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Distribution and Abundance of Zooplankton in the North Pacific Subarctic Frontal Zone and Adjacent Water Masses

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Zooplankton was collected from two depth strata (0-75 m and 75-150 m) with oblique tows of a Tucker trawl at 40 stations across the Subarctic Frontal Zone of the North Pacific Ocean and adjacent water masses in October and November 1989. Thirteen taxonomic groups were identified, and their vertical and spatial distributions were compared and summarized by three water-mass types: 1) Subarctic Domain (SD), 2) Subarctic Frontal Zone (SAFZ), and 3) Transition Zone (TZ). Chaetognaths and mysids were the only taxa that were more abundant in the deeper stratum, primarily due to the overlapping distributions of the two predominant chaetognath species, *Sagitta elegans* and *Eukrohnia hamata,* and the abundant deeper-dwelling mysid *Euchaetomeropsis merolepis* in our samples. Abundances of the predominant taxa (gastropods, polychaetes, ostracods, copepods, amphipods, euphausiids, and chaetognaths) were highest in the SD. Cirripede larvae, decapod shrimp larvae, fish eggs, and squid larvae were most abundant in the SAFZ. Fish larvae and mysids were most abundant in the TZ. Mysids were found only in the SAFZ and the TZ. Overall, the most significant change in the zooplankton community occurred between the SD and the SAFZ.

CONTENTS

INTRODUCTION

Zooplankton is an important food source in the pelagic ecosystem of the North Pacific Ocean and is the basis for seasonal feeding migrations of many pelagic nekton species (Shimazaki 1986). Hence, those who interpret the zoogeography and migratory strategies of predators at higher trophic levels need to understand the distribution and abundance patterns of zooplankton. Because distribution and abundance of zooplankton are often linked to primary production and mixing dynamics associated with different water-mass types (McGowan and Williams 1973, Miller et al. 1991), zooplankton can be an important link between water-mass type and zoogeography of pelagic nekton.

The Subarctic Frontal Zone (SAFZ)-a large-scale, semipermanent frontal region separating the Subarctic Domain (SD) and the Transition Zone (TZ) (Fig. 1)-is the primary zoogeographic feature of the subarctic North Pacific Ocean. The SD is identified by its permanent halocline, which forms as a result of precipitation exceeding evaporation. The SD is typically bounded by the 33.0 and 33.8 isohalines (Roden and Robinson 1988). The SAFZ delineates the southern limit of the subarctic water mass and is identified by the surfacing of the permanent halocline (Roden and Robinson 1988).

In this paper we examine zooplankton community structure in the SAFZ and adjacent water masses and quantify differences in these zooplankton communities.

METHODS

Zooplankton Collection and Sample Processing

Zooplankton was collected from 40 stations with a 0.5-mm mesh, l-m^2 messenger-tripped Tucker trawl (Davies and Barham 1969) aboard the *NOAA* ship *Miller Freeman* along five meridional transects during October and November 1989 (Fig. 2). The Tucker trawl was equipped with General Oceanics Model 2030 flowmeters and a Benthos Model 1170-E bathykymograph. Before each trawl, salinity and temperature profiles were taken to 1,000 m with a Seabird Model 19 SEACAT mini-CTD (Wing et al. 1993).

Line speeds were set at 45-50 m min^{-1} during deployment and 30-35 m min^{-1} during retrieval. Wire angles were monitored with an inclinometer, and vessel speed (approximately 1.5 knots) was adjusted to maintain a 45° wire angle during retrieval.

Trawl samples were collected during the twilight periods after sunset (between 1930 and 2130 hours) and around sunrise (between 0500 and 0830 hours). Full-daylight hours were devoted to visual census of marine mammals and seabirds and to hydroacoustic surveys of the deep-scattering layer. Evening samples were collected as the acoustic scattering layer was rising, but before it started to disperse. Morning samples were collected as the scattering layer began its descent and before there was light enough for a visual census of birds and mammals.

Three zooplankton samples were collected during each trawl deployment. The first sample was taken during the descent of the trawl to 150 m, the second during the upward oblique tow between 150 m and 75 m, and the third during the upward oblique tow between 75 m and the surface. Volumes filtered for the stratified samples ranged from 200 to over 700 m^3. We chose the 0-75 m (shallow) and 75-150 m (deep) strata to most effectively sample acoustic scattering layers observed during the cruise. Appendix 1 summarizes the station information.

Samples were preserved in 4% formaldehyde solution buffered with sodium tetraborate and transferred to alcohol after shipment to the Auke Bay Laboratory near Juneau, Alaska. All samples were scanned for large or rare specimens such as squid larvae, fish eggs, and fish larvae. Small samples were counted in entirety, and larger samples were split with a Folsom plankton splitter (McEwen et al. 1954). The fraction examined ranged from 0.12 to 1.0. All samples were processed, but only samples from the 0-75 m and 75-150 m strata were included in this analysis. Thirteen taxa were identified and counted: gastropods, squid larvae, polychaetes, ostracods, copepods, cirripede larvae, amphipods, mysids, euphausiids, decapod shrimp larvae, chaetognaths, fish eggs, and fish larvae (Appendix 2). Gelatinous zooplankton species (e.g., medusa, siphonophores, ctenophores, heteropods, doliolids, salps, larvaceans) were not counted, due to their colonial nature and their tendency for fragmentation, but were included in the measurements of displacement volume for each sample. Appendix 3 contains qualitative abundance levels of gelatinous zooplankton species.

Statistical Methods

Wilcoxon rank sum tests (Lehmann 1975) were used to test for significant differences' between dawn and evening abundance at each depth stratum, and paired Wilcoxon rank sum tests were used to test whether zooplankton abundances differed significantly between the shallow and deep samples.

Average abundances and coefficients of variation for the 13 taxa were computed for each oceanographic region. To test for significant differences between oceanographic regions, a Kruskal-Wallis rank sum test (Lehmann 1975) was used. The Kruskal test was selected because of its ability to test for significant differences between multiple groups of data.

We computed coordinates for both species and station ordinations of the zooplankton community using principal component analysis (PCA). In species ordination, a sample is placed into a hyperspace with a dimension for each species. This hyperspace is then rotated to find projections (components) that result in the least amount of spread (variability) in the data. In PCA, this is accomplished by partitioning a resemblance matrix into a set of orthogonal linear axes (components) that explain the greatest amount of variability (Pielou 1984, Ludwig and Reynolds 1988). We refer to the direction and magnitude each axis is rotated in species hyperspace as the loading of the species, and the rotation of an axis in station hyperspace as the scale (Statistical Sciences 1995). The principal components were computed using a correlation matrix, and all computations were completed in the S-plus statistical language (Statistical Sciences 1995).

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[1]$p < 0.05$, throughout this paper.

RESULTS

Oceanographic Regions

An obvious subsurface horizontal front was present in all transects and formed as the permanent halocline began to surface (Fig. 3); however, the latitude where the permanent halocline reached the surface depended on the strength of the seasonal halocline and mesoscale frontal dynamics of the mixed layer. Stations with a permanent halocline were clearly cooler and less saline at 75 m depth than stations lacking a permanent halocline (Fig. 4). This temperature and salinity property was used to separate the SD stations from the SAFZ stations.

Unlike Lynn (1986), we did not find an obvious gradient in the physical properties associated with the southern limit of the SAFZ. Lacking this gradient, we used the 33.8 (Practical Salinity Scale) isohaline to separate the SAFZ stations from the TZ stations.

Dawn and Evening Effects

No taxon differed significantly in abundance between dawn and evening samples (Table 1A). Hence, we pooled the data from the two periods in the subsequent analysis.

Vertical Distribution

All zooplankton taxa except chaetognaths and mysids were more abundant in the shallow stratum (Table 1B). However, not all taxa differed significantly. Abundances of polychaetes (Polychaeta), ostracods (Ostracoda), decapod shrimp (Decapoda)larvae, fish (Osteichthys) eggs, fish larvae, and squid (Cephalopoda) larvae did not differ significantly between the two depth strata (Table 1B). When each oceanographic region was considered separately, most taxa also had higher abundances in the shallow stratum. However, abundances were higher in the deep stratum for chaetognaths in all regions; for decapods, fish eggs, and fish larvae in the SD; and for mysids and ostracods in the SAFZ (Table 2).

Distribution by Oceanographic Region

The abundance of most taxa in both depth strata declined from north to south (Table 2). Chaetognaths were most abundant in the SD and least abundant in the TZ, and their abundances differed significantly in both depth strata. The low p-values for chaetognaths (0.002 and <0.00l) were largely due to the abrupt decline in their abundance between the SD and SAFZ. Amphipods were also more abundant in the SD and least in the TZ, but their abundances differed significantly only in the shallow stratum.

Euphausiids and gastropods had the same pattern, but their abundances did not differ significantly in either depth stratum.

Copepods were the most abundant zooplankton taxon, and in both depth strata they were more abundant in the SD and least in the SAFZ. Their coefficients of variation were similar in each oceanographic region, but were highest in the SAFZ, indicating that copepod abundance was more variable in the SAFZ.

Squid larvae, cirripede larvae, decapod shrimp larvae, and fish eggs were most abundant in the SAFZ. However, the abundance of squid larvae did not differ significantly in either depth stratum, and the abundance of decapod shrimp larvae and fish eggs differed significantly only in the shallow stratum. The abundance of cirripede larvae was more than 10 times as great in the SAFZ as in the SD or TZ.

Mysids and fish larvae were most abundant in the TZ, and their abundances differed significantly in both depth strata. The predominant mysid species in our samples were *Euchaetomeropsis merolepis* and a *Siriella* sp.; however, the *E. merolepis* occurred almost exclusively in the deep samples of the SAFZ, whereas the *Siriella* sp. were in the shallow samples in the TZ. Fish larvae were predominantly myctophids. *Stenobrachius* spp. were the most common myctophids, and Pacific viperfish, *Chauliodus macouni,* were the most common nomnyctophid larvae.

Ostracods had the most uniform abundance levels across water-mass types and depth strata, which reflects the cosmopolitan nature of *Conchoecia* spp., the common ostracods of the subarctic North Pacific Ocean (Angel 1972).

Displacement volumes were highest in the SD in both depth strata and were higher in the shallow stratum in all oceanographic regions. However, the difference in displacement volume was greatest between the SD and the SAFZ.

Community Ordination

Taxa that reached their highest abundance in the subarctic water mass (gastropods, polychaetes, ostracods, copepods, amphipods, euphausiids, chaetognaths; Table 2) were separated from the other taxa by the sign of their loadings (Table 1C). The separation of the subarctic taxa (taxa more abundant in the subarctic water mass) was more apparent in the shallow stratum than in the deep stratum. In the shallow stratum, these taxa were separated from other zooplankton taxa by the first principal component (PCl), which accounted for 21% of the variation in species composition. In the deep stratum, these taxa were separated by the second principal component (PC2), which accounted for only 16% of the variation in species composition. The loading for ostracods was considerably lower than for other taxa with negative loadings on PC1 and PC2, which reflects the more uniform distribution of ostracods in our samples. The separation of subarctic taxa can also be seen in the biplots (Gabriel 1971) of species and station ordinations (Figs. 5 and 6). Station scores (Figs. 5 and 6) were consistent with abundance patterns found in Table 2 and loadings in Table 1C. Scores of the SD and SAFZ stations were separated by PC1 in the shallow stratum and by PC2 in the deep stratum. The scores of the three TZ stations in the deep stratum overlapped both SD and SAFZ stations (Fig. 6).

The second principal component split the scores of the shallow stratum in both the SD and SAFZ. The shallow SD scores were split into a group with higher abundances of gastropods, polychaetes, copepods, amphipods, euphausiids, and chaetognaths and a group with higher displacement volumes (Fig. 5). Due to the colonial nature of the gelatinous zooplankton in our samples (predominantly salps and doliolids), the variability in displacement volume was determined primarily by their abundance. As a result, the two groups could be defined as a gelatinous and a nongelatinous zooplankton assemblage. PC2 also separated the shallow SAFZ samples into a group with higher abundances of squid larvae, cirripede larvae, decapod shrimp larvae, and fish eggs and a group with higher abundances of mysids and lower abundances of gastropods, polychaetes, copepods, amphipods, euphausiids, and chaetognaths. Squid larvae, cirripede larvae, decapod shrimp larvae, and fish eggs were also the taxa that reached their peak abundances in the SAFZ (Table 2). Decapod shrimp larvae abundances in the SAFZ and the SD were much more similar than those of cirripede larvae and fish eggs (Table 2), and this pattern is reflected in the decapod shrimp larvae loadings (Fig. 5). The scores of the six TZ stations in the shallow stratum overlapped the scores of the SAFZ stations.

DISCUSSION

The Tucker trawl was designed to capture macroplankton (2-20 mm) and micronekton (20-200 mm) (Davies and Barham 1969). The 1 -m^2 net is an effective sampler for macroplankton and smaller micronekton in the coastal water of the eastern Gulf of Alaska. Although the slow tow speed and relatively small mouth may allow some net avoidance by the larger micronekton, we do not believe that net avoidance was a significant factor contributing to the low abundance of macroplankton in many of our samples. Our samples had few adult euphausiids, sergestid shrimp, myctophids, or other micronekton over 20 mm compared with similar sampling in coastal areas of the eastern Gulf of Alaska.

Vertical Distribution

Most zooplankton taxa were more abundant in the shallow stratum; however, chaetognaths and mysids were significantly more abundant in the deeper stratum (Table 1B). Overlapping distributions of the two predominate chaetognath species *(Eukrohnia hamata* and *Sagitta elegans)* can explain the higher abundance of chaetognaths found in the deep stratum. *E. hamata* reaches its maximum abundance near 150 m and is typically rare in surface samples (0-50 m), whereas S. *elegans* reaches its peak abundance at the surface and is rare below 300 m (Kotori 1972). The higher abundance of mysids in the deep stratum can be explained by the higher overall abundance of *E. merolepis,* which occurred almost exclusively in the deep stratum. The other predominate mysid, *Siriella* sp., was found only in the shallow stratum and in numbers significantly less than *E. merolepis.*

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Distribution by Oceanographic Region

Abundances of predominate taxa (gastropods, polychaetes, ostracods, copepods, amphipods, euphausiids, and chaetognaths) were higher in the SD and lower in the SAFZ and TZ, which is consistent with McGowan and Williams (1973) and Taniguchi (1981). The association of these taxa with the SD was also apparent in the principal component analysis. However, only polychaetes, copepods, and chaetognaths had significantly higher abundances in the SD. The decline in polychaete abundance to the south was probably due to the absence of the common subarctic species *Tomopteris septentrionalis* in the SAFZ and TZ stations (Tebble 1962). The decline in abundance of amphipods to the south can be explained by the absence of the common subarctic amphipod *Themisto pacifica* (Bowman 1960) in the SAFZ and TZ. The decline in the abundance of chaetognaths to the south can be attributed to the absence of *Sagitta elegans* and submergence of *Eukrohnia hamata-the* predominate chaetognaths in the subarctic (Hida 1957, Alvarino 1964).

Stations where gelatinous zooplankton were the most abundant (stations with the largest displacement volumes) occurred most frequently in the SD, and based on principal component scores, appeared to have a zooplankton community that differed from the nongelatinous community. At a species level, gelatinous zooplankton provide a habitat and a food base for a unique zooplankton community. Most hyperiid amphipod species and some copepods are directly associated with and feed on gelatinous zooplankton (Hamner et al. 1975, Lava1 1980). Several nekton species are also associated with gelatinous zooplankton (e.g., smalleye squaretail, *Tetragonurus cuvieri*, feed exclusively on gelatinous zooplankton [Hart 1973], and chum salmon, *Oncorhynchus keta*, feed extensively on gelatinous zooplankton [Pearcy et al. 1988, Welch et al. 19951). Gelatinous zooplankton may provide a basis for a unique pelagic community with trophodynamics distinctly different from that of the nongelatinous community.

The SAFZ appeared to support a zooplankton community of its own beyond a simple transition from a SD community to a TZ community. Taxa associated specifically with the SAFZ included squid larvae, cirripede larvae, fish eggs, and, to a lesser extent, decapod shrimp. Stations with relatively high numbers of these taxa had principal component scores that differed from scores at other SAFZ stations. Decapod shrimp were most abundant in the SAFZ, but still were found in significant numbers in the SD. This distribution was consistent with the known distribution of *Sergestes similis, the* common subarctic decapod shrimp (Omori et al. 1972, Krygier and Pearcy 1981) and the predominant decapod shrimp in our samples. Although *S. simdis* occurs throughout the subarctic North Pacific Ocean, it reaches its peak abundance and forms dense swarms in the SAFZ (Omori et al. 1972).

Mysids were the only taxon not found in the SD. Their absence in the SD is typical of north Pacific meso- and epipelagic mysids, which are found primarily in the lower latitudes (Mauchline and Murano 1977). The coefficients of variation for mysids were high, indicating that their spatial distribution was patchy and is consistent with the patchy distribution found in neuston samples (Ebberts and Wing 1997).

Due to the loss of taxonomic resolution inherent in species aggregation, we were not able to incorporate the true complexity of the zooplankton community; however, the taxa identified in our analysis differed significantly by depth stratum and oceanographic region. The most significant change in the zooplankton community appeared to occur between the SD and SAFZ, suggesting that the presence or absence of a permanent halocline may be important in defining the distribution and abundance of zooplankton in the subarctic.

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TABLES

Table 1.--(A) Wilcoxon rank sum probabilities of difference between morning and evening samples; (B) mean paired differences between the 0-75 m (shallow) and 75-150 m (deep) depth strata and paired Wilcoxon rank sum probabilities (paired differences were computed by subtracting the zooplankton abundance in the deep stratum from that in the shallow stratum for each station); and (C) coordinates of the species ordination (loadings) for the first two principal component axes (PC1 and PC2), and the variance explained by each component. Displacement volume is the whole sample, less osteichthys larvae and cephalopod larvae. Asterisk indicates significant difference ($p < 0.05$).

	(A) Wilcoxon rank sum probabilities of differences		(B)		(C) Shallow		(C) Deep	
Taxon	Shallow	Deep	Mean paired difference (no./1000 m^3)	Wilcoxon rank sum probabilities of differences	PC1	PC2	PC1	PC2
Displacement volume	0.628	0.575	119.556	<0.001*	–0.1135	–0.210	0.110	–0.350
Mollusca								
Gastropoda	0.419	0.687	969.461	<0.001*	–0.304	0.233	0.257	–0.070
Cephalopoda larvae	0.213	0.840	3.850	0.065	0.284	0.473	0.380	0.202
Annelida								
Polychaeta	0.490	0.944	25.035	0.700	–0.256	0.481	0.227	–0.319
Crustacea								
Ostracoda	0.116	0.495	126.047	0.169	–0.169	0.008	0.406	–0.086
Copepoda	0.058	0.877	6303.751	0.001*	–0.428	0.171	0.228	–0.311
Cirripedia larvae	0.755	0.251	848.791	0.005*	0.357	0.363	0.095	0.135
Amphipoda	0.883	0.687	1322.726	<0.001*	–0.299	0.206	0.366	–0.006
Mysidacea	0.028	0.150	–5.758	0.046*	0.122	–0.087	0.117	0.510
Euphausiacea	0.212	0.637	2210.499	<0.001*	–0.275	0.146	0.421	0.020
Decapoda	0.778	0.056	12.778	0.279	0.049	0.265	0.231	0.094
Chaetognatha								
Sagittoidea	0.481	0.411	–493.352	0.004*	–0.207	0.136	0.225	–0.320
Vertebrata								
Osteichthys eggs	0.776	0.445	3.053	0.142	0.300	0.354	0.202	0.324
Osteichthys larvae	0.746	0.171	10.777	0.207	0.308	0.006	0.178	0.361
Variance (%)					21	16	22	16

Table 2.--Comparisons of mean abundance and coefficients of variation (CV) between oceanographic regions with the Kruskal-Wallis test of significance. Shallow = 0-75 m depth; deep = 75-150 m depth. Displacement volume is the whole sample less osteichthys larvae and cephalopod larvae. Asterisk indicates significant difference (p < 0.05).

		Subarctic Domain		Subarctic Frontal Zone		Transition Zone		
Taxon	Stratum	Mean (no./1000 m^3)	CV	Mean (no./1000 m^3)	CV	Mean (no./1000 m^3)	CV	*p*
Displacement volume	Shallow	272.50	123	106.97	77	61.11	49	0.040*
	Deep	97.50	142	28.57	100	38.23	48	0.025*
Mollusca								
Gastropoda	Shallow	2129.32	144	428.50	105	368.96	58	0.065
	Deep	260.88	104	189.28	118	62.40	76	0.274
Cephalopoda larvae	Shallow	5.75	95	9.96	131	2.94	189	0.121
	Deep	2.61	159	4.49	90	1.17	138	0.181
Annelida								
Polychaeta	Shallow	224.60	90	100.57	88	28.29	73	0.036*
	Deep	181.95	92	53.08	86	11.58	70	0.014*
Crustacea								
Ostracoda	Shallow	628.51	61	392.93	83	661.77	77	0.159
	Deep	449.30	61	464.99	118	219.70	43	0.182
Copepoda	Shallow	15913.94	70	3380.81	134	8672.88	110	0.001*
	Deep	4460.80	61	2306.97	120	2964.95	88	0.064
Cirripedia	Shallow	62.16	255	1941.40	133	146.19	218	<0.001*
	Deep	21.42	181	172.63	170	25.94	128	0.004*
Amphipoda	Shallow	2809.41	164	680.83	98	139.69	42	<0.001*
	Deep	199.99	49	196.11	75	77.13	86	0.114
Mysidacea	Shallow	0.00	0	5.52	209	32.82	245	0.040*
	Deep	0.00	0	19.26	92	3.55	155	0.001*
Euphausiacea	Shallow	4251.71	102	2921.16	101	1969.42	58	0.456
	Deep	961.46	122	1078.71	108	827.67	45	0.715
Decapoda	Shallow	15.38	242	40.24	100	3.26	130	0.023*
	Deep	19.25	174	20.09	149	3.07	107	0.489
Chaetognatha								
Sagittoidea	Shallow	970.28	160	108.73	105	47.90	156	0.002*
	Deep	1686.47	90	209.83	82	73.81	114	<0.001*
Vertebrata								
Osteichthys eggs	Shallow	6.16	196	32.00	113	7.02	95	0.002*
	Deep	8.47	117	28.50	122	2.00	110	0.101
Osteichthys larvae	Shallow	7.78	67	28.96	90	78.17	88	0.001*
	Deep	9.88	81	26.19	80	40.30	72	0.020*

FIGURES

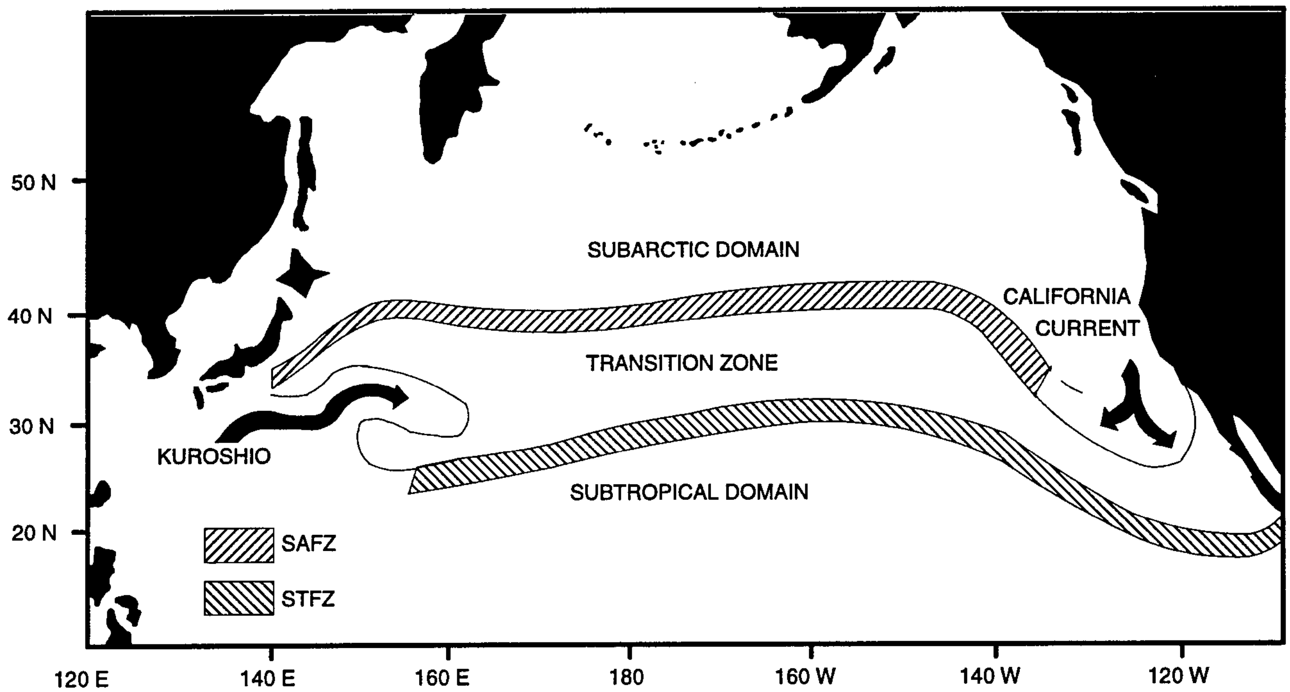

Figure l.--Schematic diagram showing the locations of the Subarctic and Subtropical Domains, the Transition Zone, and the associated Subarctic Frontal Zone (SAFZ) and Subtropical Frontal Zone (STFZ). Black arrows indicate boundary current intrusions (from Roden 1991).

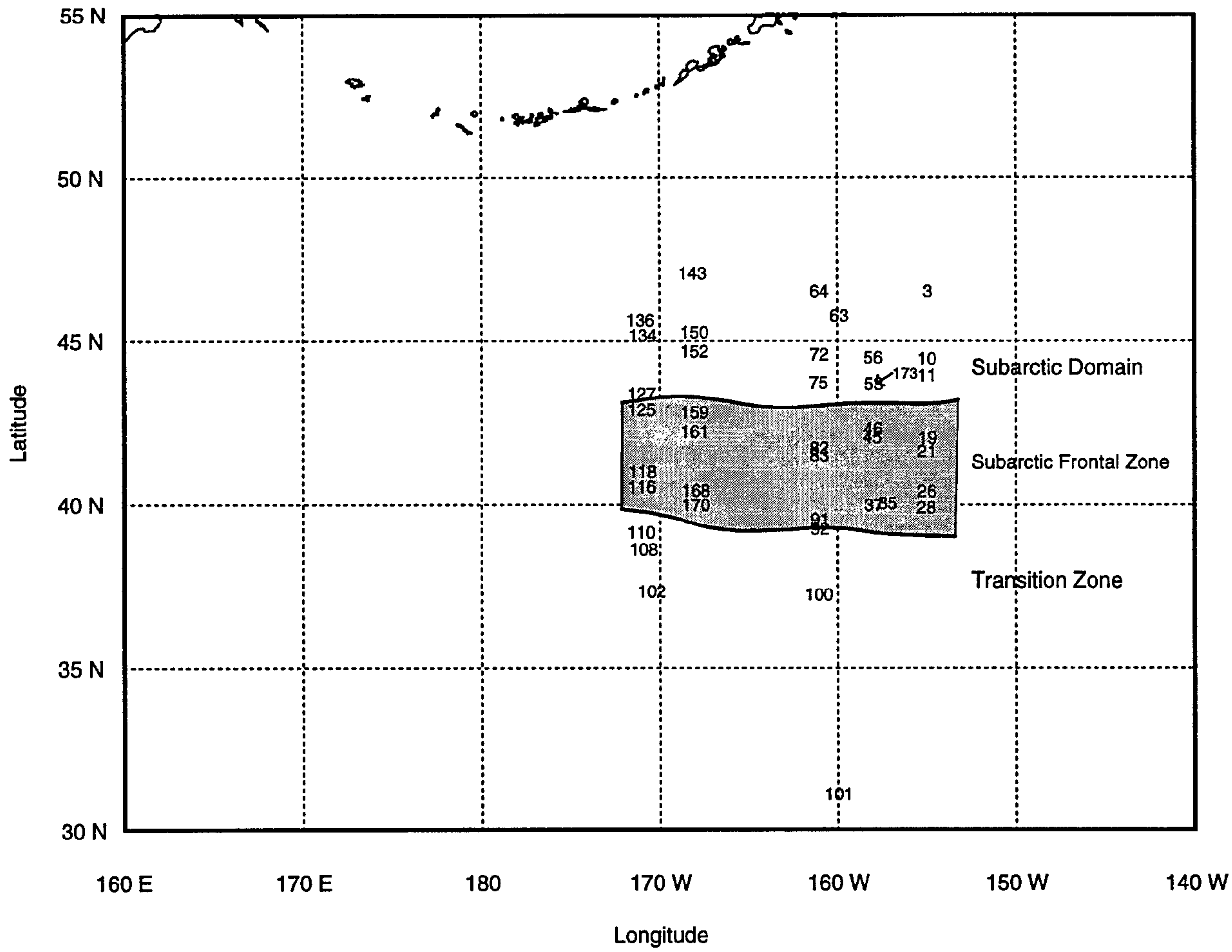

Figure 2.--Oceanographic regions and Tucker trawl sample locations and numbers, October and November 1989.

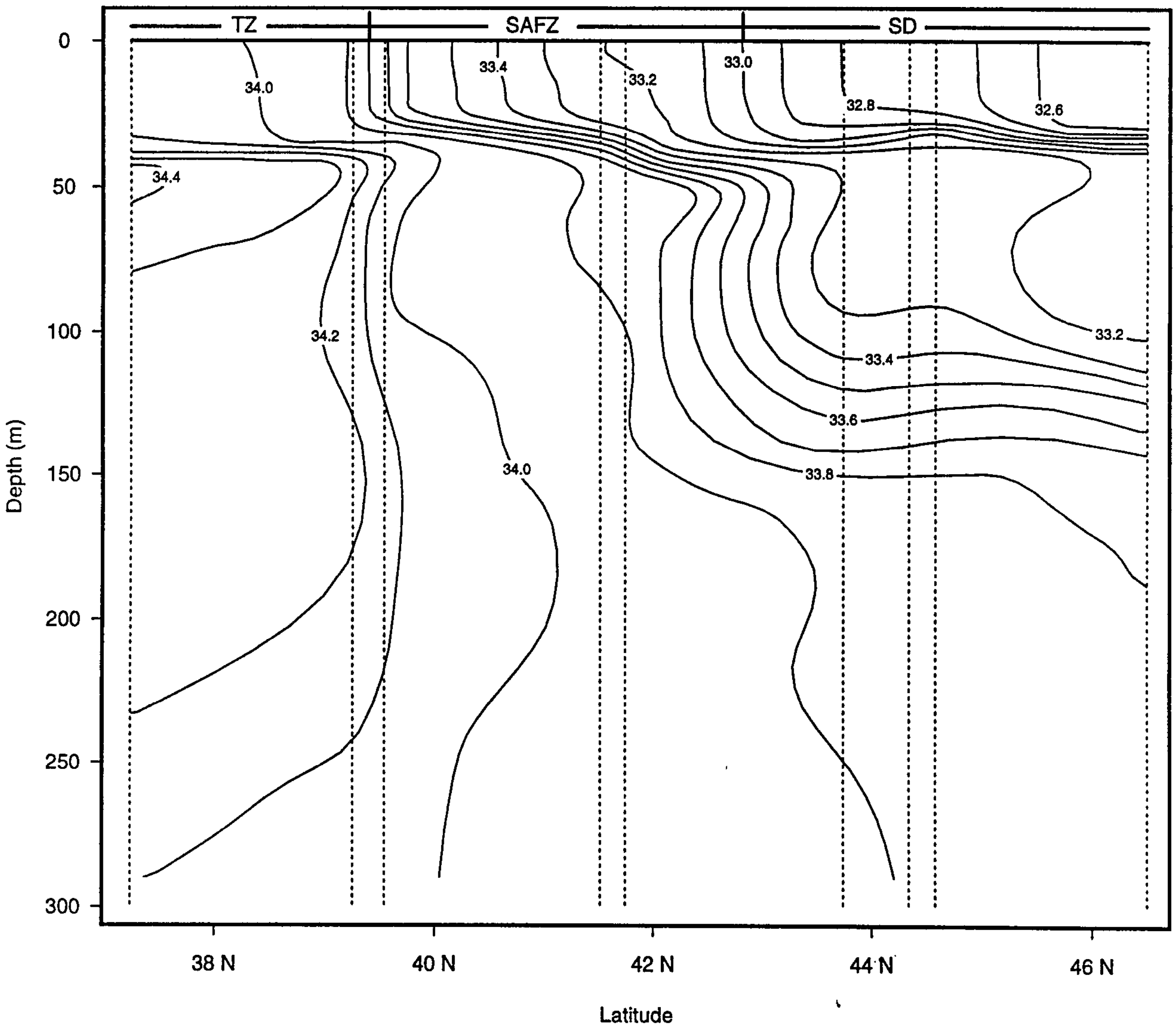

Figure 3.--Salinity along 161°W in October 1989. Oceanographic domains are labeled on top as TZ (Transition Zone), SAFZ (Subarctic Frontal Zone), and SD (Subarctic Domain). Dotted lines indicate station locations.

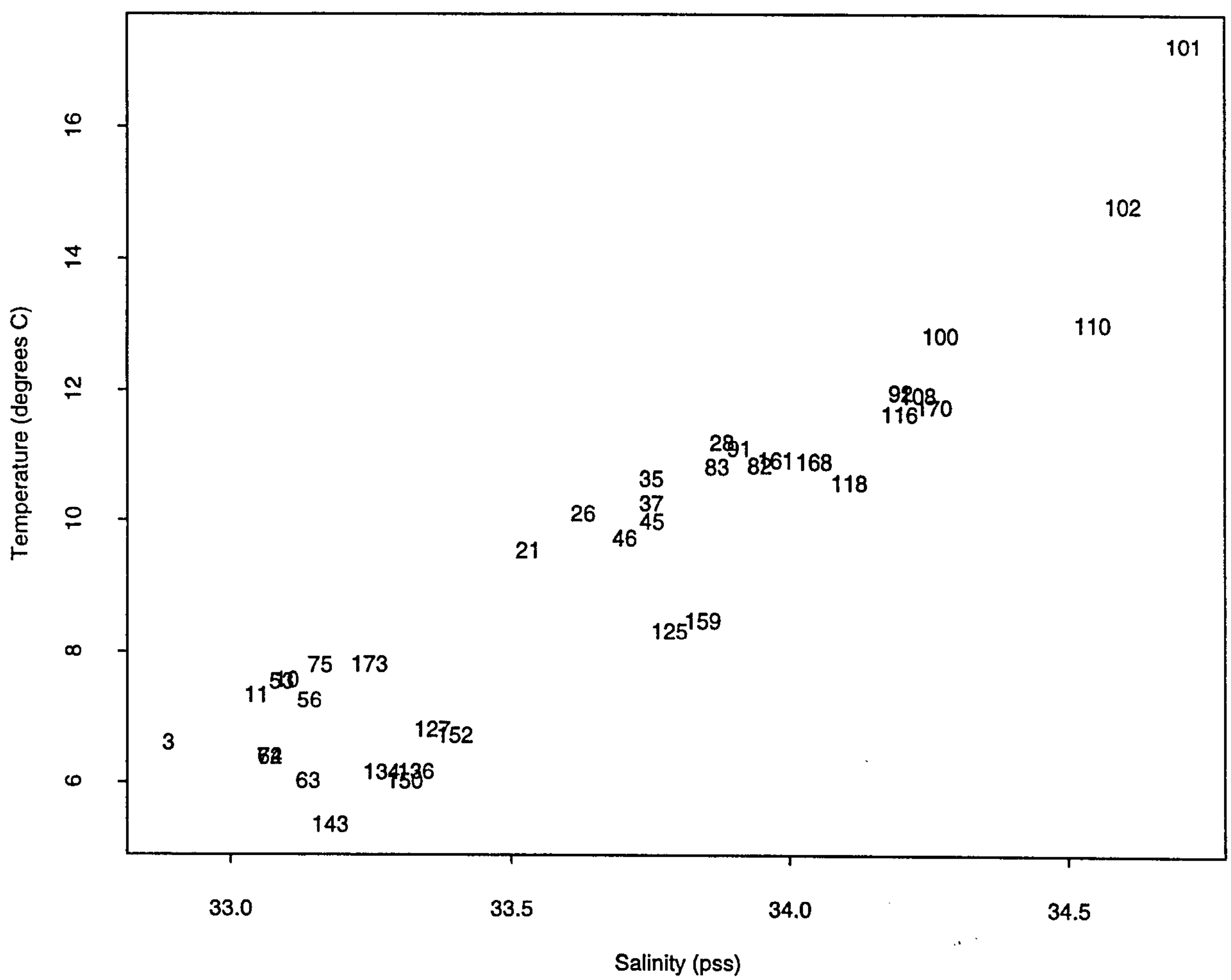

Figure 4.--Temperature and salinity at 75 m depth. Station numbers label each point.

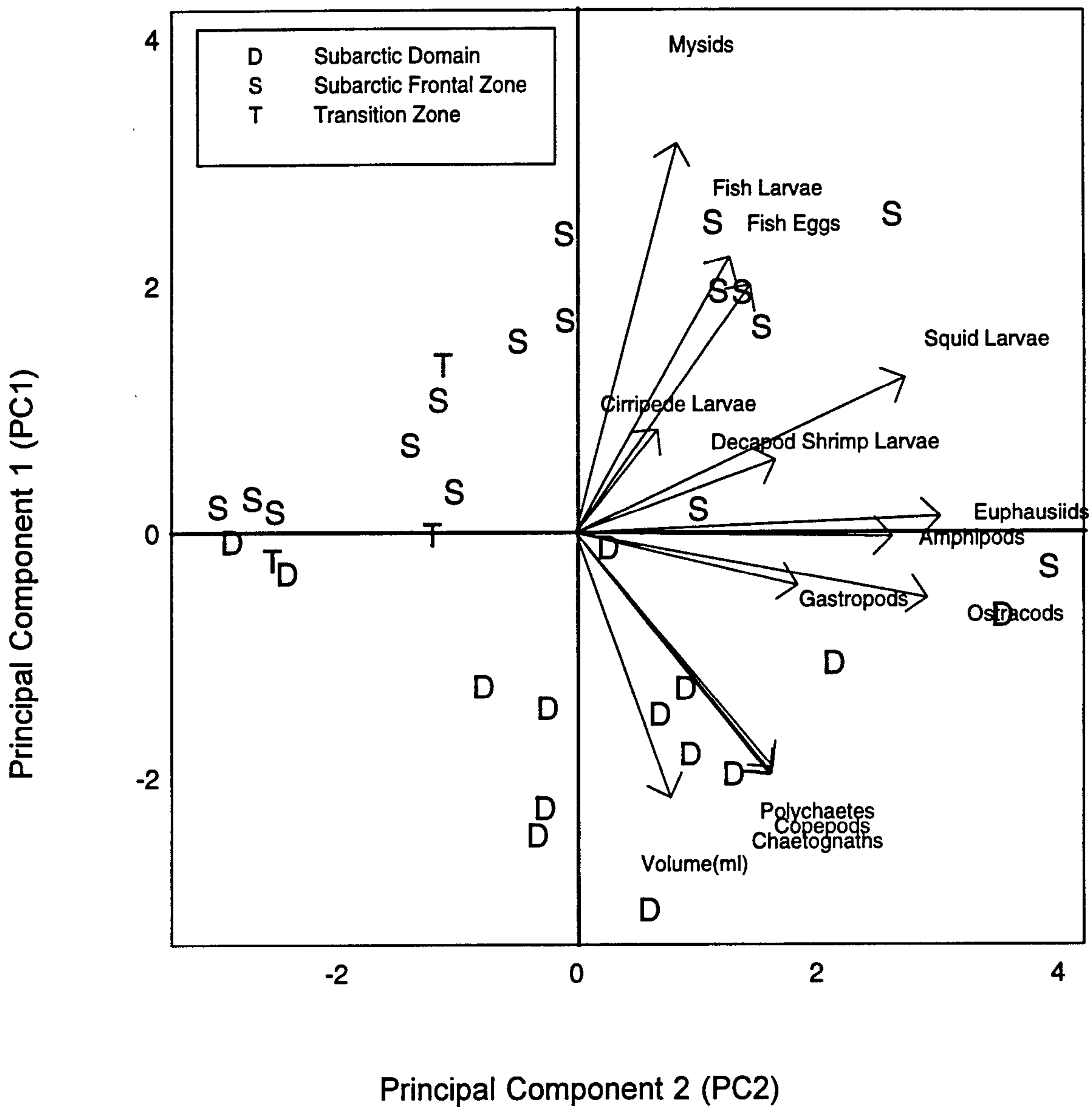

Figure 5.--Biplot of the zooplankton community ordinations using principal component analysis (PCA). Zooplankton were collected between 0 and 75 m depths. Vector coordinates are the species loadings on the first (x-axis) and second (y-axis) principal components of the species ordination. Letter (D, S, and T) coordinates are the station scores from the station ordination. Volume refers to displacement volume.

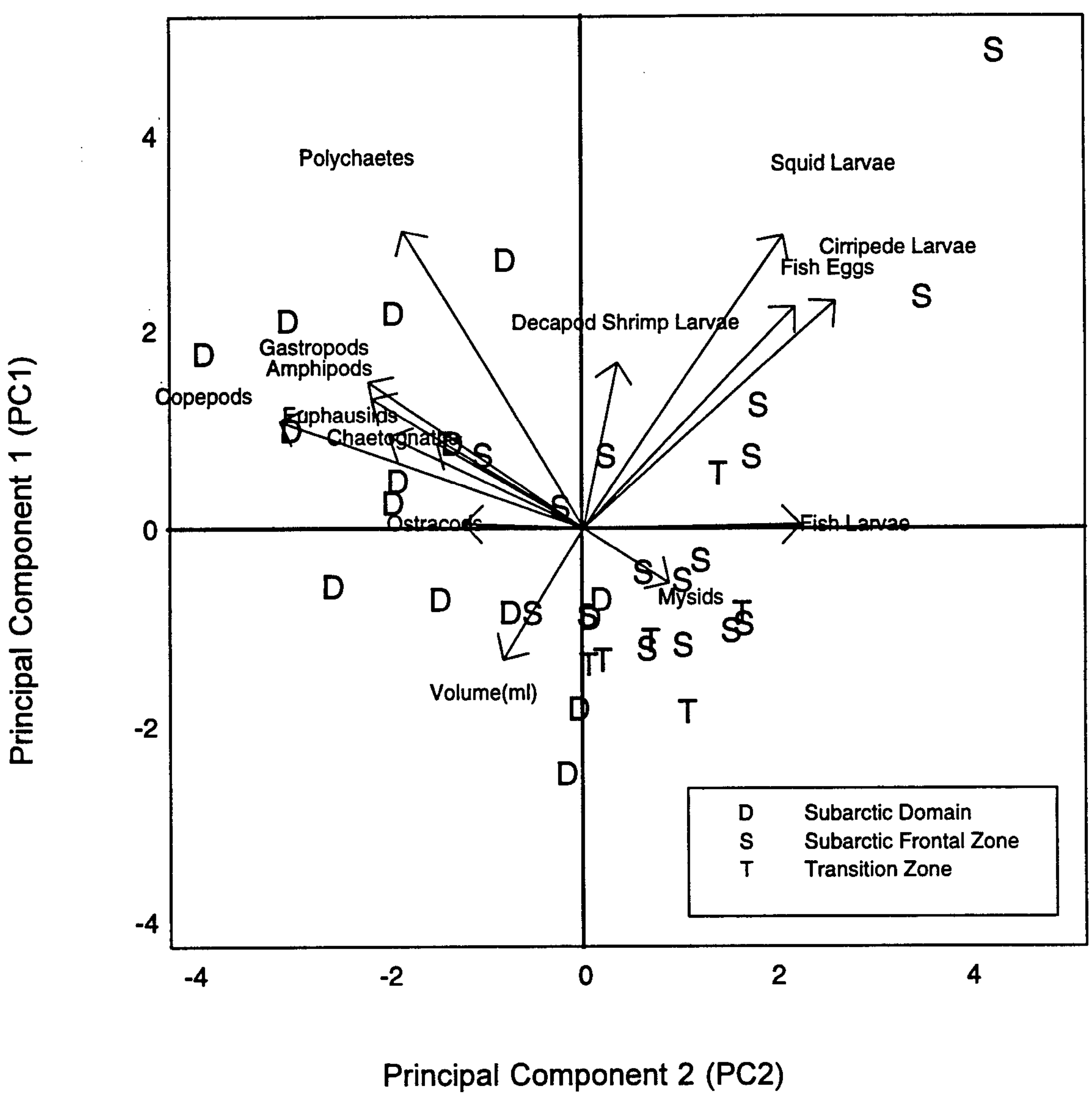

Figure 6.--Biplot of the zooplankton community ordinations using principal component analysis (PCA). Zooplankton were collected between 75 and 150 m depths. Vector coordinates are the species loadings on the first (x-axis) and second (y-axis) principal components of the species ordination. Letter (D, S, and T) coordinates are the station scores from the station ordination. Volume refers to displacement volume.

APPENDICES

Appendix l.--Station information, including the station number, sample number, depth of sample, time and location of sample, and volume of seawater filtered during collection. Times are Alaska Daylight Saving Time.

Station	Sample	Depth stratum (m)	Date	Time	Latitude (°N)	Longitude (°W)	Volume filtered (m^3)
3	T2-1	0–75	10/5/89	0845	46.500	154.952	324.73
3	T2-2	75–150	10/5/89	0838	46.500	154.952	448.01
10	T3-1	0–75	10/5/89	2306	44.455	154.989	327.82
11	T4-1	0–75	10/6/89	0836	43.953	154.984	367.87
11	T4-2	75–150	10/6/89	0830	43.953	154.984	349.67
19	T5-1	0–75	10/5/89	2110	42.067	154.956	344.59
19	T5-2	75–150	10/5/89	2104	42.067	154.956	376.76
21	T6-1	0–75	10/7/89	0931	41.658	154.998	393.58
21	T6-2	75–150	10/7/89	0925	41.658	154.998	275.45
26	T7-1	0–75	10/7/89	2008	40.424	154.980	376.25
26	T7-2	75–150	10/7/89	2002	40.424	154.980	357.95
28	T8-1	0–75	10/8/89	0833	39.919	155.016	470.09
28	T8-2	75–150	10/8/89	0829	39.919	155.016	282.89
35	T9-1	0–75	10/8/89	2004	40.055	157.208	202.84
35	T9-2	75–150	10/8/89	1958	40.055	157.208	391.30
37	T10-1	0–75	10/9/89	0815	39.984	157.985	351.58
37	T10-2	75–150	10/9/89	0809	39.984	157.985	386.54
45	T11-1	0–75	10/9/89	1956	42.070	158.031	333.52
45	T11-2	75–150	10/9/89	1950	42.070	158.031	380.39
46	T12-2	75–150	10/10/89	0823	42.321	158.022	736.56
53	T13-2	75–150	10/10/89	1951	43.708	157.976	659.14
56	T14-1	0–75	10/11/89	0823	44.488	158.006	343.03
56	T14-2	75–150	10/11/89	0817	44.488	158.006	319.39
63	T15-1	0–75	10/11/89	2105	45.762	159.913	386.27
64	T16-1	0–75	10/12/89	0804	46.496	161.037	331.34
64	T16-2	75–150	10/12/89	0756	46.496	161.037	474.12
72	T17-1	0–75	10/12/89	2058	44.580	161.031	388.61
72	T17-2	75–150	10/12/89	2052	44.580	161.031	404.01
75	T19-1	0–75	10/13/89	0820	43.740	161.041	350.61
75	T19-2	75–150	10/13/89	0815	43.740	161.041	283.40
82	T20-1	0–75	10/13/89	2116	41.743	161.008	353.89
82	T20-2	75–150	10/13/89	2110	41.743	161.008	470.73
83	T21-1	0–75	10/14/89	0836	41.512	161.014	313.39
83	T21-2	75–150	10/14/89	0830	41.512	161.014	407.10
91	T22-1	0–75	10/14/89	2120	39.542	161.000	341.85
92	T23-1	0–75	10/15/89	0826	39.254	160.998	424.97
100	T24-1	0–75	10/15/89	2115	37.245	161.046	325.93
101	T25-1	0–75	10/17/89	0915	31.105	159.970	325.93
102	T26-1	0–75	10/28/89	0553	37.357	170.472	297.75
102	T26-2	75–150	10/28/89	0547	37.357	170.472	296.95
108	T27-1	0–75	10/28/89	2042	38.621	170.926	345.94
108	T27-2	75–150	10/28/89	2036	38.621	170.926	623.80

Appendix 1 .--Continued.

Station	Sample	Depth stratum (m)	Date	Time	Latitude (°N)	Longitude (°W)	Volume filtered (m^3)
110	T28-1	0–75	10/29/89	0550	39.150	171.040	346.15
110	T28-2	75–150	10/29/89	0544	39.150	171.040	386.57
116	T29-1	0–75	10/29/89	2016	40.558	171.020	654.49
116	T29-2	75–150	10/29/89	2010	40.558	171.020	398.09
118	T30-1	0–75	10/30/89	0545	41.024	170.975	351.28
118	T30-2	75–150	10/30/89	0540	41.024	170.975	326.41
125	T31-1	0–75	10/30/89	2026	42.901	171.005	358.54
125	T31-2	75–150	10/30/89	2021	42.901	171.005	341.13
127	T32-1	0–75	10/31/89	0546	43.388	171.005	348.73
127	T32-2	75–150	10/31/89	0541	43.388	171.005	321.11
134	T33-1	0–75	10/31/89	2024	45.169	170.954	331.08
134	T33-2	75–150	10/31/89	2017	45.169	170.954	389.13
136	T34-1	0–75	11/1/89	0546	45.622	171.084	339.70
136	T34-2	75–150	11/1/89	0540	45.622	171.084	415.32
143	T35-1	0–75	11/2/89	0547	47.068	168.130	363.46
143	T35-2	75–150	11/2/89	0541	47.068	168.130	371.90
150	T36-1	0–75	11/2/89	2029	45.255	168.018	319.92
150	T36-2	75–150	11/2/89	2024	45.255	168.018	340.16
152	T37-1	0–75	11/3/89	0545	44.682	168.019	339.27
152	T37-2	75–150	11/3/89	0539	44.682	168.019	380.41
159	T38-1	0–75	11/3/89	2009	42.840	168.033	365.90
159	T38-2	75–150	11/3/89	2003	42.840	168.033	374.21
161	T39-1	0–75	11/4/89	0546	42.248	168.024	338.84
161	T39-2	75–150	11/4/89	0541	42.248	168.024	323.95
168	T40-1	0–75	11/4/89	2035	40.438	167.980	380.04
168	T40-2	75–150	11/4/89	2029	40.438	167.980	362.25
170	T41-1	0–75	11/5/89	0548	39.999	167.975	300.47
170	T41-2	75–150	11/5/89	0542	39.999	167.975	380.93
173	T43-1	0–75	11/7/89	0544	43.708	157.822	337.69
173	T43-2	75–150	11/7/89	0539	43.708	157.822	336.40

Appendix 2.--Zooplankton sample counts and displacement volumes. Counts are the number of individuals per sample.

		MOLLUSCA		ANNELIDA	CRUSTACEA							CHAETOG-NATHA	VERTEBRATA		
Station number	Depth stratum (m)	Gastropoda	squid larvae	Polychaeta	Ostraccda	Copepoda	Cirripedia larvae	Amphipoda	Mysidacea	Euphausiacea	Decapoda larvae	Sagittoidea	Fish eggs	Fish larvae	Displace-merit volume (ml)
3	0–75	1104	2	72	88	13120	0	6040	0	216	0	504	0	5	20
3	75–150	17	0	0	6	237	0	26	0	8	0	19	0	0	2
10	0–75	72	3	52	124	7176	0	100	0	1028	0	1992	0	1	30
11	0–75	100	0	32	48	7424	0	1380	0	72	0	60	0	3	11
11	75–150	124	2	96	208	1092	4	120	0	16	0	1652	2	5	11
19	0–75	40	0	24	552	1408	488	96	0	1440	16	16	6	13	60
19	75–150	20	1	16	160	3572	40	60	0	1212	8	112	3	7	23
21	0–75	16	1	8	8	184	104	96	0	624	0	0	11	8	67
21	75–150	0	1	0	1	8	4	1	0	7	1	2	0	1	2
26	0–75	192	7	48	320	376	720	256	0	3560	16	40	5	2	116
26	75–150	71	0	14	139	398	8	37	7	111	0	170	15	7	7
28	0–75	22	0	0	39	154	1206	119	10	174	0	2	7	9	2
28	75–150	0	0	0	4	6	57	2	0	7	0	2	0	1	1
35	0–75	60	10	64	160	372	1496	172	8	316	8	76	18	16	17
35	75–150	30	1	33	79	404	21	118	16	160	1	149	25	10	3
37	0–75	88	8	56	84	264	2480	120	0	608	4	68	20	30	18
37	75–150	27	0	31	236	93	39	88	15	593	2	84	13	7	12
45	0–75	28	2	30	92	220	392	122	2	286	24	18	5	13	65
45	75–150	25	4	19	164	464	22	38	11	60	4	50	5	3	4
46	75–150	208	8	36	92	504	260	264	8	800	28	100	15	32	20
53	75–150	244	1	28	208	1188	92	124	0	132	84	1184	9	6	22
56	0–75	1089	2	2	117	1604	4	49	0	113	4	113	4	3	11
56	75–150	336	2	8	152	824	0	56	0	1072	4	1008	4	3	21
63	0–75	896	6	272	248	1992	0	1608	0	2848	0	256	0	2	45
64	0–75	56	4	4	224	708	4	368	0	1580	0	40	0	0	60
64	75–150	16	0	8	96	4868	0	116	0	144	4	1796	0	5	37
72	0–75	1888	1	128	320	5600	224	864	0	6336	0	64	0	0	98
72	75–150	128	0	152	336	1160	8	36	0	872	8	432	2	8	26
75	0–75	496	6	112	176	8488	96	1216	0	776	48	520	15	3	30
75	75–150	16	4	72	224	1196	0	76	0	992	8	996	9	8	23
82	0–75	48	4	8	60	460	232	176	0	416	12	60	3	3	16

Appendix 2.--Continued.

Station number	Depth stratum ON	MOLLUSCA Gastropoda	Squid larvae	ANNELIDA Polychaeta	CRUSTACEA Ostracoda	Copepoda	Cirripedia larvae	Amphipoda	Mysidacea	Euphausiacea	Decapoda larvae	CHAETOGNATHA Sagittoidea	VERTEBRATA Fish eggs	Fish larvae	Displacement volume (ml)
82	75–150	240	3	32	260	1028	124	192	24	1320	16	56	16	13	19
83	0–75	480	2	16	28	268	1500	200	0	504	24	24	5	8	16
83	75–150	252	1	16	148	260	460	192	0	544	0	56	1	3	47
91	0–75	10	1	12	94	161	22	88	0	576	9	0	1	7	22
92	0–75	192	0	4	656	220	368	88	0	1024	0	4	2	5	47
100	0–75	189	0	12	132	1471	0	41	70	869	2	68	0	16	7
101	0–75	68	7	17	26	2240	0	99	0	135	35	208	2	20	12
102	0–75	190	0	6	150	2826	4	36	0	174	2	18	2	9	22
102	75–150	3	0	5	35	481	0	11	0	88	0	66	1	1	5
108	0–75	14	5	8	266	1418	22	36	2	204	0	6	0	48	13
108	75–150	84	2	8	148	466	40	40	0	390	0	8	1	51	28
110	0–75	68	0	12	376	5216	4	68	0	1188	0	4	2	64	23
110	75–150	12	0	8	118	2696	2	22	2	358	2	22	0	16	13
116	0–75	168	4	44	104	150	8	118	6	852	0	8	10	78	27
116	75–150	26	0	3	49	489	0	77	5	427	3	15	2	10	12
118	0–75	208	3	52	136	2644	128	112	0	872	0	32	45	17	36
118	75–150	196	1	52	150	1414	16	80	6	256	0	136	41	10	13
125	0–75	72	1	64	344	4520	16	856	0	3544	40	104	5	11	28
125	75–150	16	3	32	764	3296	28	40	0	1412	16	52	5	14	16
127	0–75	144	1	144	128	7088	8	232	0	2720	8	72	7	6	30
127	75–150	8	2	132	84	2580	8	72	0	184	12	680	3	4	13
134	0–75	376	1	64	492	3440	0	112	0	936	0	640	1	5	179
134	75–150	22	0	16	35	893	1	13	0	37	1	202	2	2	1
136	0–75	8	2	0	110	1756	0	132	0	316	0	12	0	2	440
136	75–150	176	0	60	232	1652	0	144	0	312	4	108	0	1	230
143	0–75	256	0	144	344	5328	0	1512	0	1072	0	456	0	3	57
143	75–150	76	1	156	324	1348	0	104	0	220	0	304	10	6	18
150	0–75	86	1	10	140	734	0	322	0	574	0	36	0	3	195
150	75–150	72	0	140	92	2402	0	52	0	120	8	124	0	0	53
152	0–75	552	0	32	440	10144	0	432	0	3080	0	152	0	3	143
152	75–150	144	0	36	232	1844	16	92	0	196	0	236	1	3	51

Appendix 2.--Continued.

		MOLLUSCA		ANNELIDA	CRUSTACEA							CHAETOG-NATHA	VERTEBRATA		
Station number	Depth stratum (m)	Gastropoda	Squid larvae	Polychaeta	Ostracoda	Copepoda	Cirripedia larvae	Amphipoda	Mysidacea	Euphausiacea	Decapoda larvae	Sagittoidea	Fish eggs	Fish larvae	Displace-ment volume (ml)
159	0–75	404	1	0	320	1192	8	716	0	940	0	44	10	2	41
159	75–150	20	2	0	222	1900	10	80	8	490	40	94	0	28	10
161	0–75	128	1	56	80	4616	296	184	0	1032	40	0	1	0	66
161	75–150	26	3	26	126	1614	12	44	12	338	10	164	16	17	6
168	0–75	304	1	36	96	1008	8	76	4	1096	12	16	12	7	14
168	75–150	17	0	0	50	392	9	19	1	50	1	0	0	4	2
170	0–75	126	0	2	49	8050	17	13	0	842	3	3	5	4	23
170	75–150	27	1	0	120	1621	23	13	0	464	1	15	0	19	25
173	0–75	4032	1	136	272	7736	12	184	0	1152	20	4	5	1	43
173	75–150	44	0	12	136	2428	20	52	0	336	0	276	2	1	24

Appendix 3.--Qualitative summary of the abundance of gelatinous zooplankton in the Tucker trawl samples. The codes used are - = absent, 2 = few, 4 = some, 6 = many, 10 = >98% of sample.

Station number	Depth stratum	Medusae	Siphonophora	Ctenophora	Heteropoda[1]	Doliolida	Salpa	Larvacea
3	0–75	—	—	—	—	—	—	—
3	75–150	4	—	—	—	—	—	—
10	0–75	—	2	—	—	—	—	—
11	0–75	—	—	—	—	—	—	—
11	75–150	—	—	—	—	—	—	—
19	0–75	—	—	—	—	10	—	—
19	75–150	—	—	—	—	—	—	—
21	0–75	—	—	—	—	—	—	—
21	75–150	6	6	—	—	6	—	—
26	0–75	—	6	—	—	6	6	—
26	75–150	4	6	—	—	6	6	—
28	0–75	—	—	—	—	—	—	—
28	75–150	—	—	—	—	—	—	—
35	0–75	—	—	—	—	—	—	2
35	75–150	2	2	—	—	2	—	2
37	0–75	6	—	—	—	—	6	2
37	75–150	—	—	—	—	—	—	—
45	0–75	—	—	—	—	—	—	—
45	75–150	6	6	—	—	—	6	—
46	75–150	—	2	—	—	6	—	2
53	75–150	—	—	—	2	—	—	—
56	0–75	—	2	—	—	—	—	—
56	75–150	2	2	—	—	—	—	—
63	0–75	—	—	—	—	—	2	2
64	0–75	2	2	—	—	—	2	—
64	75–150	6	—	—	—	—	—	—
72	0–75	6	—	—	—	6	—	—
72	75–150	—	—	—	—	—	—	—
75	0–75	—	2	—	—	2	—	2
75	75–150	—	2	—	—	—	—	—
82	0–75	—	—	—	—	—	—	—
82	75–150	—	6	—	—	6	6	2
83	0–75	2	2	—	—	2	2	—
83	75–150	2	2	—	—	—	—	—
91	0–75	—	2	—	—	2	—	—
92	0–75	—	2	—	—	—	—	—
100	0–75	—	—	—	—	—	—	—
101	0–75	2	2	—	—	—	2	—
102	0–75	—	2	—	—	—	—	—
102	75–150	—	—	—	—	—	—	—
108	0–75	—	—	—	—	—	—	—
108	75–150	—	—	—	—	—	6	—
110	0–75	—	—	—	—	—	—	—
110	75–150	2	2	—	—	2	—	—

Appendix 3.--Continued.

Station number	Depth stratum	Medusae	Siphonophora	Ctenophora	Heteropoda	Doliolida	Salpa	Larvacea
116	0–75	2	2	—	—	2	2	—
116	75–150	—	—	—	—	—	—	—
118	0–75	2	2	—	—	2	2	2
118	75–150	2	2	—	—	2	—	6
125	0–75	—	6	2	2	—	—	2
125	75–150	—	—	—	—	—	—	—
127	0–75	—	2	—	—	—	—	2
127	75–150	—	2	—	—	—	—	—
134	0–75	—	—	—	—	—	6	—
134	75–150	—	—	—	—	—	—	—
136	0–75	—	2	—	—	—	10	—
136	75–150	—	2	—	—	—	10	—
143	0–75	2	—	—	—	—	2	—
143	75–150	—	6	2	—	—	—	—
150	0–75	—	—	—	—	—	10	—
150	75–150	—	2	—	—	—	4	—
152	0–75	—	—	—	—	—	—	—
152	75–150	—	—	—	—	—	—	—
159	0–75	—	2	—	—	—	—	—
159	75–150	2	2	—	—	—	—	—
161	0–75	—	2	—	—	—	—	—
161	75–150	—	—	—	—	—	—	—
168	0–75	—	2	—	—	—	2	—
168	75–150	2	—	—	2	4	—	—
170	0–75	2	2	—	—	—	—	—
170	75–150	—	2	—	—	—	2	—
173	0–75	2	2	—	—	—	—	—
173	75–150	—	2	—	—	—	—	—

[1] Gelatinous heteropods were *Carinaria* spp.

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