table 6. Male silver hake classification coefficients by area.

VARIABLE	BASIN	SHELF
Eye-Snout	137.7140	343.9810
Head length	676.9220	574.9709
Pelvic fin length	542.8423	505.0588
Second dorsal fin length	506.8660	544.6602
Ventral fin length	205.3293	185.2362
Constant	-263.7067	-260.9037

Table 7. Overall classification coefficients for silver hake by area.

VARIABLE	BASIN	SHELF
Eye diameter	1179.977	1254.195
Eye-Snout	-290.3981	-136.8426
Head length	845.8024	742.8257
Snout-Anus	493.8810	510.8742
Snout-Pelvic fin	704.1902	677.8090
Pelvic fin length	328.7870	305.3682
Pectoral fin length	512.4803	488.9002
Second dorsal fin length	756.2771	772.1838
Constant	-506.5680	-502.1094

Table 8. Classification (%) of silver hake from La Have Basin sampled in July 1982.

Sex	Area classified	
	Emerald Basin	Shelf Slope
Male	67.1	32.9
Female	80.8	19.2

Table 9. Classification of male silver hake sampled in May 1982 from the Emerald Basin and Shelf Slope using Almeida (1982) equations. Chi-square is 3.173 with 3 degrees of freedom (Significance = .3657).

COUNT / ROW PCT / COL PCT / TOT PCT	Summer '78 South	Summer '78 North	Autumn '78 South	Autumn '78 North	Spring '79 South	Spring '79 North	ROW TOTAL
BASIN	0	0	109.0	0	2.0	0	111.0
	0	0	98.2	0	1.8	0	59.7
	0	0	60.6	0	50.0	0	
	0	0	58.6	0	1.1	0	
SHELF	1.0	0	71.0	1.0	2.0	0	75.0
	1.3	0	94.7	1.3	2.7	0	40.3
	100.0	0	39.4	100.0	50.0	0	
	0.5	0	38.2	0.5	1.1	0	
COLUMN TOTAL %	1.0	0	180.0	1.0	4.0	0	186.0
	0.5	0	96.8	0.5	2.2	0	100.0

Table 10. Classification of female silver hake sampled in May 1982 from the Emerald Basin and Shelf Slope using Almeida (1982) equations. Chi-square is 14.585 with 5 degrees of freedom (Significance = .0123).

COUNT / ROW PCT / COL PCT / TOT PCT	Summer '78 South	Summer '78 North	Autumn '78 South	Autumn '78 North	Spring '79 South	Spring '79 North	ROW TOTAL
BASIN	96.0	23.0	4.0	1.0	12.0	16.0	152.0
	63.2	15.1	2.6	0.7	7.9	10.5	74.5
	82.1	57.5	80.0	50.0	57.1	84.2	
	47.1	11.3	2.0	0.5	5.9	7.8	
SHELF	21.0	17.0	1.0	1.0	9.0	3.0	52.0
	40.4	32.7	1.9	1.9	17.3	5.8	25.5
	17.9	42.5	20.0	50.0	42.9	15.8	
	10.3	8.3	0.5	0.5	4.4	1.5	
COLUMN TOTAL %	117.0	40.0	5.0	2.0	21.0	19.0	204.0
	57.4	19.6	2.5	1.0	10.3	9.3	100.0

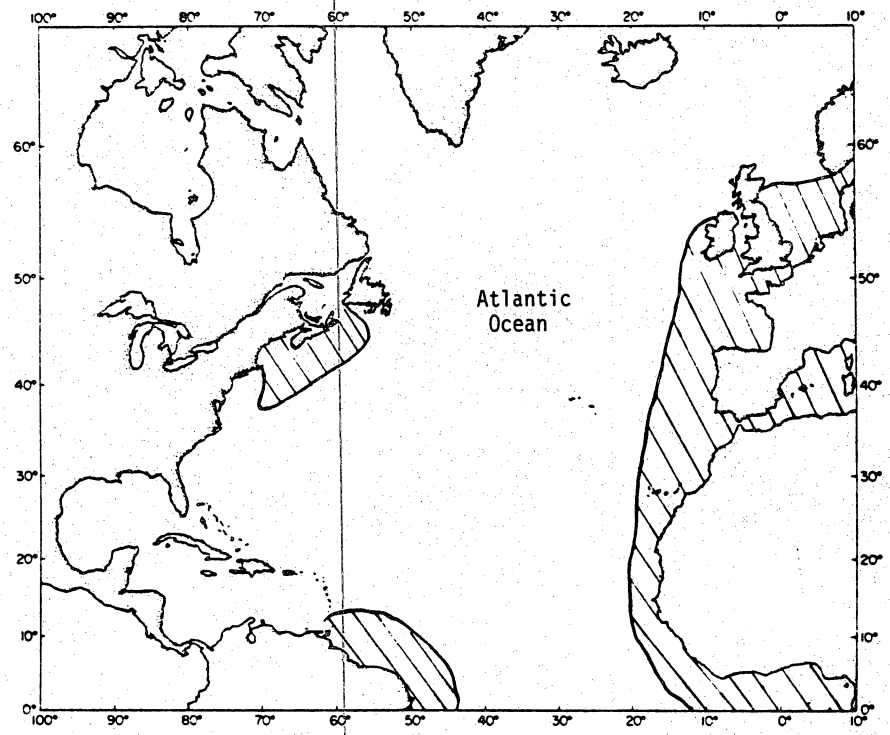


Figure 1. Atlantic Ocean distribution of Merlucciidae. (Hakes)

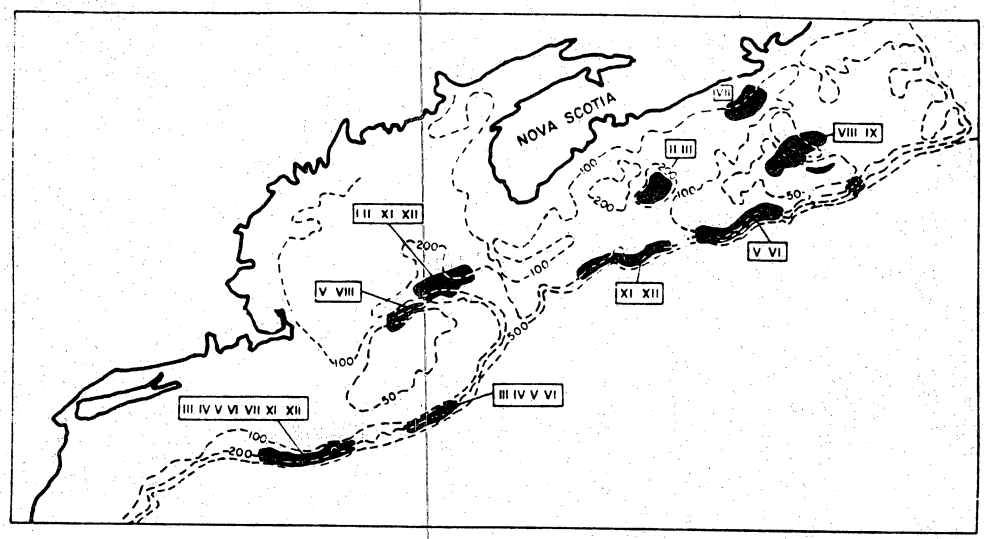


Figure 2. Distribution of silver hake concentrations on Georges Bank and the the Scotian Shelf in the different months of 1964 (from Sarnits and Sauskan , 1967).

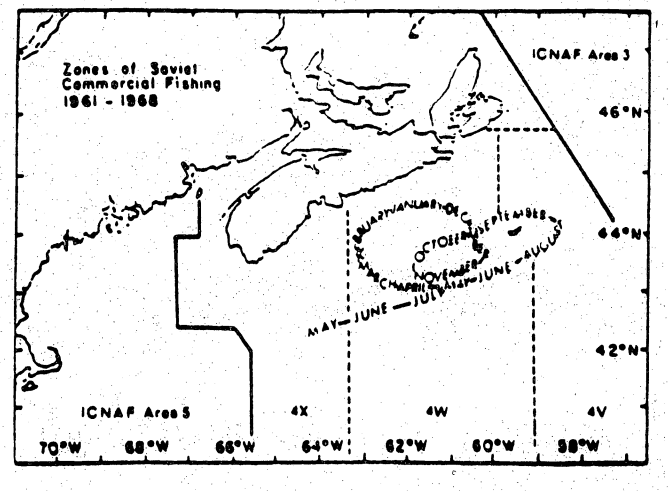


Figure 3. Summary of the annual movements of the Soviet commercial fleet from 1961-1968 in ICNAF Subarea 4 (Clay, 1969).

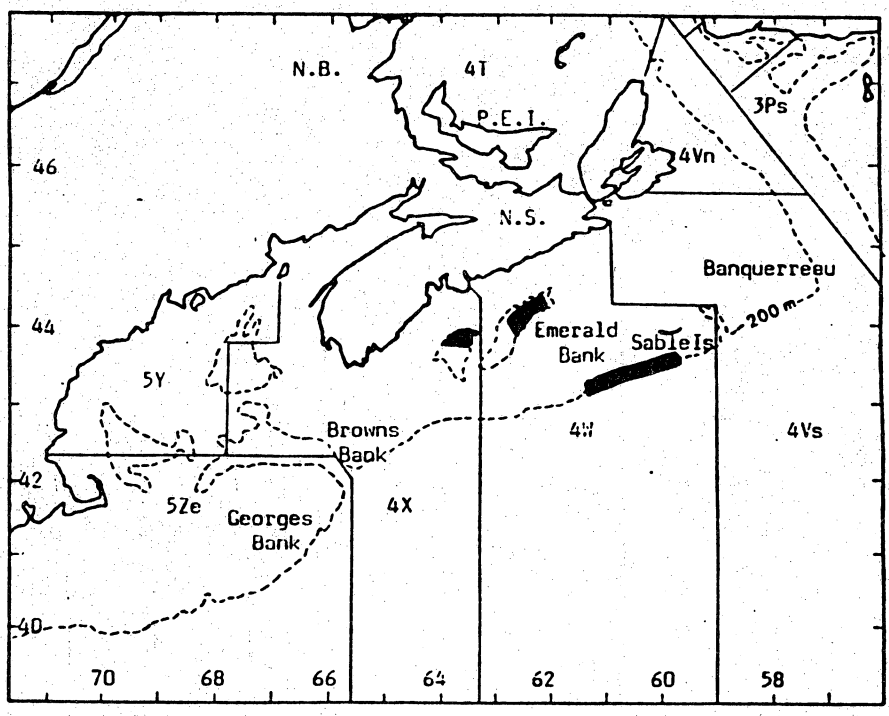
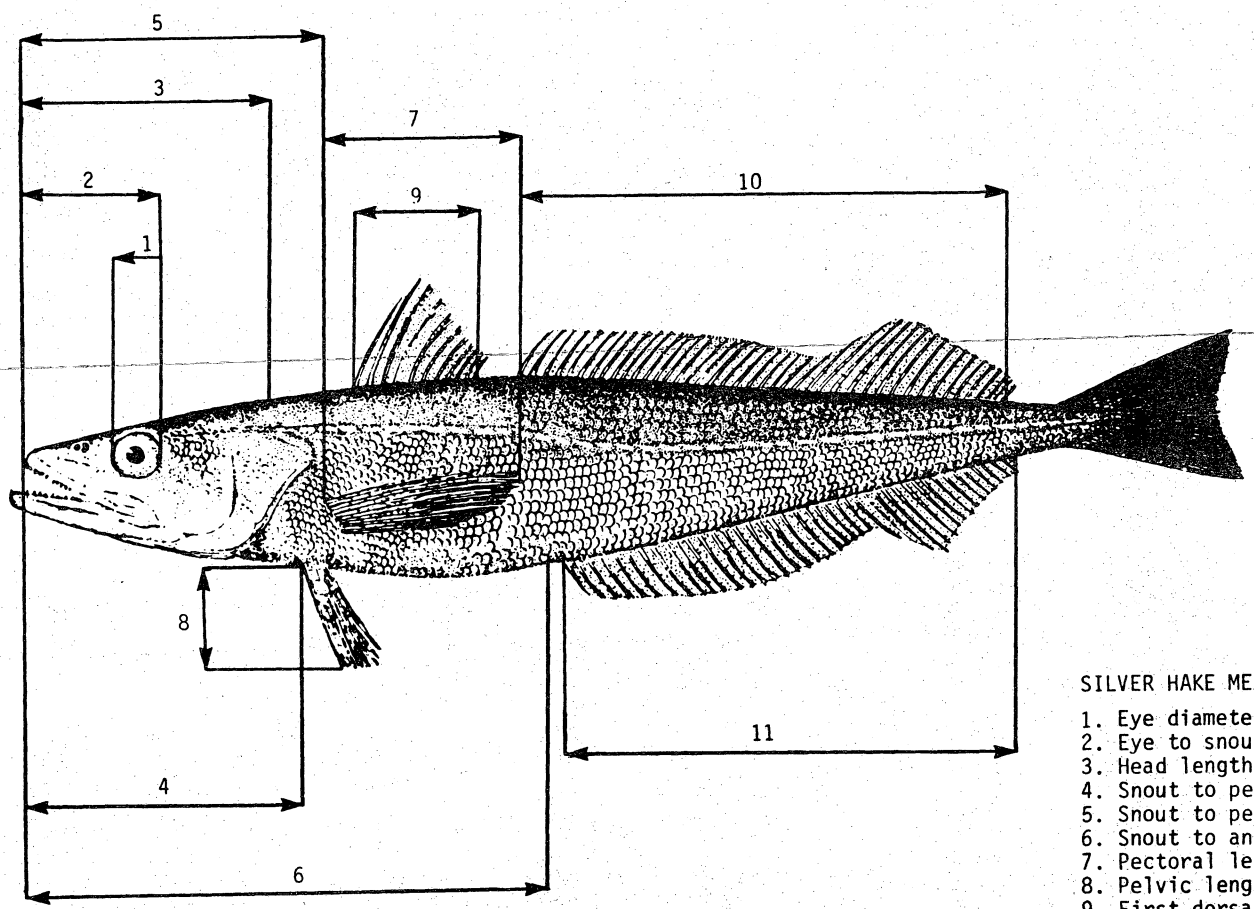


Figure 4. Map of the Scotian Shelf indicating the sampling areas.



SILVER HAKE MEASUREMENTS

1. Eye diameter
2. Eye to snout
3. Head length
4. Snout to pelvic insertion
5. Snout to pectoral insertion
6. Snout to anal opening
7. Pectoral length
8. Pelvic length
9. First dorsal fin length
10. Second dorsal fin length
11. Ventral fin length

Figure 5.

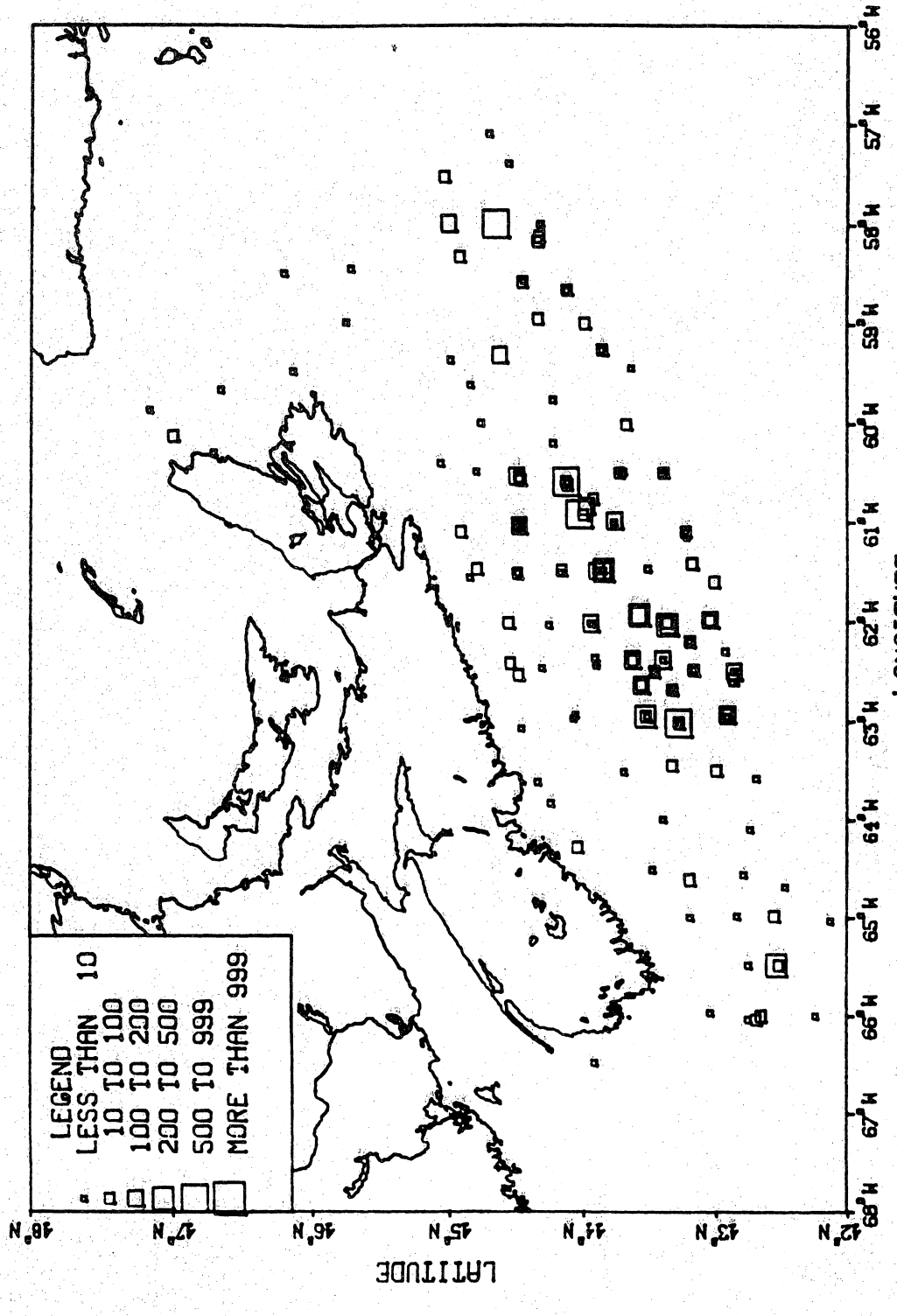


Figure 6. Distribution of silver hake eggs on the Scotian Shelf from SSIP data. (1979-1980)

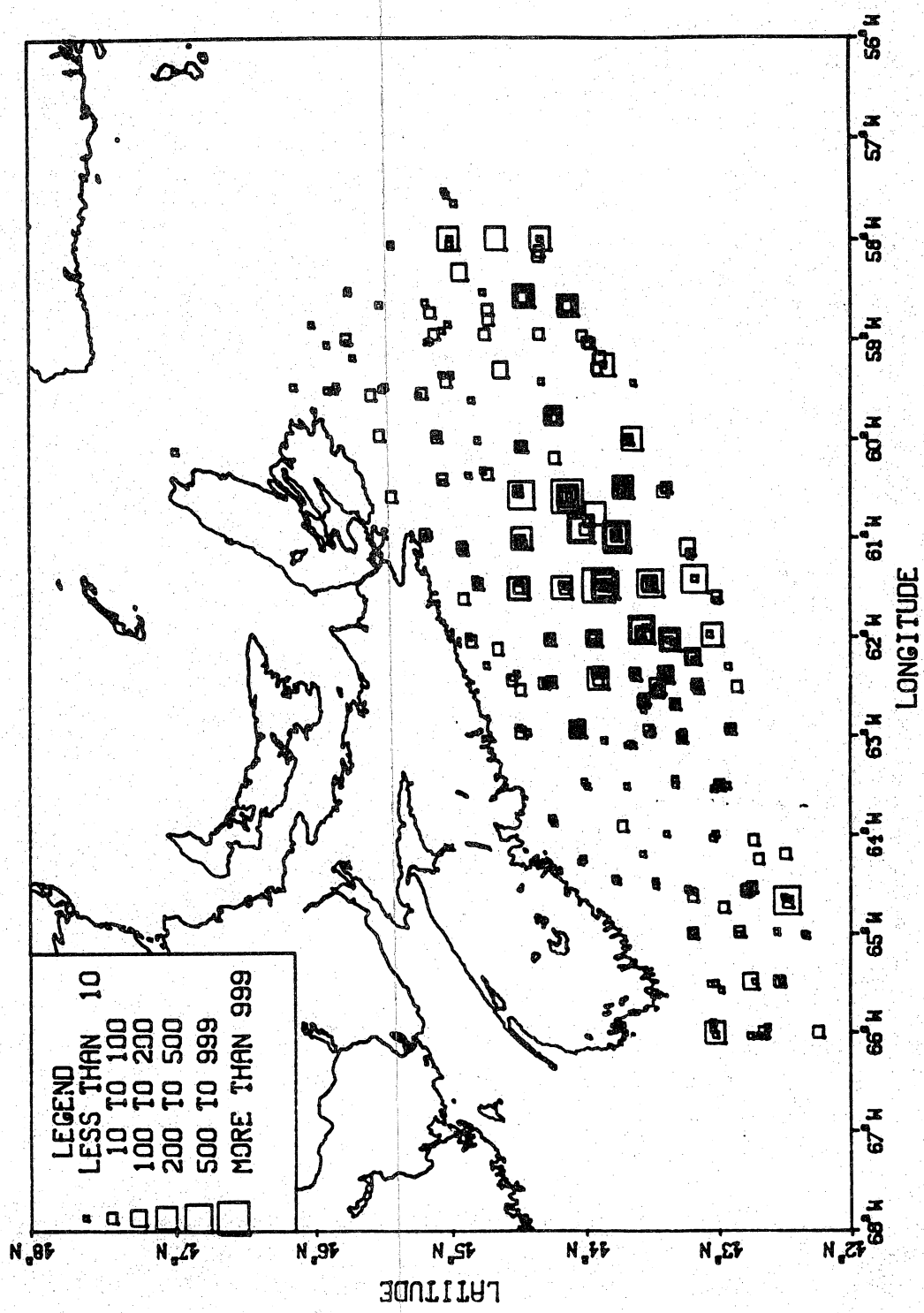


Figure 7. Distribution of silver hake larvae on the Scotian Shelf from SSIP data. (1979-1980)

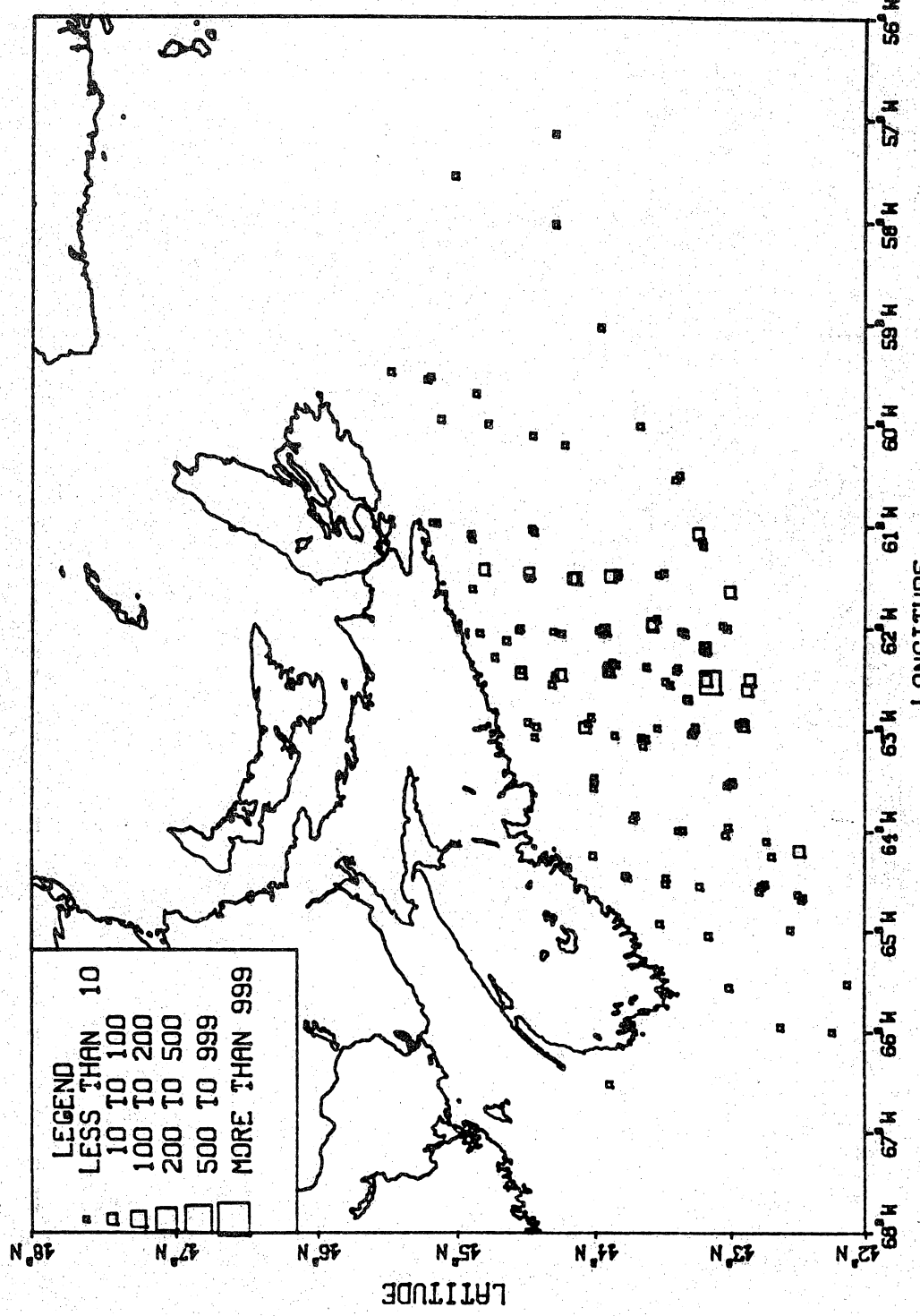


Figure 8. Distribution of silver hake juveniles on the Scotian Shelf from SSIP data. (1979-1980)

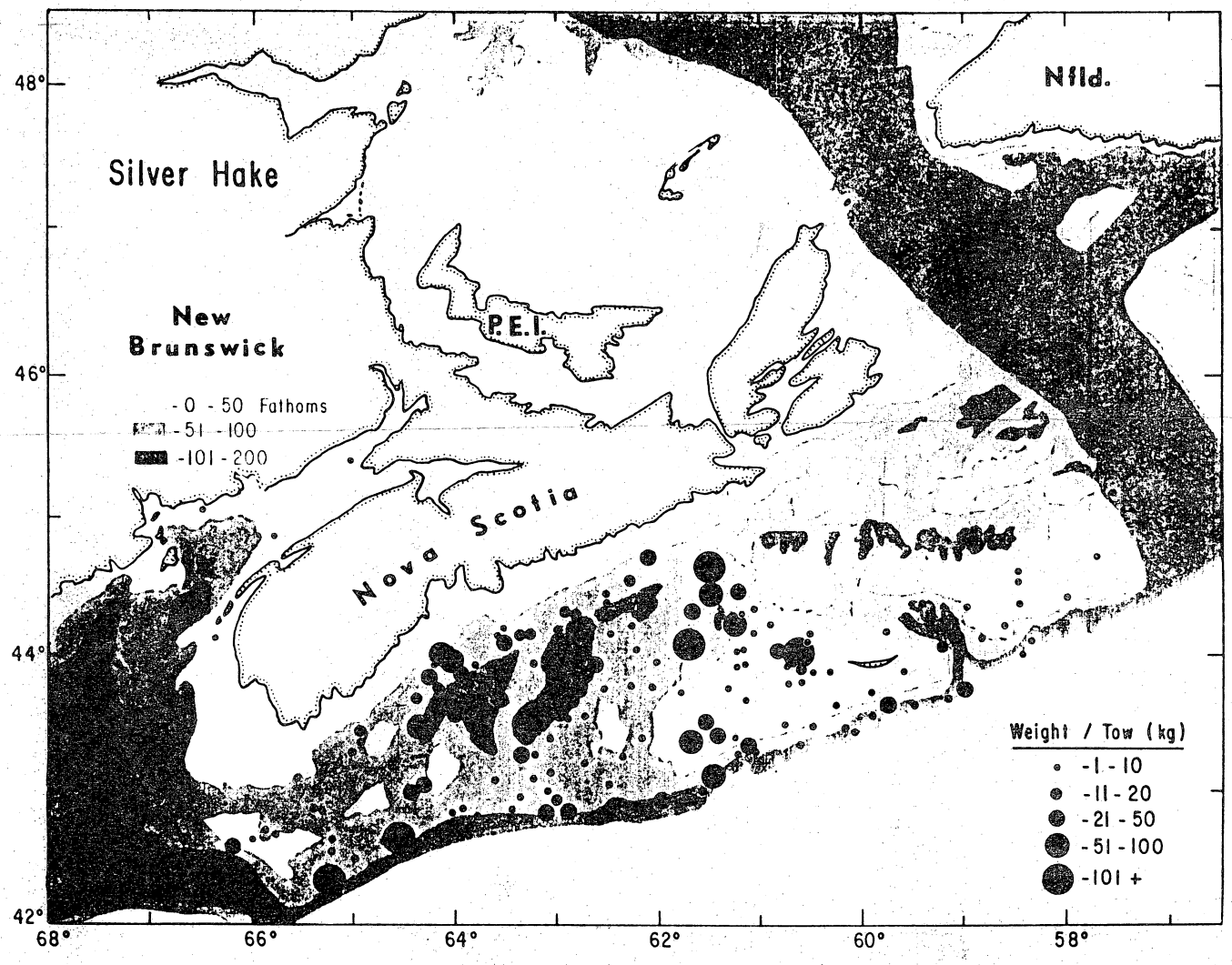


Fig. 9. Silver hake (*Merluccius bilinearis*).

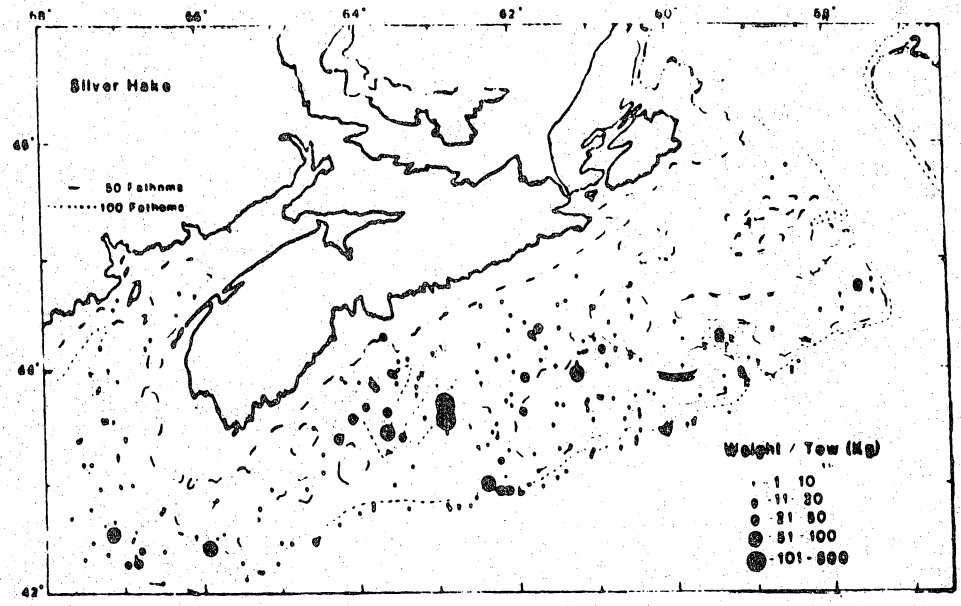


Fig. 10. Spatial pattern of silver hake mean 1+ population weight/tow (kg) from the August 1975-1979 Canadian research vessel cruises. (Map courtesy of Dr. J.S. Scott from unpublished data).

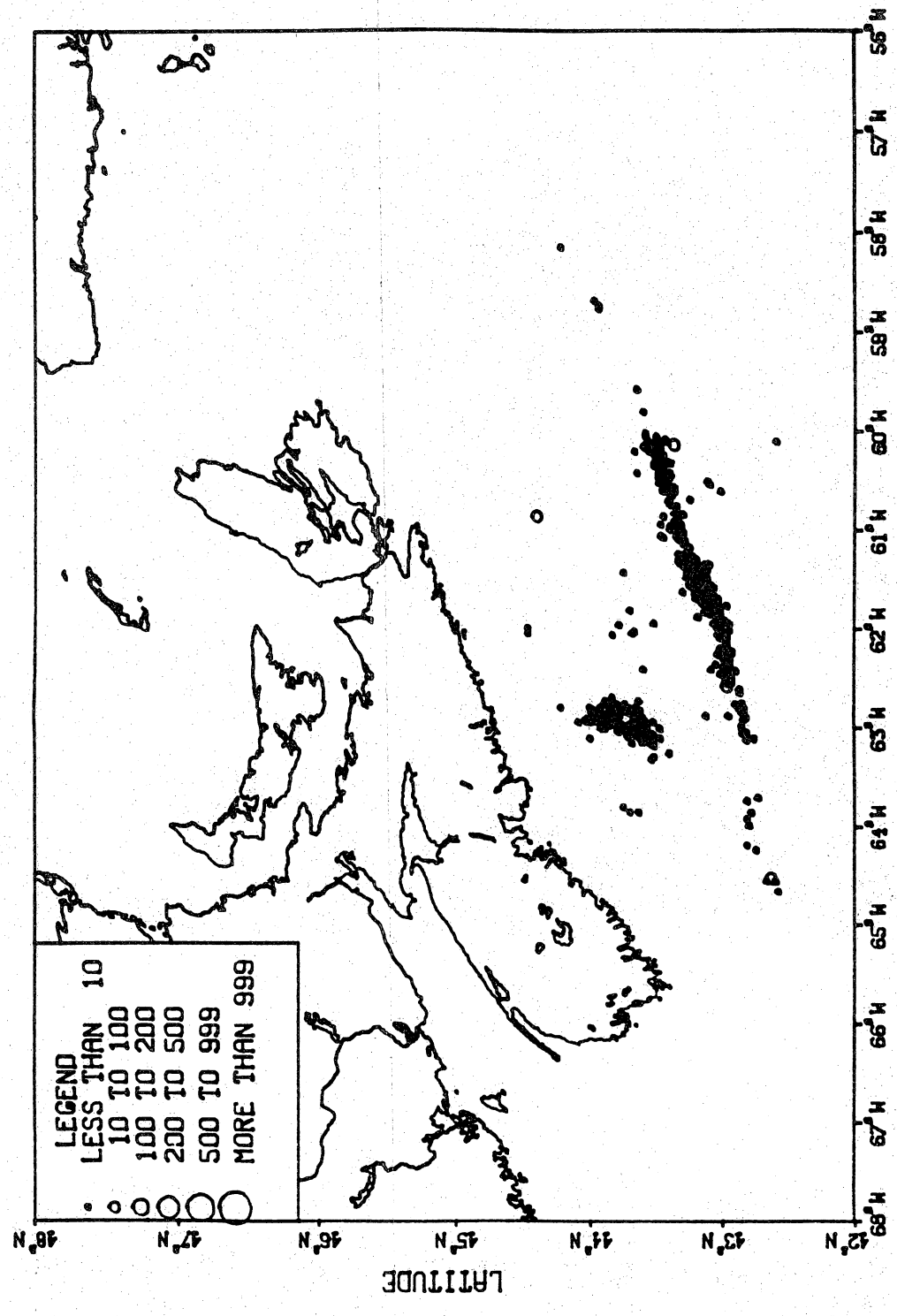


Figure 11. Distribution of adult silver hake catches (t) as observed in the 1977 Scotian Shelf USSR fishery.

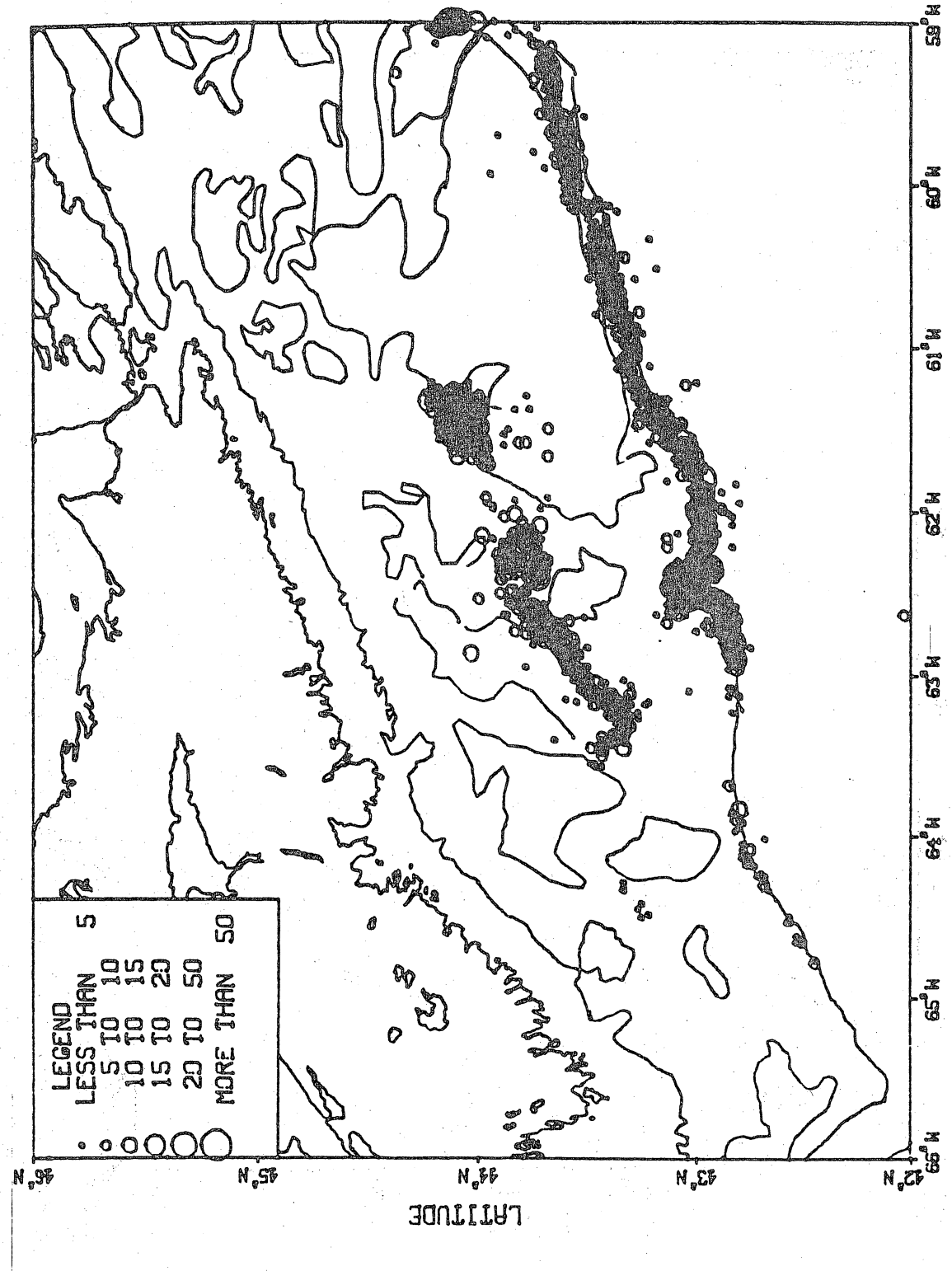


Figure 12. Distribution of adult silver hake catches (t) as observed in the 1978 Scotian Shelf USSR fishery.

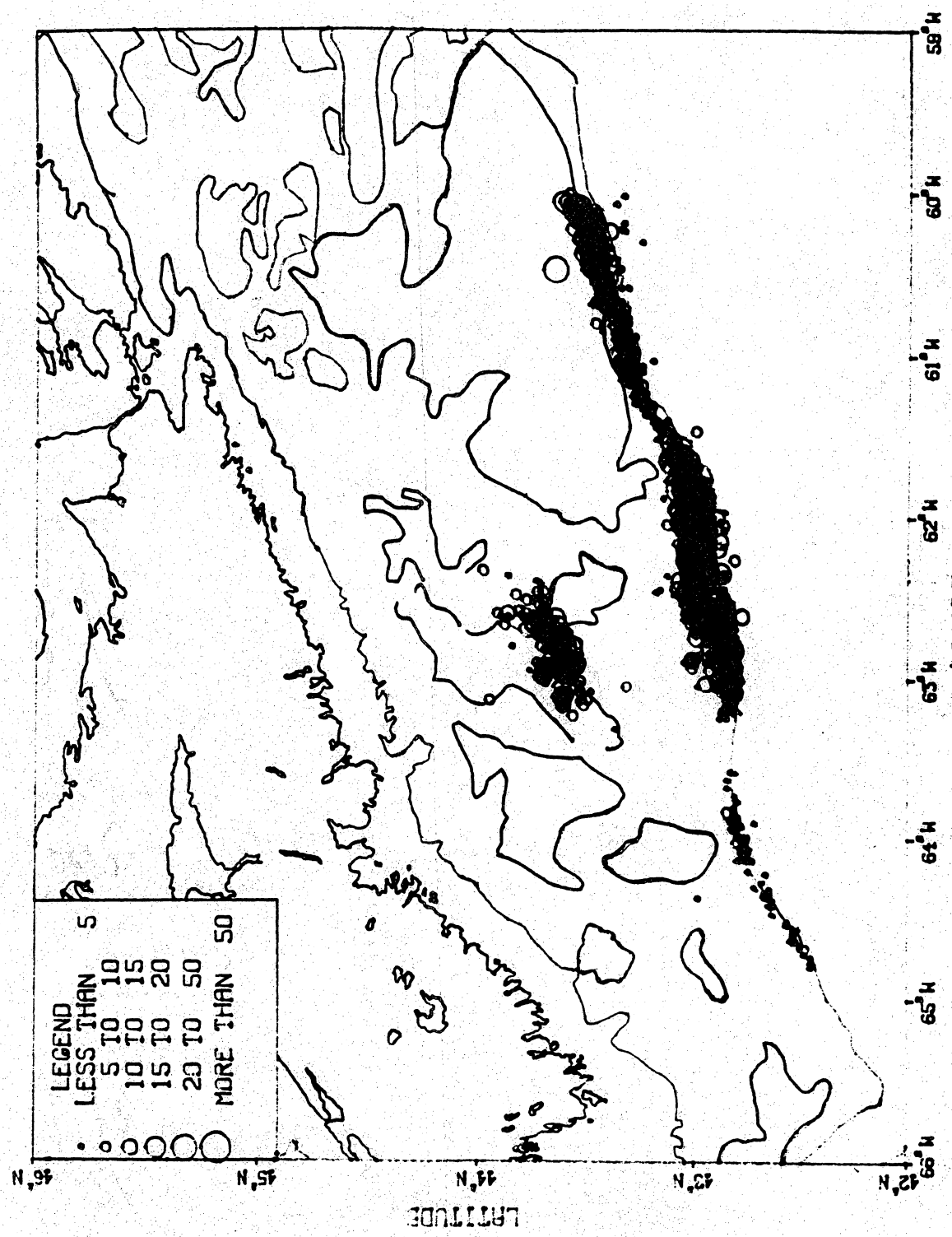


Figure 13. Distribution of adult silver hake catches (t) as observed in the 1979 Scotian Shelf USSR fishery.

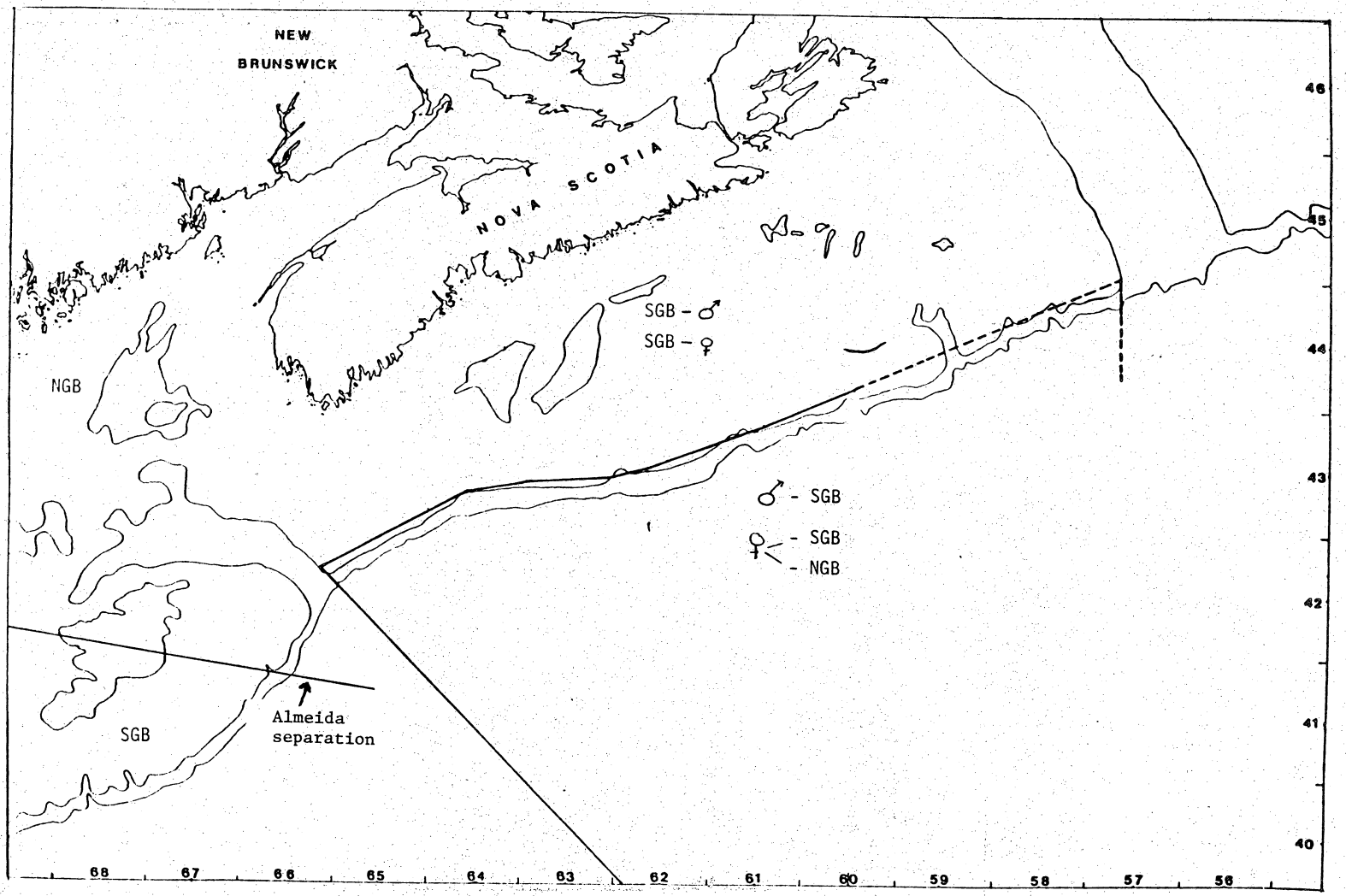


Figure 14. Summary of classification analysis using Scotian Shelf Samples and Almeida's (1982) equations.