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ZOOPLANKTON COMPOSITION AND SPATIAL PATTERN IN THE NORTH PACIFIC SUBARCTIC FRONTAL ZONE, AUGUST 1991

by

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ABSTRACT

An intensive oceanographic and zooplankton survey of a small portion of the North Pacific's subarctic frontal zone (SFZ) was conducted in 1991 in conjunction with an international monitoring program of nekton caught by squid driftnet vessels operating in that region. The study's objective was to assess the relationship between nekton spatial patterns, zooplankton abundance, and oceanographic conditions.

Over 91% of the total displacement volume or biomass of the plankton samples consisted of salps, followed by copepods (2.1%), euphausiids (2.0%), chaetognaths (1.7%), and amphipods (1.0%). Salps also accounted for almost half (44.7%) of the total caloric value in the samples. Salp abundance was uncorrelated with abundances of the crustacean zooplankton groups in our study. Pair-wise correlations between chaetognath, copepod, amphipod, and euphausiid abundances were all significant, especially those of euphausiids and amphipods ($\underline{r}$ = 0.71).

Generalized Additive Models were used to estimate the time-of-day adjusted abundance and distribution of plankton. Salps exhibited a crepuscular vertical migration pattern; other species exhibited diurnal patterns. Model residuals were plotted spatially, and comparisons were made among nekton species and to the physical oceanographic conditions.

Abundance of most nekton species captured in the driftnets was generally not associated with plankton abundance. Zooplankton abundances were not related to absolute temperature, but somewhat related to temperature gradient. The power of these tests was low, however, due to the low numbers of observed driftnet operations and the high variability of zooplankton abundances in the survey area. More extensive nekton and zooplankton data (or perhaps different sampling methods--e.g., accoustics) would be needed to better define these relationships.

INTRODUCTION

Salmonid abundances vary extensively on a variety of space and time scales near the North Pacific's Subarctic Frontal Zone (SFZ). Catch rates of salmonids differ by several orders of magnitude between the western and eastern portions (longitudes 170°E and 145°W, respectively) of the SFZ (Ignell and Murphy 1993). This same level of variability also was observed near 170°E, as salmonid catches ranged from 0 to 2000 fish per driftnet operation in the space of a few tens of kilometers. Using satellite imagery, Ignell and Murphy (1993) showed that at least some of the coarse scale (1-100 km) variability in catch rates was associated with changes in sea surface temperature (SST). The patchiness in salmonid spatial patterns was positively associated with mean SST and with variance in SST (Ignell and Murphy 1993).

Spatial differences in nekton abundances, however, may also reflect changes in forage. Growth and survival are functions of habitat conditions. Forage type and availability are major components of these conditions, especially for species such as salmon where growth is considered to be the primary factor in the selection of habitat (Pearcy 1992).

To better understand the relative importance of forage and oceanographic conditions in affecting nekton spatial patterns, an intensive oceanographic and zooplankton survey of a small portion of the SFZ was conducted in 1991 (Fig. 1). The survey occurred in conjunction with an international monitoring program of squid driftnet vessels operating in that region, resulting in fine-scale data on the physical environment, zooplankton abundances, and nekton spatial patterns. This paper presents the results of this survey, and compares patterns in the zooplankton and temperature field with abundance patterns of various nekton species caught in the driftnets.

MATERIALS AND METHODS

The survey location was originally set at 45°04.5'N, 171°55.6'E, but then moved eastward to 174°00.0'E and 178°00.0'E, 45°00.0'N and 43°40.0'N because of inclement weather. A total of 41 Bongo stations arranged in a grid were generally spaced every 20 minutes latitude and every 30 minutes longitude (Fig. 1).

Six more tows were made at 44.6°N and between 183.2°W and 184°W longitude (Fig. 1) in close proximity and parallel to a driftnet set by a commercial fishing vessel (hereafter called the eastern samples). The vessel was located by transponder data processed by the U.S. National Marine Fisheries Service, Enforcement Division. By an international agreement, the driftnet vessels were required to carry transponders which provided daily information on vessel location. An observer aboard the driftnet vessel recorded the numbers of squid and fish captured per section of net. One net section is about 3 km in length, and there were 10 net sections consecutively deployed.

Sampling at each station consisted of a CTD cast to 300-500 m (Ebberts et al., 1994) and a double oblique Bongo net tow to 100 m. The Bongo nets were 0.6 m in diameter, with a 0.505 mm mesh net. Depth of tow was measured by a bathykymograph attached to the Bongo net. The amount of water filtered through each net was measured with a flow meter attached inside the net opening.

After the net was washed, the plankton were removed from the cod end, placed in labeled glass jars, and immediately preserved in buffered 10% formalin. In the laboratory, the samples were first immersed in tap water for 1-3 days and then placed in Petri plates for examination under a microscope. Squid and fish larvae were removed and placed into glass vials for later identification. The composition of the sample volume was visually estimated for the following seven taxonomic categories: gelatinous zooplankton, arrowworms, copepods, amphipods, euphausiids, fish, and other. Displacement volume (DV) was measured by methods in Smith and Richardson (1977).

The total volume of plankton per m^3 was computed by dividing DV by the volume of water filtered, and then apportioned into the seven taxa categories according to the estimate of sample composition, and averaged across each pair of Bongo tows. The total plankton volume was also converted into calories per m^3 by a species-independent ratio of DV to wet weight (WW) computed from data in Nakai and Honjo (1961) and WW to caloric value data in Davis (1993) (Table 1). The concentration of non-gelatinous zooplankton was computed by first subtracting estimated salp DV from measured total DV, and then multiplying the result by the DV/WW ratio. Means of total volume, caloric value, and concentration are presented with $\pm$ one standard deviation.

Salinity and temperature data at 10- and 100-m depth intervals (temperature data are hereafter denoted as t10 and t100) were extracted from the CTD data. Caloric and DV values were log-transformed for use in statistical tests and contour plots. Statistical tests consisted of correlations between taxa categories and *t*-tests of night/day differences in plankton abundance. Plankton abundance data were fit by a lowess function to a single variable (time of day) generalized additive model (GAM), which allows for non-linearity in the explanatory term (Hastie 1992). Fitted values of the resulting GAM models were plotted as a function of time of day, and the residuals plotted as a function of latitude and longitude. The latter plots allowed us to identify spatial variation in plankton abundances independent of time-of-day effects.

Driftnet data from an international monitoring program aboard Japanese commercial squid driftnet vessels were used to provide data on the spatial distribution of large nekton in the survey area. Although the data from individual fishing operations, such as those used in our analyses, are proprietary, a description and summarized version of the data are in Int.

North Pac. Fish. Comm. (1992).

We used species counts and fishing effort by driftnet section for our analyses. A driftnet section has approximately 150 tans of net sewn together (a tan is defined as a continuous piece of gillnet which can vary in length between 35 to 50 m from vessel to vessel). A day's fishing operation usually consisted of 10 consecutively placed net sections (tans) deployed for an overnight soak; observers typically monitored 6-7 of these sections. Data from latitude 43.5° to 45.1°N, longitude 173.75° to 178.25°E, and August 3 to August 14 were extracted for the analyses.

Species counts were converted to catch per standardized tan (50 m) to give equivalent-scaled rate of catch per unit effort (CPUE). Symbolic scatter plots of CPUE were made for selected species; latitude and longitude comprised the x- and y-coordinates of these plots, and CPUE was proportional to circle size. Driftnet data were also aggregated by statistical areas of size 0.2° latitude x 0.5° longitude and centered on the plankton sampling locations. Average CPUE for the resulting 10 areas containing concurrently sampled driftnet, CTD, and plankton data were computed for selected species. The stratified CPUE data were fit to a regression model comprised of plankton abundance (caloric value and abundance by taxa category) and temperature variables (t10 and t100). Model selection was based on Mallow's C_p statistic (Draper and Smith 1981) and used an all possible subset selection algorithm.

RESULTS

Plankton Data

Total DV of net plankton in the survey area varied between 0.048 and 9.529 $ml{\cdot}m^{-3}$, a 198-fold difference between stations (Table 2). Computed caloric value ranged from 23.6 to 1111.0 $cal{\cdot}m^{-3}$, a 47-fold difference between stations. Concentrations of non-gelatinous zooplankton ranged from 1.9 to 515.6 $g{\cdot}1000{\cdot}m^{-3}$, a 271-fold difference between stations. Average DV was 1.7 ± 2.2 $ml{\cdot}m^{-3}$, average caloric value was 286.0 ± 251.1 $cal{\cdot}m^{-3}$, and average concentration of non-gelatinous zooplankton was 110.8 ± 126.8 $g{\cdot}1000{\cdot}m^{-3}$.

Over 91% of the total DV or biomass of the samples in the survey area consisted of salps, followed by copepods (2.1%), euphausiids (2.0%), chaetognaths (1.7%), and amphipods (1.0%). This order among taxonomic categories persisted for the caloric value data; even though salps are composed primarily of water, they still accounted for almost one-half (44.7%) of the total caloric value in the samples. Copepods were dominant (45.1% of DV) in the eastern samples, followed by euphausiids (25.9%) and amphipods (23.4%). Few chaetognaths (4.3%) and practically no salps (0.3%) were present in these samples.

Total DV and caloric value were greatest west of 180°

longitude (survey area) due to the predominance of salps. The DV of copepods, amphipods, and euphausiids, however, was greatest in the eastern samples. The lower caloric and DV values in the eastern samples were due to the reduction in salp abundance.

The approximate species composition of taxonomic categories based on visual estimates of biomass was 1) gelatinous zooplankton: about 100% salps; arrowworms: about 100% Sagitta elegans; copepods: about 60% Neocalanus cristatus, 20% Neocalanus plumchrus, and 20% Calanus pacificus; euphausiids: about 60% Thysanoessa spp. and 40% Euphausia pacific; and amphipods: about 100% Themisto pacifica (Table 1).

Caloric value and DV of samples taken during night exceeded that of samples taken during day (Table 3). In the survey area, night-day differences were greatest for euphausiids (17.8-1) and lowest for salps (1.3-1). The night-day differences were highly significant ($P < 0.005$) for euphausiids, copepods, and caloric values, and significant ($P < 0.05$) for amphipods and chaetognaths. Salps and total DV showed no significant night-day differences. Similar night-day differences in caloric value and DV also occurred in the eastern samples.

Lowess plots of log-transformed abundance versus time of day showed that plankton abundances changed gradually between night and day (Fig. 2). Except for salps, peak abundances occurred near midnight and low abundances from about 1000 to 1700 hours. Fitted lowess values between nighttime peaks and daytime lows varied about 9-fold for euphausiids and about 2.5-fold for chaetognaths, copepods, and amphipods. Salps exhibited a crepuscular abundance pattern, with peak abundances occurring near dawn and dusk and low abundances near midnight (Fig. 3).

The time-of-day adjusted abundance and distribution of plankton varied extensively throughout the western survey area. Salps were broadly abundant along the northeast, southwest, and southeast regions (Fig. 3), and constituted over 80% of the total plankton displacement volume in about one-half of the survey area. Non-gelatinous plankton were abundant in the northeast, central southern, and northern areas (Fig. 3). Euphausiids, copepods, and amphipods were abundant along two northern and one southern areas. Chaetognaths were primarily abundant in the northwest portion of the survey area (Fig. 4). Except for chaetognaths, highest abundances of each plankton group occurred in areas exhibiting gradual changes in temperature at 100m (Fig. 5).

The correlation between gelatinous and non-gelatinous abundances (time-of-day adjusted) was nearly zero ($r = 0.045$). Salps were negatively correlated with chaetognaths ($r = -0.52$; $P < 0.01$); otherwise they were uncorrelated in abundance with any other zooplankton group. Pair-wise correlations between chaetognath, copepod, amphipod, and euphausiid abundances were all significant ($P < 0.05$); of these, euphausiids and amphipods were most closely related ($r = 0.71$).

Plankton caloric values generally followed the distribution pattern of salps. Highest caloric values occurred in the boundary in the study area is characteristic of fronts in the SFZ (Roden 1991).

Along the 174°E longitude transect, temperature had no apparent effect on squid and pomfret CPUE, but a significant effect on albacore CPUE. These nekton-temperature relationships were consistent with those reported in Pearcy (1991) and Carlson and Ignell (1994). Flying squid and pomfret are species that occupy a wide range of habitats from subtropical waters through the SFZ into subarctic waters. Albacore, however, is a subtropical species that is temperature limited within the SFZ.

Temperature also had no apparent effect on zooplankton abundances, probably because the survey area occured within the geographic range of most zooplankton species captured in the study (Bowman 1960; Brodsky 1950; Fager and McGowan 1963). The abundance of some zooplankton species may be related to the presence or absence of fronts. Additional, fine-scale studies of zooplankton within the SFZ, however, are needed to confirm this relationship.

We found little evidence linking coarse-scale (1-100 km) spatial patterns of large nekton to variation in forage densities. The power of our tests, however, was very low due to the paucity of observer coverage within the survey area and the large-scale of variation in our data (e.g., sampling variation, patchiness of plankton and nekton abundances, and stocasticity in consumer selection of habitat). For example, the apparent significance between salps and albacore abundance would likely not persist if observer sampling occurred in other parts of the survey area where salps were abundant and water temperature low (albacore abundance in the SFZ is strongly related to temperature). Additional, spatially separated nekton data would be needed before more definitive conclusions based on covariance or distributional analyses (Rosenzweig 1985) could be reached.

The plankton data revealed that salps, not copepods, were the most abundant taxa (in terms of biomass) and food item (in terms of calories) in our plankton samples. Salp abundance was also uncorrelated with abundances of the crustacean zooplankton groups in our study. These findings are of significant interest because of the paucity of data on gelatinous zooplankton in subarctic oceanic waters, and because of their importance in oceanic food webs.

Gelatinous zooplankton are poorly studied because they are often excluded from plankton samples or inadequately sampled by nets (Parsons and Lalli 1988). For example, McAllister (1961) excluded medusae from measures of zooplankton concentration because they were not "edible" species. As a result, analyses of zooplankton populations in the subarctic North Pacific are often restricted to non-gelatinous species, giving results such as those summarized in Parsons and Lalli (1988) where copepods are reported to comprise from 75% to 95% of the planktonic biomass in subarctic waters.

Gelatinous zooplankton occupy an important, but often overlooked, role in pelagic and neritic ecosystems. Many of the northeastern and southwestern regions where salps comprised over 90% of the total plankton biomass (Fig. 6). Caloric values were also high in a small area along the southern portion of the survey area, reflecting the high abundance of copepods and euphausiids there.

Oceanographic Data

Based on latitude-by-depth sectional plots of temperature along each end of the survey area, the SFZ's northern boundary was located inside of the survey area (Fig 7). Along the 174°E longitude transect, the boundary ranged from 44.4°N to 44.8°N; along the 178°E longitude transect, the boundary ranged from south of the survey area to 44.0°N latitude. The northern boundary was clearly visible in the contour plot of temperature at 100 m and partially visible in the remaining salinity and temperature contour plots (Fig. 5). Surface salinities north of the boundaries were less than 32.7‰; south of the boundaries, surface salinities never exceeded 33.1‰. The boundary was also highly variable, exhibiting sharp turns and meanders across the survey area (see plot of temperature at 100 m, Fig. 5).

Zooplankton abundances and caloric value in areas with a large temperature (t100) gradient were generally lower than those in areas with little gradient. Large differences were observed for chaetognath abundance (P = 0.089), euphausiid abundance (P = 0.087) and caloric value (P = 0.048).

Nekton-Plankton Interactions

The symbolic scatter plots showed differences in spatial patterns between species (Fig. 8), but gave little information about spatial correlations between plankton and nekton abundances because the observed fishing operations occurred in only a small portion of the survey area.

The regression analyses revealed that average CPUE of salmon shark and flying squid were uncorrelated with plankton abundance and with temperature. Albacore abundance, however, was significantly related to salps, amphipods, and t10 (adjusted r^2 = 0.82; P = 0.004). Pomfret abundance was possibly related to chaetognaths, copepods, amphipods, euphausiids, and t100 (adjusted r^2 = 0.71; P = 0.064).

DISCUSSION

The SFZ's northern boundary along the 175°30' transect occured very near the boundary position reported by Ignell et al. (1994), which was based on Japanese research vessel data collected one week prior to the Acania survey. The low salinities (at 10 m and 100 m, Fig. 5) along the transect indicate that the SFZ's southern boundary occured south of the survey, which is also consistent with the findings of Ignell et al. (1994). The highly meandering course of the SFZ's northern nekton species, such as the chum salmon, ocean sunfish, louvar, and pelagic armorhead that inhabit the survey area feed on salps (Eschmeyer et al. 1983; Uchida 1986; Salo 1991). More generally, over 47 fish species from differing regions of the world are known to feed on salps (Kashkina 1986). Salps can respond almost instantaneously to favorable food conditions, replacing other zooplankton in a region (Paffenhofer and Lee 1987). This rapid growth can lead to such high densities, however, that some fish species move to other regions (Kashkina 1986).

Dense patches of salps such as those observed in our study have also been reported for a wide variety of pelagic and neritic waters. At ocean weather station I in the North Atlantic Ocean, salps comprise 10-40% of the total dry weight zooplankton biomass from April to October (Parsons and Lalli 1988). Salps are the dominant zooplankton off Tasmania in windy periods, and are co-dominant during normal years (Harris et al. 1992). Salps are often found in high concentrations along coastal regions of California, Ivory Coast, and Florida (Paffenhofer and Lee 1987; Cailliet and Ebeling 1990).

Concentrations of non-gelatinous zooplankton in our study were more than double those of ocean station "P," the Sargasso Sea, Norwegian Sea, and the Central Equatorial Pacific, but less than those of the Bering Sea, British Columbia coastal waters, and the NW Pacific Ocean (McAllister 1961). The relatively high concentrations found in our study might be expected, as our survey area lies within the SFZ, which is a prominent area of convergence across the North Pacific Ocean (Roden 1991). Zooplankton production is typically high in areas where physical processes promote high primary production. Such areas often occur along coasts, in the centers of cyclonic gyres, between currents, and in convergence areas (Laevastu 1957).

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Table 2.--Station, day, position, depth, time and duration of tow, computed calories per unit volume (m^3), and displacement volume for all Bongo stations from RV *Acania* cruise, August 1991.

Sta.	Day	Lat. (N)	Long. (E)	Max. Depth (m)	Begin Time	Tow Dur. (min)	Cal.	Displacement Volume ($ml \cdot m^{-3}$) Total	Salp.	Chae.	Cope.	Amph.	Euph.
69	03	45.075	171.927	80.3	920	20	132	0.301	0.150	0.053	0.045	0.015	0.038
70	03	44.665	171.995	99.0	1343	11	615	0.777	0.012	0.040	0.580	0.118	0.028
72	05	43.664	173.997	100.4	857	14	498	4.836	4.788	0.012	0.012	0.012	0.012
73	05	44.009	173.997	135.0	1154	13	298	2.890	2.861	0.007	0.007	0.007	0.007
74	05	44.348	174.016	103.2	1545	16	41	0.268	0.247	0.001	0.019	0.001	0.001
75	05	44.670	174.003	97.5	1843	15	75	0.180	0.058	0.090	0.032	0.000	0.000
76	05	45.005	173.996	100.0	2153	11	60	0.093	0.014	0.019	0.042	0.014	0.005
77	06	45.010	174.498	96.4	116	12	349	0.382	0.000	0.100	0.060	0.020	0.201
78	06	45.008	175.002	106.1	455	12	608	0.727	0.000	0.182	0.227	0.091	0.227
79	06	44.664	175.007	100.3	1147	12	76	0.141	0.014	0.091	0.035	0.000	0.000
80	06	44.334	174.997	102.8	1459	15	41	0.183	0.144	0.020	0.009	0.004	0.006
81	06	43.999	174.999	103.2	1814	14	430	4.174	4.132	0.010	0.010	0.010	0.010
82	06	44.003	175.506	97.5	2149	13	110	0.181	0.024	0.079	0.050	0.009	0.018
83	07	44.010	176.017	109.3	113	14	155	0.433	0.283	0.049	0.037	0.001	0.062
84	07	44.333	176.002	102.8	906	12	84	0.839	0.834	0.002	0.002	0.001	0.000
85	07	44.673	176.006	102.8	1233	13	75	0.479	0.412	0.059	0.006	0.001	0.001
86	07	45.008	176.002	106.1	1548	15	77	0.132	0.007	0.086	0.026	0.007	0.007
87	07	44.996	175.513	102.8	2240	11	369	1.111	0.717	0.123	0.188	0.025	0.057
88	08	44.667	175.517	106.1	1056	12	25	0.048	0.015	0.012	0.017	0.001	0.002
89	08	44.321	175.503	106.1	1447	15	24	0.122	0.105	0.002	0.013	0.000	0.002
90	08	43.658	175.002	106.1	2032	11	361	3.499	3.463	0.009	0.009	0.009	0.009
91	09	43.664	175.508	109.3	6	16	151	0.183	0.000	0.058	0.053	0.012	0.060
92	09	43.667	176.007	112.5	330	16	468	1.369	1.040	0.004	0.019	0.019	0.287
93	09	43.667	176.507	115.7	651	17	937	5.885	5.397	0.068	0.099	0.160	0.160
94	09	43.997	176.505	114.9	1128	14	77	0.205	0.101	0.054	0.049	0.001	0.001
95	09	44.322	176.482	102.5	1450	15	137	1.267	1.245	0.003	0.012	0.003	0.003
96	09	44.667	176.497	106.1	1934	12	357	2.190	1.987	0.005	0.186	0.005	0.005
97	09	45.001	176.505	114.7	2317	13	204	0.411	0.202	0.046	0.067	0.011	0.084

Table 1.--Data used to compute calories/ml of net plankton collected aboard the Acania cruise to the Subarctic Frontal Zone of the North Pacific Ocean, August 1991. Caloric value (per g) data are from Davis (1993) and the volume/weight (0.674) ratio is an average of data given in Nakai and Honjo (1961). Percent composition of taxonomic category in group was based on visual estimates by one of the authors.

Group/Taxonomic Category	Composition of Taxa in Group	$g \cdot ml^{-1}$	$cal \cdot g^{-1}$	$cal \cdot ml^{-1}$
Salp/Gelatinous				
Salpidae	100%	0.674	96	64.7
Chaetognaths				
Sagitta elegans	100%	0.674	488	328.9
Copepods				
Neocalanus cristatus	60%	0.674	748	504.2
Neocalanus plumchrus	20%	0.674	995	670.6
Calanus pacificus	20%	0.674	872	587.4
		Weighted Average:		554.1
Euphausiids				
Thysanoessa spp.	60%	0.674	1197	806.8
Euphausia pacifica	40%	0.674	1138	767.0
		Weighted Average:		790.9
Amphipods				
Themisto pacifica	100%	0.674	725	488.7

Displacement Volume/Wet Weight Data (Nakai and Honjo 1961)

Calanus spp.	0.729
	0.662
	0.529
	0.679
	0.716
Euphausia recurva	0.679
Salpa fusiformis	0.724
Average:	0.674

Table 3.--Caloric and displacement volume (DV; $ml \cdot m^{-3}$) statistics--ratio of night to day averages, overall average, and percent of total DV by taxa category for stations located in the western and eastern survey areas.

	Western Survey Area			Eastern Survey Area		
	Night/Day Ratio	Mean	(%)	Night/Day Ratio	Mean	(%)
Calories	2.143	292.460		1.990	213.330	
DV: Total	1.460	2.033		1.646	0.246	
Salps	1.349	1.859	(91.5)	--	0.001	(0.3)
Chaetognaths	2.150	0.035	(1.7)	1.075	0.011	(4.3)
Copepods	3.535	0.043	(2.1)	1.872	0.111	(45.1)
Amphipods	4.342	0.020	(1.0)	0.515	0.058	(23.4)
Euphausiids	17.811	0.040	(2.0)	26.857	0.064	(25.9)
Stations	18/22	40		4/2	6	

Table 2.-continued.

Sta.	Day	Lat. (N)	Long. (E)	Max. Depth (m)	Begin Time	Tow Dur. (min)	Cal.	Displacement Volume ($ml \cdot m^{-3}$) Total	Salp.	Chae.	Cope.	Amph.	Euph.
98	10	45.001	177.012	114.7	217	17	722	1.750	1.050	0.087	0.175	0.175	0.262
99	10	44.998	177.498	120.5	516	17	770	7.472	7.397	0.019	0.019	0.019	0.019
100	10	44.663	177.501	107.1	1022	11	1111	9.529	9.247	0.024	0.138	0.096	0.024
101	10	44.328	177.500	111.8	1319	17	60	0.598	0.594	0.001	0.001	0.001	0.000
102	10	44.004	177.491	100.0	1620	15	138	1.336	1.322	0.003	0.003	0.003	0.003
103	10	43.647	177.635	106.1	1943	10	658	6.382	6.318	0.016	0.016	0.016	0.016
104	10	43.666	177.001	109.6	2254	11	203	1.855	1.826	0.005	0.005	0.005	0.015
105	11	44.005	176.996	114.9	850	10	88	0.808	0.794	0.002	0.008	0.002	0.002
106	11	44.343	176.991	109.7	1216	10	320	3.102	3.070	0.008	0.008	0.008	0.008
107	11	44.672	176.984				station canceled						
108	12	44.999	177.997	113.1	218	12	555	5.372	5.316	0.014	0.014	0.014	0.014
109	12	44.663	177.994	116.7	610	13	412	4.012	3.976	0.005	0.010	0.010	0.010
110	12	44.331	177.994	115.7	959	12	302	2.925	2.894	0.008	0.008	0.008	0.008
111	12	43.943	177.997	122.1	1406	12	243	2.223	2.182	0.006	0.024	0.006	0.006
112	12	43.661	177.997	114.3	1737	13	29	0.282	0.279	0.001	0.001	0.001	0.001
130	28	44.582	183.186	102.8	2312	13	267	0.262	0.003	0.010	0.060	0.020	0.169
131	29	44.565	183.349	103.3	122	20	275	0.316	0.001	0.014	0.214	0.022	0.065
132	29	44.567	183.493	102.8	350	11	306	0.329	0.000	0.016	0.131	0.049	0.131
133	29	44.579	183.646	98.3	647	8	175	0.220	0.001	0.003	0.121	0.084	0.011
134	29	44.568	183.812	103.3	853	14	114	0.150	0.000	0.009	0.078	0.062	0.000
135	29	44.582	183.988	109.0	1114	13	143	0.189	0.000	0.011	0.062	0.108	0.007

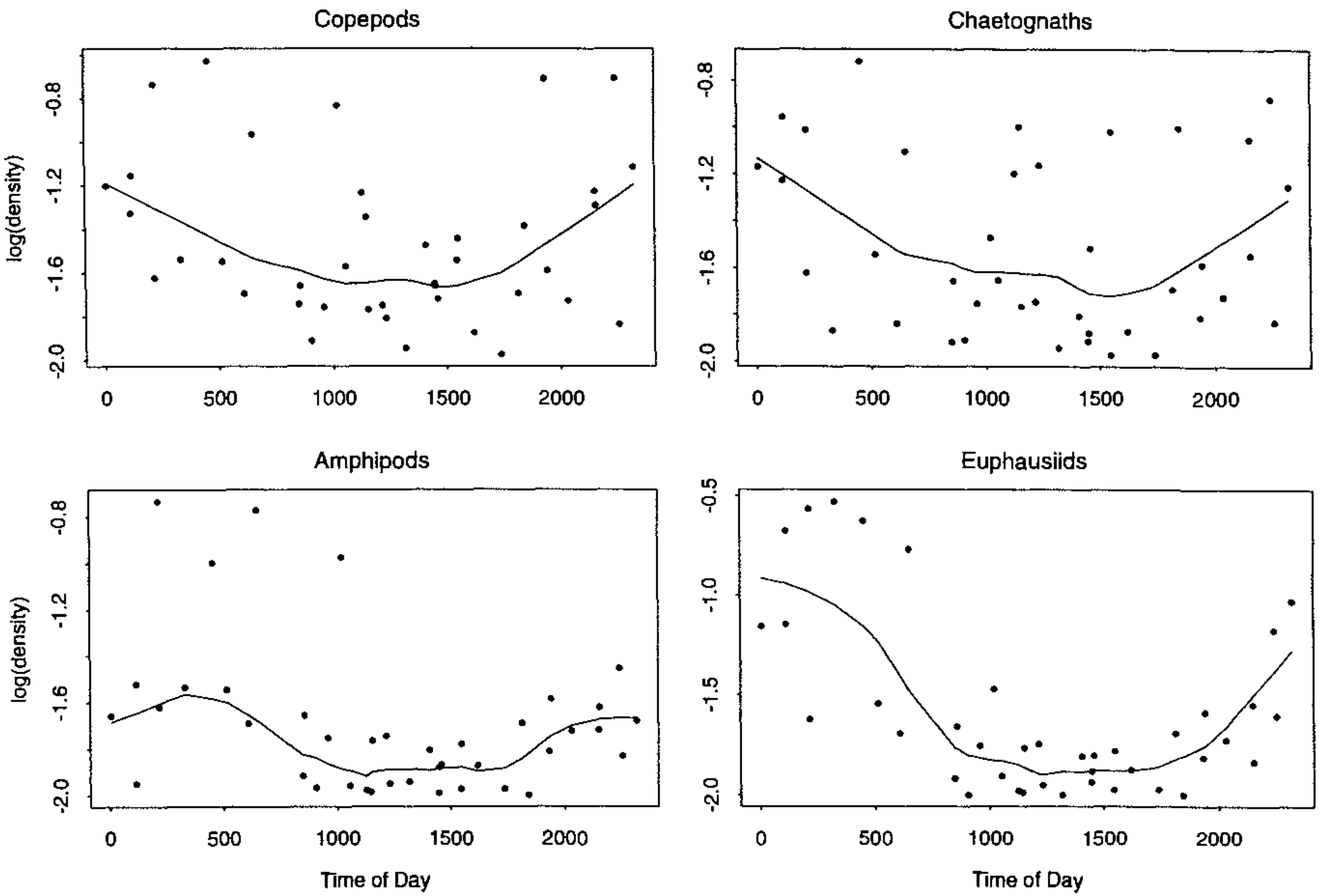

Fig. 2. Lowess plot of the log-transformed density of copepods (upper left), chaetognaths (upper right), amphipods (lower left) and euphausiids (lower right) versus time of day.

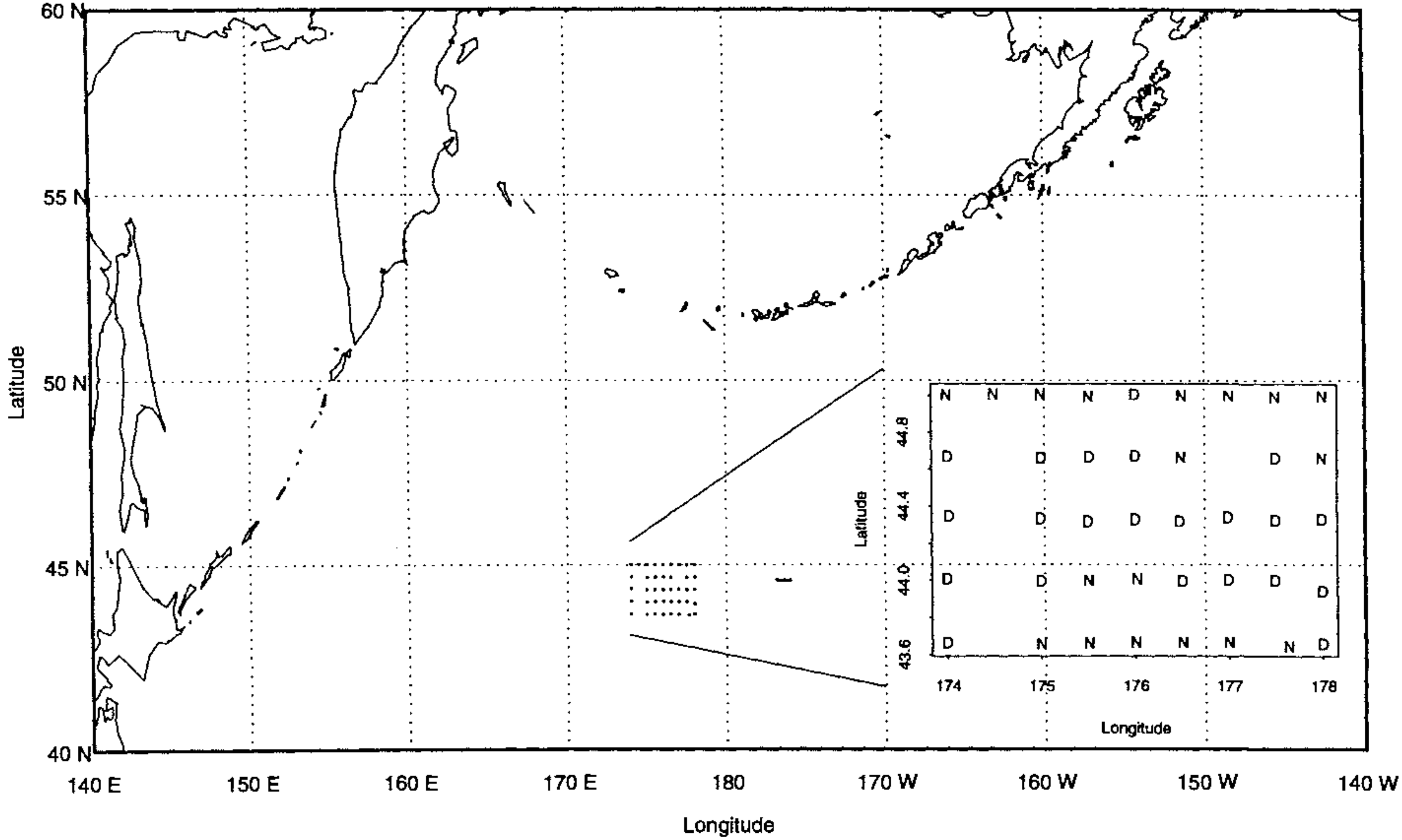

Fig. 1. Survey area and sampling locations of the R/V ACANIA North Pacific squid driftnet research cruise in 1991. An expanded view of the locations of plankton tows collected in the western survey area is given; stations labelled "D" and "N" were conducted during the day and night, respectively.

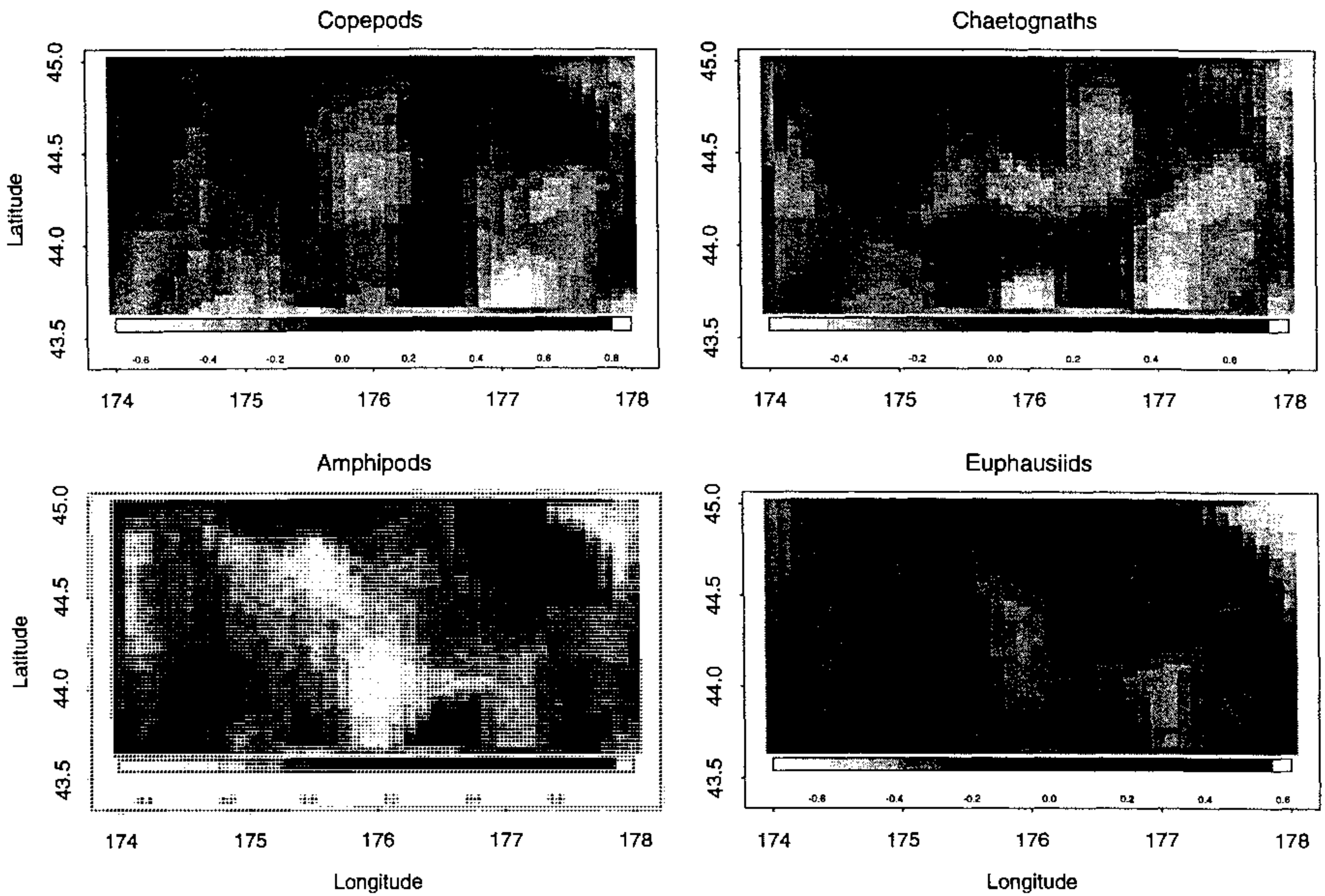

Fig. 4. Image plots of the densities ($ml \cdot m^{-3}$) of copepods (upper left), chaetognaths (upper right), amphipods (lower left), and euphausiids (lower right) in the survey area.

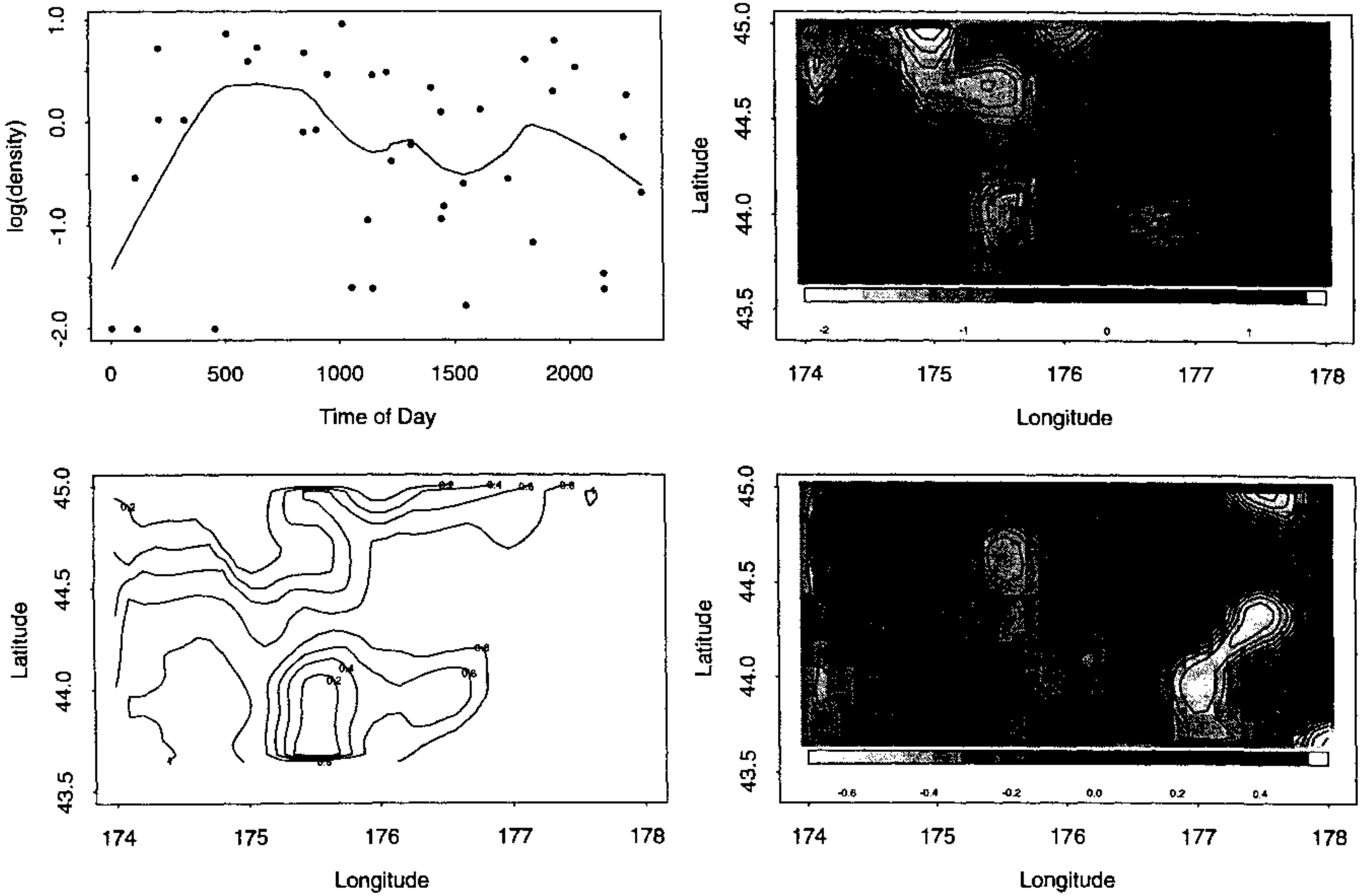

Fig. 3. Lowess plot of the log-transformed density of salps versus time of day (upper left); image plot of the density ($ml \cdot m^{-3}$) of salps in the survey area (upper right), contour plot of the ratio of salp displacement volume to total plankton displacement volume (lower left); and image plot of the density ($ml \cdot m^{-3}$) of non-gelatinous plankton in the survey area (lower right).

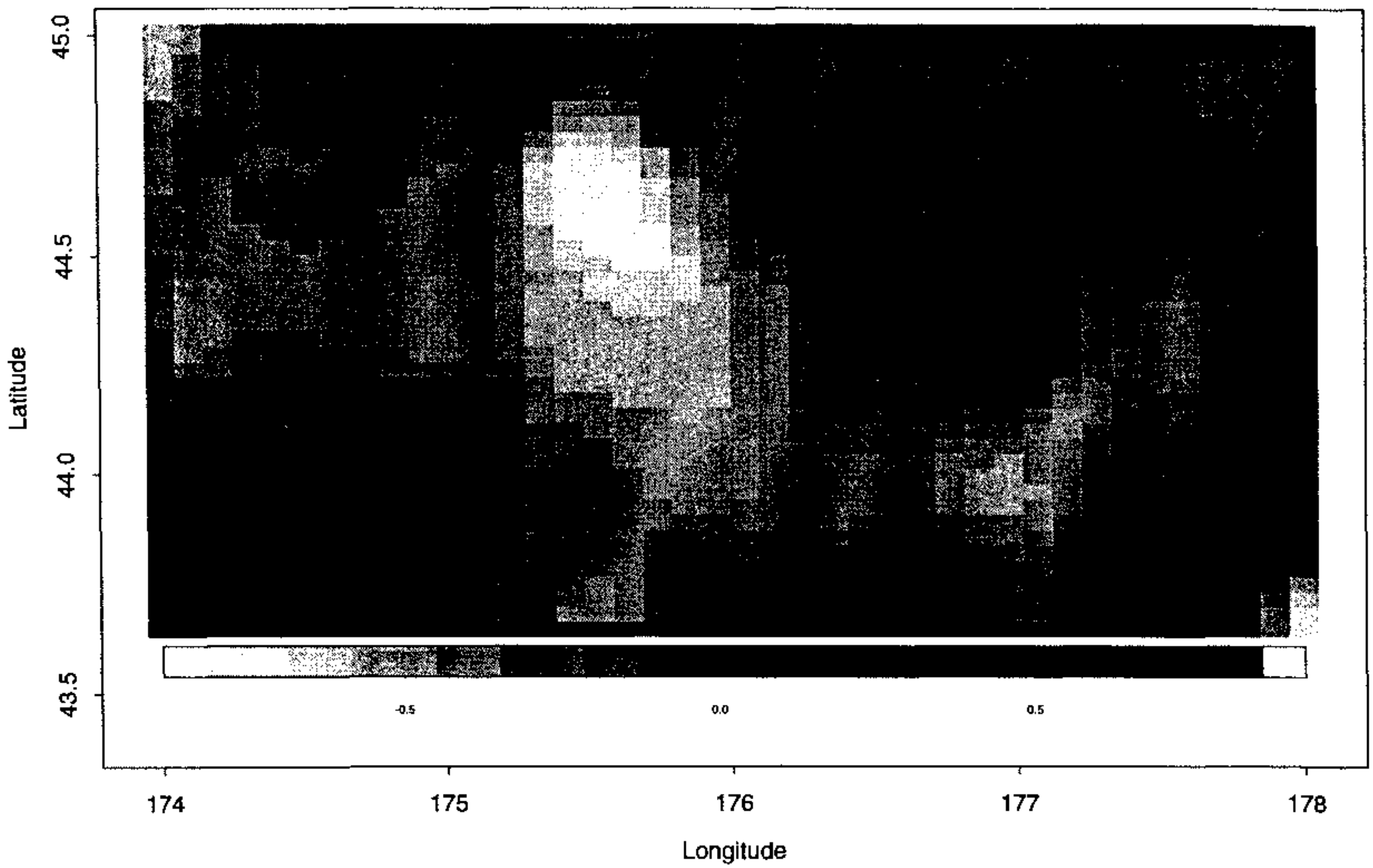

Fig. 6. Image plot of time-of-day adjusted (residuals from GAM model) caloric value in the survey area.

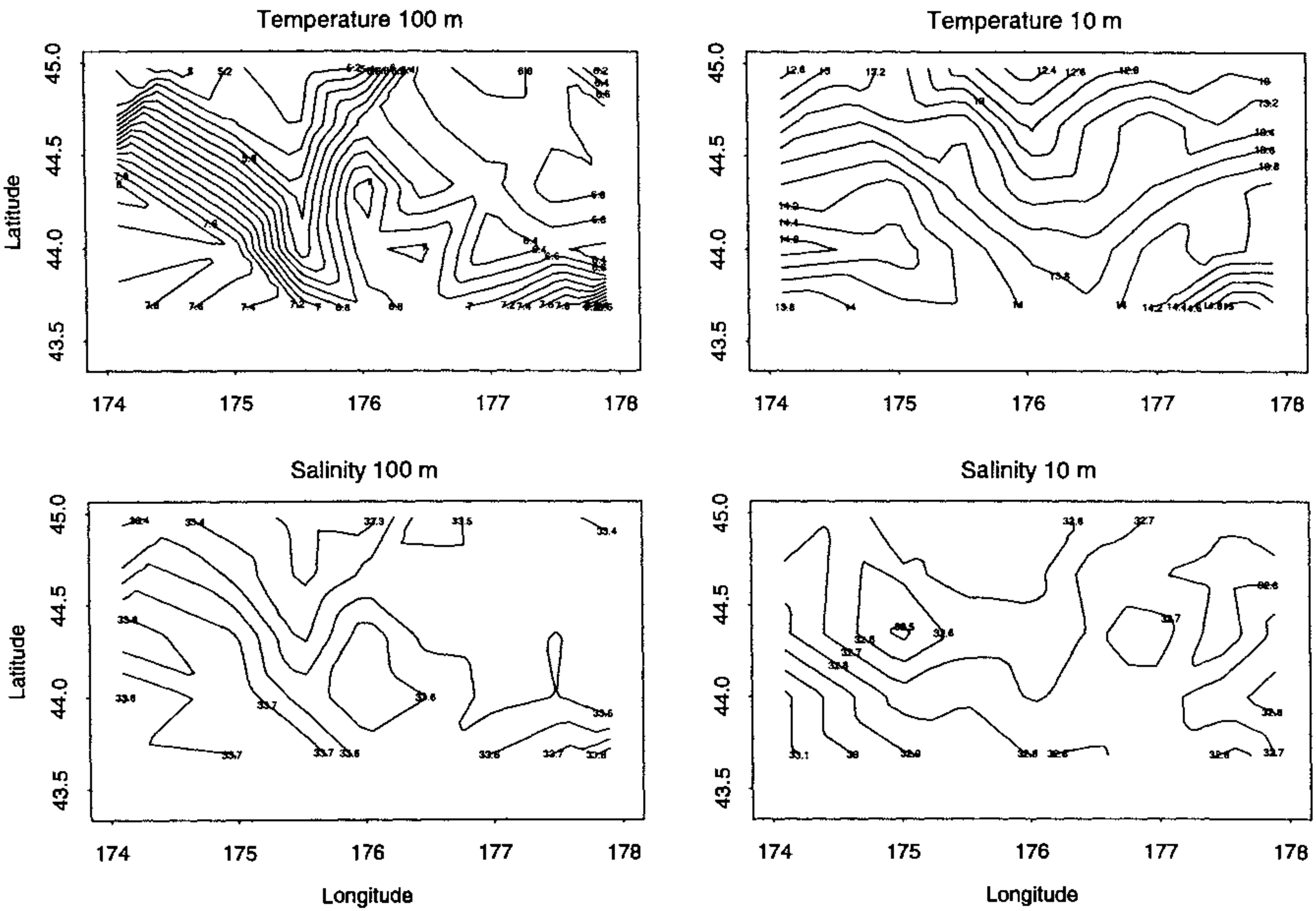

Fig. 5. Contour plot of temperature at 100 m (upper left), temperature at 10 m (upper right), salinity at 100 m (lower left), and salinity at 10 m (lower right) in the survey area.

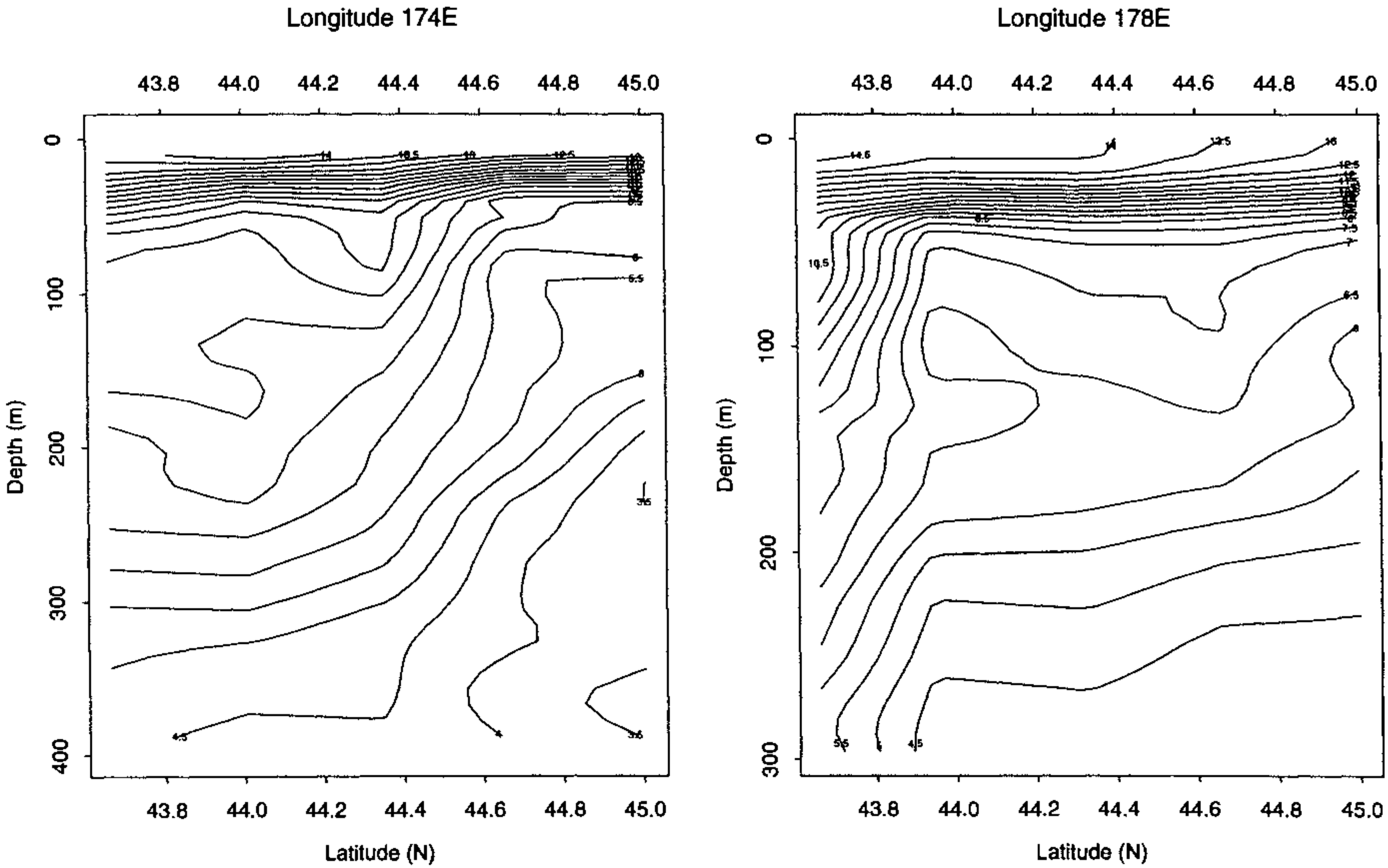

Fig. 7. Latitude by depth sectional plots of temperature along each end of the survey area: 174°E transect (left) and 178°E transect (right).

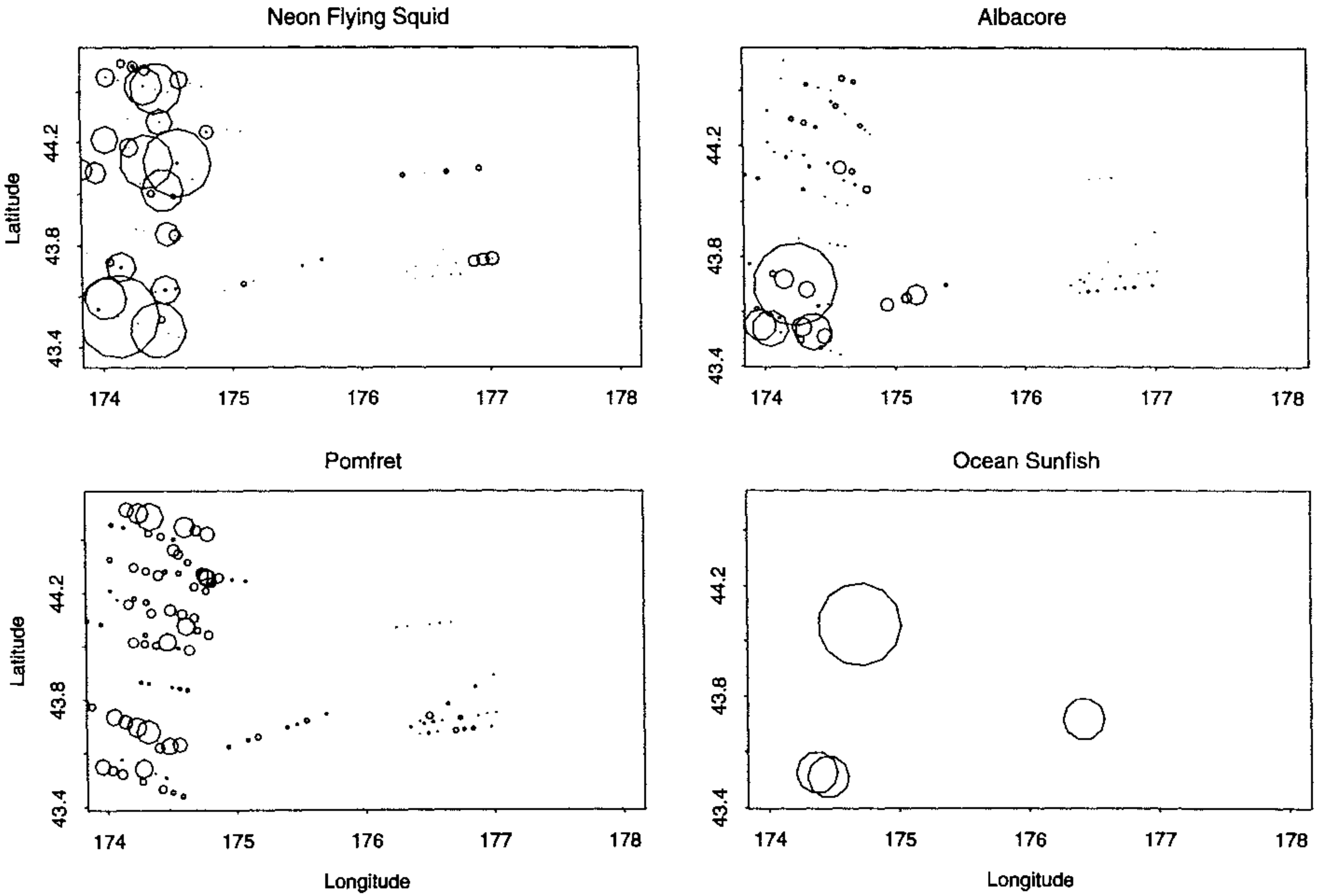

Fig. 8. Symbolic scatter plots of CPUE for neon flying squid (upper left), albacore (upper right), pomfret (lower left), and ocean sunfish (lower right) caught by driftnets in the survey area during the period August 3 to August 14, 1994. CPUE is proportion to circle size: maximum catch = 0.63 cm.