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Factors Influencing Scotian Shelf Finfish and Squid Interactions with Special Reference to Silver Hake

by

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Introduction

The management of most marine fisheries is usually complicated by underlying intra- and inter-specific species interactions. Within these broad groups, interactions can be categorized into competition, predation or coexistence models (Pielou 1974). In a multidimensional forum, the role of each of these categories in regulating a dynamic community is often confounded by environmental variables (Overholtz 1982).

Recent studies of possible relationships between temperature and species catches or abundance are many and varied in their approaches. Doubleday and Halliday (1976), Lett and Koeller (1978), and Loucks and Sutcliffe (1980) reviewed the effects of temperature on recruitment and resultant stock sizes for various commercial fish species in the western Atlantic. All indicated a direct relationship between temperature and/or recruitment and stock sizes. Mohn (1981) reported a significant correlation of research vessel squid catch per tow with both bottom temperature and depths fished on the Scotian Shelf.

Perhaps the most comprehensive description of the influence of abiotic factors on the distribution of Scotian Shelf fish species was presented by Scott (1982). He showed that gadoids, such as cod and haddock, prefer similar but different depth, temperature and salinity ranges that are quite different from those of silver hake and redfish. If species can be aggregated by abiotic factors it would be possible to provide insight into niche diversity and interactions. However, in many situations the interaction of several species within a defined space or community is not easily identified in terms of these univariate observations.

The study of possible species interactions may be more enlightening when a heuristic approach is employed. Such techniques have been applied by plants ecologists to examine diverse "polythetic" communities (Greig-Smith et al. 1967, Backham and Noris 1970, and terBraak 1983). Studies of how and why fish species respond to environmental parameters, plus their interspecific interactions will provide insight into the management of fisheries.

This paper deals with a multivariate analysis of selected Scotian Shelf fish species, with a view to identifing interspecific and environmental interactions.

Methods

Background to Analytical Technique

The interaction of several species could be investigated using simple association analysis techniques such as chi-square of presence or absence between pairs of species (Pielou, 1974). However, once the number of species increases beyond two, the number of possible combinations of 2 x 2 tables is K (K-2)/2 where K represents the number of species. To investigate the possible associations between the more common demersal finfish and invertebrates, 40 tables, or more, would be required.

Species associations based on simple chi-square tests are confounded by spatial and temporal parameters of the species or community being investigated (Pielou, 1974). Patchiness of species can also bias the interpretation of results since the chi-square test is directly affected by the number of sampling stations where neither species is present (Pielou, 1969). Moreover the boundaries of a particular sampling program can influence the outcome of these analysis.

The use of regression analysis alone, to evaluate species associations, also has problems similar to those outlined for the chi-square technique. Further, null observations of one species within a sampling unit can often produce a misleading answer in the regression. By themselves association and univariate correlation tests are seldom of prime interest. Of course they can allow the researcher to take the initial steps in testing a basic hypothesis. But a knowledge of species interactions, and the influence of environmental and trophic variables are necessary to interpret any statistical results within an ecological framework.

Although the above techniques are often used in interaction studies there are less cumbersome methods to accomplish the analysis. These techniques are classed as multivariate analyses.

Investigation of species interactions requires a definition of the biological space occupied by the species of interest. Classification of communities may be approached using a cluster analysis of various indices such as proportional similarity ($PS = 2 \sum_{v=1}^{S} \min \left| \frac{X_{iv}}{Z}, \frac{X_{jv}}{Z} \right|$) or its converse the dissimilarity indices. Examples of the latter include the Euclidean distance:

$$d_{ij}^{2} = \sum_{v=1}^{S} \Sigma (X_{iv} - X_{jv})^{2}$$

and the Bray Curtis distance:

$$\left(\frac{\Sigma | X_{iv} - X_{jv} |}{\Sigma (X_{iv} + X_{jv})} \right)$$

in which X_{iv} and X_{jv} denotes the amounts of species V in the biological spaces i and j; S is the total number of species in the two spaces combined. Clustering of the sampling units in a multidimensional coordinate framework is successful if the points fall within several compact, widely separate groups (Pielou, 1969). Such a pattern seldom emerges in natural populations and most classifications are arbitrary.

A solution to this problem is to ordinate the sampling areas rather than rigidly classify them. This techique, principal component analysis (PCA), consists of plotting the points in as few dimensions as possible which account for most of the variance. The main advantages are that this technique obviates the need for setting up arbitary criteria for defining the groupings and there is no need to assume that distinct groups are hierarchically related.

This particular paper uses PCA to investigate biological space. Then within that defined space a canonical correlation analysis (CCA) of the biological parameters for various species will be conducted to study the abiotic-biotic interrelationships. CCA is similar to PCA except that it attempts to maximize the amount of the relationship between two sets of variables rather than maximizing the variance amongst all variables, regardless of their affiliation. The identification of intercorrelations between variables within sets via a correlation matrix is tested by CCA. Examination of the loading of individual cannonical variates will either complement or refute the correlation matrix.

Although CCA is not as robust as PCA, its use in ecological research is gaining popularity. It does permit the simultaneous analysis of all variables without defining a dependent and independent set of variables. To accomplish the same set of analyses using a multiple regression would be very laborius indeed.

Data Selection

(1) Research vessel data

Research vessel data from the Scotian Shelf were analysed in this study of interspecific species interaction with environmental variables. These data consisted of set by set observations taken during the 1970-1980 Scotian Shelf summer groundfish research vessel cruises. Physical observations consist of location, depth, surface and bottom temperatures, and salinity. Catches of cod (Gadus morhua), haddock (Melanogrammus aeglefinus), pollock (Pollachius virens), squid (Illex illecebrosus), silver hake (Merluccius bilinearis), yellowtail flounder (Limanda ferruginea), red hake (Urophycis chuss), and redfish represent the biotic component.

Sediment size (bottom types) for the study area were added to the above data set and are transposed from contoured geological map numbers 4039-G, 4040-G and 4041-G printed by the Surveys and Mapping Branch, Department of Engery Mines and Resources, Ottawa, Ontario, Canada. These composites were based on grab samples and echogram analysis conducted at the Bedford Institute of Oceanography (Fig. 1, King 1967). Each bottom type is divided into 4 particle sizes; gravel, sand, silt and clay. The bottom type contours were ranked by mean sedimentary particle size based on the percentage of each of the above 4 particle sizes in each contour (Table 1 after Mahon, pers. comm.)

The other physical parameters collected or assigned at each station (set) were bottom and surface temperatures, collected by reversing bottle (Nansen) and surface bucket methods (Koeller, P., MS 1982), and salinity samples collected and later processed at the Bedford Institute of Oceanography.

Species catches were expressed as numbers based on actual counts or a conversion from weights to numbers using a length weight key for the total cruise. These were standardized to towed distance (numbers x 1.75/tow distance (miles)). Numbers were used because certain species, most notably squid, were too small to weigh with any precision on the vessel. Species counts were modified to stabilize variance by a square root transformation (Snedecor and Cochran 1967).

(ii) Trophic data

There is a paucity of food and feeding data for the Scotian Shelf. Several sources from species specific studies have been amalgamated. However, these data do not take into consideration both spatial or temporal variations. Therefore these data may be regarded as a qualitative representation of possible dietary overlap. More detailed studies of Georges Bank and Browns Bank are available in Langton and Bowman (1980) and Vinogradov (1972).

Recently a new initiative has been undertaken by several scientists to collect food and feeding data for various Scotian Shelf species. Stomachs from several species excluding silver hake, were examined at sea by fisheries observers. When possible prey species were keyed to genus and in certain cases to species. Silver hake stomachs were frozen or put in 10% buffered formalin. These were returned to the lab for later analysis.

Dietary overlap was calculated using the method of Shorygin (Ivelev, 1961) as outlined by Langton and Bowman (1980);

$$PS = 100 - 0.5 \Sigma |a-b|$$

where PS = percent similarity, a = percent occurrence for a given prey group for predator a and b = percent occurrence of the same prey group for predator b.

Results

Biological Space Definition

The results from an analysis of the environmental factors using the PCA technique are presented in Tables 2 and 3. Bottom temperature, sediment size, and salinity are correlated with all physical parameters ($p < 0.1$). Both bottom temperature and salinity have been increasing over the 1970-80 period demonstrating a consistent gradient over the Scotian Shelf (Table 2). As latitude increases (northward) the bottom temperature and salinity decrease. As longitude increases (westward) both of the above environmental variables as well as sediment size increase simultaneously. Thus, moving from Banquereau Bank towards the western areas of the Scotian Shelf and into the southern Fundian Channel, the bottom temperature, sediment size and salinity increase (Figure 2). Areas along the Scotian Shelf - Nova Scotian coastline have colder more saline waters than those near the Shelf slope and adjacent areas.

Contours of bottom temperature and salinity support the above observations (Figures 3 and 4). Water along the Shelf Break and Nova Scotian coastline is colder (1-5°C) than waters in the central portion of the Shelf (9°C) during the months of July and August. Salinities range between 30 and 34‰ with the middle areas of the Shelf more saline than those along the Shelf Break. There is a slightly noticeable gradient effect of salinity from Banquereau through to Browns Bank.

The area associated with Sable, Emerald, and the western and eastern parts of Browns Banks are usually dominated by warm (7-9°C) and saline (34‰) water during July and August. The Banquereau and Middle Bank areas have bottom temperatures in the range of 3-5°C and salinities slightly less (33‰) than the other above mentioned area. This would suggest two separate hydrological areas.

The depth ranges surveyed (31 to 499, mean = 132 ± 74 m) generally decreased from Banquereau westward to the Fundian Channel. Salinity, bottom temperature, and sediment size show positive correlations with increasing depth: greater depths are associated with colder more saline water. The particle size of sediment found in deeper areas is in the range of sand or gravel with fine silt and sandy clay generally found on the Banks (Figure 1).

The first three components from the PCA of the above environmental variables account for 72% of the total variance (Table 3). As suggested by the correlation matrix of Table 2, depth, sediment size, and salinity load more on the first component explaining approximately 34% of the total variance associated with the research vessel environmental data. The second component accounts for 22% of the residual variance. Latitude is largely described by the second component while bottom temperature, salinity, and longitude are inversely related. The third component delineates the surface temperature variate. The other variables are marginally contributing to the ascribed residual variance of the third component (15%). Graphically, these variable loadings show that bottom type (sediment size) and depth and salinity are strongly loaded on component 1 while latitude, longitude, and bottom temperature are loaded almost equally but of opposite signs on the second component (Figure 5).

Although these results reflect the correlations described in Table 2, the definition of biological space may be oversimplified. Case loadings for component 1 against components 2 and 3 suggest no clear pattern or clustering (Figure 6). However, there may be some east-west gradients but these are not accounting for much of the variance. This places any further studies of interactions in this paper within the confines of the Scotian Shelf rather than within subareas or pockets of the total area surveyed.

Abiotic-Biotic Interrelationships

Canonical correlation of environmental (abiotic) and species (biotic) variables is used to identify and describe the significant interrelationships on the Scotian Shelf. A correlation matrix of these variables indicates a large number of significant correlations ($p < .01$) (Table 4). Many of these are obvious and can be explained as responses to the geography of the Scotian Shelf: these will not be dealt with in this paper.

Of interest are the three types of interaction relationships described by this canonical correlation analysis. These are the biotic, abiotic, and biotic-abiotic interactions. The abiotic interrelationships were described above (Table 2). The species (biotic) correlations give some indications of causal relationships (Table 4). For example, silver hake abundance is positively correlated with catches of squid (Illex) and red hake, while they are negatively correlated to cod abundance. Squid catches are negatively correlated to both cod and yellowtail catches and positively correlated to red hake catches. Cod abundance increases simultaneously with those of haddock, red hake, and yellowtail while there is a negative relationship of cod with deeper water species such as silver hake, squid, and redfish. Haddock are positively correlated with pollock abundance and negatively correlated with redfish.

The interrelationship of species catches to abiotic variables display some rather obvious alignments of species with depth and bottom temperature. These are well documented in the available literature (Scott, 1982). As an example, previously mentioned deep water species, such as silver hake, squid, and redfish are positively correlated with increasing depth and salinity. Conversely shallow water species, such as haddock, show positive correlations to warming bottom temperatures at decreasing depth and particle size of the bottom sediment (Table 4). Interestingly, cod and yellowtail, generally regarded as a shallow water species display a negative correlation to depth, salinity, bottom type, and bottom temperature. It would appear that cod and yellowtail prefer shallow water areas with silt or clay sediments and where the bottom hydrography is cold and saline. Haddock prefer geologically similar shallow water areas but those which have warm bottom temperatures. Haddock, unlike all the other species studied, does not show a response to salinity.

During the period studied (1970-1980), the abundance of squid, red hake, and haddock have been increasing while redfish have been decreasing. Interestingly, the Shelf wide abundance of silver hake, cod, pollock, and yellowtail do not show a similar trend in abundance. These observations reflect the biomass trends of the major finfish stocks of the Scotian Shelf (Figure 7). The fluctuations in cod, silver hake, and pollock abundance are significant biologically but are not detected in the correlation coefficients over the 1970-1980 time period (Table 4).

Geographically, silver hake, haddock, and pollock abundance increases while that of cod and yellowtail decrease from east to west (Figures 8a and 8b). In a south to north direction cod and redfish catch abundance increases whereas that for silver hake, squid, haddock, and red hake decreases.

The above observations suggest that the cod, redfish, and yellowtail abundance in the Banquereau and Sable Island Banks area are the largest on the shelf. Silver hake, hadock, and pollock favour the western areas of the Scotian Shelf. Further as the western areas of the shelf have continued to warm over the study period, stocks such as squid, red hake, and haddock have responded to this trend and continued to increase in abundance in this area.

With the many significant interactions outlined above, it is difficult to determine which are the most important in describing the observed species distributions. Canonical correlation analysis provides a technique of sorting out these biotic-abiotic interactions and to indicate those which are most significant. Since this analysis relaxes the multinomial criterion which most other statistical analysis require (Morrison 1976), a linear equation may be constructed from Table 5.

The first two canonical variates have a correlation of .723 and .625 accounting for 53% and 39% of the variance respectively. Variates beyond the second have statistically significant correlaton coefficients but are of little use in this study as the amount of variance accounted for is small compared to the first two variates. The linear equations used to describe these variates are:

First Canonical Variate:

U_1 = .596 yellowtail + .377 haddock - .367 redfish - .209 silver hake
V_1 = .527 depth - .487 salinity - .451 latitude - .330 longitude

Second Canonical Variate

U_2 = .709 haddock + .469 silver hake - .213 redfish
V_2 = .505 longitude + .390 salinity - .298 depth + .291 bottom temperature

Although biological space was not clearly identified in this study using PCA there appears to be a gradient of environmental factors identified by the equations V_1 and V_2 above. The first canonical variate suggests a Sable Island - Banquereau Banks area. The second canonical variate suggests an Emerald-Browns Banks area.

The first canonical variates (V_1, U_1) indicate that in areas where depth increases and salinity, latitude, and longitude decrease (e.g. Sable Island Bank), yellowtail and haddock are found to be strongly correlated with each other. Conversely, redfish and silver hake are negatively correlated with yellowtail and haddock but occur in the same area.

The second canonical variate (V_2, U_2) describe a gradient of biological space from east to west on the Scotian Shelf where salinity and bottom temperature are increasing at shallower depths. The biotic correlations, between haddock and silver hake increase while the relationship of redfish to these two species decrease. Concisely stated, in areas such as Sable Island Bank, yellowtail and haddock appear to dominate and have a positive interrelationship. Of all the species studied, both redfish and silver hake are generally not present in this defined area. In western areas of the Shelf, such as Browns Bank, silver hake and haddock are dominant and highly correlated. Again, redfish is most conspicuous by its strong negative correlation with these species in this area.

Trophic Relationships

Results from historical studies of trophic relationships on the Scotian Shelf generally agree in their description of species diet (Table 6). Newly collected trophic data however do not agree for cod, pollock, haddock, and red hake (Table 7a). This is easily accounted for by the areas sampled. Langton and Bowman (1980) sampled the western Scotian Shelf while this current study sampled the total Shelf. Samples for yellowtail flounder have not been collected to date.

The most striking observation from these data are the heavy consumption of crustacea, especially euphasids by haddock, pollock, and silver hake, and the low percentage of silver hake stomachs which demonstrate cannibalism.

Diet similarity indices (Table 7b) show the relative degree of competition between species for the same food items.

Discussion

The interrelationships between the major groundfish and squid species on the Scotian Shelf have been reported by only a few authors. Knight and Tyler (1973) suggested a species assemblage structure for the Sable Island, Roseway and general deep Plains areas. These authors argued that species groups were found to cluster in distinct geographic assemblages which provided some benefit to the resident species. Those benefits were not explored.

Hare (1977) and Scarratt (1980) presented synoptic overviews of single species distributions. These plots provide a useful back drop to this study by illuminating those areas where species do co-occur and may be interacting. The most noteable work has been done by Scott (1976, 1982). In these papers, Scott introduces abiotic factors as possible controlling variates. This paper permits a closer examination of the interactions between and amongst species and their environment on the Scotian Shelf.

The wide range of variable geographic and hydrographic conditions on the Scotian Shelf as well as the fact that only one time period in the year is investigated is perhaps the main contributor to an inability to clearly define unique species assemblages or biological space at this time. Regardless, some rather interesting ordination (gradient) effects and interreltaionships have been identified. The alignment of species correlations on what appears to be a depth gradient is as expected. The deep water species such as silver hake and squid are positively correlated with each other as are shallow water species cod, haddock, and pollock (Table 4). Of special note is the observation that haddock is correlated (negatively) with only one other species that being redfish. In any area on the Scotian Shelf, redfish and haddock appear to be mutually exclusive. The positive correlation of silver hake with red hake is probably a response to silver hake sqawning in shallow waters.

Individual species responses to abiotic variables are generally described in Scott (1982) but certain other interesting phenomena have been seen in this study. For example, bottom temperature, salinity, sediment size, and depth are all positively correlated with each other. Only silver hake and squid show positive responses to all of these variables simultaneously. A further observation is that cod and haddock are positively correlated yet react differently to the same abiotic variables. Both prefer shallow areas where the bottom is clay or silt. However, cod prefer colder more saline bottom regimes while haddock prefer warmer bottom temperatures and show no reaction to salinity. Further, there is a gradient effect of both species from the northeast, where cod is more abundant, to the southwest, where haddock are more abundant. Thus ordination of these two species strongly suggests that cod and haddock may not be as interrelated as earlier data analyses suggest (Table 4). This would suggest that on the Scotian Shelf there are areas to the west which are exclusive to haddock and areas to the northeast which are exlusive to cod. This observation is supported by Figure 8a. The area where cod and haddock appear to be most prevalent is in the Sable Island, Middle Bank area. This area is well identified as a "lucrative" fishing ground for cod and haddock (Waldron, 1980).

The description of Sable Island Bank-Middle ground as an area of interaction between haddock and yellowtail requires further data on trophic interactions. Shelfwide similarity in diet between haddock and silver hake does not suggest competition for food resources (Table 7b). Silver hake are known to spawn in the shallow waters of this area during the July-August period (Noskov et al., 1982). This could account for the high correlation between the two species. There is no evidence which suggests that silver hake do not feed during the spawning period and thus it could be assumed that predation by the mature silver hake on juvenile haddock present in the area would occur (Tables 6 and 7a). A more subtle impact is that during periods when bottom temperature and silver hake biomass are increasing the chance of the silver hake placing predatory and/or competitive pressure on haddock could increase. Further studies of competition and predation of these two species in this area is encouraged.

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Table 1. Scotian Shelf bottom (sediment) types expressed in percent Composition and Mean Rank (data interpreted from King 1967).

Class	Map Code	PARTICLE SIZE Gravel %	Sand %	Silt %	Clay %
Emerald Silt	5A	0	30	25	45
	5B	15	50	25	10
Sambro Sand	6A	10	60	15	10
	6B	20	50	20	10
La Have Clay	7A	0	0	75	25
	7B	0	0	25	75
Sable Island Sand	8A	25	75		
	8B	75	25		

Ranks: Gravel = 4, Sand = 3, Silt = 2, Clay = 1

Table 2. Correlation matrix of canonical variables produced from Principal Components Analysis.

	YEAR	LAT	LONG	DEPTH	TEMPS	TEMPB	BTMT	SALT
YEAR	1.000							
LAT	-.010	1.000						
LONG	.003	-.492	1.000					
DEPTH	-.020	-.128	.052	1.000				
TEMPS	.021	-.057	-.530	.144	1.000			
TEMPB	.119	-.418	.529	.236	-.176	1.000		
BTMT	.024	.031	.263	.589	-.174	.336	1.000	
SALT	.081	-.380	.105	.705	.251	.484	.400	1.000

Temps = surface temperature, Tempb = bottom temperature
BTMT = sediment type, Salt = salinity.

Table 3. Variance explained and sorted factor loadings for the environmental variables.

		FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
DEPTH	5	.897	0.000	0.000	0.000
BTMT	9	.833	0.000	-.354	0.000
SALT	11	.736	-.463	.299	0.000
LAT	3	0.000	.919	0.000	0.000
TEMPB	7	.359	-.656	-.297	0.000
TEMPS	6	0.000	0.000	.916	0.000
LONG	4	0.000	-.612	-.691	0.000
YEAR	2	0.000	0.000	0.000	.989
			1.879	1.649	1.028

FACTOR	VARIANCE EXPLAINED	CUMULATIVE PROPORTION OF TOTAL VARIANCE
1	2.746026	.343253
2	1.752707	.562342
3	1.224135	.715358
4	1.011524	.841799
5	.492210	.903325
6	.376062	.950333
7	.222710	.978172
8	.174626	1.000000

Table 4. Canonical correlations of abiotic and biotic variables from July-August 1970-1980 research vessel cruises.

Correlations

	HKS	SQI	COD	HAD	POK	HKR	YEL	RED	YEAR
HKS	1.000	-	-	-	-	-	-	-	-
SQI	0.123	1.000	-	-	-	-	-	-	-
COD	-.147	-.109	1.000	-	-	-	-	-	-
HAD	-.074	-.032	0.131	1.000	-	-	-	-	-
POK	0.053	0.006	-.001	0.183	1.000	-	-	-	-
HKR	0.236	0.087	-.083	0.022	0.034	1.000	-	-	-
YEL	-.089	-.121	0.342	-.002	-.131	-.038	1.000	-	-
RED	0.073	0.032	-.092	-.131	0.096	-.006	-.173	1.000	-
YEAR	0.043	0.137	0.059	0.209	0.073	0.159	0.019	-.111	1.000
LAT	-.202	-.087	0.157	-.331	-.077	-.081	0.068	0.119	-.021
LONG	0.173	-.045	-.144	0.283	0.234	0.035	-.333	-.073	-.029
DEPTH	0.260	0.132	-.353	-.285	0.022	0.047	-.446	0.392	-.014
TEMPS	0.025	0.128	-.014	-.099	-.145	0.036	0.119	0.083	-.082
TEMPB	0.377	0.182	-.206	0.198	0.173	0.147	-.181	0.031	0.133
BTMT	0.209	0.098	-.258	-.253	0.125	0.050	-.367	0.249	0.007
SALT	0.343	0.272	-.367	-.077	0.124	0.135	-.414	0.269	0.070

	LAT	LONG	DEPTH	TEMPS	TEMPB	BTMT	SALT
LAT	1.000	-	-				
LONG	-.516	1.000	-				
DEPTH	-.117	0.059	1.000				
TEMPS	-.084	-.443	0.118	1.000			
TEMPB	-.436	0.527	0.204	-.153	1.000		
BTMT	-.028	0.251	0.607	-.151	0.310	1.000	
SALT	-.384	0.142	0.703	0.227	0.454	0.424	1.000

Temps = surface temperature, Tempb = bottom temperature
BTMT = sediment type, Salt = salinity.

Table 5a. Standardized canonical coefficients (mean zero, standard deviation one) from analysis of July-August 1970-1980 research vessel cruises.

STANDARDIZED COEFFICIENTS FOR CANONICAL VARIABLES FOR FIRST SET OF VARIABLES

	CNVRF1	CNVRF2	CNVRF3	CNVRF4	CNVRF5	CNVRF6	CNVRF7	CNVRF8
HKS	-.209	.469	.344	-.403	.398	.535	.040	-.329
SQI	-.020	.185	.534	.575	-.228	-.221	-.461	-.269
COD	.180	-.193	-.237	.349	-.238	.370	-.184	-.291
HAD	.377	.709	-.082	-.344	-.433	-.038	-.222	.275
POK	-.089	.171	-.256	.516	.692	.029	-.205	.422
HKR	.042	.095	.121	.459	-.307	.117	.789	.319
YEL	.596	-.156	.572	-.126	.388	-.136	-.044	.411
RED	-.369	-.213	.322	-.216	-.369	.279	-.296	.656

STANDARDIZED COEFFICIENTS FOR CANONICAL VARIABLES FOR SECOND SET OF VARIABLES

	CNVRS1	CNVRS2	CNVRS3	CNVRS4	CNVRS5	CNVRS6	CNVRS7	CNVRS8
		.341	.134	-.229	-.149	.422	-.238	-.696
YEAR	.152	.163	-.092	.667	-.487	.015	.630	.364
LAT	-.451	-.178	-.325	.451	-.220	.989	-.670	.006
LONG	-.320	.505	-1.073	-.031	-.503	.512	-.269	-.560
DEPTH	-.527	-.298	.056	-1.018	-.704	.389	.644	.608
TEMPS	.017	.103	.212	-.024	-.435	.419	.021	-.847
TEMPB	.077	.291	.740	-.298	.501	.714	.053	.559
BTMT	-.099	-.137	.125	.489	.785	-.238	.611	-.809
SALT	-.487	.390	-.095	.929	-.065	-.624	-1.144	-.081

1. CNVRFI = The first canonical variate coefficients for the first set of variables.
   CNVRSI = The first canonical variate coefficient for the second set of variables.
2. Temps = surface temperature BTMT = sediment type
   Tempb = bottom temperature Salt = salinity

Table 5b. Eigenvalues for canonical correlation analysis of abiotic and biotic variables.

EIGENVALUE	CANONICAL CORRELATION	NUMBER OF EIGENVALUES	BARTLETT'S TEST FOR REMAINING EIGENVALUES CHI-SQUARE	D.F.	TAIL PROB.
			2471.82	72	0.0000
.52655	.72564	1	1285.21	56	0.0000
.39108	.62537	2	497.94	42	0.0000
.18284	.42760	3	177.49	30	0.0000
.06253	.25006	4	75.02	20	.0000
.02679	.16366	5	31.93	12	.0014
.01653	.12857	6	5.48	6	.4841
.00258	.05080	7	1.39	2	.5022
.00087	.02946				

Table 6. Summary of various food and feeding studies from the Scotian Shelf.

Prey	▲Cod[1]	▲Haddock[1]	▲Pollock[1]	▲Silver Hake[1]	▲Red Hake[1]	*Squid (Illex)[2]	*Squid[3]	*Silver Hake[4]	*Silver Hake[5]
Polychaeta	0.8	11.8	0.1	+	2.4	-		+	
Crustacea	27.6	14.4	61.2	33.8	88.5	59.5	36.5	89.0	81.3
Amphipoda	0.1	5.0	+	+	1.9			13.0	6.2
Mysidacea	+	+	-	0.1	0.2				
Euphausiacea	8.8	1.7	53.7	28.4	2.3	0.3	30.5	35	65.0
Pandalidae	3.9	1.0	3.1	0.4	71.2	0.3		33.0	4.4
Mollusca	0.6	3.0	+	-	-	26.0		+	1.1
Gastropoda	0.3	0.3	-	-		-		+	
Cephalopoda	+	0.5	+	-		26.0	18.5	+	1.1
Echinodermata	3.6	49.0	-	-	-	-	3.9	+	
Pisces	60.6	3.8	37.1	65.1	0.6	14.5	32.4	8.0	17.6
Clupeidae	12.1	-	4.0	-	-	-			-
Gadidae	6.5	0.8	1.3	51.2	-	10.2	2.8	4.0	.4
Scombridae	1.7	-	-	-	-	-			-
Bothidae	-	-	-	-	-	-			-
Pleuronectidae	-	-	-	-	-	-			-
Others	39.4	3.0	30.5	13.9	0.6	4.3	8.6	4.0	5.9
Unidentified							23.8		11.4
Other groups	0.3	2.0	0.3	+	5.4	-	+	3.0	
Animal remains	5.4	13.0	1.3	1.1	2.9	-	8.5		
Sand and rock	1.1	3.0	+	+	0.2				
No. of stomachs	441	510	224	282	17	304	538	1593	42515
% stomachs empty	8.1	10.0	18.8	33.3	11.8	49.3		50.0	39.0

Source: 1 Langton & Bowman (1980)
2 Vinogradov and Noskov (1979) Emerald Bank
3 Amaratunga et al., (1979)
4 Swan & Clay (1979)
5 Vinogradov (1972). NAFO area 4 - total number of fish for NAFO areas 4-6 were 42,515 of which 61% were empty.

* Percent occurrence

▲ Percent by weight

Table 7a. Percent (occurence) of prey species in predators from the Scotian Shelf during the period 1980-83. Data from Observer Program.

Prey/Predator	Cod	Haddock	Pollock	Silver Hake	Red Hake	Redfish
Polychaeta	3.6 (24)	18.1 (61)	3.2 (2)	.2 (3)	6.1 (2)	
Crustacea	17.9 (120)	50.0 (168)	62.0 (39)	88.0 (1526)	30.3 (10)	43.3 (13)
Mollusca	12.7 (85)	30.8 (104)	6.4 (4)	3.2 (56)	21.2 (7)	
Gastropoda	4.5 (30)	12.4 (42)				
Cephalopoda	8.2 (55)	8.6 (29)	6.4 (4)	3.2 (56)	21.2 (7)	
Echinodermata	2.8 (19)	9.8 (33)				
Pisces	6.3 (42)	1.8 (6)	6.4 (4)	1.7 (30)	18.2 (6)	
Clupeidae				.1 (1)		
Gadidae						
silver hake	6.0 (40)	1.2 (4)	6.4 (4)	1.6 (27)	18.2 (6)	
cod		.3 (1)		.1 (2)		
haddock	.3 (2)	.3 (1)				
Other pisces	33.1 (222)	.3 (1)		4.9 (86)		3.3 (1)
Ammodytidae	32.5 (218)			2.1 (37)		
Scorpaenidae	.5 (3)	.3 (1)		.2 (4)		
Myctophids	.2 (1)			2.6 (45)		3.3. (1)
Unidentified						
Pisces	6.4 (43)	23.1 (78)	28.6 (18)	7.3 (127)	60.6 (20)	13.3 (4)
Fluid	1.6 (11)	22.2 (75)		2.5 (43)		
Total stomachs	671	338	63	1740	33	30

Table 7b. Diet similarity[1] (percent) of main finfish and squid on the Scotian Shelf.

	Cod	Haddock	Pollock	Silver Hake	Red Hake	Redfish
Cod	X					
Haddock	37.15	X				
Pollock	45.50	64.25	X			
Silver Hake	40.25	43.10	68.45	X		
Red Hake	37.30	47.35	53.40	21.85	X	
Redfish	56.25	60.00	73.35	71.30	45.45	X
Squid[2]	55.65	69.70	53.15	52.80	43.85	73.40

[1] % Similarity = $100 - 0.5 \Sigma |a-b|$

[2] Squid data from Amaratunga et al. (1979). Remainder of species data from Table 3(a).

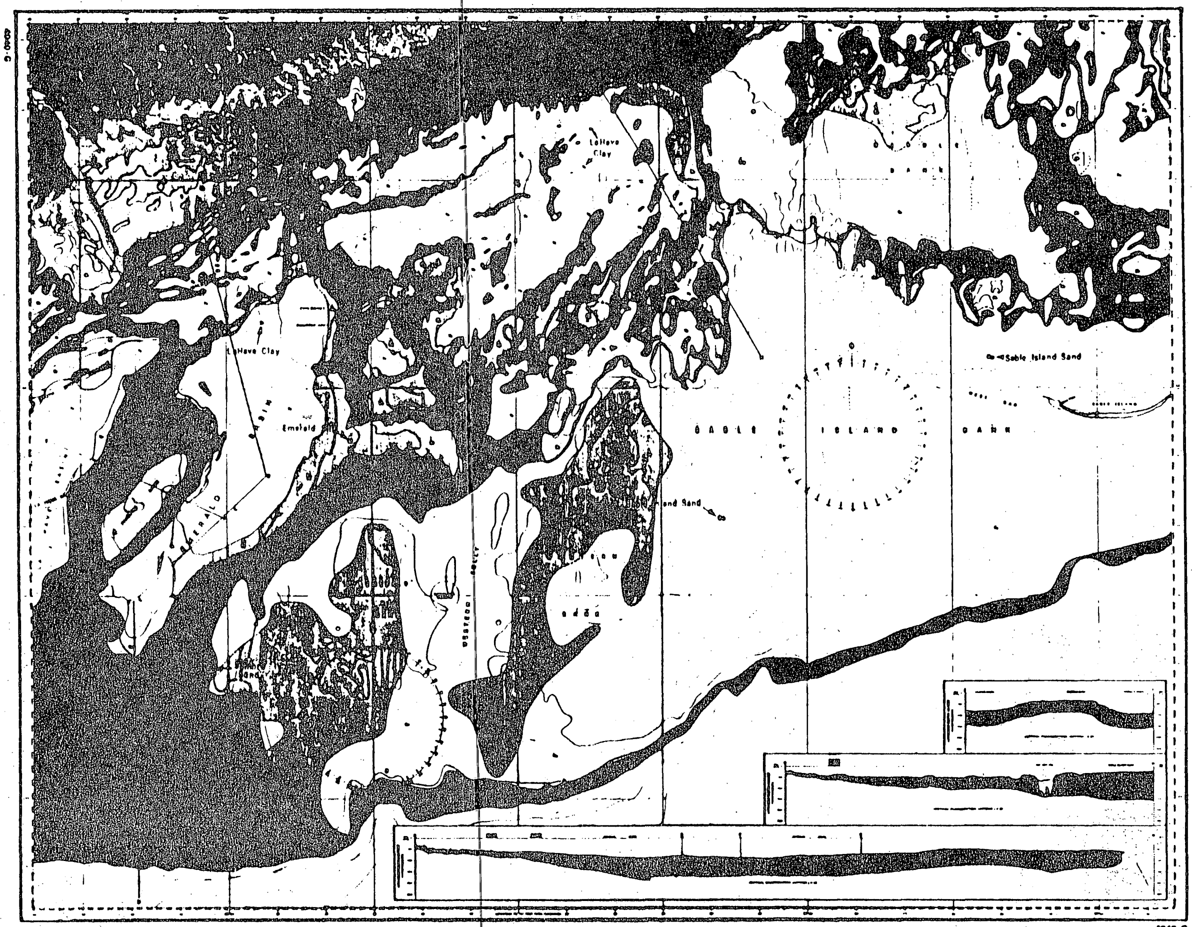

Fig. 1. Sediment types on the Scotian Shelf from Map No. 4040-G, Department of Energy, Mines and Resources.

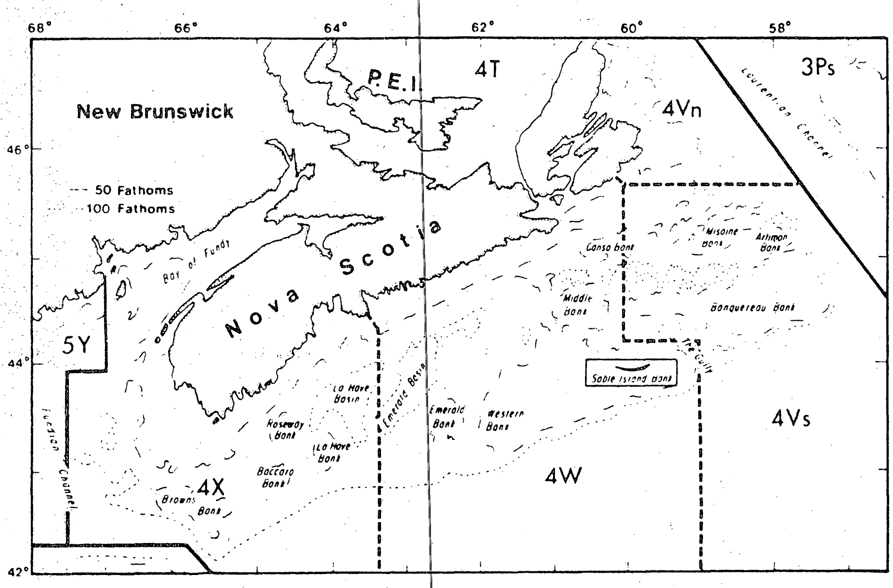

Figure 2. Map of the Scotian Shelf banks.

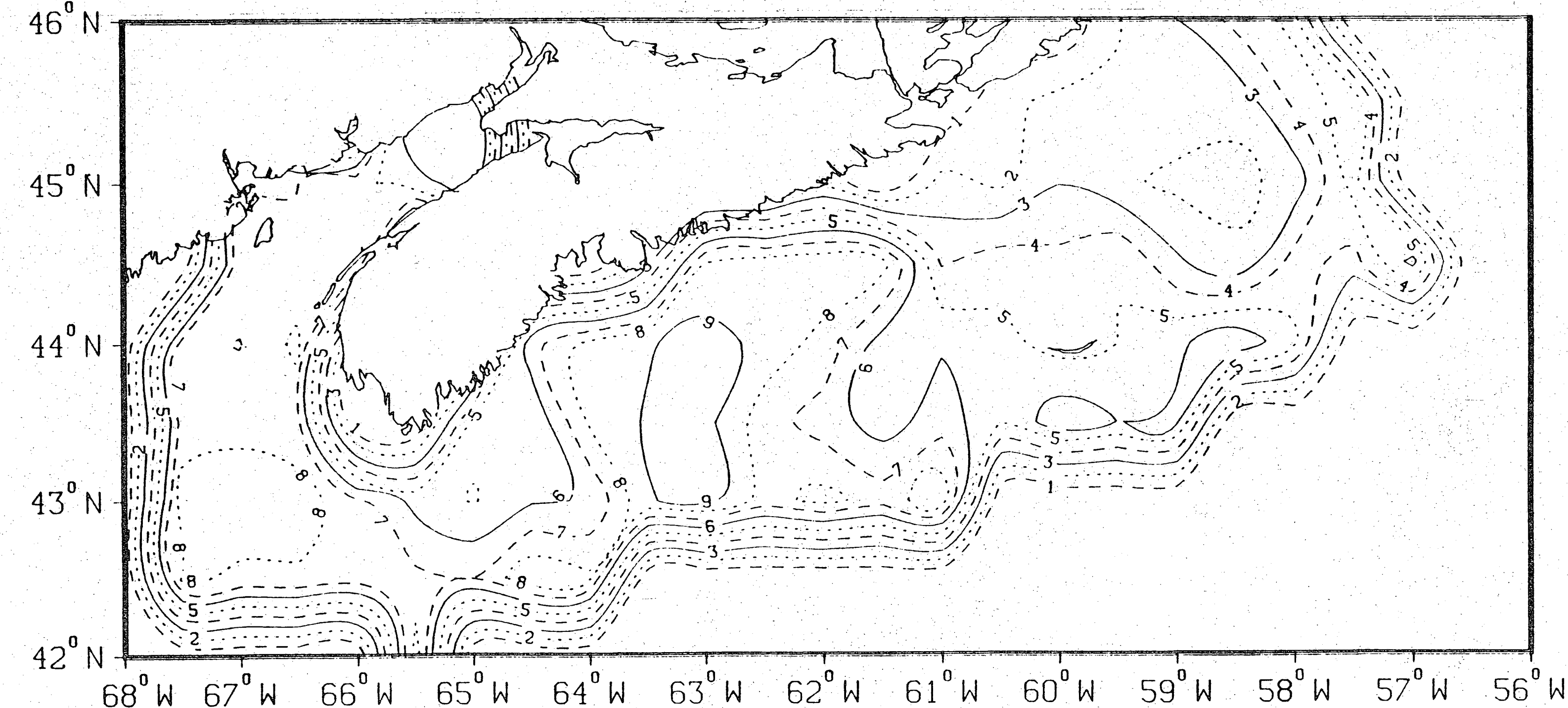

Figure 3. Bottom temperature contours* on the Scotian Shelf based on July-August research vessel data from 1970-1980.

*USING CONMAP: A Computer Program for Contouring Oceanographic Data.

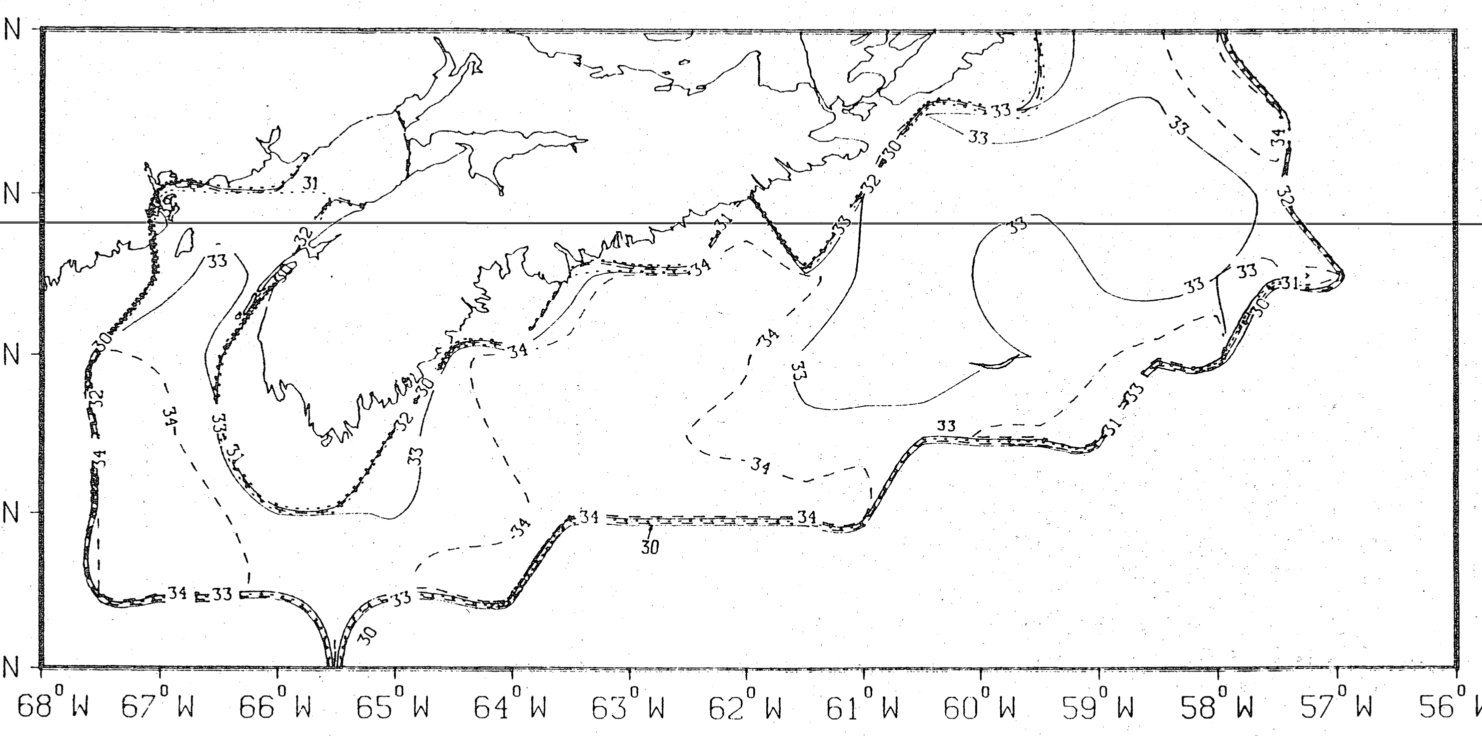

Figure 4. Salinity contours* on the Scotian Shelf based on July-August research vessel data from 1970-1980.

* USING CONMAP: A Computer Program for Contouring Oceanographic Data.

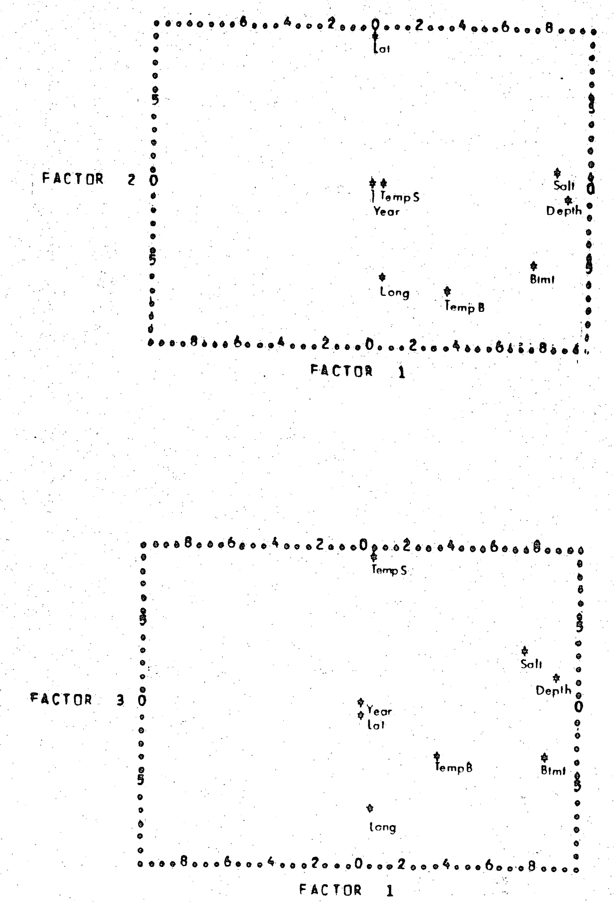

Figure 5. Rotated factor loadings of abiotic variables.

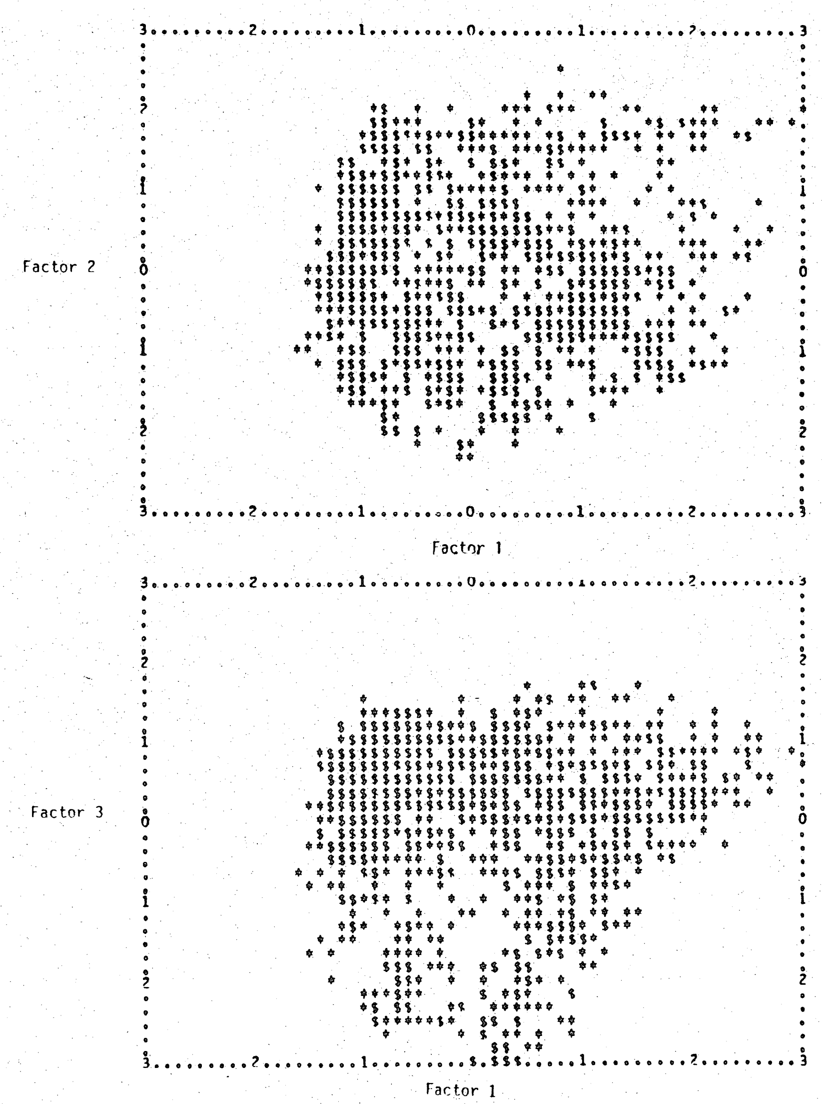

Figure 6. Case plots of PCA factors.

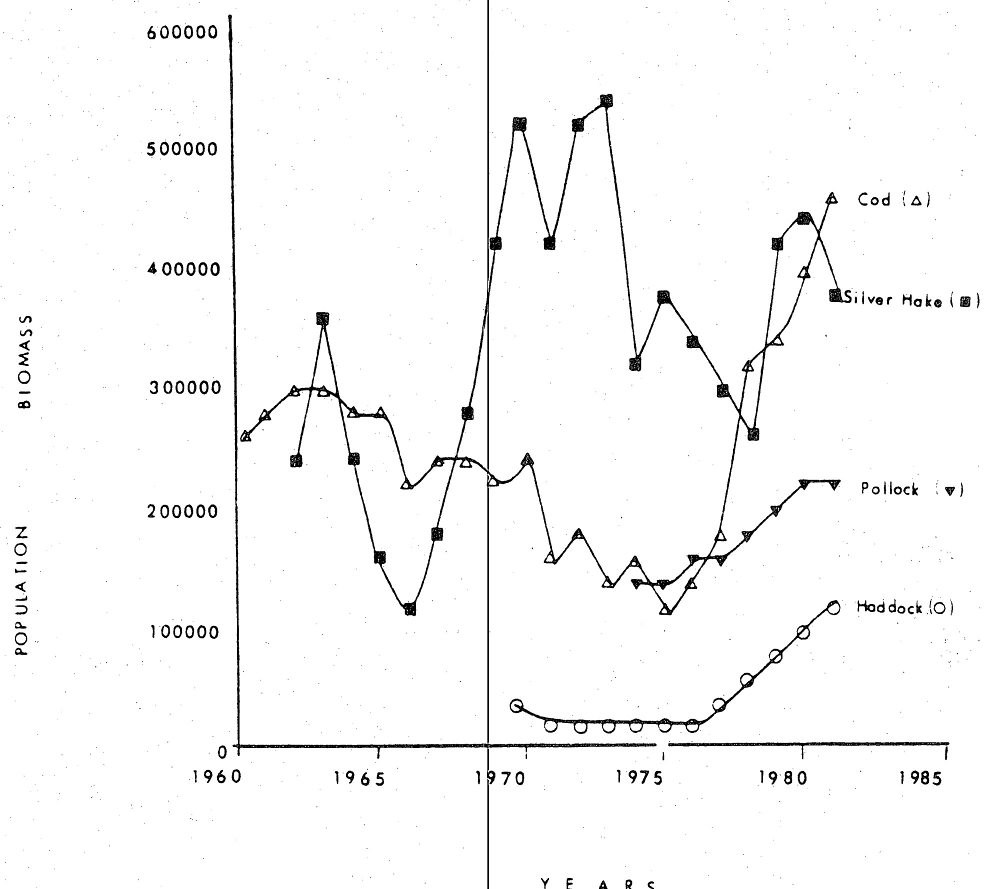

Figure 7. Population biomass trends for major finfish on the Scotian Shelf.

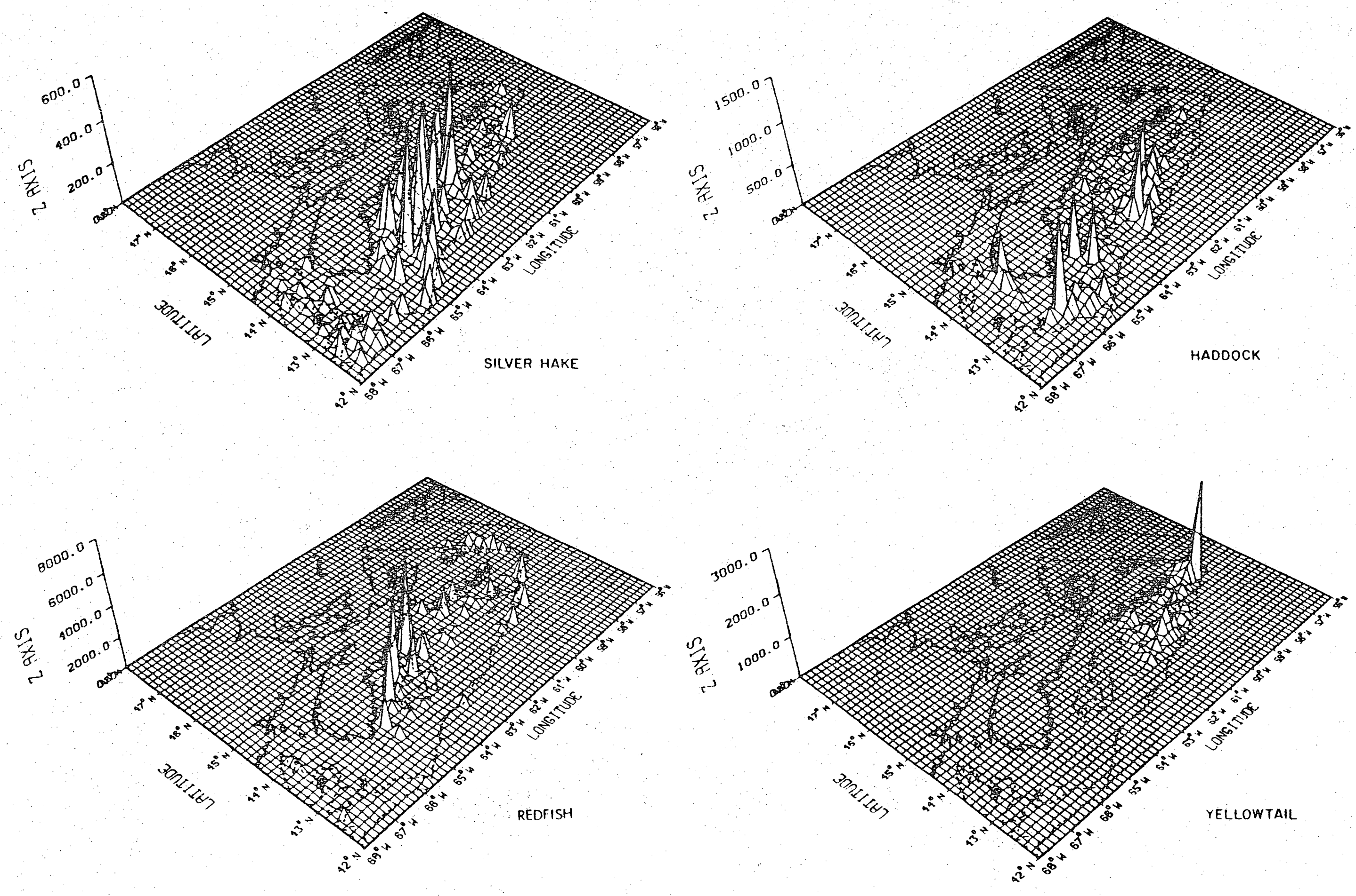

Figure 8(a). Standardized catch numbers per tow from July-August research vessel data from 1970-1980.

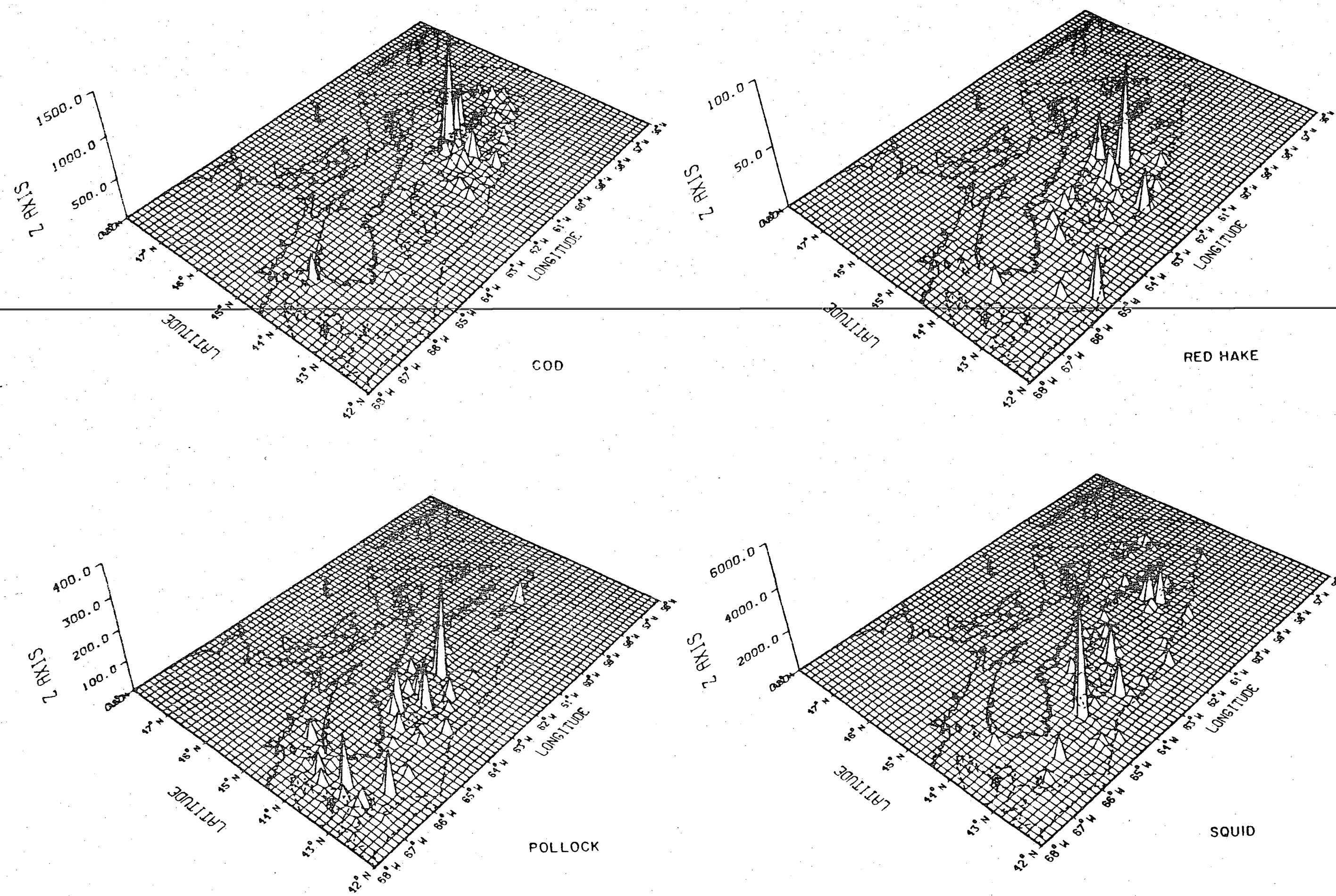

Figure 8(b). Standardized catch numbers per tow from July-August research vessel data from 1970-80.