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Diversity and Abundance of Neustonic Zooplankton in the North Pacific Subarctic Frontal Zone

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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

Neustonic zooplankton were collected at 42 stations between latitude 31°N and 47°N during research on the biogeography of the North Pacific Subarctic Frontal Zone. Sea surface temperatures at the stations during the 4 October-9 November 1989 research period ranged from 9.7 at the northernmost station to 24.1°C at the southernmost station. Distribution of nine phyla (134 taxa) was characterized by low abundance and high species diversity in the southerly latitudes (warm waters), and high abundance with low species diversity in the northerly latitudes (cool waters). Highest abundance was about 1 degree north of the area separating subarctic and subtropical waters (43°30'N) in the North Pacific Subarctic Frontal Zone. Arthropods (77 taxa) were the most abundant and most frequently collected zooplankton group. Molluscs (19 taxa) were the second most frequently collected group. This study indicates that because zooplankton distribution and abundance may be affected by frontal zones, neuston distribution and diversity may be used as indicators of various North Pacific Ocean water masses.

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INTRODUCTION

The Driftnet Impact Monitoring, Assessment, and Control Act of 1987 required the U.S. Government to negotiate with foreign governments conducting North Pacific driftnet fisheries to assess the number of commercial and non-commercial fisheries resources impacted by the driftnet fisheries. Although a primary target of these fisheries was the flying squid, *Ommastrephes bartrami*, driftnets also captured non-target species including salmonids, sharks, other fish, seabirds, and mammals (INPFC 1990). Much of this fishery was concentrated in the North Pacific Transition Region or Subarctic Frontal Zone. Because of the large ‘area covered by the driftnet fisheries in the North Pacific Ocean, the impact on non-target species was believed to be substantial (Wetherall 1991). This potential impact prompted U.S. scientists to examine the biological and physical aspects of the North Pacific Subarctic Frontal Zone (NPSFZ) to better understand factors influencing the distribution and co-occurrence of target and non-target species.

Oceanic neuston were sampled during a multidisciplinary study of the biogeography of the NPSFZ conducted during fall 1989 by elements of the National Marine Fisheries Service (Auke Bay Laboratory, Alaska Fisheries Science Center [AFSC]; Honolulu Laboratory, Southwest Fisheries Science Center; and National Marine Mammal Laboratory, AFSC) and the U.S. Fish and Wildlife Service. The neuston layer is a unique habitat with obligate and facultative residents (Zaitsev 1970; Hempel and Weikert 1972; Cheng 1975; Peres 1982). Some components of this assemblage may indicate changes in the physical oceanography of a region (Soule and Kleppel 1988). Assemblages may also reflect changes in biological and physical factors that influence the distribution of marine resources (Russell 1939; Aron 1962; Fager and McGowan 1963). Neuston are important food for seabirds, juvenile salmonids, and other fishes (Peterson et al. 1982; Turner 1984; Prince and Morgan 1987; Schreiber and Clapp 1987; Brodeur 1989), and prey availability is a major factor influencing the distribution of marine resources. Thus, changes in the neustonic zone provide an important “first look” into the physical and biological factors that affect marine fish, seabirds, and mammals.

This report presents the results of neuston sampling from the NOAA ship *Miller Freeman* during the 1989 survey. The primary objective was to evaluate changes in neuston relative to physical oceanographic variables and marine resources (birds, fish, and mammals) within the NPSFZ. Our report complements other results of the survey, including subsurface zooplankton, nekton, hydroacoustic backscattering, seabirds, mammals, and physical oceanographic data. Results of those studies will be published separately.

METHODS

Neuston samples were collected at 42 stations from 4 October to 9 November 1989. All but two stations were between lat. 37°N and 47°N and along five north-south transects: long. 155°W, 158°W, 161°W, 168°W, and 171°W (Fig. 1). Samples were collected using a rectangular 50 cm x 30 cm Sameoto neuston net (Sameoto and Jaroszynski 1969), mesh size 0.505 mm, towed for 10 minutes at 7.4 km/h (weather dependent). After retrieval, the net was thoroughly washed down to collect specimens; catches were preserved in a 4% formaldehyde-seawater solution buffered with sodium tetraborate and were later processed at the Auke Bay Laboratory.

Processing of samples consisted of scanning, subsampling if necessary, and identifying taxa present. Samples were scanned using a binocular dissecting microscope, and large organisms such as fish larvae and squid larvae were removed. Large samples were split using a Cushing subsampler (Cushing 1961) to facilitate processing. Animals were identified to the lowest taxon possible and enumerated; mean lengths were determined from subsamples. Additionally, animals that were observed in the original sample but were not present in the split portion, or were observed as pieces (e.g., Siphonophora), were listed as "present," as were the larger gelatinous animals (e.g., Thaliacea). Displacement volume of each sample was measured to + 0.1 ml in graduated cylinders. The area sampled during each tow (distance x net width) was calculated using ship's speed, and catches were standardized to number of animals per 100 m^2 [(number of animals/area sampled) x 100]. Because the neuston net lacked a flow meter, and tow depth varied with wave conditions, we assumed that the net was, on average, half submerged.

Most neuston samples were collected between sunset and sunrise in conjunction with other sampling. Sampling at sunset consisted of a conductivity-temperature-depth (CTD) profile to 1,000 m, a macrozooplankton trawl to 150 m, a neuston tow, and a mid-water diamond trawl (175-250 m) for nekton. A midnight CTD cast was taken after the mid-water nekton trawl was completed. Sampling at sunrise consisted of a CTD cast, mid-water nekton trawl, macrozooplankton trawl, and neuston tow. In some cases, the sunset and sunrise stations were as close as 0.6 km. Morning neuston tows were completed after sunrise.

Frequency of occurrence and mean abundance of all taxa were calculated for sea surface temperature (SST) intervals representing the oceanographic regimes encountered during the cruise. Tables of zooplankton abundance and frequency of occurrence were formatted numerically in ascending order using the National Oceanographic Data Center (NODC) taxonomic codes (NODC 1984). Abundance was defined as the number of animals per area sampled. Taxonomic nomenclature and groupings follow Brusca and Brusca (1990).

RESULTS AND DISCUSSION

The NPSFZ is a complex oceanographic area to which a confusing descriptive terminology has been applied by physical and biological oceanographers. In this report, we follow the terminology of Roden (1991) and Pearcy (1991), which is based on the physical and chemical characteristics of the water column, rather than that of McGowan (1971, 1974) based on recorded distribution of midwater organisms. Three different oceanographic regimes encountered during this study: 1) the Subarctic Domain (SD), characterized by a cool, low-salinity surface layer; 2) a Subtropical Domain, characterized by a warm, saline surface layer, and 3) the Subarctic-Subtropical Transition Region (SSTR), which shares thermohaline characteristics of the Subarctic and Subtropical Domains (Garcia 1990). The SSTR may be subdivided into the Transitional Domain and the Transition Zone (Pearcy 1991). The Transition Domain is narrow in the western Pacific Ocean and broad in the eastern Pacific Ocean, where it expands into the California Current and Alaska Current systems (Pearcy 1991). The northern edge of the Transition Domain is variously defined as surfacing of the $33\%_0$ isohaline, the intersection of the 7°C isotherm and the upper halocline, or the intersection of the 4°C isotherm at 100 m. The southern edge of the Transitional Domain is defined as the subarctic front distinguished by a vertical 34%0 isohaline (Pearcy 1991). The Transition Zone extends from the subarctic front to the subtropical front approximated by the 35%0 surface isohaline. Within the Transition Region, temperature, salinity, and density fronts seldom coincide or penetrate to the same depths (Garcia 1990; Roden 1991); thus, it is difficult to distinguish precisely the Transition Domain and Transition Zone in a single quasisynoptic survey. Although these water masses are usually defined by surface salinity and subsurface water properties, the SSTs generally reflect latitudinal differences between these masses. We selected four SST intervals to represent these regimes: 9.0°-12.O°C for the SD, 12.1°-15.O°C for the Transition Domain, 15.l°-18.O°C for the northern portion of the Transition Zone, and 18.1°-25.O°C for the southern portion of the Transition Zone.

Die1 vertical migrations of certain zooplankton stages and types (Cushing 1951; Vinogradov 1968) and time of collection differences could alter apparent species abundance and distribution. We found no statistically significant day-night differences in species richness, total counts, or displacement volumes for 14 pairs of adjacent stations (Table 1). Although some species were caught only at night (e.g., Myctophidae), day-night differences were not considered further for this report.

Diversity and Abundance

Nine phyla, represented by 134 taxa, were collected during this study. Forty-five taxa were identified to species level, 57 to genus, 14 to family, and 18 to order, class, or phylum. Frequency of occurrence and mean abundance for all taxa are given for each temperature interval (Table 2).

Zooplankton Diversity

Species richness was highest south of the NPSFZ, and lowest north of it (Fig. 2). Number of species did not differ significantly between adjacent temperature intervals because some taxa were found in two or more intervals; however, richness increased significantly ($F_{3\cdot38}$ *4.18*, $P < 0.01$) from cool to warm waters. Only 31 taxa were found in the coolest interval, whereas 75 taxa were collected in the warmest interval. Sixty-six taxa were collected in the northern and 78 in the southern intervals of the NPSFZ (Table 2). Although more taxa were collected in the southern NPSFZ than in the warmest interval, the mean number of species per sample was slightly greater in the warmest interval (Fig. 2). Species richness is generally greater in tropical latitudes than in higher latitudes (Omori and Ikeda 1984). Holdway and Maddock’s (1983a) survey of neuston from Fiji to the Bay of Biscay found the same species diversity trends as other studies: only 3 of their 47 taxa were most common in boreal waters. Although Aron (1962) found that the number of mid-water species in the eastern North Pacific Ocean increased markedly from subarctic to warmer intermediate waters, these generalities are altered in frontal zones. The circulation features of the NPSFZ may concentrate specific organisms at localized areas of convergence (Olson 1986) and may also concentrate different taxa from both southern and northern waters within the frontal zone.

Arthropods were the most abundant neuston group collected; 77 (57%) of the total 134 taxa collected were crustaceans. Amphipods and copepods were the most diverse groups, represented by 52 (39%) taxa. The two most abundant species, *Themisto pacifica* and *Calanus pacificus*, were also the most widely distributed and frequently collected species, occurring in 64.3% and 69.1% of the samples, respectively, and in all temperature intervals (Table 2). Their frequency of occurrence declined from north to south. Crustacean diversity was greatest (46 taxa) within the warmest interval. Thirty-four and 45 crustacean taxa were collected in the southern and northern regions of the NPSFZ, respectively, and 57 in the combined intervals. Eighteen crustacean taxa were collected in the SD (Table 2):

Molluscs were second to arthropods in frequency of occurrence. Pteropods were the most diverse group and squid larvae the most frequent group of molluscs encountered. Twelve taxa of pteropods were collected, two or more taxa in each temperature interval. Pteropod species richness did not follow the general trend of “simple” community structure in temperate latitudes and more “complex” community structure in subtropical latitudes. Pteropod species richness was greatest in the 12.l°-15.O°C interval, where all genera were represented and all but three species were collected (Table 2). Five of the pteropod species were. included in Fager and McGowan’s (1963) analysis of zooplankton co-occurrence in the North Pacific Ocean. They grouped *Limacina helicina*, three euphausiids, and one chaetognath as subarctic species. This agrees with our finding of 100% occurrence at the six stations in the coolest interval, 7% in the 12. l°-15.O°C interval, and 0% in the two warmest intervals (Table 2). Fager and McGowan (1963) grouped *Clio pyramidata* and two other pteropods as “subtropical” species. We found, however, that the frequency of C. *pyramidata* increased from warmer to cooler waters (Table 2) and was most abundant in the 12.1°-15.O°C waters, corresponding to its frequent occurrence in the Gulf of Alaska (Wing[1]).

Fishes representing 10 taxa were collected; species richness increased from cool to warmer intervals. Pacific saury, *Cololabis saira,* was the most frequently caught species (Table 2). Ahlstrom and Stevens (1976) similarly noted that in eastern Pacific neuston, saury were the most frequently collected fish. Of the nine remaining fish taxa (excluding fish eggs and unidentified fish larvae), only the myctophids *Symbolophorus* sp. and *TarZetonbeania* sp. were collected in more than one temperature interval (Table 2). This low ichthyoplankton diversity may be an artifact of 1) sampling after dawn, 2) sampling in rough waters, 3) sampling in the fall, after most species have grown beyond a size vulnerable’ to capture by a neuston net, or 4) the small area (low volume) sampled (Clarke 1991).

Zooplankton Abundance

Of the 134 taxa collected, only 22 had an abundance greater than 10 animals/l00 m^2 at any station. At almost 25% of the stations sampled, no taxon had an abundance greater than 10 animals/l00 m^2. On the 63 occasions when abundance of a taxon exceeded 10 animals/l00 m^2, 30 occasions were due to the three most abundant taxa: *Themisto pacifica*, *Calanus pacificus,* and *Euphausia pacifica.*

‘Wing, B. L. (unpubl. data). Auke Bay Lab, Alaska Fish. Sci. Cent., 11305 Glacier Hwy., Juneau, AK 99801-*8626. Clio pyromidata* occur more frequently in 9.0°-12.°C waters than in warmer waters.

Some taxa were more abundant locally or in particular temperature intervals. Mean abundance of the copepod *Scolecithricella minor* was 57 animals/l00 m^2 in the 9.0°-12.O°C interval, but less than 1 animal/l00 m^2 in the 12.1°-15.O°C interval; they were not collected in the two warmer intervals (Table 2). In contrast, pontellid copepods, although not abundant, were collected only in the warmest interval (Table 2). Mean abundance of the siphonophore *Sulculeolaria* sp. was 12.0 animals/l00 m^2 in the 12.1°-15.O°C interval (Table 2); however, this value was influenced by one sample that contained over 1,000 animals.

Although not statistically significant, neuston abundance *($F_{3,38}$1 .95, P = 0.14)* and biomass *(F,,,,O.57, P* = 0.64) generally appeared highest in the NPSFZ (Figs. 3, 4). The greatest numerical abundance (1,591 animals/100 m*) was at 43”50’N, in the northern portion of the NPSFZ as defined by Garcia (1990). Based on displacement volume, average biomass (Fig. 4) was greatest in the 15. l°-18.O”C interval (southern NPSFZ) as a result of one large catch of *Velella.* Although knowledge of the processes that regulate productivity in the NPSFZ is limited (Pearcy 1991), frontal dynamics and mesoscale circulation of that region may concentrate organisms at localized areas of convergence, thereby causing localized high densities of zooplankton (Olson 1986).

The most abundant neuston group was made up of arthropods; *Themisto pad&a* and *Calanus pacificus* were the most abundant species (81.6 and 48.7 animals/l00 m*, respectively) for all temperature intervals (Table 2). The third most abundant species was *Euphausia paciJica*, with 16.4 animals/100 m^2 for all temperature intervals sampled (Table 2). The general trend for these three species was increased abundance in the two middle temperature intervals, representing the northern and southern portions of the NPSFZ (Table 2).

Generally, planktonic amphipods are dominated by the Hyperiidae and rank third in numerical abundance behind copepods and euphausiids (Bowman 1960). They are often very abundant in high latitude regions, where they are important in the diets of seabirds, fish, and mammals (Wing 1976; Ogi et al. 1980; Ogi and Hamanaka 1982). The shallow-dwelling *Themisto pacifica* is the most abundant northeastern Pacific hyperiid, with a wide geographic distribution and broad thermal tolerance. It frequently swarms near the surface, which may account for its high abundance and dominance in our samples.

The copepod *Culunus pacificus*, a widely distributed and abundant species in the eastern North Pacific Ocean, occupies extensions of the NPSFZ in the Gulf of Alaska to Prince William Sound and of the California Current south to northern Mexico (Gardner and Szabo 1982). This species is a facultative neustonic species; its high abundance in our samples indicates its generally high abundance throughout the upper water column and in most of the transition and subarctic regions. The pontellid copepods, however, are often neustonic, and many neustonic ones are restricted to tropical and subtropical waters; pontellids were collected at only our two southernmost stations.

Fishes, 10 taxa including unidentified fish larvae and eggs, were generally scarce. No fish had a mean abundance greater than 10 animals/100 m^2 for any temperature interval. Abundance of *Cololabis saira*, the only fish larvae with more than 1 anima1/100 m* for any station, increased from cooler to warmer waters (Table 2). The only other locally abundant Osteichthyes were unidentified fish eggs: 65 were collected at one station within the NPSFZ.

Although amphipods were our most abundant zooplankton, most studies in the North Pacific Ocean and other oceans have found calanoid copepods to be the most abundant group. Holdway and Maddock (1983b), in a broad survey of neuston between Fiji and the Bay of Biscay, found copepods to be the dominant taxon in every area sampled, comprising over 50% of the neuston in all but one area. In the northeastern subtropical Atlantic Ocean, crustaceans constituted 94% of the invertebrate neuston; 50% of these crustaceans were copepods, dominated by calanoids (Hempel and Weikert 1972). LeBrasseur (1965), using both surface and vertical tows, found that two groups of zooplankton predominate in the northeastern Pacific Ocean: copepods in April-June and amphipods in July-September.

SYNOPSIS

These results should be viewed with the caveat that many factors can influence species distribution, frequency of occurrence, and abundance. Such factors include biological and physical parameters and sampling techniques (Zaitsev 1970; Hempel and Weikert 1972; Holdway and Maddock 1983a,b; Kendall and Dunn 1985). We found that “normal” patterns (high species richness and low abundance in warmer waters, and low species richness and high abundance in cooler waters) appear to be altered within frontal zones. Time of day and season dramatically affect zooplankton composition and abundance (Zaitsev 1970; Hempel and Weikert 1972; Ahlstrom arid Stevens 1976; Holdway and Maddock 1983b).

We did not attempt a comprehensive analysis of all 134 taxa collected. Although most taxa were infrequent, scarce, or both, they are not necessarily unimportant components of their particular habitats (Soule 1988).

Nevertheless, we believe that the neustonic animals are indicators of oceanic changes in the North Pacific Ocean, and that the marked geographic variation of their distribution and abundance is associated with water mass types and boundaries. Our findings correspond to those of previous investigators, who also considered zooplankton to be indicators of oceanic changes (e.g., Russell 1939; Aron 1962; Fager and McGowan 1963; Soule and Kleppel 1988). Notably, species densities (biomass) were not greatest in the SD, as is usually assumed, but within the NPSFZ, near the subarctic boundary. Species richness, generally greater in warm than in cool waters, was only slightly less in the NPSFZ. than in the warmest interval. Clearly, our study indicates that neuston distribution and diversity can indicate water masses in the central North Pacific Ocean. The sampling gear‘is inexpensive and can be fished in most weather and at speeds up to 20 km/h (Sameoto and Jaroszynski 1969), making neuston samples practical for monitoring fishery and oceanic conditions over large areas.

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TABLES

Table l.--Comparison of night and day neuston catches at,stations within each temperature interval. (Sta = Station, Spp = Number of taxa, Count = Total count standardized to number per 100 m* rounded to the nearest whole number, and Volume = Displacement volume as ml per 100 m*.)

Temp °C	Night				Day			
	Sta	Spp	Count	Volume	Sta	Spp	count	Volume
9.1°–12°	—	—	—	—	127	12	394	0.23
	134	13	25	0.85	136	5	33	0.31
	—	—	—	—	143	7	73	3.06
	150	15	69	5.08	152	7	21	0.80
12.1°–15°	1	9	615	9.01	3	11	462	1.75
	—	—	—	—	56	10	17	0.32
	63	12	56	1.62	64	10	120	3.50
	72	13	696	8.32	75	12	1591	12.02
	—	—	—	—	118	21	248	1.62
	125	14	407	0.78	—	—	—	—
	161	12	256	2.67	161	12	185	3.79
	168	13	19	2.38	—	—	—	—
	—	—	—	—	173	13	67	0.25
	—	—	—	—	179	6	7	0.02
15.1°–18°	10	15	1081	3.89	11	10	1084	3.73
	45	19	48	30.47	46	18	33	1.57
	53	12	48	0.98	—	—	—	—
	82	15	99	7.04	83	17	101	1.27
	91	13	36	1.10	—	—	—	—
	108	13	5	1.71	110	15	11	3.52
	116	18	321	1.27	—	—	—	—
	—	—	—	—	170	12	17	0.08
18.1°–24°	19	22	311	4.86	21	16	20	2.76
	26	23	35	6.48	28	10	4	0.36
	35	22	118	1.73	37	16	29	1.30
	—	—	—	—	92	13	31	4.38
	100	16	38	0.81	101	14	41	0.45
	—	—	—	—	102	11	7	0.95

Table 2. --Frequency of occurrence (FO) and mean abundance of all catches (No./100 m’) (MA) of taxa, grouped by sea surface temperature intervals; n = number of samples.

	SD		Northern NPSFZ		Southern NPSFZ		SSTZ		Total	
	9.0°–12°C n = 6		12.1°–15°C n = 14		15.1°–18°C n = 12		18.1°–25°C n = 10		n = 42	
Species	FO	MA	FO	MA	FO	MA	FO	MA	FO	MA
SARCOMASTIGOPHORA (PROTOZOA)										
Radiolaria										
Radiolaria Unidentified	0	0	3	0	1	0.01	0	0	4	0.00
PORIFERA										
Porifera Unidentified	0	0	0	0	0	0	1	0	1	0
CNIDARIA:Hydrozoa										
Hydroida										
Pandeidae	1	0.03	0	0	0	0	0	0	1	0.00
Halitholus sp.	0	0	2	0.03	1	0.12	0	0	3	0.05
Trachylina										
Aglantha sp.	0	0	3	0.97	1	0.03	0	0	4	0.33
Hydroida Unidentified	0	0	1	0.07	0	0	0	0	1	0.02
Chondrophora										
Velella velella	1	0.03	7	0.57	7	9.13	9	4.12	24	3.78
Siphonophora										
Muggiaea sp.	0	0	1	0.56	0	0	0	0	1	0.19
Sulculelaria sp.	0	0	2	11.96	0	0	0	0	2	3.99
Siphonophora Unidentified	0	0	2	0.01	7	0.07	6	0.91	15	0.24
CTENOPHORA										
Cydippida										
Euplokamis sp.	0	0	0	0	1	0.01	0	0	1	0.00
Beroida										
Beroe sp.	1	0.05	0	0	0	0	0	0	1	0.01
Ctenophora Unidentified	0	0	1	0	1	0	0	0	2	0

Table 2. --Continued.

Species	SD 9.0°–12°C n = 6 FO	SD MA	Northern NPSFZ 12.1°–15°C n = 14 FO	Northern NPSFZ MA	Southern NPSFZ 15.1°–18°C n = 12 FO	Southern NPSFZ MA	SSTZ 18.1°–25°C n = 10 FO	SSTZ MA	Total n = 42 FO	Total MA
ANNELIDA:Polychaeta										
Phyllodocida										
Alciopidae	0	0	0	0	1	0.04	0	0	1	0.01
Rhynchonereella sp.	0	0	0	0	0	0	1	0.03	1	0.01
Tomopteris sp.	0	0	3	0.1	2	0.25	1	0.05	6	0.12
MOLLUSCA:Gastropoda										
Mesogastropoda										
Janthina sp.	0	0	1	0.02	2	0.01	2	0.3	5	0.08
Atlantidae	0	0	0	0	2	0.57	7	1.12	9	0.43
Atlanta sp.	0	0	4	0.25	2	0.51	2	0.23	8	0.29
Carinaria sp.	0	0	0	0	1	0.01	0	0	1	0.00
Thecosomata										
Limacina sp.	0	0	6	1.81	3	0.32	1	0.36	10	0.78
Limacina bulimoides	0	0	1	0.25	1	0.11	1	0.02	3	0.12
Limacina helicina	6	1.21	1	0.14	0	0	0	0	7	0.22
Cavolina sp.	0	0	1	0.05	0	0	0	0	1	0.02
Cavolina inflexa	0	0	0	0	1	0.03	0	0	1	0.01
Cavolina tridentata	0	0	0	0	1	0.01	0	0	1	0.00
Clio pyramidata	0	0	4	0.22	2	0.08	1	0.06	7	0.11
Clio recurva	1	0.02	1	0.01	0	0	1	0.02	3	0.01
Creseis sp.	0	0	1	0.09	0	0	0	0	1	0.03
Diacria quadridentata	0	0	0	0	0	0	1	0.12	1	0.03
Diacria trispinosa	0	0	1	0.01	0	0	1	0.03	2	0.01
Gymnosomata										
Clione limacina	0	0	1	0.01	0	0	0	0	1	0.00
Nudibranchia	0	0	1	0.01	1	0.01	0	0	2	0.01
Gastropoda Unidentified	0	0	2	0.07	3	0.09	0	0	5	0.05
MOLLUSCA:Cephalopoda										
Teuthoida (Decapoda)										
Squid Larvae Unidentified	2	0.08	12	1.35	8	2.03	2	0.05	24	1.05

Table 2. --Continued.

Species	SD		Northern NPSFZ		Southern NPSFZ		SSTZ		Total	
	9.0°–12°C $n = 6$		12.1°–15°C $n = 14$		15.1°–18°C $n = 12$		18.1°–25°C $n = 10$		$n = 42$	
	FO	MA	FO	MA	FO	MA	FO	MA	FO	MA
ARTHROPODA:Crustacea										
Ostracoda										
Conchoecia sp.	0	0	2	0.45	3	0.11	2	0.08	7	0.2
Conchoecia alata	1	0.05	0	0	0	0	0	0	1	0.01
Conchoecia elegans	0	0	0	0	1	0.01	0	0	1	0.00
Copepoda										
Calanoida										
Calanus sp.	0	0	0	0	1	0.16	0	0	1	0.04
Calanus marshalli	1	0.02	0	0	0	0	0	0	1	0.00
Calanus pacificus	6	19.99	12	73.1	6	74.57	5	0.6	29	48.67
Eucalanus sp.	1	0.03	1	0.75	0	0	1	0.02	3	0.26
Eucalanus bungi	2	0.21	4	1.18	0	0	1	0.05	7	0.44
Eucalanus elongatus	0	0	0	0	0	0	1	0.02	1	0.00
Clausocalanus sp.	0	0	0	0	0	0	1	0.09	1	0.02
Euchaeta media	0	0	0	0	1	0.01	0	0	1	0.00
Scolecithricella sp.	1	0.9	2	11.08	3	25.1	1	0.3	7	11.06
Scolecithricella minor	4	56.98	2	0.53	0	0	0	0	6	8.32
Metridia sp.	1	0.1	4	16.1	1	10.8	1	0.05	7	8.48
Metridia lucens	2	0.72	1	0.19	0	0	0	0	3	0.17
Pleuromamma sp.	0	0	0	0	1	0.02	0	0	1	0.01
Pleuromamma borealis	0	0	0	0	0	0	2	0.13	2	0.03
Heterohabdus sp.	0	0	0	0	1	0.02	0	0	1	0.01
Heterostylites sp.	0	0	1	0.02	0	0	0	0	1	0.01
Candacia sp.	0	0	0	0	1	0.01	0	0	1	0.00
Candacia bipinnata	0	0	1	0.03	0	0	1	0.39	2	0.1
Candacia columbia	0	0	0	0	1	0.04	3	0.08	4	0.03
Labidocera bipinnata	0	0	0	0	0	0	1	0.3	1	0.07
Labidocera japonica	0	0	0	0	0	0	1	0.8	1	0.19
Labidocera pavo	0	0	0	0	0	0	1	1.67	1	0.4
Pontellidae Unidentified	0	0	0	0	0	0	2	0.17	2	0.04
Calanoida Unidentified	0	0	0	0	0	0	1	0.16	1	0.04
Harpacticoida										
Harpacticoida Unidentified	0	0	0	0	1	0.11	2	0.06	3	0.05

Table 2. --Continued.

	SD		Northern NPSFZ		Southern NPSFZ		SSTZ			
	9.0°–12°C $n = 6$		12.1°–15°C $n = 14$		15.1°–18°C $n = 12$		18.1°–25°C $n = 10$		Total $n = 42$	
Species	FO	MA	FO	MA	FO	MA	FO	MA	FO	MA
Cyclopoida										
Corycaeus lautus	0	0	0	0	0	0	1	0.05	1	0.01
Sapphirina sp.	0	0	1	0.01	1	0.02	0	0	2	0.01
Sapphrinidae Unidentified	0	0	0	0	1	0.01	0	0	1	0
Cirripedia										
Lepas sp. (naupli)	1	0.1	5	1.22	5	5.54	5	12.14	16	4.9
Lepas sp. (cyprid)	1	0.03	5	1.05	8	0.71	9	0.95	23	0.78
Mysida										
Holmesiella sp.	0	0	0	0	0	0	1	0.03	1	0.01
Siriella sp.	0	0	0	0	1	0.11	4	5.69	5	1.39
Mysida Unidentified	0	0	0	0	1	0.07	1	0.03	2	0.03
Isopoda										
Idotea metallica	0	0	3	0.03	5	0.09	4	0.24	12	0.09
Amphipoda										
Gammaridea Unidentified	0	0	3	0.03	0	0	0	0	3	0.01
Hyperiidea										
Hyperia sp.	0	0	0	0	2	0.22	4	2.4	6	0.64
Hyperoche medusarum	1	0.28	0	0	0	0	0	0	1	0.04
Themisto sp.	0	0	2	0.88	3	1.14	1	0.06	6	0.63
Themisto pacifica	6	8.78	11	162.82	5	89.73	5	1.85	27	81.61
Phronimopsis sp.	0	0	1	0.02	4	1.43	2	2.04	7	0.9
Dairella sp.	0	0	2	0.05	1	0.01	0	0	3	0.02
Dairella latissima	0	0	0	0	1	0.12	0	0	1	0.03
Phronima sp.	0	0	2	0.03	8	0.79	2	0.16	12	0.27
Anchylomera sp.	0	0	0	0	3	0.48	2	0.73	5	0.31
Primno sp.	0	0	1	0.01	0	0	0	0	1	0.00
Primno macropa	0	0	1	0.01	0	0	0	0	1	0.00
Pronoe sp.	0	0	0	0	2	0.44	0	0	2	0.12
Eupronoe sp.	0	0	2	0.05	1	0.43	0	0	3	0.14
Paralycaea sp.	0	0	1	0.03	0	0	3	2.67	4	0.65

Table 2. --Continued.

Species	SD 9.0°–12°C n = 6 FO	SD MA	Northern NPSFZ 12.1°–15°C n = 14 FO	Northern NPSFZ MA	Southern NPSFZ 15.1°–18°C n = 12 FO	Southern NPSFZ MA	SSTZ 18.1°–25°C n = 10 FO	SSTZ MA	Total n = 42 FO	Total MA
Parapronoe sp.	0	0	1	0.01	1	0.03	0	0	2	0.01
Lycaea sp.	0	0	0	0	1	0.14	0	0	1	0.04
Lycaeidae Unidentified	0	0	0	0	0	0	1	0.03	1	0.01
Brachyscelus sp.	0	0	0	0	1	0.12	0	0	1	0.03
Brachyscelus crusculum	0	0	0	0	0	0	1	0.15	1	0.03
Pseudolycaea sp.	2	0.1	1	0.01	0	0	0	0	3	0.02
Platyscelus sp.	0	0	0	0	3	0.67	1	0.03	4	0.2
Vibilia sp.	2	0.08	0	0	3	0.19	3	0.73	8	0.24
Vibilia australis	1	0.3	2	0.42	0	0	0	0	3	0.18
Euphausiacea										
Euphausia sp.	0	0	1	0.01	4	0.35	0	0	5	0.1
Euphausia pacifica	0	0	6	41.99	2	8.16	3	0.44	11	16.43
Euphausia mutica	0	0	0	0	0	0	1	2.07	1	0.49
Nematoscelis sp.	0	0	0	0	0	0	1	1.22	1	0.29
Nematoscelis difficilis	0	0	3	0.19	3	1.39	1	0.1	6	0.49
Stylocheiron sp.	0	0	0	0	0	0	2	0.31	2	0.07
Tessarabrachion oculatum	0	0	0	0	1	0.01	0	0	1	0.00
Thysanoessa sp.	0	0	1	0.02	1	1.18	0	0	2	0.34
Euphausiacea Unidentified	2	0.8	1	6.47	1	0.07	2	0.11	6	2.32
Decapoda										
Sergestidae (zoea)	1	0.03	7	0.24	4	0.73	4	0.25	16	0.35
Anomura (zoea)	0	0	0	0	2	0.43	2	0.09	4	0.15
Brachyura (zoea)	0	0	0	0	1	0.01	0	0	1	0.00
Grapsidae (zoea)	0	0	0	0	2	0.03	1	0.32	3	0.08
Grapsidae (megalopa)	0	0	0	0	2	0.05	3	0.26	5	0.08
Stomatopoda										
Stomatopoda (zoea)	0	0	1	0.01	0	0	1	0.13	2	0.03
ARTHROPODA:Insecta										
Halobates sp.	0	0	0	0	0	0	2	0.5	2	0.12

Table 2. --Continued.

Species	SD 9.0°–12°C $n = 6$ FO	MA	Northern NPSFZ 12.1°–15°C $n = 14$ FO	MA	Southern NPSFZ 15.1°–18°C $n = 12$ FO	MA	SSTZ 18.1°–25°C $n = 10$ FO	MA	Total $n = 42$ FO	MA
CHAETOGNATHA										
Eukrohina hamata	0	0	0	0	1	0.03	0	0	1	0.01
Sagitta sp.	1	0.57	1	0.36	3	0.1	3	0.29	8	0.3
Sagitta decipiens	0	0	1	0.01	0	0	0	0	1	0.00
Sagitta elegans	4	1.69	3	0.35	1	0.08	2	0.16	10	0.42
CHORDATA:Thaliacea										
Doliolida	0	0	2	0.05	4	0	5	12.58	11	3.01
Salpidae										
Cyclosalpa sp.	2	0.53	0	0	0	0	1	0.5	3	0.2
Cyclosalpa bakeri	1	0.3	0	0	0	0	0	0	1	0.04
Salpa sp.	1	0.13	0	0	0	0	0	0	1	0.02
Salpa fusiformis	1	8.47	0	0	0	0	0	0	1	1.21
Thalia sp.	0	0	0	0	2	0	4	0	6	0
Thalia democratica	0	0	1	0.18	0	0	0	0	1	0.06
Salpidae Unidentified	0	0	2	0	1	0	0	0	3	0
CHORDATA:Osteichthyes										
Myctophidae	0	0	0	0	0	0	2	0.06	2	0.02
Lampanyctus sp.	0	0	0	0	1	0.01	0	0	1	0.00
Symbolophorus sp.	0	0	0	0	1	0.01	1	0.05	2	0.02
Tarletonbeania sp.	1	0.02	0	0	1	0.04	0	0	2	0.02
Gadidae	0	0	0	0	0	0	1	0.02	1	0.00
Exocoetidae	0	0	0	0	0	0	2	0.03	2	0.01
Scomberescoidae										
Cololabis saira	0	0	7	0.21	9	0.57	9	1.37	25	0.56
Carangidae										
Naucrates ductor	0	0	0	0	0	0	2	0.03	2	0.01
Fish Eggs Unidentified	0	0	6	0.21	4	0.06	1	0.02	11	0.09
Fish Larvae Unidentified	0	0	0	0	1	0.01	3	0.06	4	0.02
TOTAL TAXA	31		66		78		75		134	

Figures

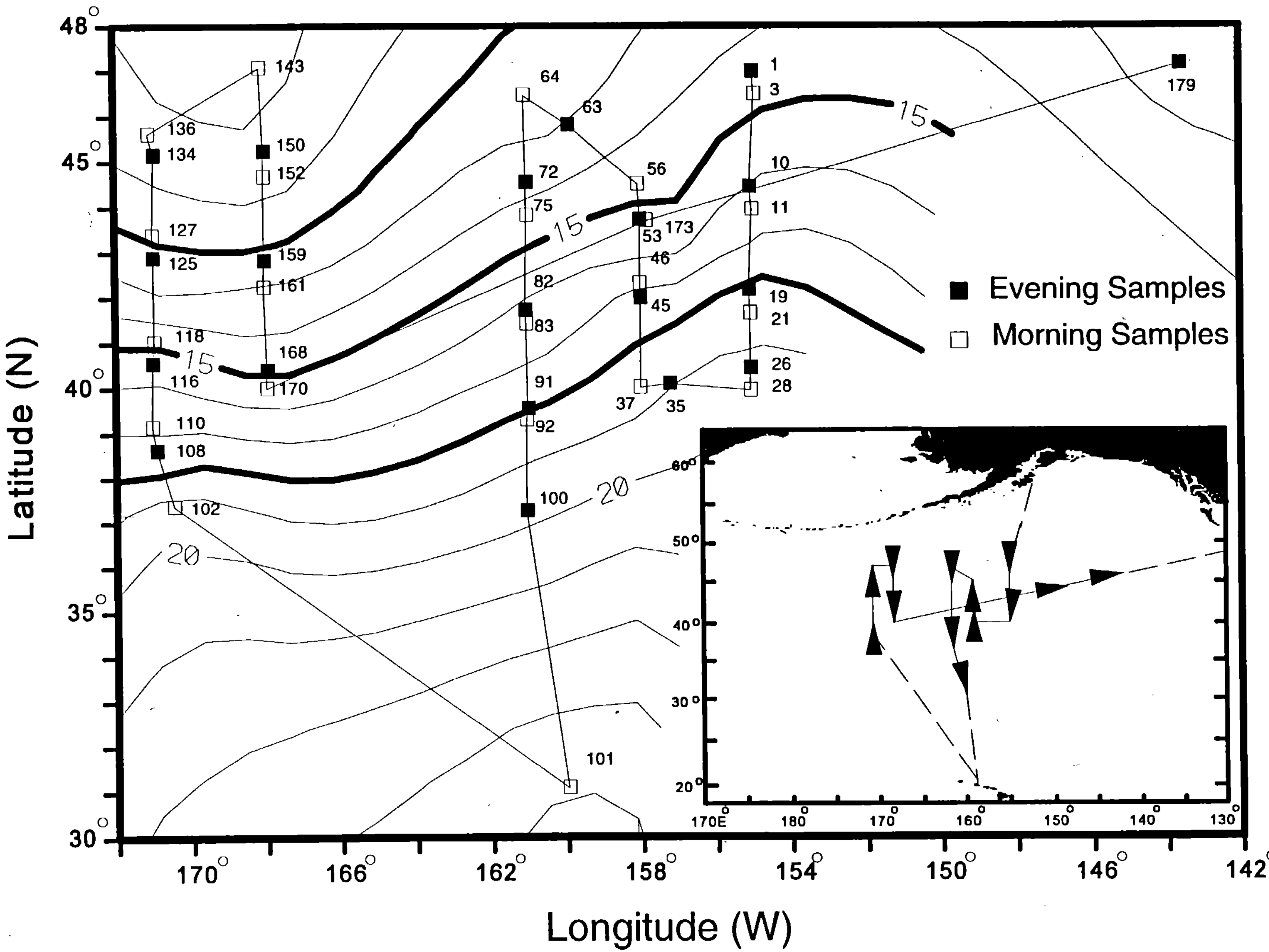

Figure l. --Sampling stations in the North Pacific Transition Zone where neustonic zooplankton were collected 4 October-9 November 1989, and sea surface temperature contours. Inset shows the entire track of the RV *Miller Freeman* cruise 1 October-l3 November 1989.

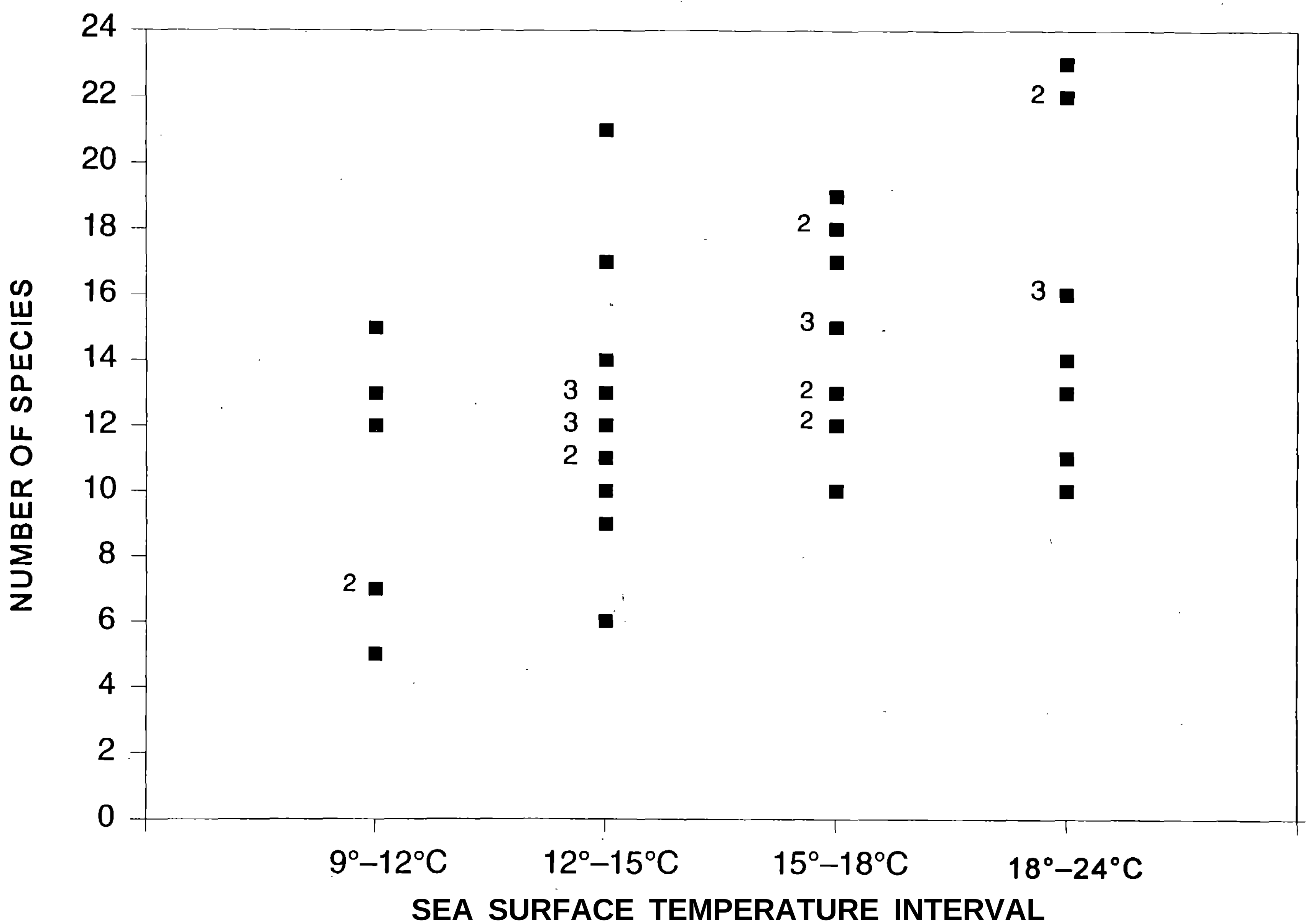

Figure 2. --Number of taxa per station for each sea surface temperature interval.

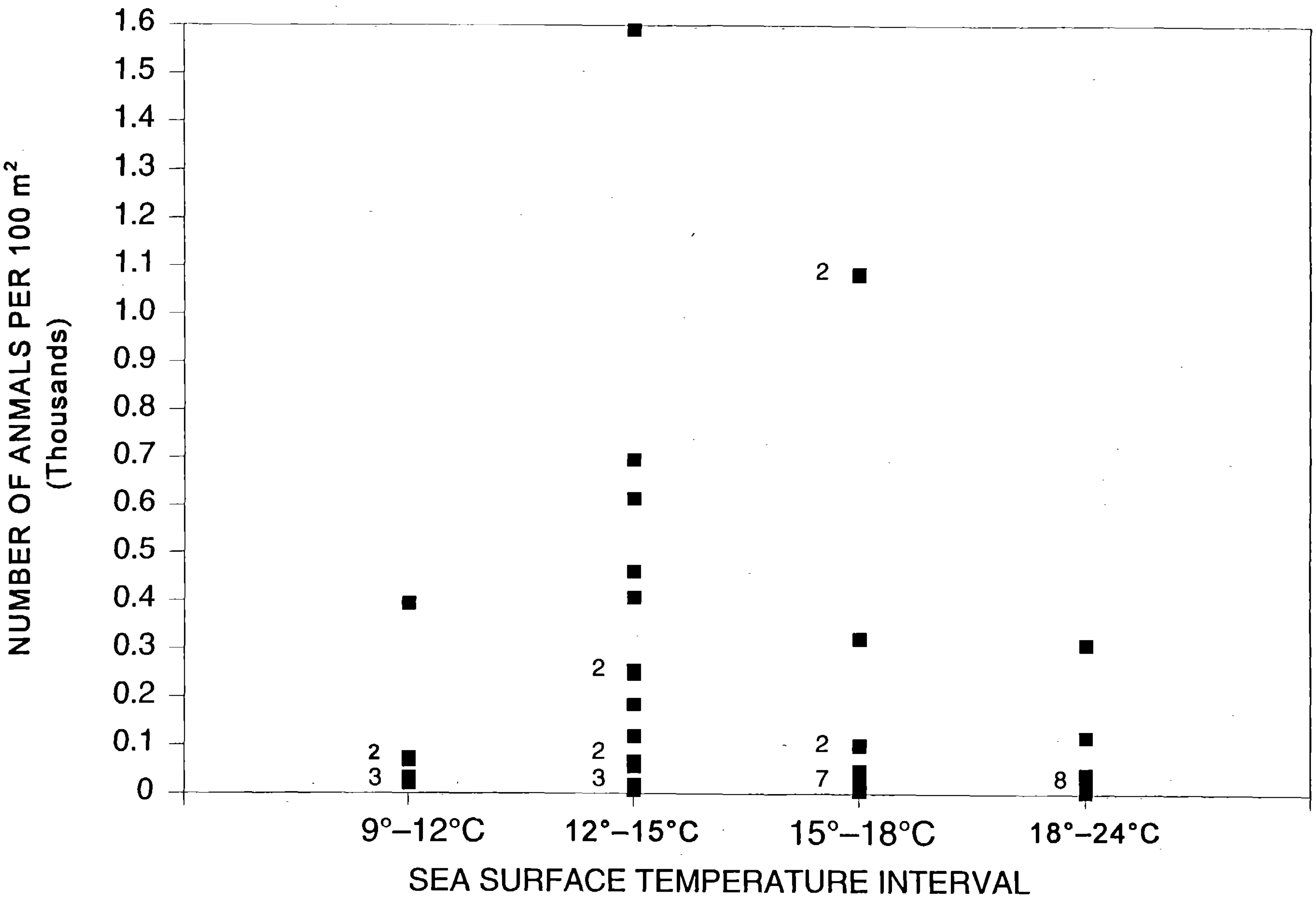

Figure 3 .--Standardized abundance of neustonic zooplankton per 100 m^2 for each sea surface temperature interval.

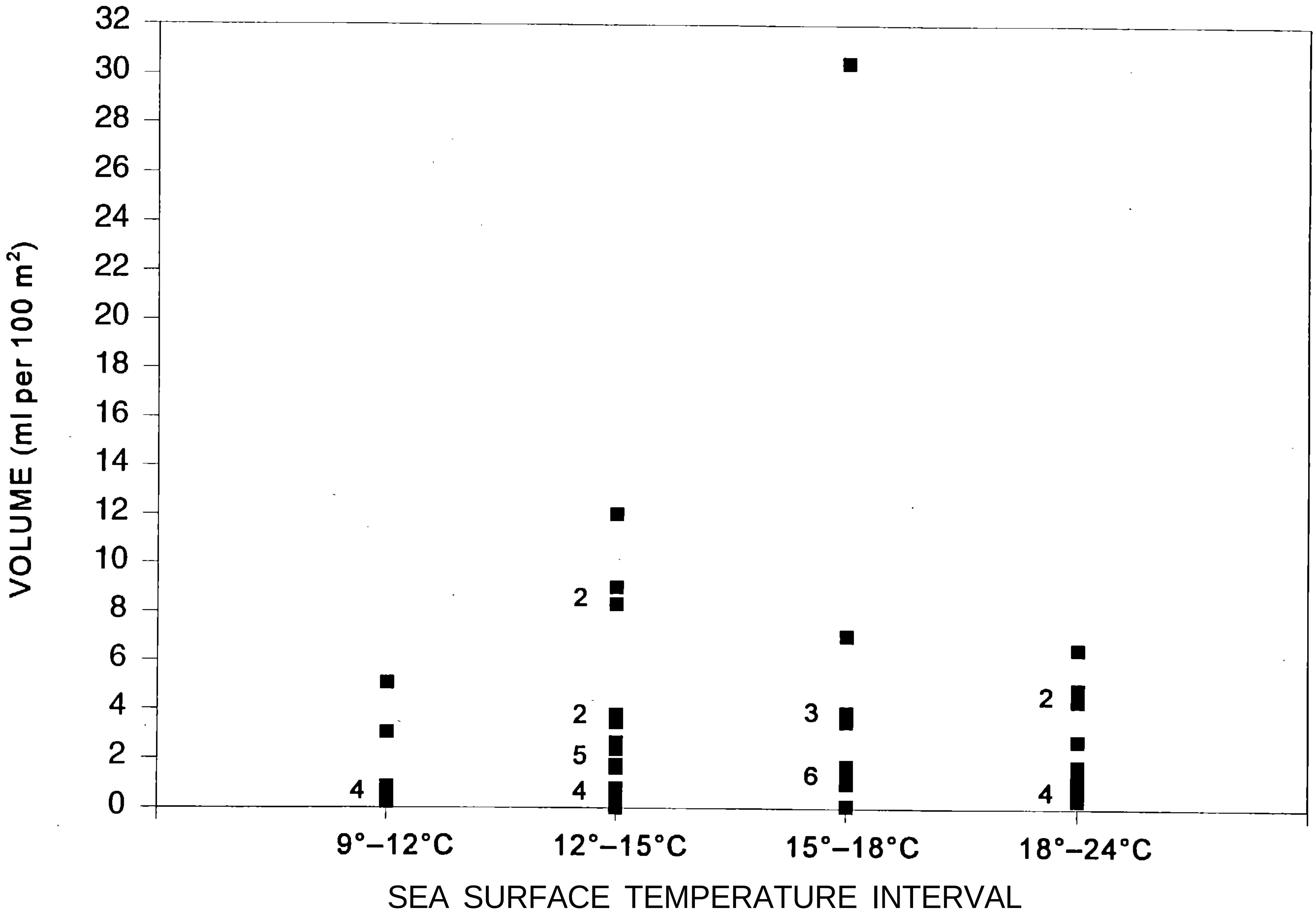

Figure 4. --Standardized displacement volume of neuston samples for each sea surface temperature interval.

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