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Characterization of the Demersal Fish Community of a Deep-Sea Radioactive Dump Site (Results of Cruise EPA-7801, R/V ADVANCE II, 21-27 June 1978)

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Contract Report Submitted to the
U.S. Environmental Protection Agency

by

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INDEX

LIST OF FIGURES

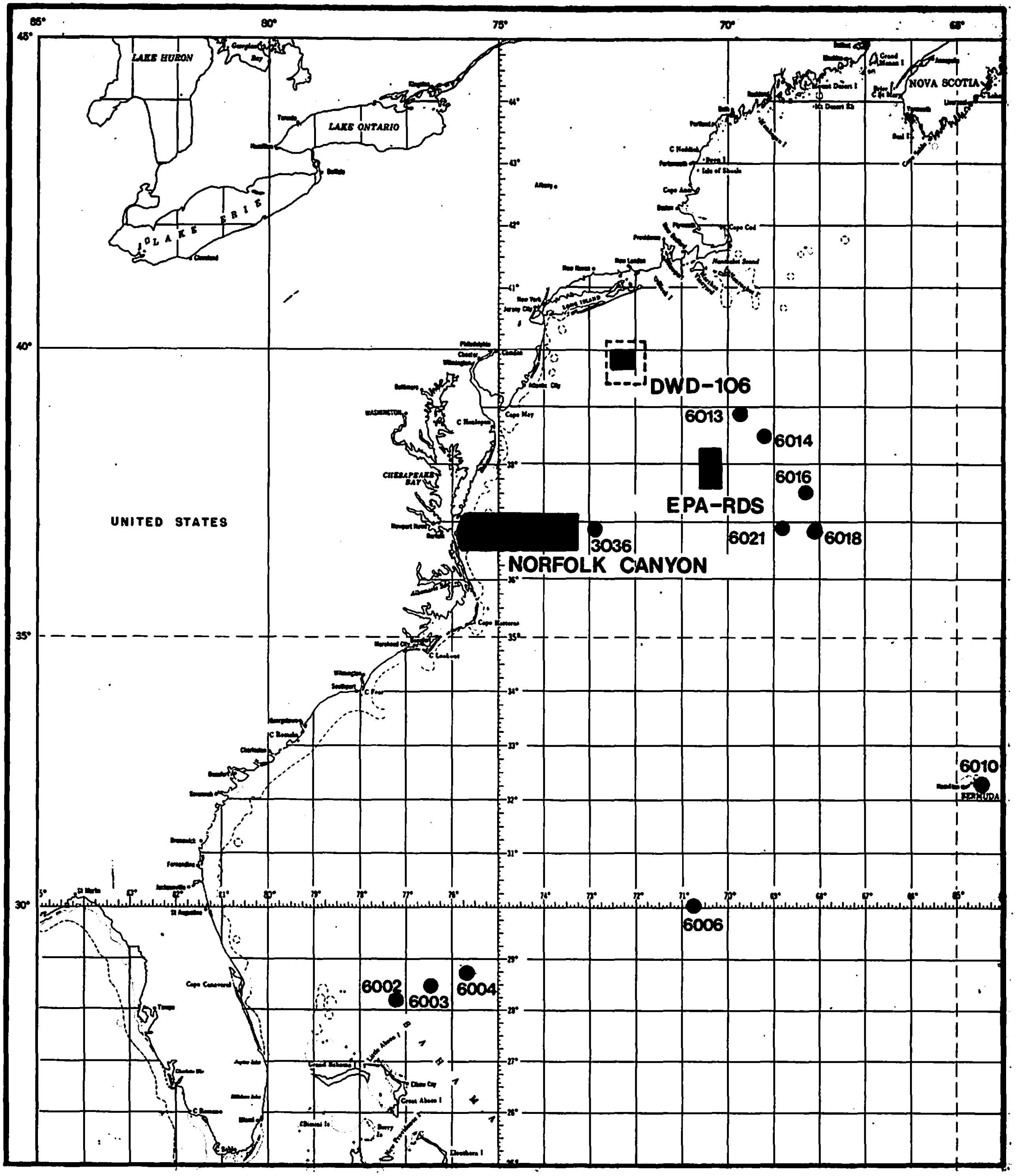
LIST OF FIGURES (Continued)

LIST OF TABLES

INTRODUCTION

The present report describes the demersal fish fauna collected by otter trawl from RV Advance II on cruise EPA-7801 in the vicinity of a radioactive waste disposal site (R.D.S.) located at a depth of about 3900 m, approximately 200 miles due east of the Virginia coast (Figs. 1, 2). Because the sampling effort at the R.D.S. was restricted by time and funding, the limited data base accrued from there was analyzed and compared with a much larger data set collected during previous deep-sea trawling studies using the same trawl gear.

Figure 1. Areas of VIMS deep-sea trawling activities, 1973-1978. Solid rectangles indicate study areas: DWD-106 = Deepwater Dumpsite 106, EPA-RDS = EPA Radioactive Dumpsite. Norfolk Canyon = N.S.F. Norfolk Canyon Study Area (Cruises CI-7310, GI-7404, GI-7508, GI-7601). Station 3036 = a deep station conducted during GI-7508. Other dots indicate additional stations outside of defined study areas.



85°
80°
75°
70°
65°
45°
40°
35°
30°
LAKE HURON
LAKE ONTARIO
LAKE ERIE
NOVA SCOTIA
UNITED STATES
CHESAPEAKE BAY
WASHINGTON
Cape Cod
Cape May
Cape Hatteras
Cape Canaveral
BERMUDA
DWD-106
6013
6014
6016
EPA-RDS
6021
6018
3036
NORFOLK CANYON
6010
6006
6002
6003
6004

Figure 2. Location of otter trawl tows at Deepwater Dumpsite 106, EPA Radioactive Dumpsite, and tows made during N.S.F. Cruise CI-7802 (6000 series station numbers).

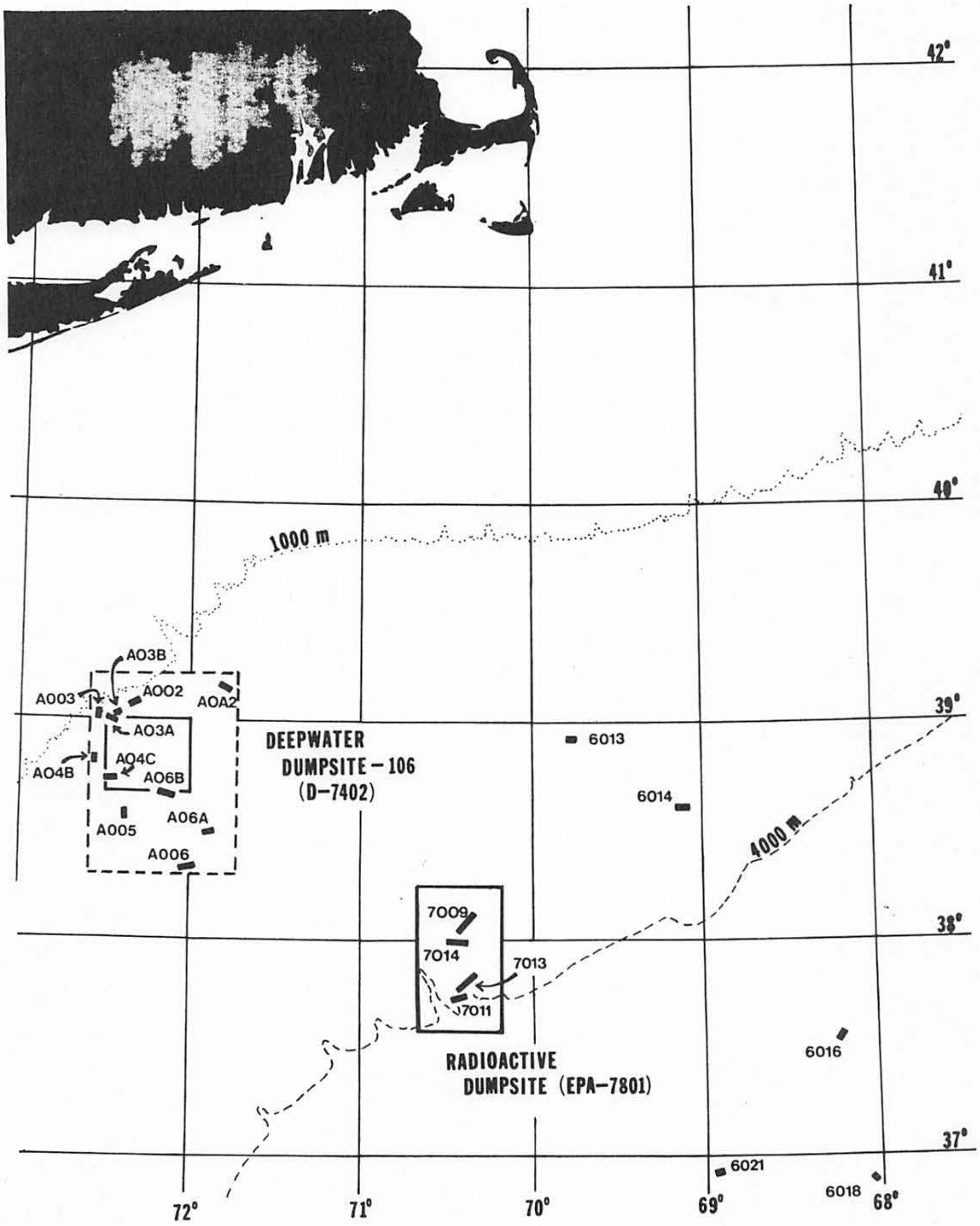
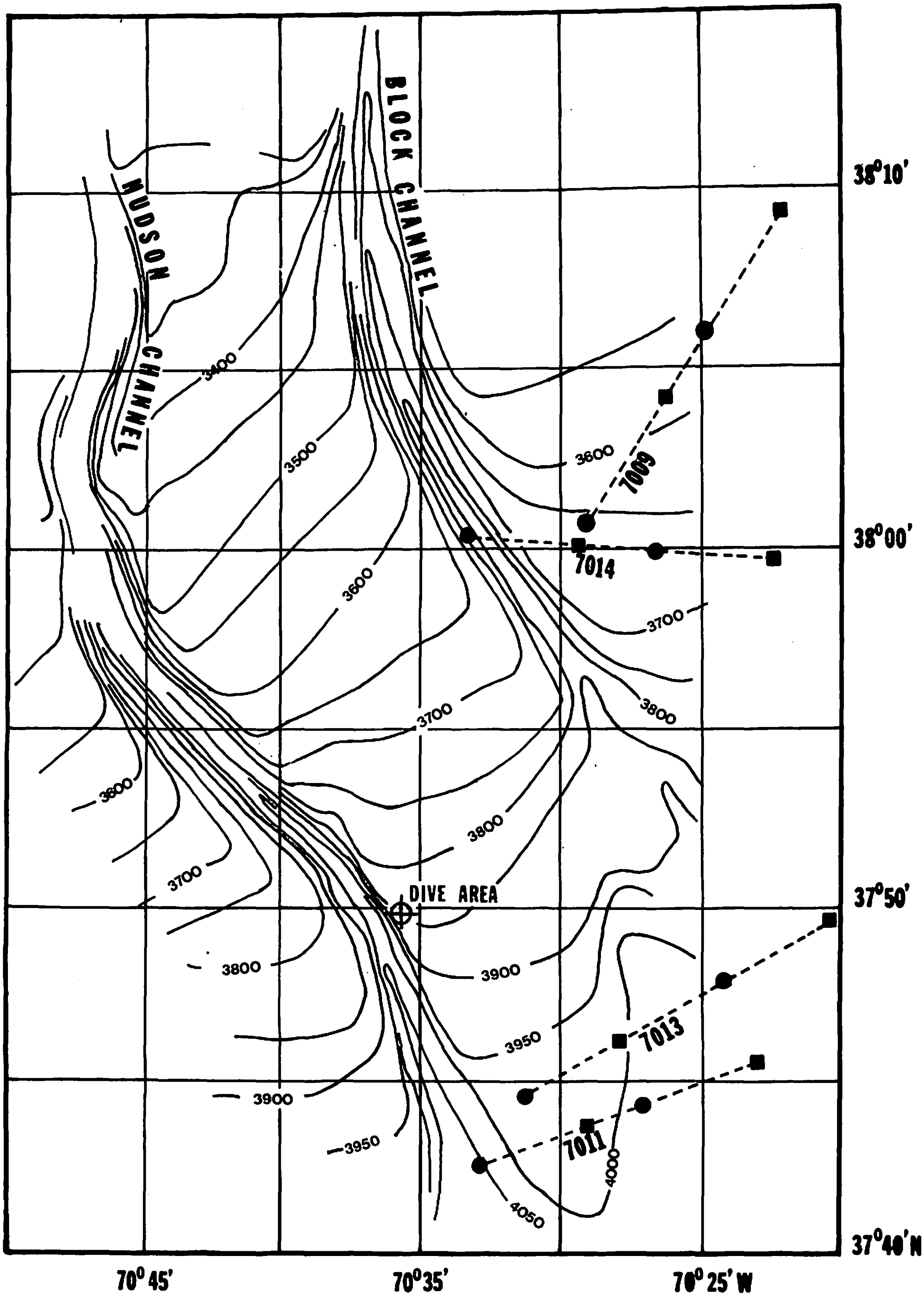

42°
41°
40°
1000 m
39°
A03B
A003
A002
A0A2
A03A
A04C
A04B
A06B
A005
A06A
A006
DEEPWATER
DUMPSITE – 106
(D–7402)
6013
6014
4000 m
38°
7009
7014
7013
7011
RADIOACTIVE
DUMPSITE (EPA–7801)
6016
37°
6021
6018
72°
71°
70°
69°
68°

Figure 3. The tracks of individual 13.7 m SBT stations during EPA-7801 in relation to bottom contours. Depths given are in meters. ■- - - - - -■ indicates ship's track as determined by LORAN-C. ●- - - - - -● indicates probable net positions behind ship from SET to HAUL (determined from the tables of Kullenberg, 1956, based on ship's speed and meters of wire out).


BLOCK CHANNEL
HUDSON CHANNEL
3400
3500
3600
3600
3600
3700
3700
3700
3800
3800
3800
3900
3900
3950
3950
4000
4050
7009
7014
7013
7011
DIVE AREA
38°10'
38°00'
37°50'
37°40'N
70°45'
70°35'
70°25' W

METHODS AND MATERIALS

Sampling

Four successful trawl stations (numbers 9, 11, 13 and 4) were made in the vicinity of the R.D.S. (Figs. 1-3; Table 1) with a 13.7 m semi-ballon otter trawl, with 4.45 cm stretch mesh in wings and body, 1.27 cm stretch mesh lines in the codend, steel China "V" otter doors and 27.4 m bridle and swivel fished from a single warp. Four glass floats, 25.4 cm in diameter were attached to the headrope. Tow duration (3 hrs) was timed from the moment the winch completed wire payout to the moment the winch began to haul back. This tow duration is only an approximation of the actual period that the net effectively fished on the bottom. The catenary and resistance of the towing wire in the water usually results in the trawl contacting bottom somewhat after wire payout has been completed; the trawl tends to continue bottom contact for some time after wire haul-back has begun. These two factors tend to cancel out one another.

Historical Data Base

The data collected near the R.D.S. were compared with a data matrix based on about 170 trawl collections made at depths of 1000 m to 5000 m in the western north Atlantic on six previous research cruises (Figs. 1 and 2). Three of these cruises were made on <u>RV Gilliss</u> (GI-7404, GI-7508, GI-7601) and two cruises were made on <u>RV Columbus Iselin</u> (CI-7310, CI-7802) as part of a study of deep-sea demersal fish ecology

Table 1. Station Data for Cruise EPA-7801, (R/V Advance II), Radioactive Dumpsite.

							BOTTOM DEPTH (M)		
STA #	GEAR	DATE	TIME AT SET[1] (DST)	LATITUDE N SET (TO HAUL)	LONGITUDE W SET (TO HAUL)	BOTTOM TIME (MIN)	PDR[2]	CONTOUR[3] MAP	MWO[4]
7001	Gravity core	21 VI 1978	2300	37°51.2	70°32'	-	3902	3855	8000
7002	Box core	22 VI 1978	2100	37°50.83'	70°35.50'	-	3826	3810	3705
7003	Box core	23 VI 1978	0205	37°49.30'	70°36.71'	-	3939	4015	—
7004	Box core	23 VI 1978	0840	37°45.03'	70°35.75'	-	3825	3950	--
7005	Box core	23 VI 1978	1340	37°46.75'	70°34.01'	-	3967	3945	--
7006	Box core	23 VI 1978	2005	37°54.65'	70°32.69'	-	3642	3740	--
7007	Box core	24 VI 1978	0050	37°48.10'	70°37.11'	-	3850	3885	—
7008	Box core	24 VI 1978	0515	37°49.79'	70°36.13'	-	--	3995	3911
7009	45'SBT	24 VI 1978	2215	38°04.24-09.25'	70°26.38-22.17'	180	--	3655-3560	7572
7010	60 liter bottle	25 VI 1978	1940	37°51.01'	70°34.92'	-	--	3810	—
7011	45' SBT	26 VI 1978	0117	37°43.37-45.55'	70°29.04-23.18'	180	—	3750-3670	8000
7012	60 liter bottle	26 VI 1978	1450	37°49.94'	70°35.90'	-	--	3850	--
7013	45'SBT	26 VI 1978	2020	37°46.17-49.57'	70°27.87-20.28'	180	--	4050-4025	7800
7014	45'SBT	27 VI 1978	1112	38°00.02'-37° 59.82'	70°29.73-33.53'	180	--	3975-4000	7602
7015	Box core	27 VI 1978	2320	37°43.81	70°32.38'	-	—	ca. 4100	—

---

[1] SET = time gear presumed to have contacted bottom; HAUL = time at beginning of haul back.
[2] PDR = precision depth recorder depth, corrected for velocity of sound variation.
[3] Depth as determined by correspondence of Loran-C positions with fine scale Contour Map.
[4] Meter wheel readings unreliable by a factor of ± a few hundred meters in 8000 meters of wire out (MWO).

The focus for most of these cruises was the vicinity of Norfolk Submarine Canyon sponsored by the National Science Foundation (Musick 1976, 1978, 1979). (Figs. 1, 2). One cruise was made on RV Delaware II (D-7402) as part of a biological reconnaissance of a deep-water dumpsite (DWD 106) off the New Jersey Coast (Figs. 1, 2) sponsored by the National Oceanic and Atmospheric Administration (Musick et al., 1975).

Data Analyses

Our previous research (Musick, 1976, 1979) has shown that a major faunal change occurs on the continental slope at about 1000 m and that there is little or no detectable seasonal change in relative abundance and species composition below that depth. Consequently, the data from the four R.D.S. stations were analyzed and compared with a data matrix comprised of all valid trawl collections from $\geq$ 1000 m in our historical data base. Valid collections were those made without net damage or fouling and with proper wire/depth scope. All catches were standardized to catch per hour.

Numerical Classification

Assemblages of fishes were defined by computing a similarity coefficient, $D_{(j,k)}$, among species and subsequently classifying species into clusters or groups (Sneath and Sokal 1973). Stations were clustered in the same manner, and species and station (site) groups were compared by nodal analysis (Lambert and Williams 1962).

The similarity coefficient used was the Canberra Metric which is particularly effective when the organisms under study are contagiously distributed (W. Stephenson, pers. comm.), as most fishes are. The Canberra Metric coefficient was defined by Lance and Williams (1967) as:

$$D_{(j,k)} = \frac{1}{m} \sum_i \frac{|X_{ij} - X_{ik}|}{(X_{ij} + X_{ik})}$$

where, in species analysis (inverse analysis), X = the number of species j and k at station i and m = the total number of stations, and in site analysis (normal analysis) X = the number of species i at stations j and k and m = the total number of species.

The Canberra Metric is a dissimilarity function, but in practice the complement is used to yield a similarity function before clustering (Williams 1971). The clustering strategy used herein was flexible with $\beta = -0.25$. This is an agglomerative hierarchical procedure which avoids chaining and is space dilating (Clifford and Stephenson, 1975). The resulting hierarchical groups were arranged into dendrograms (Figs. 4, 5). Species were eliminated from cluster analysis if they occurred

Figure 4. Dendrogram of 13.7 m SBT station assemblages (station clusters) for all samples (1973-1978) from depths exceeding 1000 m. Stations from EPA-7801 and D-7402 (DWD-106) are identified with a star.

STATION CLUSTER
ALL >1000 M DEPTH, 13.7 M OTTER TRAWLS, 1973-1978

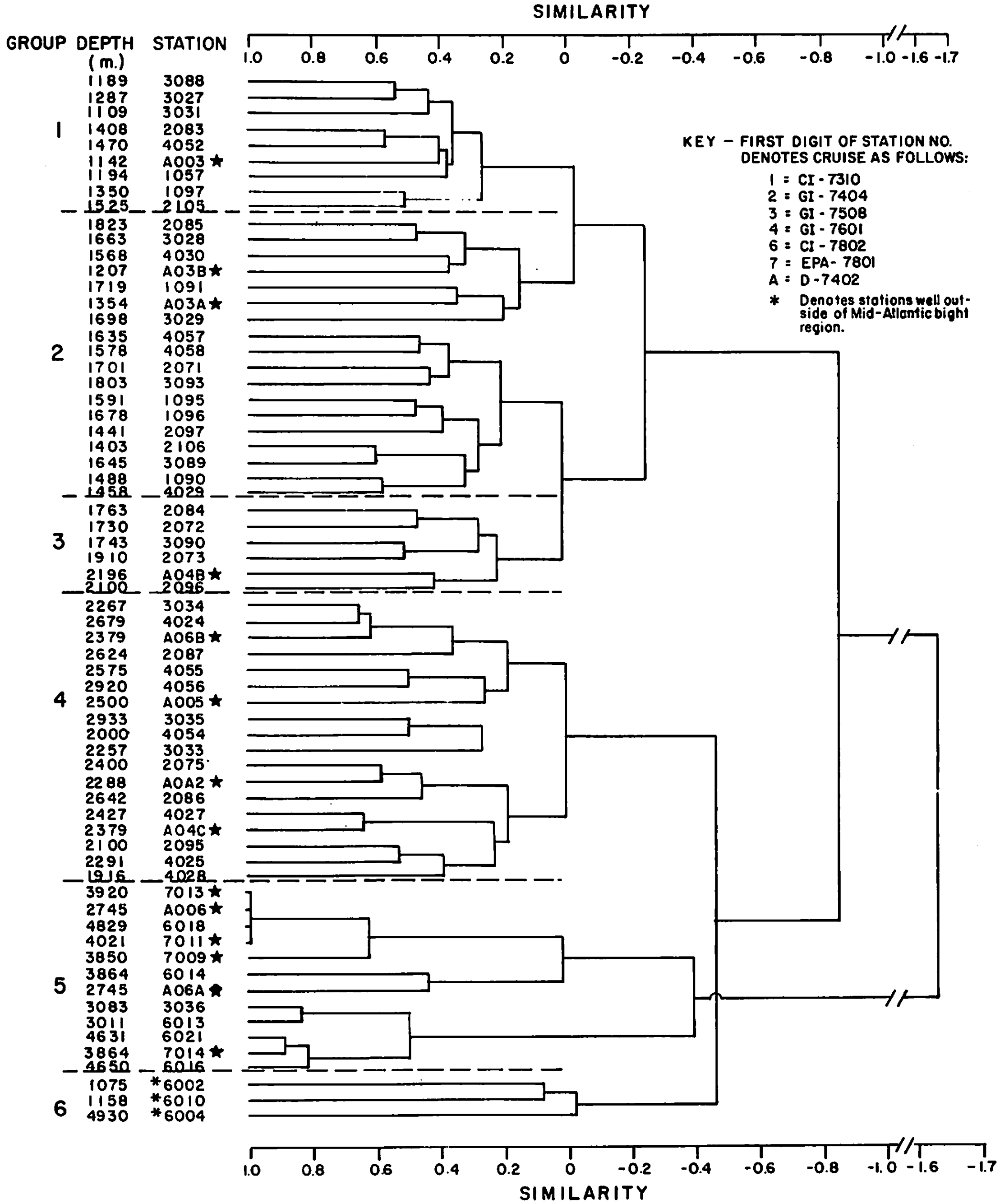
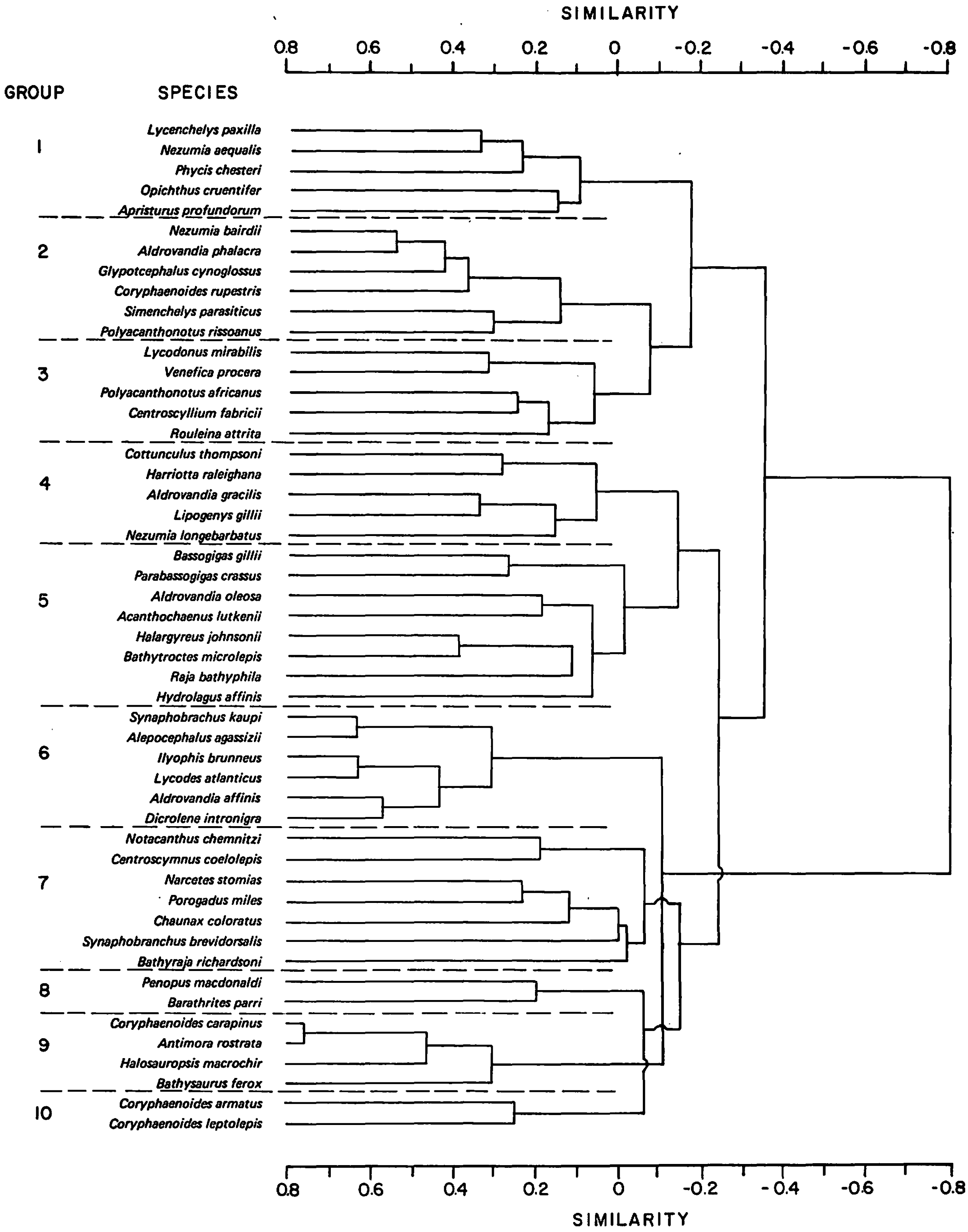


Figure 5. Dendrogram of demersal deep-sea fish assemblages (species cluster) for all 13.7 m SBT samples (1973-1978) from depths exceeding 1000 m. Species groups are arranged by approximate depth occurrence from shallowest (1) to deepest (10).

SPECIES CLUSTER

ALL >1000 M DEPTH, 13.7 M. OTTER TRAWLS, 1973-1978



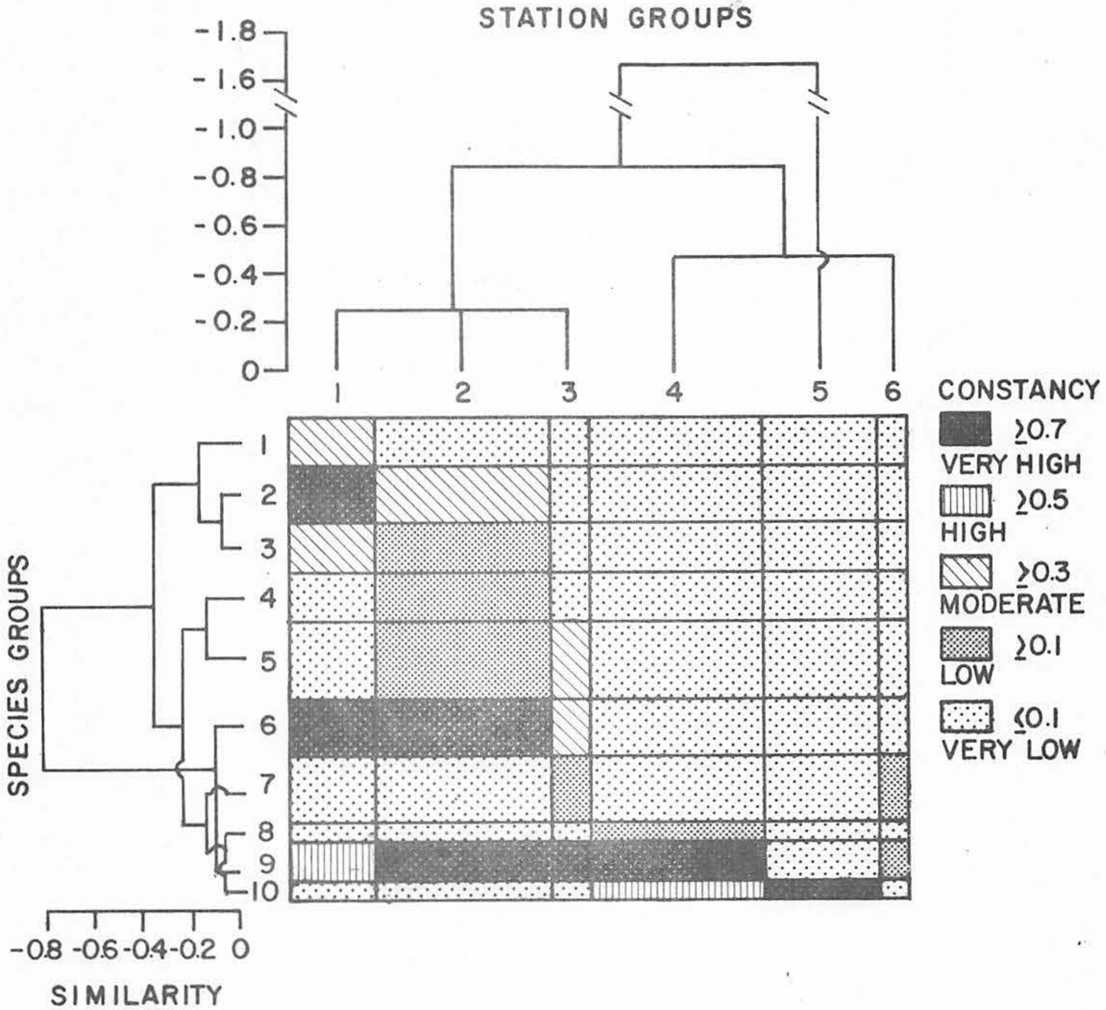
at less than four percent of the stations occupied during a sampling period. To further reduce the effects of contagion, the numerical abundance data were transformed [$\log_e (x + 1)$] before analysis (Taylor 1953), and the log abundance of each species at each station was standardized on the total log abundance for the species (Clifford and Stephenson 1975). The choice of a stopping rule (Boesch 1977) (or of which level of similarity might be biologically significant) was based on two criteria: 1) Each site cluster identified must reflect faunal homogeneity relative to other clusters, 2) Each species cluster identified must be distributed consistently among site clusters. Comparison of site clusters with species clusters through nodal analysis was performed to determine whether clusters represented artificial (excessively divisive or agglomerative) or natural (recurring, cohesive) groups.

Two methods of nodal analysis were performed. The patterns of "constancy" of species belonging to particular species groups in particular site groups were expressed as relative densities of cells of a two-way table (Fig. 6) (Stephenson et al. 1972). These densities were based on proportions of the number of occurrences of species in the site group to the total number of occurrences (Boesch, 1977). Constancy is a relative frequency of occurrence measure; e.g., high constancy indicates high relative abundance for a species within a particular group. Algebraically, this constancy index is:

$$C_{ij} = a_{ij}/(n_i n_j)$$

Figure 6. Constancy matrix relating species groups and station groups determined for all 13.7 m SBT stations (1973-1978) from depths exceeding 1000 m.

CONSTANCY MATRIX: ALL >1000 M DEPTH,
13.7 M OTTER TRAWLS, 1973-1978.



where a_{ij} is the actual number of occurrences of members of species group i in site group j, and the n_i are the numbers of entities in the respective groups. The index will take a value of one when all species occur in all collections in the group, and zero when none of the species occur in the collections.

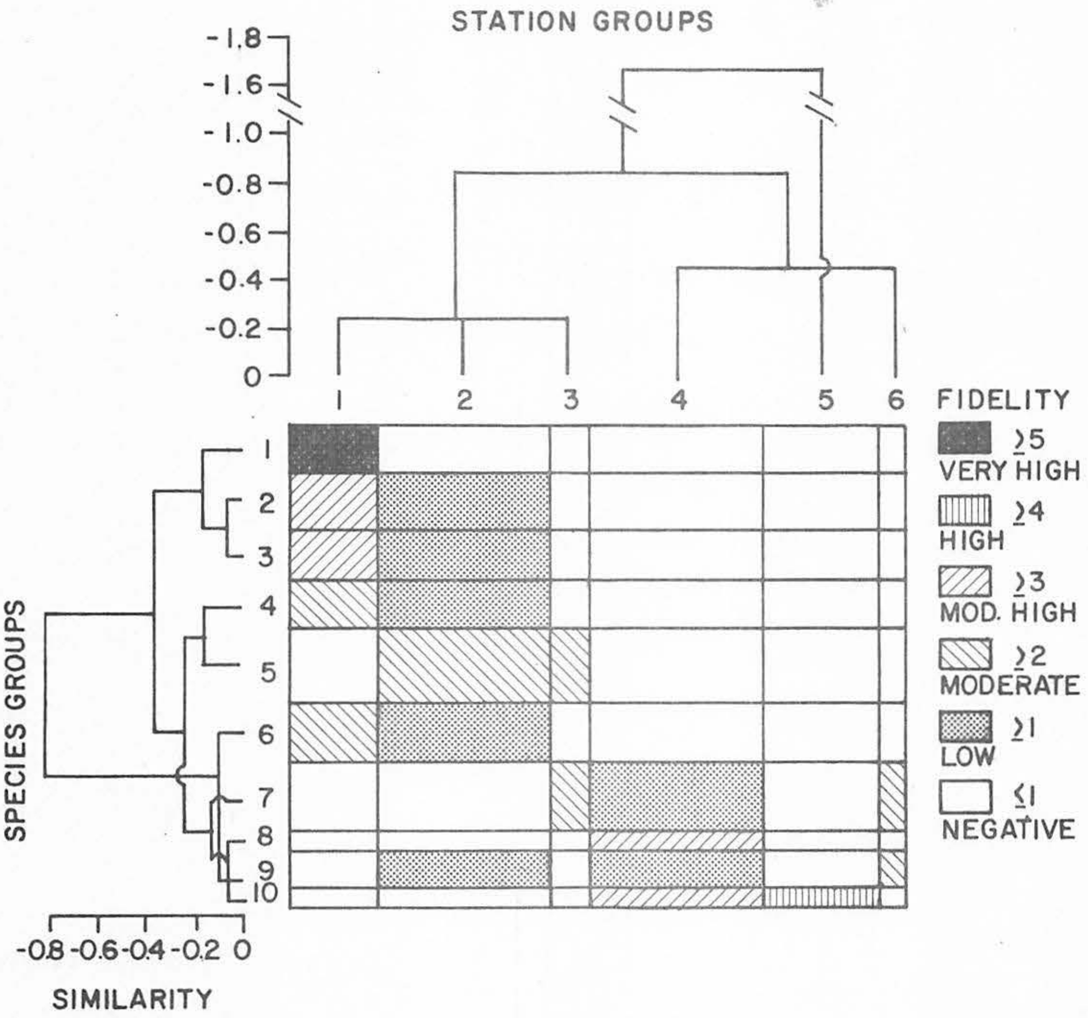
The patterns of "fidelity" of species groups to site groups also were expressed as relative densities of cells on a two-way table (Fig. 7). Fidelity is a measure of the degree to which species are limited (i.e., faithful) to site groups. The fidelity index used was an expression of the constancy of species in a site group compared to the constancy over all sites. The fidelity of species group i in site group j was defined as:

$$F_{ij} = (a_{ij} \sum_j n_j)/(n_j \sum_j a_{ij})$$

This index is unity when the constancy of a species group in a site group is equivalent to its overall constancy, greater than one when its constancy in the site group is greater than that overall, and less than one when its constancy is less than its overall constancy. Values of the index greater than two suggest strong association of species in a group with a site group (i.e. indicating that the average frequency of occurrence of those species at those sites is twice that for all site groups together). Index values less than one suggest "negative" association of species in a group with a site group (Boesch 1977). All nodal diagrams were drawn with the width of the rows and columns proportional to the number of entities in the respective site and species groups.

Figure 7. Fidelity matrix relating species groups and station groups determined for all 13.7 m SBT stations (1973-1978) from depths exceeding 1000 m.

FIDELITY MATRIX: ALL >1000 M DEPTH,
13.7 M OTTER TRAWLS, 1973 - 1978.



Species Dominance

Numerically dominant species have been used to characterize communities by ecologists for many years (Thorson 1957), and changes in dominant species often reflect faunal changes. In the present study, patterns of species dominance were compared among site groups. A species was considered dominant if it occurred among the five most abundant species in at least 20% of all the stations from a site group. The five most abundant species comprised 90% or more of the total number of individuals at most stations.

Diversity and Related Parameters

Species diversity as measured by the information theoretical measures, H' (Lloyd, Zar and Karr 1968), and the Brillouin formula, H (Brillouin 1962), was computed for all stations. Results were similar for both values and only the H' analysis will be discussed herein.

Pielou (1969) and others have noted that H' depends both on the number of species in a sample and on the distribution of individuals among species present. The latter has often been called evenness and the former, species richness. Evenness, measured by J' (Pielou 1969), and species richness by Margalef's (1951) index, D, were computed for all stations. The following equations describe these three indices:

$$H' = \frac{1}{N} (N \log N - \frac{S}{i-1} n_i \log n_i)$$

$$J' = \frac{H'}{\log S}$$

$$D = \frac{(S - 1)}{\log N}$$

where n_i is the number of individuals of i^{th} species, N is the total number of individuals, and S is the total number of species.

RESULTS AND DISCUSSION

General Description of Fish Faunal Patterns

Demersal Fish Assemblages

Numerical classification yielded five major station clusters between depths of about 1000 to 4900 m (Fig. 4). A sixth cluster was comprised of a unique group of tropical stations near Bermuda and the Blake-Bahamas outer ridge. These stations were extralimital to the present study and will not be discussed further herein. Station groups were bathymetrically coherent. Bathymetric limits for each group were: group 1, 1109 to 1525 m; group 2, 1207 to 1823 m; group 3, 1730 to 2196 m; group 4, 1916 to 2933m ; group 5, 2745 to 4650 m. Thus, there were three major station groups on the lower slope between 1000 and 2000 m, one major group on the upper rise between 2000 and 2800 m, and one group on the lower rise and abyssal plain deeper than 2800 m.

Ten major species groups were recognized (Figure 5). Group 1 had moderate constancy and very high fiedlity to the shallowest station group (1) (Figs. 6 and 7). None of the species comprising group 1 were classified as dominants (Table 2) in the present analysis because they occurred in low abundances. Most of these species were common members of upper slope assemblages (<1000 m) and were near their lower bathymetric limits at station group 1 (Musick 1976). Species group 2 was comprised of abundant middle-slope species and had very high and moderate constancy at station groups 1 and 2 respectively, and high and low fidelity at station groups 1 and 2 respectively. This species group

Table 2. Species dominance*, All > 1000 m depth, 13.7 m otter trawls, 1973-1978. Key to faunal affinity: B = boreal, M = mid-slope, L = lower slope, R = continental rise, A = abyssal plain.

			STATION GROUP											
	FAUNAL	SPECIES	1		2		3		4		5		6	
SPECIES	AFFINITY	GROUP	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$
Polyacanthonotus rissoanus	M	2			56	1.5								
Coryphaenoides rupestris	B-M	2	89	2.8										
Glyptocephalus cynoglossus	B-U,M	2	89	10.8										
Aldrovandia phalacra	M	2	89	6.0									33	5.2
Nezumia bairdii	M	2	100	8.9									33	2.1
Parabassogigas crassus	L,R	S					33	1.4						
Dicrolene intronigra	M,L,R	6	100	11.6	67	4.6	73	3.4						
Lycodes atlanticus	B-M	6					100	2.9						
Ilyophis brunneus	M	6			72	2.7	100	3.7						
Alepocephalus agassizii	M,L,R	6			94	6.7	83	3.3						
Synaphobranchus kaupi	M,L,R	6	100	38.0	94	20.0	100	12.9					33	12.5
Coryphaenoides carapinus	L,R	9	89	3.3	100	10.3	100	16.3	78	5.5				
Antimora rostrata	M,L,R	9	100	7.7	100	32.6	100	42.6	100	32.9				
Bathysaurus ferox	L,R	9							50	0.8			33	4.2
Halosauropsis macrochir	L,R	9			67	2.4	100	14.8	83	9.6			33	4.2
Porogadus miles	L,R	7							33	1.1				
Coryphaenoides armatus	L,R,A	10							83	42.2	100	79.7		
Coryphaenoides leptolepis	L,R,A	10							33	0.8	42	1.1		
Chaunax coloratus	L,R	7											33	8.3
Synaphobranchus brevidorsalis	L	7											67	13.5

*% = percent of stations in each site group at which a dominant species occurred

$\bar{x}$ = average percent contribution of a dominant species to stations within a station group

(A species was defined to be dominant in a station group if it occurred among the five most abundant species in at least 20% of all stations in that group) included *Coryphaenoides rupestris*, *Glyptocephalus cynoglossus*, *Aldrovandia phlacra* and *Nezumia bairdii* which were dominant at station group 1 and *Polyacanthonotus rissoanus*, a dominant at station group 2. Species group 3 was comprised of less abundant middle-slope species and had constancy and fidelity patterns that were similar to those of species group 2. None of the species included were classified as dominant (Table 2). The classification of abundant and less abundant species into separate clusters regardless of their similar constancy and fidelity patterns is a common artifact when using the Canberra Metric similarity measure. Thus species group 4 had constancy and fidelity patterns similar to those in groups 2 and 3, but was comprised of rare middle-slope species. Species group 5 was comprised of less abundant lower slope species with low and moderate constancy and moderate fidelity to station groups 2 and 3 respectively. Only *Parabassogigas crassus* was recognized as a dominant (at station group 3). Species group 6 was comprised of abundant lower slope species, and had very high constancy at station groups 1 and 2, moderate constancy at group 3, but moderate, low, and negative fidelity respectively at these station groups. Among the species in this group, *Synaphobranchus kaupi* and *Dicrolene intronigra* were dominant at station groups 1, 2 and 3, *Ilyophis brunneus* and *Alpocephalus agasizzii* were dominant at station groups 2 and 3, and *Lycodes atlanticus* was a dominant species at station groups 3 (Table 2).

Species group 7 was comprised of less abundant slope/rise transition species, and had low constancy at station group 3, and moderate and low fidelity at groups 3 and 4 respectively. Porogadus miles was the only species recognized as dominant (at station group 4) among species in group 7. (Chaunax coloratus and Synaphobranchus brevidorsalis were also listed as dominant, but only at the extralimital station group 6).

Species group 8 was comprised of only 2 rare species with low constancy but moderately high fidelity at the upper rise station group 4.

Species group 9 was comprised of eurybathic species abundant on the lower slope and upper rise, and had high constancy at station group 1 and very high constancy at station groups 2, 3 and 4 but low fidelity values (indicative of eurybathic distributions). Among species in group 9, Antimora rostrata and Coryphaenoides carapinus were dominant at station groups 1, 2, 3 and 4, Halosauropsis macrochir was dominant at station groups 2, 3 and 4, and Bathysaurus ferox was dominant at group 4.

Species group 10 was comprised of only 2 species, Coryphaenoides armatus and C. leptolepis, both dominant on the continental rise and abyssal plain. Species group 10 had high and very high constancy and moderately high and high fidelity at station groups 4 and 5 respectively, suggesting that its species are abundant within and highly faithful to these station groups.

The fish faunal assemblages of fishes on the continental slope and rise of the middle Atlantic coast of the U.S. comprise a coenocline of species mosaics which overlap in bathymetric distribution. The relative gradient of this coenocline reflects rate of faunal change and is not constant over all depths. The coenocline is steepest where environmental gradients are steepest. Thus, three station groups (1,2,3) were recognized between 1000 m and 2000 m where the topographic gradient is steeper than at greater depths (Musick et al 1975) the temperature drops from 6°C to 3°C, and the relative pressure increases twofold. However, only one major station group (4) was recognized between 2000 m and 3000 m where the topography changes more gradually, the temperature varies little and the relative pressure increases by a factor of 1.5, (a few peripheral stations from shallower group 3 and deeper group 5 were also located between 2000 and 3000 m). From 3000 m to 5000 m, where environmental gradients are very low, only one station group was found. Similarly, S species groups were recognized between 1000 and 2000 m, 4 species groups were recognized between 2000 to 3000 m, and only one species group was recognized below 3000 m. Patterns of species group distribution reflect species diversity and in the area of study are affected not only by environmental gradients (indicators of habitat heterogeneity) but also by patterns of energy available to demersal ecosystems. Diversity and related parameters will be discussed below.

Numerical Abundance, Biomass and Body Size

Demersal fishes are most abundant at about 300 m then abundance declines exponentially out to a depth of about 4000 m (Fig. 8). Biomass increases to the shelf break (100-200 m) and remains high out to a depth of ca. 1800 m. Between 1800 m and 4000 m there is an order of magnitude decrease in fish biomass (Fig 9). Haedrich and Rowe (1977) and Haedrich et al. (1975) noted similar patterns for fishes collected off the same coast; however, their estimates were lower for the upper slope because they used small nets that were avoided by some fishes (Musick 1976, 1979). Cohen and Pawson (1977), analyzing visual observations made from the submersible DSRV Alvin, reported an exponential decrease in demersal fish abundance similar to that found by us using otter trawls in the same region. In 1974 we noted that the average size of individual fishes increases greatly between 1000 m and 2000 m (Musick et al. 1975). The mean weight per individual fish (Fig. 10) increases by almost an order of magnitude (Musick 1976, 1979). Haedrich and Rowe (1977) also noted this phenomenon.

Thiel (1975) suggested that small size should be evolved in the deep-sea benthos because the very low energy available in the abyss could support only a small biomass, yet species require some minimum population level to insure success of sexual reproduction. Thus body size is probably correlated with both feeding and reproductive strategies in the benthos. Musick (1976) noted that large size in fishes increases the potential foraging range (both vertically and horizontally) and increases the speed with which an individual can contact occasional large falls of food which may be important food sources for lower bathyal and abyssal fishes (Haedrich and Henderson 1974; Isaacs and Schwartlose 1975; Pearcy and Ambler 1974; Sedberry and Musick 1978). In addition, large size increases the size range and variety of food

Figure 8. Numerical abundance, LOG_{10} (x + 1) specimens/ 1000 m^2, of demersal deep-sea fishes as a function of depth (m) for all 13.7 m SBT stations (1973-1978). Large dots indicate station values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).

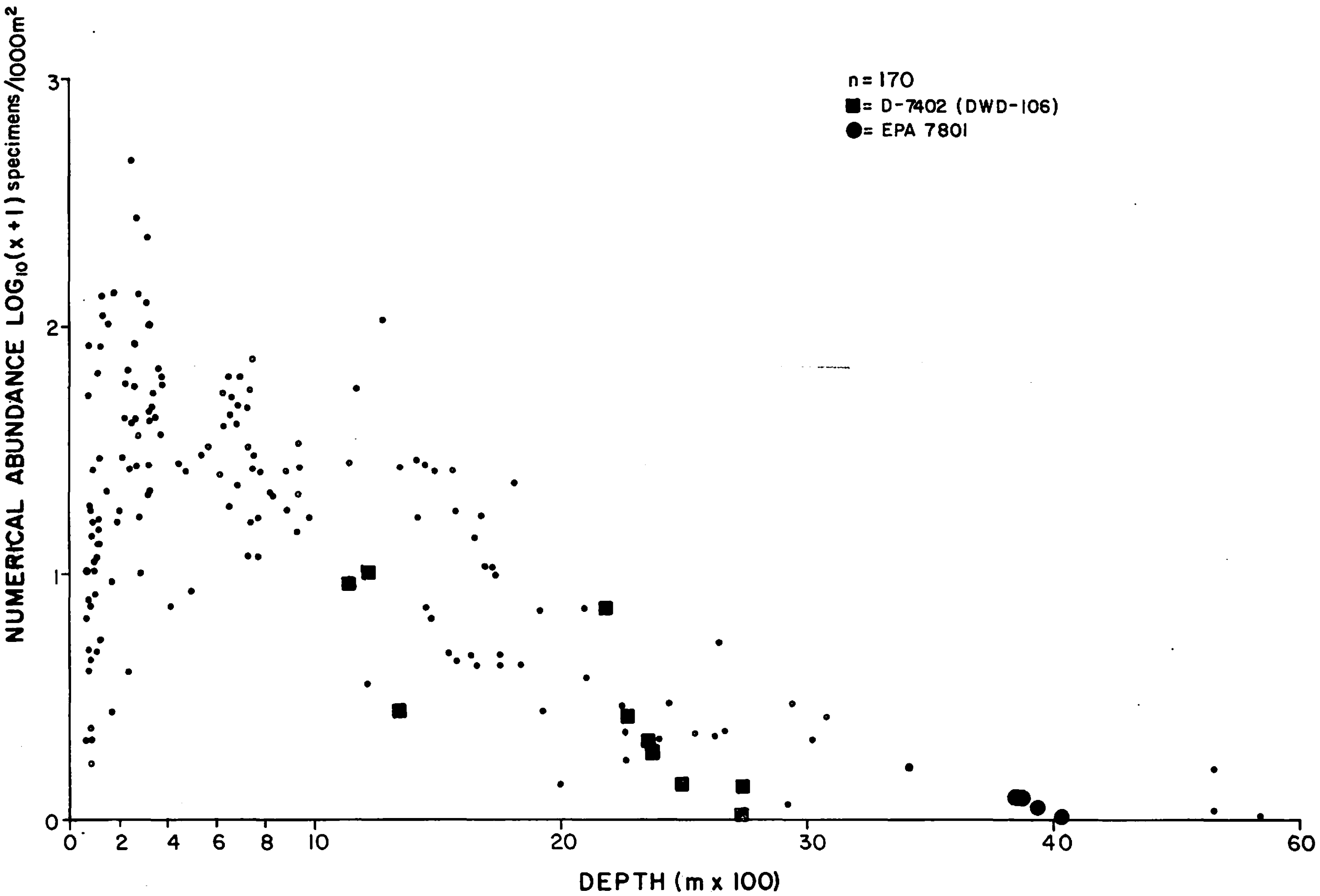

n=170
■= D-7402 (DWD-106)
●= EPA 7801
NUMERICAL ABUNDANCE LOG$_{10}$(x+1) specimens/1000m^2
3
2
1
0
0
2
4
6
8
10
20
30
40
60
DEPTH (m x 100)

Figure 9. Biomass, LOG_{10} (x + 1) $^{gm}/1000\ m^2$, of demersal fishes as a function of depth (m) for all 13.7 m SBT stations (1973-1978). Large dots indicate station values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).

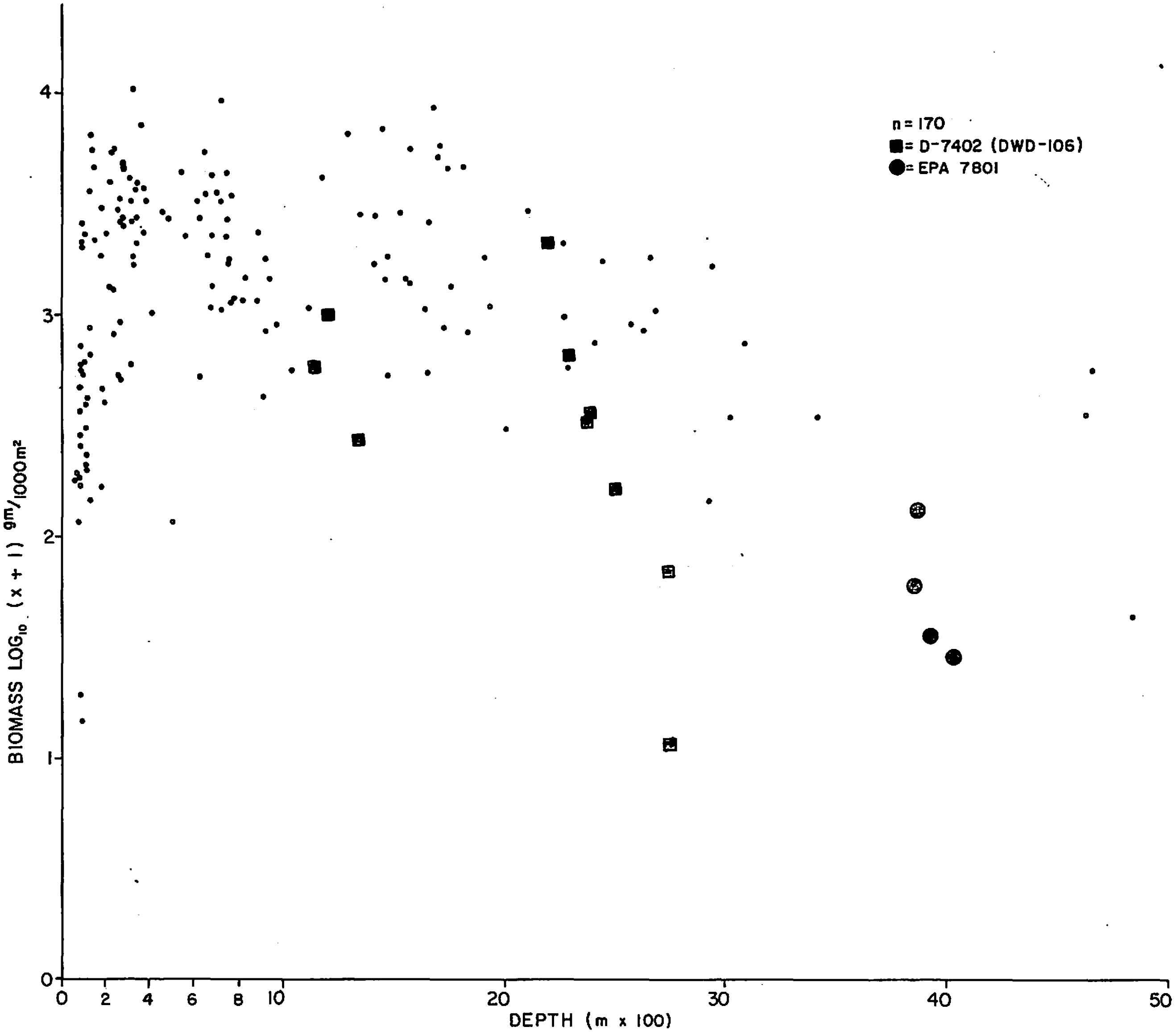
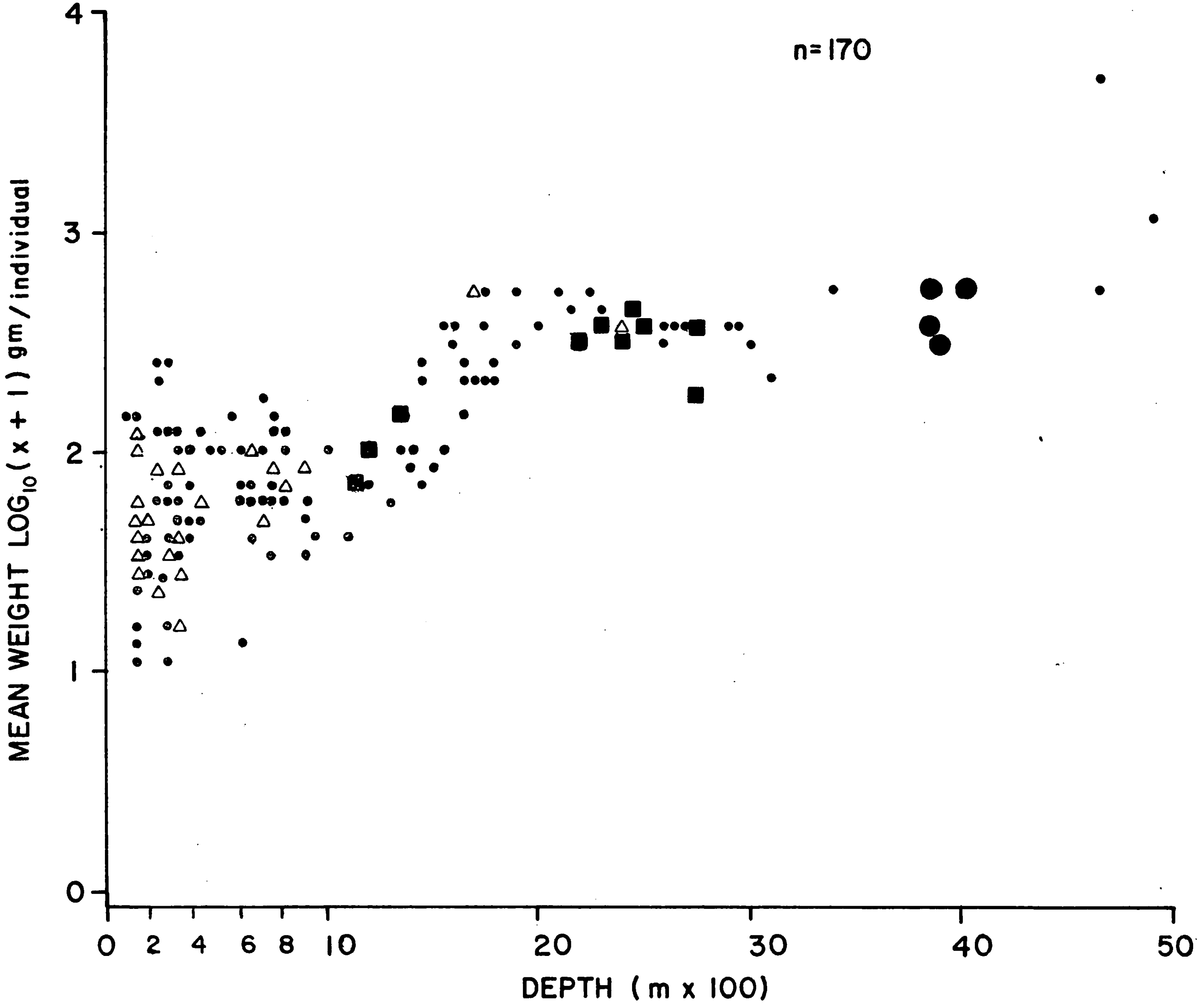

n = 170
■ = D-7402 (DWD-106)
● = EPA 7801
BIOMASS LOG10 (x + 1) gm/1000m²
DEPTH (m x 100)
0
1
2
3
4
0
2
4
6
8
10
20
30
40
50

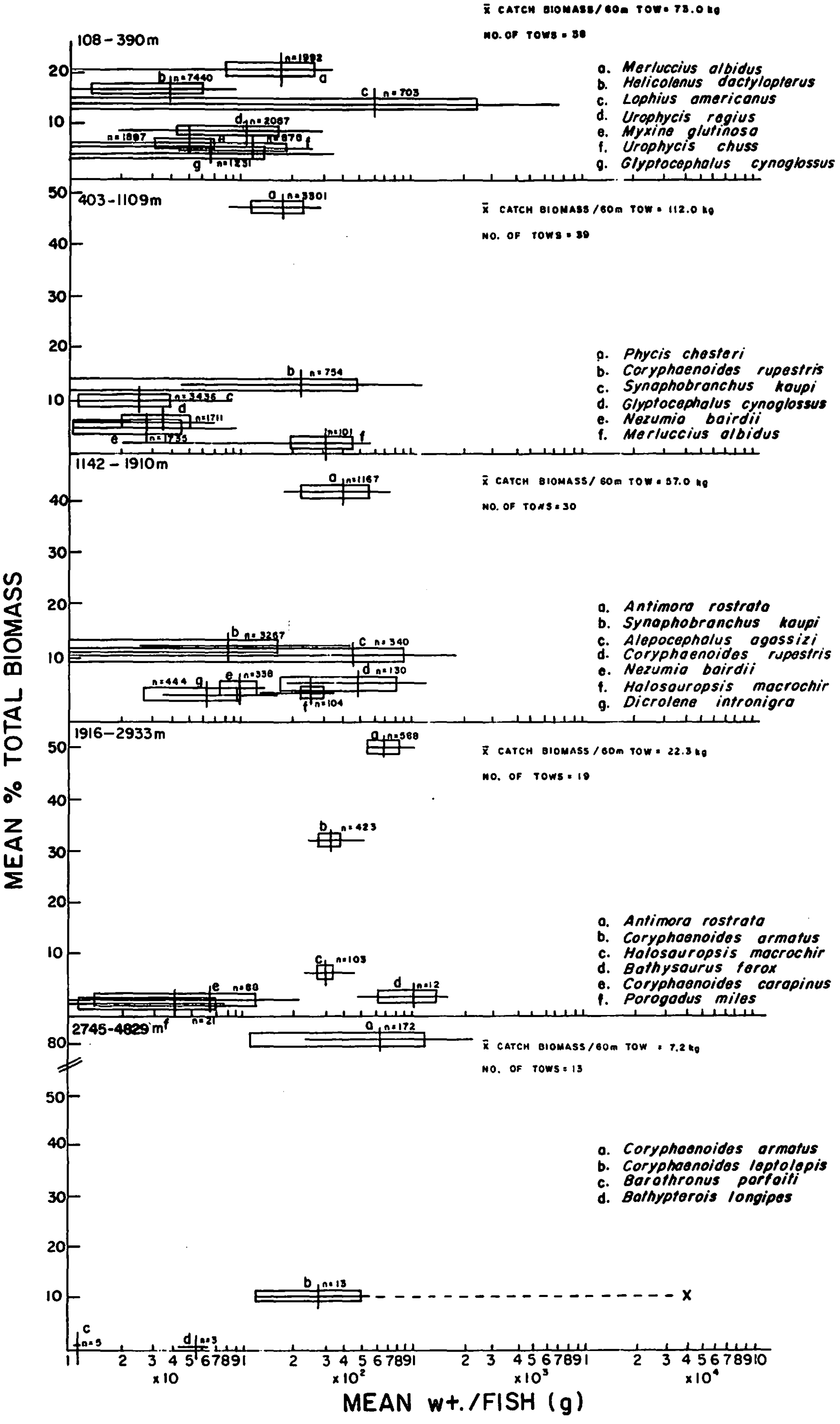
Figure 10. Mean weight, LOG_{10} (x + 1) gm, per individual demersal fish as a function of depth for all 13.7 m SBT stations (1973-1978). Triangles indicate multiple points. Large dots indicate values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).


n=170
MEAN WEIGHT LOG$_{10}$ (x + 1) gm / individual
4
3
2
1
0
0
2
4
6
8
10
20
30
40
50
DEPTH (m x 100)

items that can be ingested thus allowing large fishes to have very generalized food habits (Haedrich and Henderson 1974; Pearcy and Ambler 1974; Sedberry and Musick 1978), an important advantage to animals subjected to intense competition for food (Schoener 1971). Musick (1976) also noted that large mobile fishes are able to maintain viable sexually reproducing populations at much smaller population sizes than the sessile benthic invertebrates described by Thiel (1975), since fishes can move over great distances to contact potential mates or form temporary spawning aggregations. Two of the most successful groups of bathyal and abyssal fishes are the Macrouridae and Neobythitinae (=Brotulidae) which can communicate sonically by vibration of gas-filled swimbladders. Two other major groups (Moridae, Halosauridae) have swimbladders with no drumming muscles but may create sound by stridulation (Marshall 1971). Sonic communication may facilitate aggregation for spawning. Other successful abyssal fish groups which are benthic and have restricted mobility and no sonic communication (*Bathysaurus* and the Ipnopinae) are synchronus hermaphrodites (Mead, Bertelson and Cohen 1964; Sulak 1977; Wenner 1978). We have recently begun a more detailed analysis of the relationship of body size in fishes with depth and have found that the pattern shown in Fig. 10 is the result of two phenomena. One, many dominant bathyal fishes tend to occur deeper as they grow larger. Such is the case for many of the macrourids (Middleton 1979) synaphobranchid eels, the gadid, *Phycis chesteri*, the morid, *Antimora* rostrata, the halosaur, Halosauropsis macrochir, the ophidioid, Dicrolene intronigra, and two zoarcids of the genus Lycenchelys (Wenner 1978; Wenner and Musick 1977). Bullis and Struhsaker (1970) have noted a similar correlation between body size and depth for several species of upper bathyal fishes in the Caribbean. The second factor contributing to the "bigger-deeper" relationship in bathyal fishes is the dominance on the lower slope and rise in our study area of large euryphagous predator-scavenger species. Figure 11 summarizes the percentage contribution by biomass of dominant species within five depth strata between 108 and 4879 meters and shows the mean, standard deviation and range of biomass values for each species within each stratum. In the two shallowest strata (≤ 100 gm mean weight) and medium (100-200 gm) species with a maximum of about 15% of the biomass contributed by large species with a mean weight > 200 gm). On the lower slope (1000-2000 m) more than 60% of the biomass is contributed by species with a mean weight > 200 gm. On the continental rise (> 2000 m) about 90% of the biomass is contributed by fishes weighing more than 200 gm and more than 50% is contributed by fishes weighing more than 500 gm, mean weight. Note however that a small but persistent percentage of the biomass is still contributed by small species on the continental rise and even in the abyss (> 2,900 m). There, more than 80% of the biomass is contributed by fishes having an average wieght of about one kg.

Haedrich et al. (1975), Haedrich and Rowe (1977) and Sedberry and Musick (1978) noted that the biomass of fishes on the lower slope and rise was of the same order of magnitude as that of the

Figure 11. Demersal fish biomass by depth category partioned by dominant species.


MEAN % TOTAL BIOMASS
MEAN wt./FISH (g)
1 2 3 4 5 6 7 8 9 1 x10
2 3 4 5 6 7 8 9 1 x10²
2 3 4 5 6 7 8 9 1 x10³
2 3 4 5 6 7 8 9 10 x10⁴
108 - 390m
x̄ CATCH BIOMASS/60m TOW = 73.0 kg
NO. OF TOWS = 38
a n=1992
b n=7440
c n=703
d n=2087
e n=1897
f n=876
g n=1231
a. Merluccius albidus
b. Helicolenus dactylopterus
c. Lophius americanus
d. Urophycis regius
e. Myxine glutinosa
f. Urophycis chuss
g. Glyptocephalus cynoglossus
403-1109m
x̄ CATCH BIOMASS/60m TOW = 112.0 kg
NO. OF TOWS = 39
a n=3301
b n=754
c n=3436
d n=1711
e n=1735
f n=101
a. Phycis chesteri
b. Coryphaenoides rupestris
c. Synaphobranchus kaupi
d. Glyptocephalus cynoglossus
e. Nezumia bairdii
f. Merluccius albidus
1142 - 1910m
x̄ CATCH BIOMASS/60m TOW = 57.0 kg
NO. OF TOWS = 30
a n=1167
b n=3267
c n=340
d n=130
e n=338
f n=104
g n=444
a. Antimora rostrata
b. Synaphobranchus kaupi
c. Alepocephalus agassizi
d. Coryphaenoides rupestris
e. Nezumia bairdii
f. Halosauropsis macrochir
g. Dicrolene intronigra
1916-2933m
x̄ CATCH BIOMASS/60m TOW = 22.3 kg
NO. OF TOWS = 19
a n=568
b n=423
c n=103
d n=12
e n=88
f n=21
a. Antimora rostrata
b. Coryphaenoides armatus
c. Halosauropsis macrochir
d. Bathysaurus ferox
e. Coryphaenoides carapinus
f. Porogadus miles
2745-4829m
x̄ CATCH BIOMASS/60m TOW = 7.2 kg
NO. OF TOWS = 13
a n=172
b n=13
c n=5
d n=3
X
a. Coryphaenoides armatus
b. Coryphaenoides leptolepis
c. Barathronus parfaiti
d. Bathypterois longipes

benthic macrofauna, suggesting that much of this fish biomass may depend on food sources other than the macrobenthos (relative turnover rates are poorly known).

Diversity, Species Richness and Equitability

Our research has shown that diversity (H', H), species richness (Margalef's index: Margalef 1968) and species density values for demersal fishes follow similar patterns with depth beyond about 200 m (Musick et al. 1975; Musick 1976, 1979). We could find no definitive pattern for equitability values (Fig 12). Diversity of demersal fishes increases dramatically at the shelf-slope break (100-200 m) and remains high out to a depth of about 1800-2000 m beyond which there is a rapid and exponential decrease with depth (Fig. 13). Workers on other taxa also have found a marked increase in diversity between the outer continental shelf and lower slope.

Sanders (1968) showed that the diversity of slope infauna off New England increases with depth and remains high out to the abyss. He attributed this surprisingly high abyssal diversity to the stable deep-sea environment, and discussed his now well-known "stability-time" hypothesis. Gray (1974), reinterpreting some of Sander's data on the polychaete-bivalve fraction of the infauna, showed that the maximum diversity was found between 300 and 1500 m with lower diversity at 2086 and 2500 m. Gray attributed the lower diversity values below 2000 m to reduced sediment heterogeneity, and argued convincingly that increased sediment heterogeneity should produce greater infaunal diversity,

Figure 12. Evenness, J', as a function of depth (m) for all 13.7 m SBT stations (1973-1978). Triangles indicate multiple points. Large dots indicate values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).

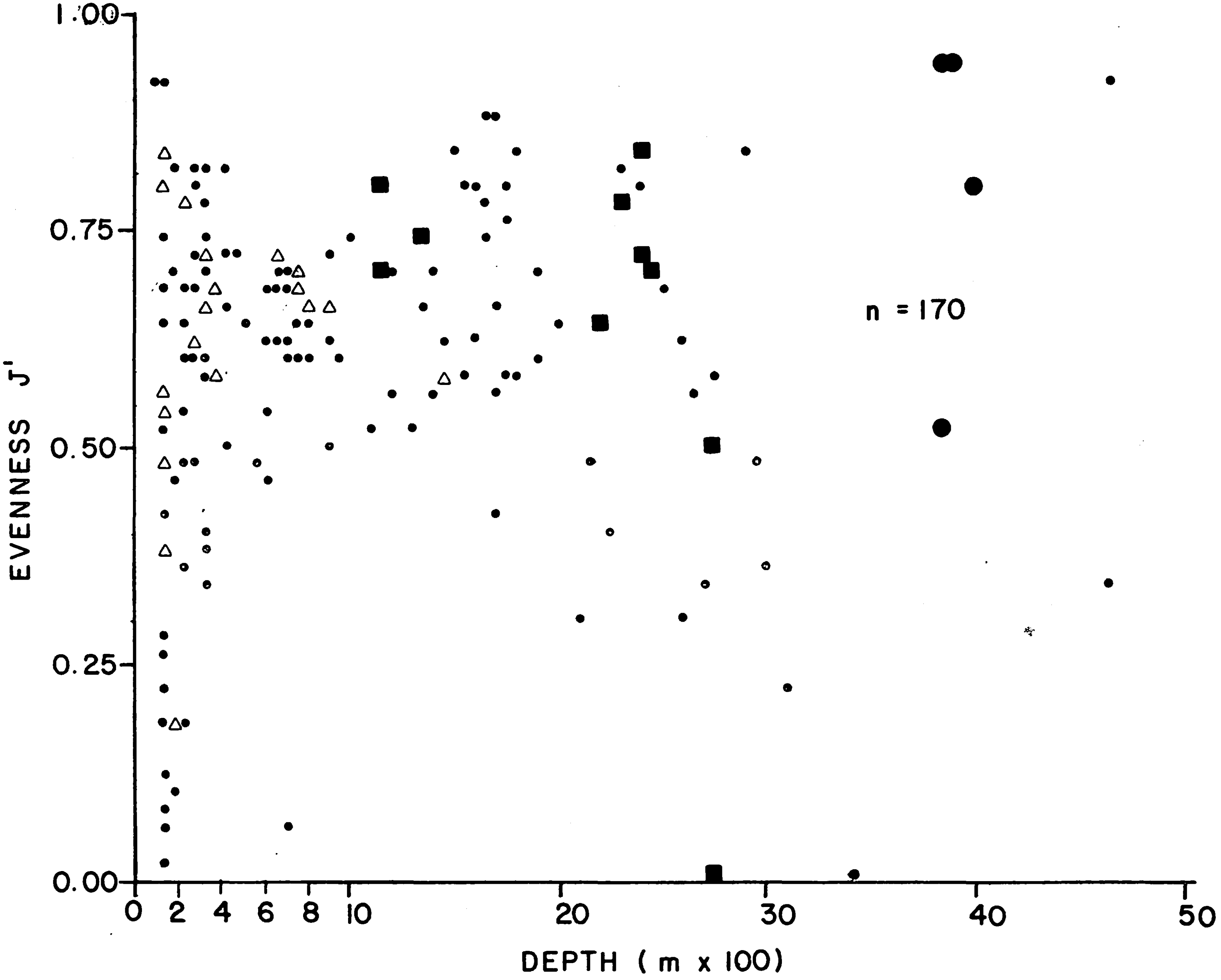

1.00
0.75
0.50
0.25
0.00
EVENNESS J'
0
2
4
6
8
10
20
30
40
50
DEPTH (m x 100)
n = 170

Figure 13. Diversity, H', as a function of depth (m) for all 13.7 m SBT stations (1973-1978). Triangles indicate multiple points. Large dots indicate values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).

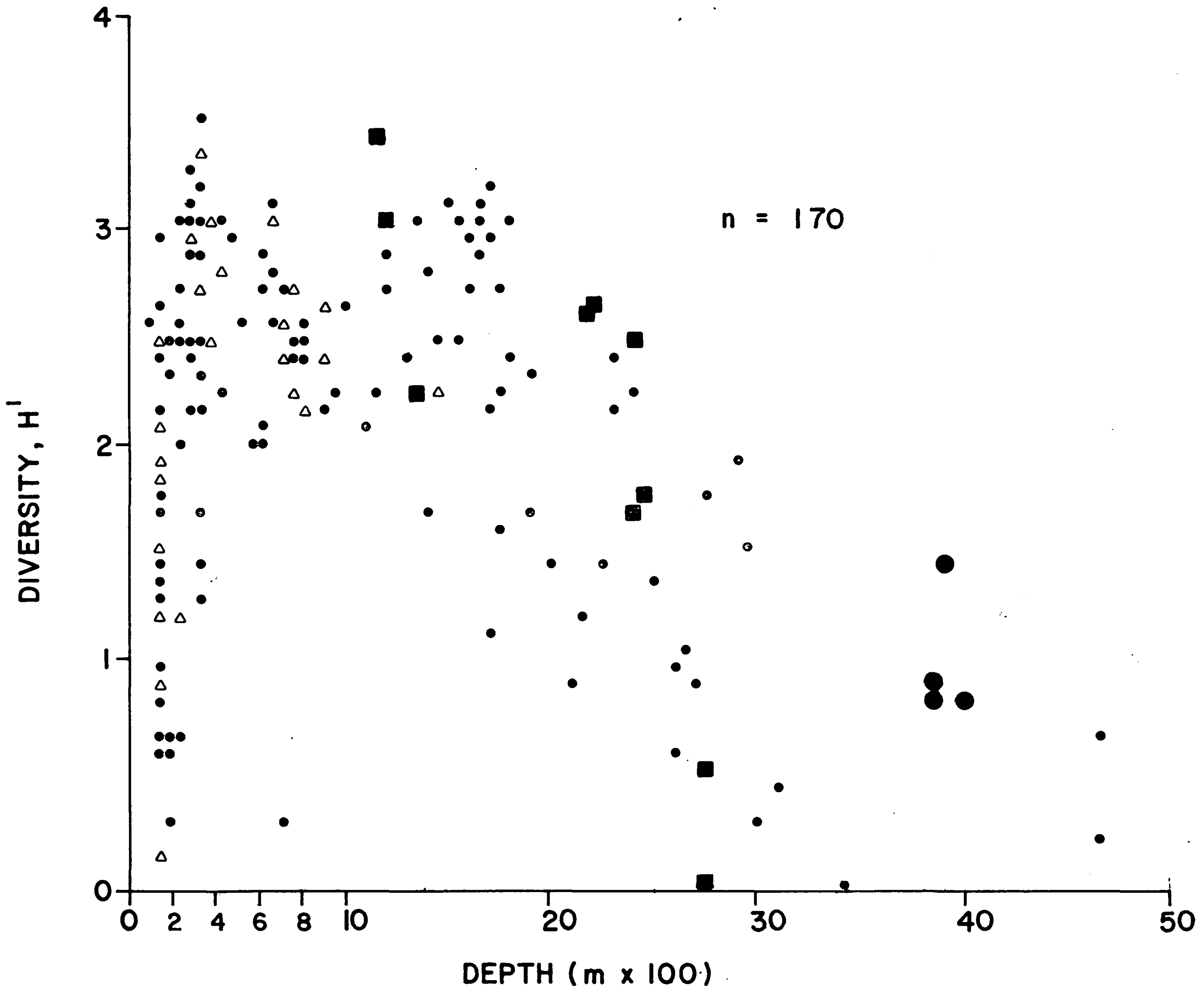
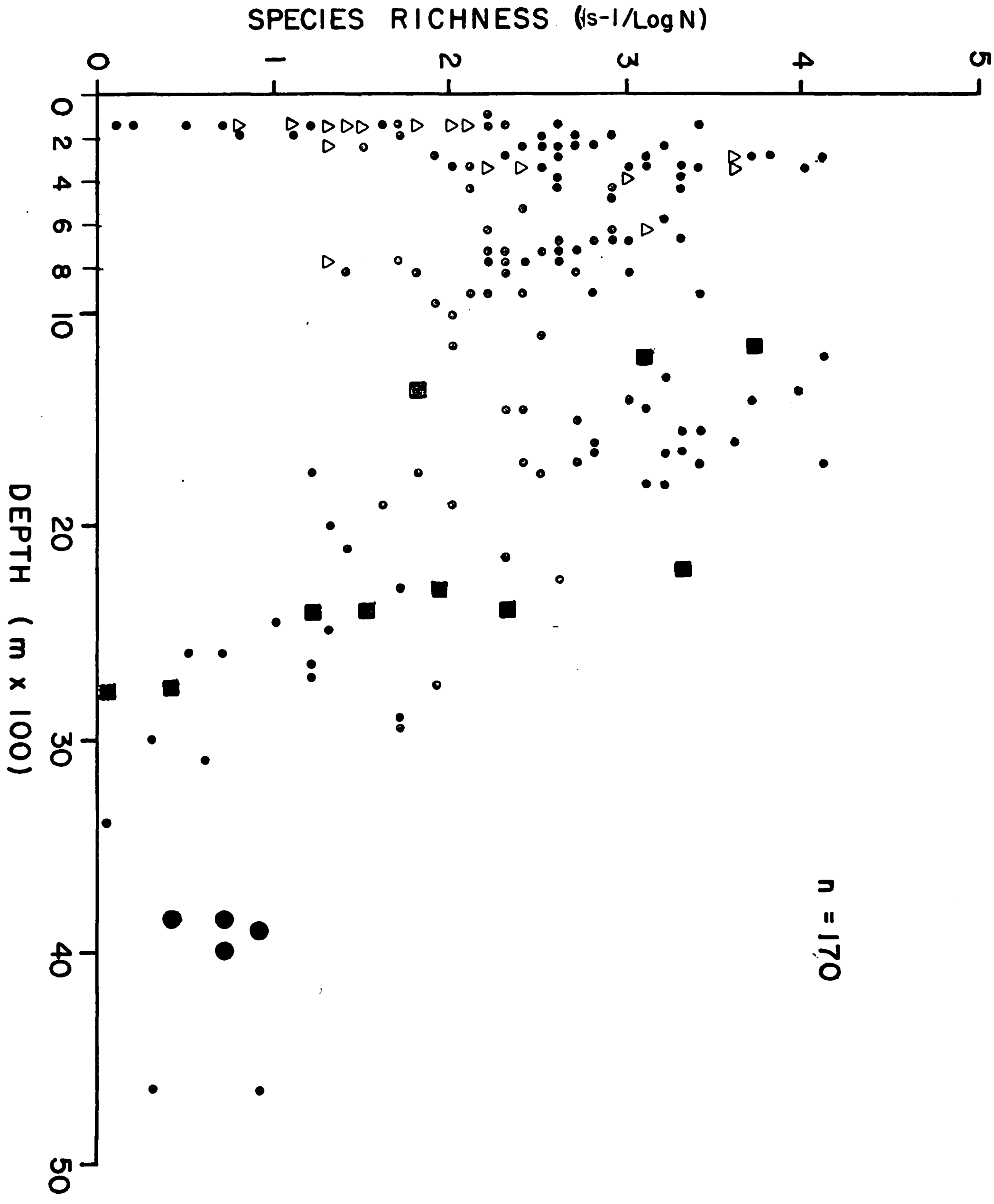

DIVERSITY, H'
0
1
2
3
4
0
2
4
6
8
10
20
30
40
50
DEPTH (m x 100)
n = 170

Figure 14. Species Richness, $S-1/\mathrm{LOG}_{10}N$ (Margalef), as a function of depth (m) for all 13.7 m SBT stations (1973-1978). Triangles indicate multiple points. Large dots indicate values for EPA-7801; solid squares indicate values for D-7402 (DWD-106).



SPECIES RICHNESS (s-1/Log N)
0
1
2
3
4
5
DEPTH (m x 100)
0
2
4
6
8
10
20
30
40
50
n = 170

other factors being equal. Coull (1972), working with the meiofauna between North Carolina U.S.A. and Bermuda, found that species diversity increased greatly from the shelf to the upper slope, and remained high out to at least 3940 m. Diversity differences between stations at 500 m and 3000 m were not great, and the 500 m rarefaction curve was practically identical with that from a station at 3940 m.

Hessler and Jumars (1974) showed that bivalves and polychaetes collected by boxcore in the central North Pacific had diversities as high as those from samples from shallow-water tropics, and higher than those from Sanders' New England slope stations. Also from the same samples, the meiofaunal copepods had a higher diversity than found by Coull (1972) off North Carolina. They stated that, whereas such high diversity required long-term environmental "stability/predictability", stability could not act as a mechanism for production or maintenance of diversity. They also concluded that because their samples came from one of the poorest areas for productivity known in the world's oceans, food availability was not limiting the diversity of the animals they studied.

Rex (1973) found that diversity of gastropods off New England was low on the continental shelf and became high and remained fairly uniform from the upper slope out to the abyss where, between 3834 m and 4667 m, there was a drop in diversity equal in magnitude to that we found for fishes at a depth of about 1800 m. Rex attributed this drop in diversity to a drop in productivity and available food between the continental rise and abyss. Jones and Sanders (1972) found a similar drop in diversity in cumaceans along the same transect. Rex (1973) noted that small organisms such as foraminiferans reached their greatest diversity at abyssal depths (Buzas and Gibson 1969), so that productivity probably affects diversity of taxa only when the lower limits of adaptation in size are approached.

Thiel (1975) also found high diversity of meiofaunal animals in the deep sea, and showed that although overall abundance decreased, the meiofaunal fraction of the benthos increased with depth. He theorized that species associations governed by constantly limited food availability will be composed of small individuals. Further, he wrote that although energy requirements of smaller organisms are higher per unit weight than those of large organisms, a minimum population density must be maintained to guarantee metazoan reproduction by sexual fertilization. Thus, "organism size and population density are balanced out with energy resources." Jumars (1975) recently proposed that species which have smaller ambits will be more diverse than species having larger ambits if an environmental grain of relatively small dimensions has been important in structuring the community. His ideas complement those of Thiel.

Haedrich et al. (1975) found that diversity of echinoderms increased between 141 and 1928 m by a factor of two or three. They attributed this increase to greater habitat heterogeneity at the bottom of the continental slope off New England. They also reported that the diversity in fishes remained constant from 141 to 1095 m but that a large decrease occurred between 1095 and 1270 m. As pointed out above, their trawl catches were not representative of the fish fauna because of gear selectivity. Consequently, the apparent drop in diversity observed was an artifact of collection technique.

Menge and Sutherland (1976) reconciled the apparently contradictory theories that state on one hand that predation maintains species diversity by keeping prey populations below levels at which competitive exclusion operates, and on the other that competition maintains species diversity by selection for niche segregation. The former theory was suggested by Dayton and Hessler (1972) to account for the high benthic diversity in the deep sea, where the latter was embraced by Grassle and Sanders (1973) to explain the same phenomenon.

Our data on the diversity of fishes (Musick 1976) appear to support Dayton and Hessler (1972). Fishes are among the largest organisms in deep-sea communities. They are predators that occupy the highest levels of the deep-sea trophic system. Of the taxa for which quantitative data are available, the fishes decrease in diversity closest to the continental margin at about 1800 m. This slope-rise border also probably marks the region beyond which food sources of continental origin are regularly available to the ecosystem. Given their trophic position fishes should be among the first group of organisms to reflect decreasing productivity and availability of food through increased competition for food resources and resultant competitive exclusion. This appears to be true, and consequently predation on the benthos must be intense.

Rex (1976) more recently showed that the diversity of predatory gastropods relative to total gastropod diversity increased on the slope to a maximum, on the upper rise then declined rapidly beyond 3000 m. A rapid decline in diversity of deposit feeders occurred deeper at 4000 m. Rex's findings support our conclusion that deep-sea diversity is directly linked to trophic position and energy availability. Predatory gastropods eat deposit feeders and are primary predators, whereas fishes that eat benthos consume both predatory and deposit-feeding macrobenthos as well as small megabenthos, which themselves may be primary or even secondary predators (Sedberry and Musick 1978). In addition, the very large sharks (the major fish predators) which may control fish population densities and competition levels on the continental slope may be eliminated from the trophic system at depths beyond 2000 m (see above). Further substantiation of our argument comes from Carey (1972) who reported on the food sources of asteroides off the Oregon coast. Although he did not deal with species diversity directly, he showed that the percentage of predatory asteroid species decreased while the percentage of ominivorous asteroids increased drastically from the outer shelf to the abyss.

FINDINGS AT EPA RADIOACTIVE DUMP SITE

Fish Assemblages

Fish assemblages sampled between 3850 and 4021 m near the EPA R.D.S. were similar to those sampled at comparable depths elsewhere in the western North Atlantic. The four R.D.S. trawl stations clustered in group 5 with other stations from abyssal depths (3000-5000 m) (Fig. 4).

The large macrourid _Coryphaenoides_ _armatus_ was the overwhelmingly dominant fish species at abyssal stations (Table 2) including those near the R.D.S. (Table 3), with _C_. _leptolepis_ second in both biomass and numerical dominance (Table 3). The numerical abundance (Fig. 8) biomass (Fig. 9) and average size (Fig. 10) of fishes captured near the R.D.S. fell within the range of values estimated for other abyssal stations (Table 4). Likewise species diversity (H'), richness (D) and evenness J' values (Figures 13,12,14) all were within the range estimated for other abyssal stations (Table 4). The fish assemblages at the R.D.S. (and other abyssal stations near 4000 m were typified by relatively low biomass and low species diversity and richness. In addition the average body wt. (size) of fishes at the R.D.S. and other abyssal stations was relatively large (300-600 gm) (Fig. 11, Table 4)

Food Habits and Trophic Relationships

Coryphaenoides _armatus_

This macrourid fish has been reported from abyssal depths around the world (Iwamoto and Stein, 1974). The food habits of

Table 3. Cruise EPA-7801, R/V Advance II: Demersal Fishes obtained at 13.7 m semi-balloon trawl stations.

SPECIES	STATION 7009		7011		7013		7014	
Demersal Fishes:	No.	Wt.(g)	No.	Wt.(g)	No.	Wt.(g)	No.	Wt.(g)
Coryphaenoides armatus	7	4556	3	2095	4	2548	14	9071
Coryphaenoides leptolepis	-	-	-	-	-	-	2	340
Bathypterois longipes	-	-	1	60	2	80	-	-
Barathronus parfaiti?	4	25	-	-	-	-	1	11
Bassozetus normalis	-	-	-	-	2	130	-	-
TOTAL	11	4581	4	2155	8	2758	17	9411

Table 4

Comparison of demersal fish data for 13.7 m trawl
stations at depths ≥ 2500 m: EPA-7801
compared with all other cruises

CRUISE	STATION	DEPTH (m)	SPECIMENS PER HR.	GRAMS PER HR	# SPECIES	MEAN WT. PER FISH	MEAN # SPECIMENS PER SPECIES	DIVERSITY H'	EVENNESS J'	RICHNESS D
EPA-7801	7009	3850	3.7	1527	2	416.5	5.5	0.83	0.53	0.71
	7011	4021	1.3	718	2	533.8	2.0	1.50	0.95	0.96
	7013	3920	2.7	919	3	344.8	2.7	0.81	0.81	0.72
	7014	3864	5.7	3141	3	554.2	5.7	0.95	0.95	0.42
$\bar{x}$			3.4	1576	2.5	462.3	4.0	1.02	0.81	0.70
stand. dev.			1.8	1098	0.6	99.1	1.9	0.32	0.20	0.22
CI-7802	6013	3011	28.0	8943	2	319.4	14.0	0.26	0.37	0.30
	6014	3393	15.0	8984	1	598.9	15.0	0	0	0
	6016	4650	3.0	14628	2	4876.0	1.3	0.64	0.92	0.91
	6018	4879	0.5	1100	1	1100.0	1.0	0	0	0
	6021	4631	16.0	9259	2	578.7	8.0	0.23	0.34	0.36
D-7402	A005	2500	10.0	3953	4	395.3	2.5	1.36	0.68	1.30
	A006	2745	0.7	267	1	267.0	1.0	0	0	0
	A06A	2745	9.0	1625	2	180.6	4.5	0.50	0.50	0.46
GI-7404	2086	2642	107.0	42220	7	393.6	15.3	1.09	0.56	1.28
	2087	2624	60.0	21151	4	352.5	15.0	0.59	0.30	0.73
GI-7508	3035	2933	64.0	24723	9	386.3	7.1	1.57	0.49	1.77
	3036	3083	92.0	39644	9	430.9	10.2	0.47	0.23	0.68
GI-7601	4024	2679	63.0	25634	6	406.8	10.5	0.89	0.34	1.21
	4055	2575	55.0	22667	3	412.1	18.3	1.00	0.63	0.50
	4056	2920	10.0	3664	5	366.4	2.0	1.96	0.84	1.73
$\bar{x}$			35.6	15231	3.9	737.6	8.4	0.70	0.41	0.75
stand. dev.			35.1	13621	2.8	1163.8	6.1	0.60	0.29	0.60

this very dominant R.D.S. species have been studied in detail by Pearcy and Ambler (1974), Haedrich and Henderson (1974) and Sedberry and Musick (1978). A euryphagous animal, *C. armatus*, feeds mostly on benthic polychaetes and small benthic crustacea when small (<300 mm total length), and on pelagic cephalopods, fishes and crustaceans when large (> 300 m total length). In addition, it opportunistically scavenges dead items from the bottom. Thus at one stage in its life history, *C. armatus* may act as an important predator on the macrobenthos, and at a later stage it may serve to accelerate energy flow to the macrobenthos by consuming pelagic prey and isolated falls of large dead food items and distributing them over the bottom as feces. Smith et al. (1979) reported that *C. armatus* may forage as high as 685 m off the bottom (at a depth of 5700 m). But their gear may have attracted the fish, and *C. armatus* probably usually confines its foraging to areas much closer to the bottom (Sedberry and Musick, 1978).

Other Species

In addition to *C. armatus*, bottom trawl collections from R.D.S. yielded specimens of these demersal fish species (Table 3): *C. leptolepis*, *Bathypterois longipes*, *Bassozetus normalis*, and *Barathronus* sp. (= *B. parfaiti* or a closely-related undescribed species). The food habits of these species can be summarized as follows below.

The large macrourid, *C. leptolepis*, is found primarily at depths between 2000 and 4000 m and is probably circumglobal in distribution. Pearcy and Ambler (1974) found that C. leptolepis feeds on a variety of crustacea, as well as polychaetes, bivalves and ophiuroids. Fishes and cephalopods, which constitute common food items for C. armatus, were not recorded from C. leptolepis stomachs. Benthic crustacea constitute the most important food item of small (less than 500 mm SL) C. leptolepis, whereas pelagic crustacea are of increased importance to larger individuals.

The ipnopine species B. longipes is a typical inhabitant of abyssal depths (2600 to 5600 m) and is probably circumglobal (Sulak 1977). Nybelin (1957) indicated that it may be the commonest abyssal bottom fish in the northeastern Atlantic. As with other species of Bathypterois, B. longipes probably feeds primarily on copepods and other small benthopelagic crustacea (Marshall and Merrett 1977, Sulak 1977).

The ophidioid species B. normalis occurs at lower bathyal to abyssal depths (Cohen and Nielsen 1978). Its biology is poorly known. However, its large size, large sub-terminal mouth, small jaw teeth, well-developed crushing pharyngeal pads, and unspecialized gill rakers of moderate length suggest a varied diet of benthic invertebrates. It seems likely that B. normalis is a mobile foraging predator-scavenger.

Aphyonids, including Barathronus, are small, scaleless, neotenous fishes (Nielsen, 1969). They probably have limited mobility; their reduced gelatinous musculature, reduced sensory capabilities, and viviparous reproduction are adaptations consistent with a less active life style. Food habits are poorly known, but recorded stomach contents for the genus include copepods (Nielsen, 1969). A diet of small benthopelagic crustacea seems probable.

Relevance of This Study to Deep-Sea Disposal of Radioactive Wastes:

Even though the present study found no demonstrable differences in the fish assemblages at the R.D.S. and those from other localities at similar depths, we cannot prudently conclude that radioactive waste disposal has had no effect on the fishes. The reasons for this are threefold:

1. Nature of sampling methodology: In recent years our methods of deep-sea otter trawling have improved to the point where we have confidence in the quantitative nature of our data. The steel "V" otter doors we use are much more stable hydrodynamically than the older wooden doors previously in use. In addition through assistance from the National Marine Fisheries Service we have accurately measured the height and sweep of our nets with acoustic devices while the nets were under tow at different ship speeds. Also observations from <u>DSRV Alvin</u> (Cohen and Pawson 1977, Sedberry and Musick 1978) indicate that our net samples are representative of fish assemblages observed on the slope rise and abyss. (Our nets do not provide representative samples of continental shelf fishes

because these more active animals may avoid the net differentialy, some species being more adept at avoidence than others). Notwithstanding the foregoing, we cannot unequivocally state that our net samples represent the fish assemblage in the immediate vicinity of the R.D.S. because the R.D.S. is located on the edge of a deep-sea canyon, and is restricted in area. In order to attain an adequate sample at great depths the trawl must be towed for several miles (unlike sampling with box cores or benthic grabs which may take "point" samples). Also it is impossible to trawl along a rocky canyon wall which would simply destroy the net. Lastly, trawl sampling at the R.D.S. as at other deep-water dump sites (Musick et al. 1975) must necessarily be conducted around the periphery of such sites in order to avoid inadvertent catches of dumped materials that may be hazardous to the ship's party.

2. Mobility of the Fishes: We have shown that the dominant fishes near the R.D.S. are large and mobile. These fishes are capable of migrating long distances, and we do not know the duration of time that any individual fish may reside in the vicinity of the R.D.S.
3. Insidious Effects: Many pollutants including radioactive wastes may cause insidious biological effects

on growth or reproduction of organisms, or may cause genetic damage that is not readily apparent. Such effects cannot be ruled out in the present study, and because of the migratory nature of most of the fishes, might be particularly difficult to detect.

Final Cautionary Note

There are at least two major pathways by which radionuclides might be transported out of the dumpsite to distant regions. One pathway is biological, the other is physical. We have noted that most of the fishes near the R.D.S. are large and migratory. Coryphaenoides armatus is the dominant species and our past studies of reproduction in this species have suggested that, although abundant in the abyssal western North Atlantic at temperate latitudes, it apparently spawns elsewhere. We have never captured any individuals with fully ripe gonads and have captured few small individuals (Middleton 1979). A bathyal congener C. rupestris has been shown to be migratory, spawning in the boreal Atlantic near Iceland. In addition Wenner and Musick (1977) have suggested that the large lower-bathyal morid, Antimora rostrata, also abundantly frequents the lower slope and rise off the middle Atlantic Coast of the U.S. as a feeding area, but that the species probably also migrates to boreal latitudes to spawn. The same may be true of C. armatus, which probably lays large numbers of pelagic eggs (Middleton 1979, Wenner 1978, Marshall 1973), that develop in the upper part of the thermocline. These eggs may provide a means by which radionuclides could be transported from the abyss into epipelagic ecosystems.

Studies by Eittreim et al (1976) on the nepheloid layer in the Atlantic Ocean show that a very dense layer of suspended particulate matter exist near the bottom in the vicinity of the R.D.S. studied herein. This nepheloid layer is maintained in suspension and is being transported southwest by the Western Boundary Under Current (WBUC) (Lal 1977, Zimmerman 1971, Amos and Gerard 1979). The axis of the WBUC lies around a depth of 3000 m off southern New England but sweeps inshore to as shoal as 1000 m off Cape Hatteras (Heezen and Hollister 1971, Menzies et al. 1973). Radionuclides adhering to suspended particulate matter at 1000 m could be introduced into near surface ecosystem easily and quickly. Sedberry and Musick (1978) suggested that particulate organic carbon (POC) suspended in dense nepheloid layers might provide the energetic base for benthopelagic food webs. There is mounting evidence for the existense of such webs (Marshall and Merrett 1977). If POC in the nepheloid layer were contaminated with radionuclides it could become incorporated into benthopelagic food webs. Some of the dominant benthopelagic fishes on the middle slope make seasonal bathymetric migrations from below 1000 m to shallower depths (500-1000 m) (Middleton 1979). The benthopelagic fauna in this region has intensive trophic interactions with the mesopelagic fauna, which undergoes diel vertical migrations from near the surface at night to near the bottom during the day

(Sedberry and Musick 1978). Thus radionuclides can be transported from dump sites as deep as 4000 m by horizontal and vertical migration of fishes or their gametes, by transport of suspended sediment, or by combinations of these mechanisms.

Future Studies

Future studies on radioactive waste disposal sites must have more ship time than allowed in the present study. Our temporal sampling constraints were such as to allow us only a cursory glimpse at the fauna. The sampling effort could be increased by an order of magnitude. In addition, biologists must have time allocated on a DSRV to document the fauna in the immediate vicinity of waste contaminants. Fish traps could be used in conjunction with the DSRV to obtain specimens from such areas for laboratory analyses of radionuclides etc. Finally, future studies must be planned far enough in advance to allow charter of an adequate research vessel. The vessel used in the present study *RV Advance II* had an inadequate winch system which was directly responsible for very inefficient use of ship time. Had a ship been available with a faster winch (i.e. *RV Gilliss*, *RV Iselin*, etc.) two or three times as many successful stations could have been occupied in the same period of time.

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APPENDICES

Appendix 1. CRUISE EPA-7801, R/V ADVANCE II: Megafaunal Crustacea from 13.7 m SBT Stations.

Appendix 2. Comparison of Megafaunal Crustacea (Specimens per hour) from Cruises EPA-7801 and CI-7802.

Appendix 3. Comparison of Decapod Crustacean Data for 13.7 m trawl stations at depths ≥ 2500 m from EPA-7801 and CI-7802.

Appendix 4. Cruise EPA-7801, R/V ADVANCE II: Cephalopods obtained at 13.7 m semi-balloon trawl stations.

Appendix 5. Cruise EPA-7801, R/V ADVANCE II: Midwater Fishes obtained in 13.7 m semi-balloon trawl.

APPENDIX 1. CRUISE EPA-7801, R/V ADVANCE II: Megafaunal Crustacea from 13.7 m SBT stations.

STATION	SPECIES	SPECIMENS
7009	*Plesiopenaeus armatus* (Bate)	2
	Ethusina abyssicola Smith	6
	Pontophilus abyssi Smith	6 (one with new species of bopyrid - send to J. Markham)
	Acanthephyra purpurea A. Milne Edwards	1
	Nematocarcinus ensifer (Smith)	4 (heads only)
	Hymenodora gracilis Smith	2
	Parapagurus pilosimanus (subspecies to be determined at USNM)	64
	Scalpellum sp. (Cirripedia) on clinkers	
7011	*Munidopsis crassa* Smith	1
	Munidopsis geyeri ? (sent to L. Pequegnat)	1
	Munidopsis sharreri ? (sent to L. Pequegnat)	5
	Acanthephyra pelagica (Risso)	4
	Ethusina abyssicola Smith	3
	Plesiopenaeus armatus (Bate)	1
	Acanthephyra microphthalma Smith	1 (mangled)
	Penaeid (mangled)	1
	Parapagurus pilosimanus (subspecies to be determined)	39
7013	*Plesiopenaeus armatus* (Bate)	8
	Acanthephyra microphthalma Smith	5
	Parapasiphae sulcatifrons Smith	2
	Acanthephyra pelagica (Risso)	3
	Acanthephyra purpurea A. Milne Edwards	4
	Pontophilus abyssi Smith	6
	Hepomadus tener Smith	1
	Hymenodora gracilis Smith ?	2
	Parapagurus pilosimanus (subspecies to be determined	23
	Eryoneicus sp. (larvae of Polychelidae)	2
	Sergestes arcticus Kryer	2
	Benthesicymus sp.	1
	Gennadas sp.	1
	Sergestes sp.	2
	Meningodora mollis Smith	1
	Acanthephyra stylorostratis (Bate)	1
7014	*Plesiopenaeus armatus* (Bate)	2
	Hepomadus tener Smith	4
	Notostomus robustus Smith ? (mangled)	1
	Munidopsis geyeri Pequegnat and Pequegnat	2
	Ethusina abyssicola Smith	13

7014	Parapagurus pilosimanus (subspecies to be determined)	240
	Nematocarcinus sp. (damaged)	2
	Sergestes robustus Smith	1
	Acanthephyra purpurea A. Milne Edwards	2
	Pontophilus abyssi Smith	2

APPENDIX 2

Comparison of Megafaunal Crustacea (Specimens Per Hour)
from cruises EPA-7801 and CI-7802

	CRUISE: EPA-7801				CI-7802							
SPECIES	STATION: 7009	7011	7013	7014	6013	6014	6015	6016	6018	6020	6021	6022
Munidopsis crassa		0.33									1.0	
Munidopsis geyeri		0.33		0.33								
Munidopsis sharrei				1.67								
Parapagurus pilosimanus	21.33	13.0	7.67	80.0								
Ethusina abyssicola	0.50	1.0		4.33	5.0	2.0						
Pontophilus abyssi												
Plesiopenaeus armatus	0.67	0.33	2.67	0.67	1.0	5.0					1.0	
Plesiopenaeus edwardsianus									0.5			
Hymenopenaeus laevis						2.0						
Parapasiphae sulcatifrons			0.67				1.0			1.0	2.0	2.5
Acanthephyra pelagica		1.33	1.0		2.0				1.0		1.0	0.5
Acanthephyra purpurea	0.33		1.33	0.67	4.0	1.0					1.0	
Acanthephyra stylorostratis			0.33									
Acanthephyra brevirostris						2.0	2.0			3.0		
Acanthephyra microphthalma		0.33	1.67			2.0	1.0					
Sergestes arcticus			0.67		2.0	4.0	1.0					
Sergestes robustus				0.33								
Sergestes japonicus						1.0						0.5
Sergestes sp.			0.67				3.0					
Benthesicymus bartletti						1.0						
Benthesicymus sp.			0.33									
Hymendora gracilis	0.67		0.67			2.0	1.0				1.0	
Meningodora mollis			0.33									
Notostomus robustus				0.33								
Notostomus elegans					1.0							
Pontophilus abyssi	2.0		2.0	0.67								
Nematocarcinus ensifer	1.33				17.0	11.0						
Nematocarcinus sp.				0.67								
Hepomadus tener			0.33	1.33		1.0		1.0			1.0	
Ephyrina bifida					1.0						1.0	
Systellaspis braueri						1.0						0.5
Systellaspis debilis									0.5			
Bentheogennema interrnedia							1.0					
Eryoneicus sp.			0.67				2.0					
Gennadus sp.			0.33									0.5
Gnathophausia sp.						1.0	4.0			2.0		1.0
Penaeid (unidentified)		0.33										
Scalpellum sp.		+			+	+						

APPENDIX 3

Comparison of decapod crustacean data for 13.7 m trawl stations at depths ≥ 2500 m from EPA-7801 and CI-7802

CRUISE	STATION	DEPTH(m)	SPECIMENS PER HOUR	GRAMS PER HOUR	# SPECIES
EPA-7801	7009	3850	28.3	149	7
	7011	4021	18.7	232	9
	7013	3920	21.3	283	16
	7014	3864	89.7	741	10
$\bar{x}$			37.0	351	10
stand. dev.			35.2	266	4
CI-7802	6013	3011	33.0	394	8
	6014	3393	46.0	585	15
	6016	4650	2.0	-	1
	6018	4879	2.0	46	3
	6021	4631	8.0	214	7
			18.2	310	7
$\bar{x}$			20.1	232	5
stand. dev.					

APPENDIX 4. CRUISE EPA-7801, R/V ADVANCE II: Cephalopods obtained at 13.7 m semi-balloon trawl stations.

	STATION		
SPECIES	7009	7011	7013*
Cephalopods:	No.	No.	No.
Bathypolypus arcticus	1	1	
Onychoteuthidae		1 (beak)	
Histioteuthis corona			1
Leachia cyclura			1
Gonatus sp.			1 (beak)

* No cephalopods were obtained at station 7014

APPENDIX 5. CRUISE EPA-7801, R/V ADVANCE II: Midwater Fishes Obtained in 13.7 Semi-balloon Trawl.

Station	Family	Species	Number
7009	Gonostomatidae	Gonostoma elongatum	1
(Possible Range Extension)		Gonostoma atlanticum *	1
	Eurypharyngidae	Eurypharynx pelecanoides	1
	Serrivomeridae	Serrivomer beanii	1
	Myctophidae	Lobianchia gemellari	1
		Notoscopelus resplendens	2
		Benthosema glaciale	6
	Bathylagidae	Bathylagus sp. Δ	1
	Melamphaidae	Scopeloberyx robustus	1
7011	Gonostomatidae	Gonostoma bathyphilum(?)Δ	1
	Myctophidae	Lampanyctus sp. Δ	1
		Diaphus dumerilii	2
	Sternoptychidae	Argyropelecus aculeatus	1
	Melamphaidae	Scopelogadus beanii	1
7013	Myctophidae	Hygophum hygomii	5
		Benthosema glacials	10
		Lampanyctus intricarius(?)*	1
		Lepidophanes guentheri	1
		Ceratoscopelus maderensis	1
		Diaphus dumerilii	6
		Diaphus	1
		Lobianchia dofleini	1
		Unidentifiable (probably Benthoseam) Δ	1
	Serrivomeridae	Serrivomer beanii	1
	Eurypharyngidae	Eurypharynx eplecanoides	1
	Melamphaidae	Melamphaes microps	1
		Scopeloberyx opisthopterus	3
	Paralepdiidae		
	Gonostomatidae	Gonostoma elongatum	1
		Gonostoma bathyphilum	1
		Cyclothone microdon	16
7014	Melamphaidae	Scopelogadus beanii	4
	Sternoptychidae	Sternoptyx diaphana	1
	Eurypharyngidae	Eurypharynx pelecanoides	1
	Serrivomeridae	Serrivomer sp. Δ	1
	Malacosteidae	Malacosteus niger	1
	Gonostomatidae	Gonostoma elongatum	2
		Gonostoma bathyphilum	2
		Cyclothone microdon	4
	Myctophidae	Hygophum hygomii	4
		Benthosema glaciale	1
		Lampanycius cuprarius	1
		Notoscopelus caudispinosus	1
		Unidentifiable Δ (5 of 6 are either Hygophum or Benthosema)	6
	Coryphaenidae	Coryphaena sp.	1

Note: Δ = Specimen too damaged for complete I.D.; * = Rare in sampling area.