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**ABUNDANCE AND DISTRIBUTION PATTERNS OF
ZOOPLANKTON ALONG THE OREGON
AND SOUTHERN WASHINGTON COASTS
DURING THE SUMMER OF 1981**

RICHARD D. BRODEUR

FINAL REPORT

TO

NATIONAL COASTAL RESOURCES RESEARCH & DEVELOPMENT INSTITUTE
NEWPORT, OR

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Approved

R. P. Fournier

Director

TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	Iv
INTRODUCTION	1
MATERIALS AND METHODS	2
Sample Collections	2
Sample Processing.....	4
Statistical Analysis.....	4
RESULTS.....	5
Environmental Conditions	5
Taxonomic Composition.....	6
Zooplankton Abundance and Biomass by Cruise.....	11
Zooplankton Distributions	16
Diel Variations.....	16
Relation to Environmental Variables.....	16
DISCUSSION.....	22
APPENDICES.....	26

LIST OF FIGURES

Figure	Page
1. Location of study area and transects sampled during 1981	3
2. Environmental data collected during 1981	7
3. Means and \pm standard errors of the zooplankton volumes measured during the four cruises	8
4. Means and \pm standard errors of the abundance per 100 m ³ of water filtered for the dominant taxonomic categories collected during each cruise.....	12
5. Means and \pm standard errors of the abundance under 10 m ² of sea surface area for the dominant taxonomic categories collected during each cruise.....	13
6. Means and \pm standard errors of the wet weight per 100 m ³ of water filtered for the dominant taxonomic categories collected during each cruise.....	14
7. Means and standard errors of the wet weight under 10 m ² of sea surface area for the dominant taxonomic categories collected during each cruise.....	15
8. Total abundance of the sorted zooplankton for each cruise.....	17
9. Total biomass of the sorted zooplankton for each cruise.....	18
10. Total abundance of all euphausiid species for each cruise	19
11. Total biomass of all euphausiid species for each cruise.....	20
12. Diel variations in numbers and weight of the major zooplankton taxa collected during the diel series	21
 Appendix	
Figures	
1. Distribution of surface temperature, salinity and chlorophyll <i>a</i> in May based on 1981 sampling at each purse seine station.....	30
2. Distribution of surface temperature, salinity and chlorophyll <i>a</i> in June based on 1981 sampling at each purse seine station.....	31
3. Distribution of surface temperature, salinity and chlorophyll <i>a</i> in July based on 1981 sampling at each purse seine station.....	32
4. Distribution of surface temperature, salinity and chlorophyll <i>a</i> in August based on 1981 sampling at each purse seine station.....	33

LIST OF TABLES

Table	Page
1. Environmental and station data used in multiple regression analysis.....	5
2. Correlations between independent variables.....	5
3. Listing of taxa identified in plankton collections during each cruise and measure of importance during those cruises.....	9
4. Environmental and station correlates of abundances of major taxonomic categories	22
Appendix	
Table	
1. Station and environmental data for zooplankton collection in 1981.	27

INTRODUCTION

The coastal upwelling zone off the Oregon coast is a highly dynamic system in both space and time during the summer months (Huyer 1983). Following a strong upwelling event, hydrographic conditions may change substantially with vigorous mixing of the euphotic zone. The intensity and frequency of these events exerts a major influence on the abundance and distribution patterns of the plants and animals living in this zone (Peterson et al. 1979, Small and Menzies 1981). In contrast, the oceanic plume of the Columbia River, which forms the northern and western boundary of the Oregon upwelling zone in summer, exhibits a relatively stable vertical structure maintained by strong density gradients (Barnes et al. 1972). Although the geographic location of the plume changes seasonally, temperature and salinity conditions within the core of the plume change little through the summer months.

Although a number of studies have examined abundance and distribution patterns of zooplankton off Washington and Oregon, they generally emphasized the smaller mesozooplankton size-fractions, mainly copepods, commonly caught in small-mesh (<300 μm) plankton nets and pumps (Cross 1964, Peterson and Anderson 1966, Peterson 1972, Peterson and Miller 1976, Peterson et al. 1979, Landry and Lorenzen 1989). Those that examined the macrozooplankton taxa (e.g., euphausiids, decapod larvae, hyperiid amphipods, fish larvae) either sampled limited geographic areas (Smiles and Percy 1971, Alton and Blackburn 1972, Lorz and Percy 1975, Lough 1975, Percy 1976) or examined areas to the north (Day 1971, Mackas and Sefton 1982, Fulton and LeBrasseur 1984) or south (Lauris 1967) of the area considered in the present study (from 46°35' N to 43°11' N). The purpose of this report is to examine the abundance and distribution patterns of the major taxonomic categories of macrozooplankton collected during four cruises in the summer of 1981. I have operationally defined macrozooplankton to include those taxa that exceed 5 mm in their greatest dimension and which are caught in standard plankton nets. Principal taxa included in this category are juvenile and adult stages of Euphausiacea, Amphipoda, and Chaetognatha, adult stages of larger Copepoda, and larval and early juvenile stages of Mollusca, Decapoda, and Chordata. These larger zooplankton serve as the forage base for most of the intermediate-level carnivores in coastal waters (Peterson et al. 1982, Brodeur et al. 1987, Brodeur and Percy, in press). The seasonal occurrence and spatial distribution patterns of the dominant zooplankton were examined in relation to the physical dynamics of the upwelling and plume water masses.

MATERIALS AND METHODS

SAMPLE COLLECTIONS

Zooplankton were collected as part of the Early Marine Life History of Salmon cruises conducted by the School of Oceanography at Oregon State University. The purpose of these cruises was to assess the abundance and distribution patterns of juvenile salmonids (*Oncorhynchus* spp.) in coastal waters off Oregon and southern Washington and to examine these patterns in relation to physical and biological conditions. Ten-day cruises were made once a month during May, June, July, and August of 1981, during which the area extending from 36 km north of the Columbia River to 18 km south of Coos Bay, Oregon was sampled (Wakefield et al. 1981).

Quantitative purse seine sets ($n = 267$) were made at stations along parallel transects (Fig. 1) starting at the 37 m isobath and continuing at stations 7, 9, 18, 28, 37, and 46 km offshore. Summaries of the salmonid and nonsalmonid fish catches and the larger gelatinous zooplankton caught in seine hauls are given in Wakefield et al. (1981), Brodeur and Percy (1986), and Shenker (1984), respectively.

Zooplankton tows were routinely made at stations at 7, 9, 18 and 28 km following the purse seine sets, with additional tows made as time allotted. In order to examine diel differences in catches, one station (44°38' N, 124°18' W) was sampled six times over a 24-hr period. A 70-cm bongo frame, fitted with 0.333- and 0.571- μm mesh Nitex nets, was towed in a stepped-oblique fashion (5-m steps) from the surface to just above the bottom (or to a maximum depth of 150 m in deeper water). Tow durations ranged from 10-25 min (depending on depth) and were made at a vessel speed of 3 knots. An otter-kite depressor was used to maintain a 50-65° wire angle. The volume filtered in each net was estimated from calibrated TSK flowmeters located off-center in the mouth opening of each net. A time-depth recorder was used to determine the depth of each tow.

Following retrieval and thorough washing of the nets, the samples were examined at sea and any large debris, detritus or gelatinous zooplankton were noted and discarded after rinsing with freshwater to remove the smaller zooplankton. The remaining samples were preserved in a 10% buffered formalin-seawater solution for later analysis. Sea surface temperature, salinity and chlorophyll *a* concentration and were measured at each seine station. Laboratory methodology for the analyses of these samples is given in Wakefield et al. (1981). Results of these analyses are given in Appendix Table 1. Surface light intensity was measured from the deck of the research vessel before each tow with a Spectra Lumicon light meter.

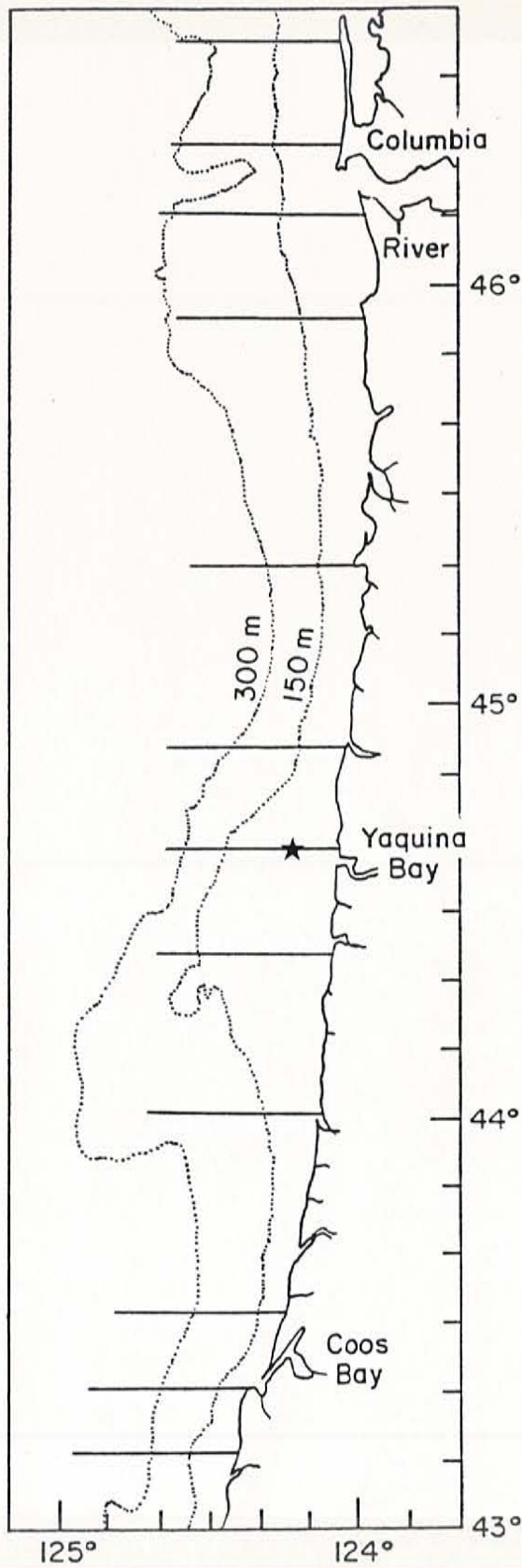


Figure 1. Location of study area and transects sampled during 1981. The star denotes the location of the diel series.

SAMPLE PROCESSING

Since the interest was only in the larger zooplankton present, only the coarser (0.571 μm) mesh samples were analyzed in the laboratory. Prior to sorting, settled volumes of zooplankton were measured as follows. All larger organisms and pieces of detritus not discarded at sea were rinsed and removed from the sample. The remaining sample was rinsed into a graduated cylinder and allowed to settle for 15 min. Settled volumes were measured to the nearest 1 ml. Samples exceeding 1000 ml were split with a Folsom Plankton Splitter until subsamples below this volume were achieved.

The total sample was sorted without the aid of magnification using glass trays illuminated from below. All organisms with a largest dimension of more than 5 mm were removed from the sample. Most gelatinous forms (ctenophores, cnidarians and siphonophores) were badly damaged and difficult to identify beyond phyla; thus, they were only noted. After all individuals >5 mm had been removed from the sample, the percent contribution of the major taxonomic groups of smaller zooplankton to the remaining fraction was visually estimated. This unsorted fraction was then returned to the graduated cylinder and allowed to settle for 15 min, after which its volume was measured.

The sorted fractions were separated into major taxonomic categories. All organisms in each category were counted, blotted with paper towels to remove excess water, and weighed to the nearest 0.01 g. The sorted samples were then stored in 50% isopropyl alcohol. Dominant species in terms of number or weight were identified. Displacement volumes, abundances, and biomass of all the taxa were first calculated per 100 m^3 of water volume filtered, assuming a net efficiency of 100%. Catches were also standardized for the different tow depths by converting to volume, number, or weight below 10 m^2 of sea surface area as described by Smith and Richardson (1977).

STATISTICAL ANALYSIS

The standardized abundances of the seven dominant taxonomic categories (Table 1) were transformed ($\sqrt{x + 0.5}$) as needed according to the results of a Kolmogorov-Smirnoff test of normality and used as dependent variables in a stepwise multiple regression analysis. These abundances were then related to station or environmental variables (water depth, distance from shore, surface temperature, surface salinity, surface chlorophyll *a* concentrations, and light intensity), which were also transformed as needed (Table 1). Both a forward inclusion and a backward elimination process was used so that the final model represented only those variables contributing significantly to the model. The use of multiple regression analysis was necessitated by the frequent correlations among the environmental variables (Table 2).

Table 1. Environmental and station data used in multiple regression analysis.

	Units	Abbreviation	Transformation
<u>Environmental and Station Variables</u>			
Distance offshore	km	DIST	log (x)
Bottom depth	m	DEPTH	log (x)
Surface temperature	°C	TEMP	n.t.
Surface salinity	‰	SALIN	n.t.
Surface chlorophyll <i>a</i>	µg/l	CHLOR	log (x+1)
Light intensity	lux	LIGHT	log (x+1)
<u>Taxonomic Categories</u>			
Fish larvae	no. 10 m ⁻²	FISH	$\sqrt{x+0.5}$
Euphausiids	no. 10 m ⁻²	EUPH	$\sqrt{x+0.5}$
Decapod larvae	no. 10 m ⁻²	DECA	$\sqrt{x+0.5}$
Amphipods	no. 10 m ⁻²	AMPH	$\sqrt{x+0.5}$
Chaetognaths	no. 10 m ⁻²	CHAET	$\sqrt{x+0.5}$
Copepods	no. 10 m ⁻²	COPE	$\sqrt{x+0.5}$
Pteropods	no. 10 m ⁻²	PTER	$\sqrt{x+0.5}$
Total zooplankton	g 10 m ⁻²	TOTZP	log (x+1)
Sorted zooplankton	g 10 m ⁻²	SORZP	log (x+1)

Table 2. Correlations between independent variables. Single starred values are significant at P <0.05 and doubled starred values are significant at P <0.005.

	DIST	DEPTH	TEMP	SALIN	CHLOR	LIGHT
DIST	--	0.76	0.12	-0.16	-0.14	-0.22
DEPTH	**	--	0.12	-0.02	-0.32	-0.06
TEMP	n.s.	n.s.	--	-0.40	0.00	0.08
SALIN	n.s.	n.s.	**	--	-0.26	0.10
CHLOR	n.s.	**	n.s.	*	--	0.08
LIGHT	*	n.s.	n.s.	n.s.	n.s.	--

RESULTS

ENVIRONMENTAL CONDITIONS

Upwelling conditions were highly variable among the cruise months examined. During May and June, upwelling was well below the 1948-67 long-term mean values for these months

(Fig. 2a). July showed strong upwelling conditions and was well above the long-term mean, whereas August was slightly below the long-term average.

The mean temperatures taken from all the seine collections sites followed the trend expected from the upwelling conditions. Seasonal warming caused a substantial elevation in June sea surface temperatures in the absence of strong upwelling (Fig. 2b). Temperatures dropped dramatically in July in response to the upwelling of cooler subsurface water. Relaxation of upwelling in August allowed surface temperature to increase slightly.

Mean surface salinities, however, did not show a pattern consistent with the upwelling (Fig. 2c). Mean salinity rose from May to August, which would be indicative of coastal upwelling. The May value was fairly low and was probably influenced by runoff of freshwater, mostly from the Columbia River, which tends to decrease as the summer progresses. The Columbia River Plume (indicated by surface salinities $<30\text{‰}$) is evident over much of the sampling area in the early summer months (App. Figs. 1 and 2).

Mean surface chlorophyll *a* values were low early in the summer but nearly doubled in July, most likely in response to the higher nutrient concentrations in the newly upwelled water (Fig. 2d). Mean chlorophyll values dropped the following month with the reduced upwelling intensity. Chlorophyll concentrations were highest inshore during May and June and were advected offshore later in the summer (App. Figs. 1 through 4).

PLANKTON VOLUMES

The mean volumes of zooplankton containing only the size fraction $>5\text{ mm}$ (in $\text{ml}/100\text{ m}^3$) were generally only one-half to one-third those of the total unsorted sample (Fig. 3a). The mean volumes of both the $>5\text{ mm}$ and total samples were higher in May than June, although these differences were not significant (paired *t*-test, $P > 0.05$). Total and $>5\text{mm}$ volumes from the July and August cruises were significantly higher than those from the June cruise. The data expressed as volumes under 10 m^2 sea surface area showed somewhat different results with July showing the highest $>5\text{mm}$ and total volumes and the other three cruises showing about the same overall volumes (Fig. 3b). The mean volume on the July cruise, however, was based on only 11 samples and these differences may be an artifact of this small sample size.

TAXONOMIC COMPOSITION

Although no effort was made to identify all taxa occurring in the samples to species, the occurrence of many of the dominant taxa was noted for each collection. Each taxa was classified as common (occurred in $>50\%$ of all samples), uncommon ($\leq 50\%$ but $>10\%$) or rare ($\leq 10\%$). Table 3 summarizes the relative occurrence of these taxa within each cruise. Only three species,

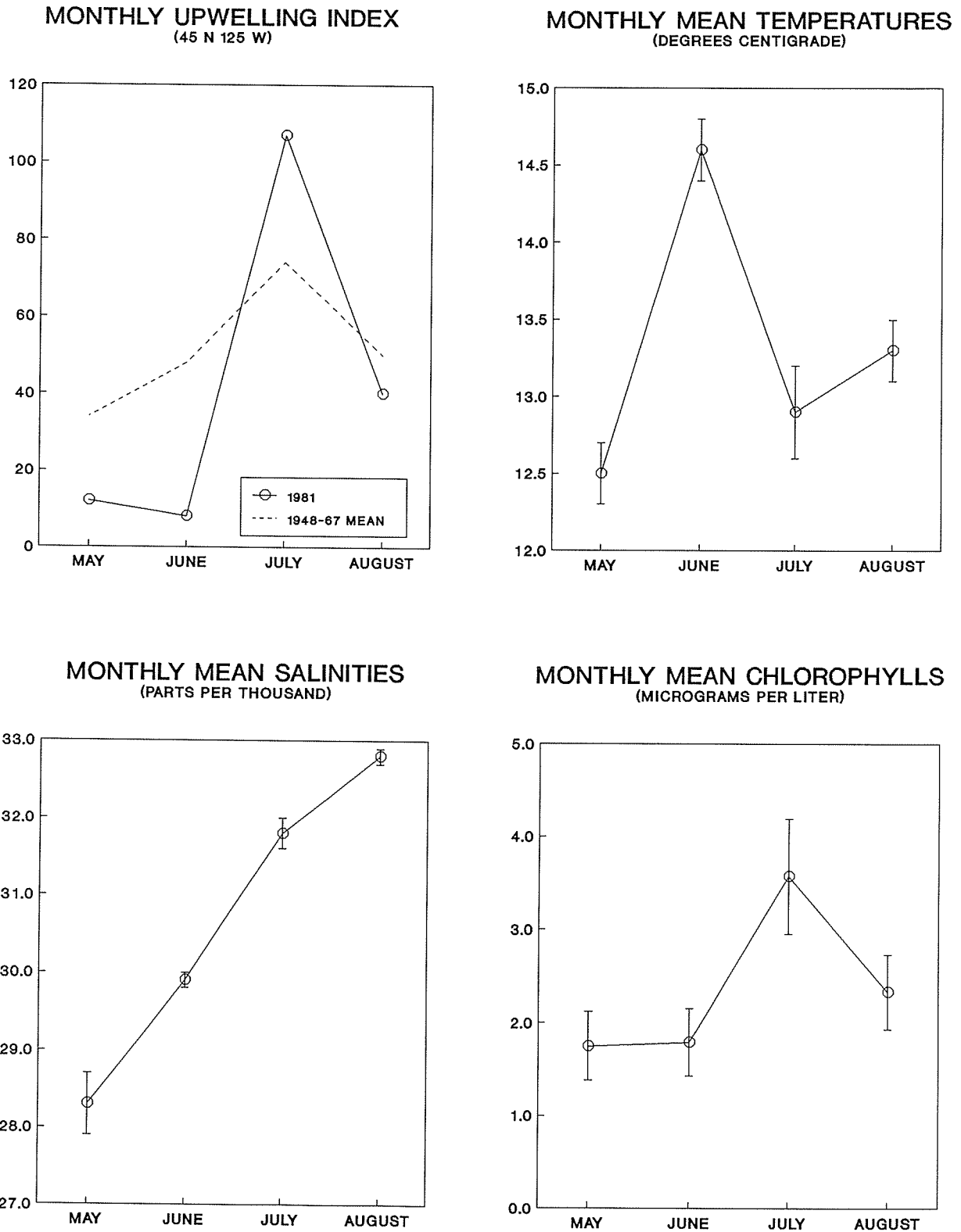
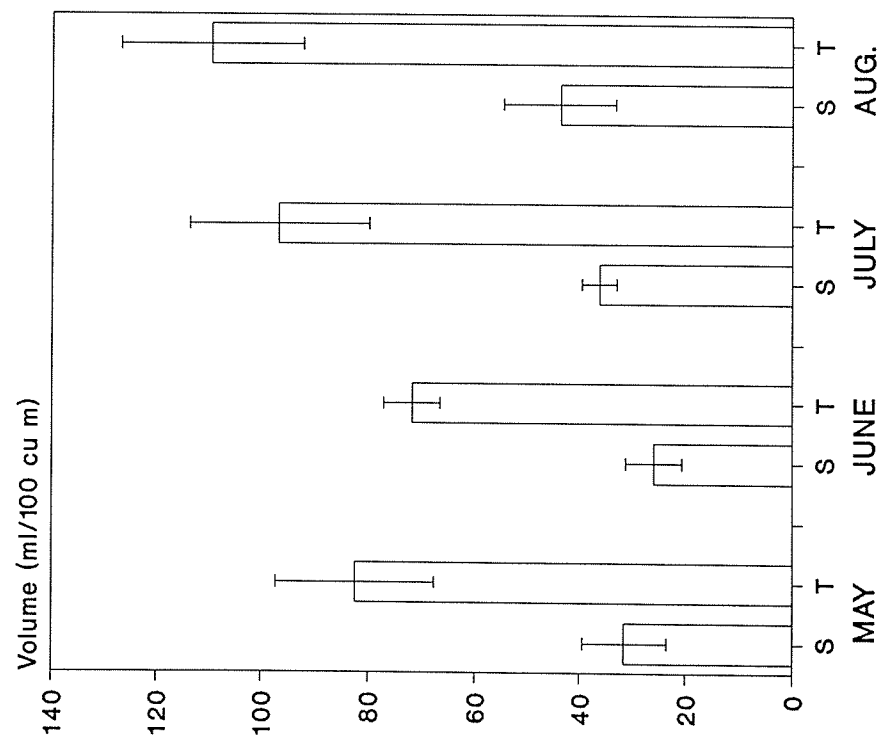


Figure 2. Environmental data collected during 1981: (a) Monthly Bakun upwelling indices for 1981 compared to the longterm (1948-67) mean values; (b-d) mean (circle) and standard errors of the mean (error bars) of the surface temperature, surface salinity, and surface chlorophyll *a* values for the 1981 purse seine collection sites.

MEAN ZOOPLANKTON VOLUMES 1981 CRUISES



MEAN ZOOPLANKTON VOLUMES 1981 CRUISES

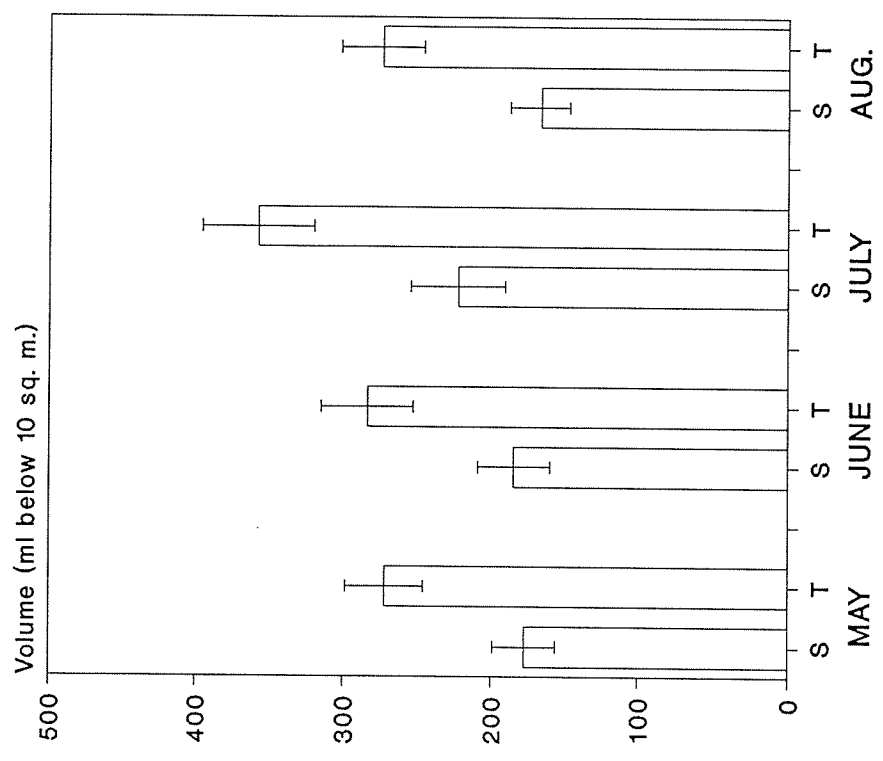


Figure 3. Means (bar) and \pm standard errors (vertical bars) of the zooplankton volumes measured during the four cruises. Data in left panel are for volumes per 100 m³ of water filtered and in right panel are for volumes under 10 m² sea surface area.

Table 3. Listing of taxa identified in plankton collections during each cruise and measure of importance during those cruises (C = common, U = uncommon, R = rare, - = not observed during this cruise). Number of collections per cruise are given in parentheses.

Taxa	May (28)	June (29)	July (11)	August (18)
POLYCHAETA				
<i>Tomopteris septentrionalis</i>	C	C	C	U
Unidentified	U	C	U	R
MOLLUSCA				
Gastropoda				
<i>Limacina helicina</i>	R	R	U	U
<i>Clione limacina</i>	C	C	U	R
Unidentified	C	C	-	R
Nudibranchia				
	R	-	-	-
Cephalopoda				
<i>Loligo opalescens</i>	U	C	U	U
COPEPODA				
<i>Neocalanus cristatus</i>	U	U	C	C
<i>Neocalanus plumchrus</i>	R	-	U	U
<i>Euchaeta elongata</i>	U	R	C	U
<i>Eucalanus bungii bungii</i>	R	R	U	U
<i>Calanus marshallae</i>	R	-	-	-
<i>Pleuromanna</i> sp.	-	-	-	R
Unidentified	C	C	-	-
CUMACEA				
<i>Diastylopsis dawsoni</i>	-	-	U	-
Unidentified	R	-	U	R
MYSIDACEA				
<i>Acanthomysis macropsis</i>	-	-	U	U
Unidentified	C	C	C	U
AMPHIPODA				
Gammaridea				
<i>Atylus tridens</i>	-	R	U	R
<i>Corophium</i> sp.	R	-	-	-
Ampeliscidae	-	-	U	R
Unidentified	U	U	U	-
Hyperidea				
<i>Hyperia medusarum</i>	R	U	-	U
<i>Hyperoche medusarum</i>	U	C	C	C
<i>Themisto pacifica</i>	C	C	C	C
<i>Primno macropa</i>	U	-	U	U

Table 3—cont.

Taxa	May (28)	June (29)	July (11)	August (18)
AMPHIPODA—cont.				
Hyperiidea—cont.				
<i>Paraphronima sedentaria</i>	R	U	U	R
<i>Oxycephalus clausi</i>	R	R	R	-
Unidentified	C	C	-	U
ISOPODA				
Unidentified	R	-	-	-
EUPHAUSIACEA				
<i>Euphausia pacifica</i>	U	C	C	C
<i>Thysanoessa inermis</i>	-	-	R	-
<i>Thysanoessa spinifera</i>	C	C	C	C
<i>Nematoscelis difficilis</i>	-	-	-	R
Unidentified	C	C	R	R
DECAPODA				
Hippolytidae zoea	R	R	R	R
<i>Pandalus</i> sp. zoea	R	-	-	-
<i>Crangon</i> spp. zoea	U	U	C	U
Natantia unidentified	C	C	C	C
<i>Cancer magister</i> megalopae	C	R	R	-
<i>Cancer antennarius</i> meg.	R	R	U	R
<i>Cancer oregonensis</i> meg.	C	C	C	C
<i>Cancer</i> sp. zoea	U	R	R	-
Pinnotheridae zoea	R	C	C	R
<i>Oregonia gracilis</i>	R	-	-	-
Porcellanidae megalopae	-	R	-	-
Unidentified Brachyura zoea	C	C	R	R
INSECTA				
Unidentified	R	R	-	R
CHAETOGNATHA				
<i>Eukrohnia hamata</i>	R	-	R	R
<i>Sagitta elegans</i>	C	C	C	C
Unidentified	C	C	C	C
OSTEICHTHYES				
<i>Clupea harengus pallasii</i>	-	R	-	-
<i>Engraulis mordax</i>	R	-	-	-

Table 3—cont.

Taxa	May (28)	June (29)	July (11)	August (18)
OSTEICHTHYES—cont.				
Osmeridae	R	-	C	-
<i>Microgadus proximus</i>	R	R	R	R
Myctophidae	-	R	-	-
<i>Sebastes</i> spp.	R	-	U	-
<i>Hexagrammos decagrammus</i>	-	-	R	-
<i>Ophiodon elongatus</i>	-	-	-	R
Agonidae	U	R	-	-
<i>Scorpaenichthys marmoratus</i>	-	-	R	-
Unid. Cottidae	U	U	R	-
Liparididae	-	R	-	-
<i>Ronquilus jordani</i>	R	-	-	-
<i>Ptilichthys goodei</i>	R	-	-	-
<i>Glyptocephalus zachirus</i>	R	R	-	-
<i>Isopsetta isolepis</i>	R	R	-	-
<i>Psettichthys melanostictus</i>	U	U	-	R
Unid. Pleuronectidae	C	C	R	-
Unidentified	C	C	R	R

Themisto pacifica (Hyperiididae), *Thysanoessa spinifera* (Euphausiacea), and *Sagitta elegans* (Chaetognatha), were common throughout the sampling period, although many other species were frequently caught during each cruise. Larval fishes were generally uncommon or rare during all cruises.

ZOOPLANKTON ABUNDANCE AND BIOMASS BY CRUISE

The abundances of the seven dominant taxonomic categories showed much between-station variability. Euphausiids and chaetognaths were the most numerous taxa for all cruises (Figs. 4 and 5). Decapod larvae were abundant in May and June but declined in late summer relative to euphausiids and chaetognaths. Fish abundance was low compared to the other taxa and declined through the summer. Pteropods were unimportant during July but increased substantially during August. Similar patterns were observed when the abundances were standardized under a 10-m² sea surface area with the exception of this pteropod peak (Fig. 5).

The total weight composition was dominated in all cruises by euphausiids and chaetognaths (Figs. 6 and 7). These groups showed higher mean biomasses in July and August relative to May and June. Fish, decapods, and pteropods contributed to a minor extent in early summer, but their contribution to the total biomass decreased by July and August.

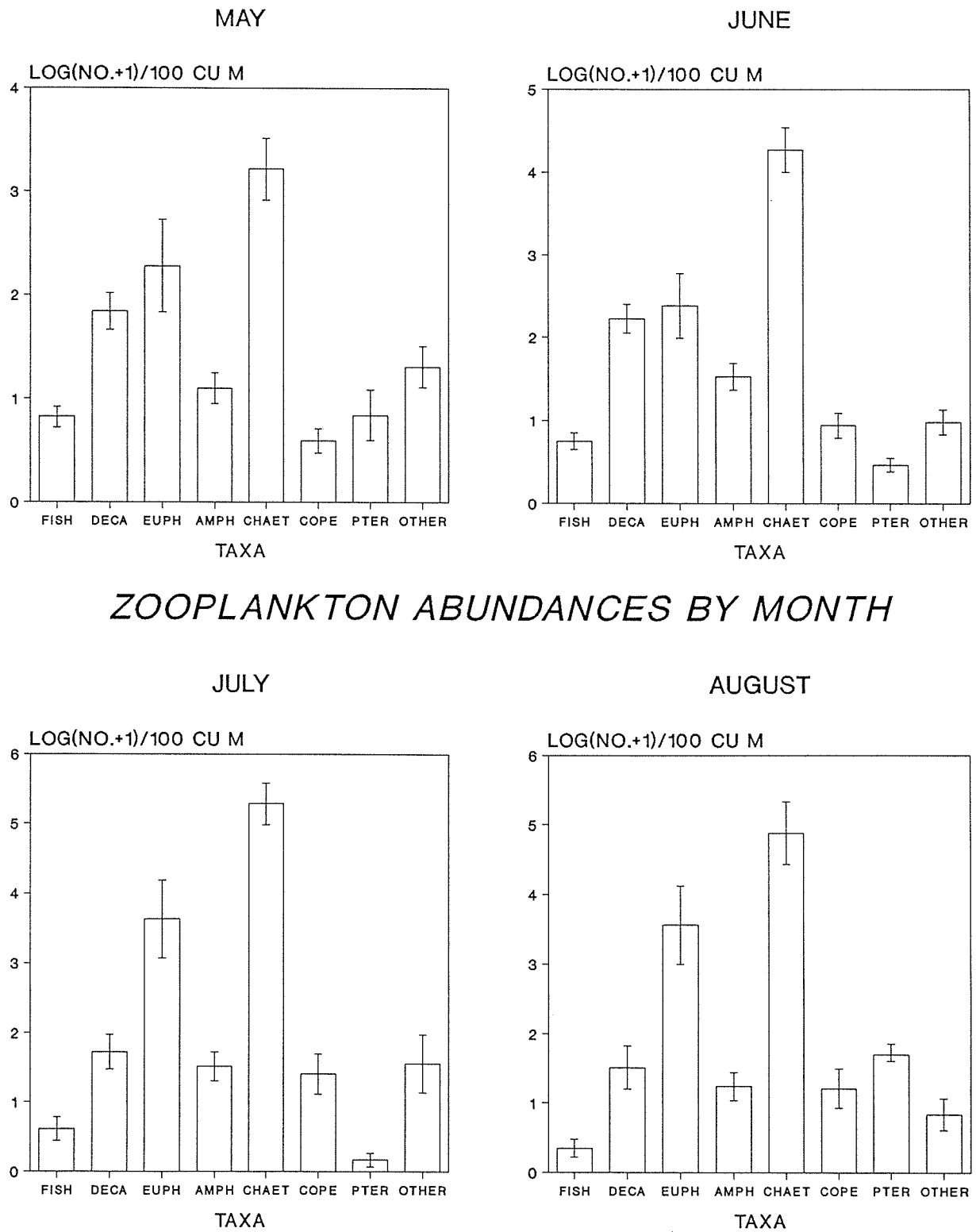


Figure 4. Means (bar) and \pm standard errors (vertical bars) of the abundance per 100 m³ of water filtered for the dominant taxonomic categories collected during each cruise.

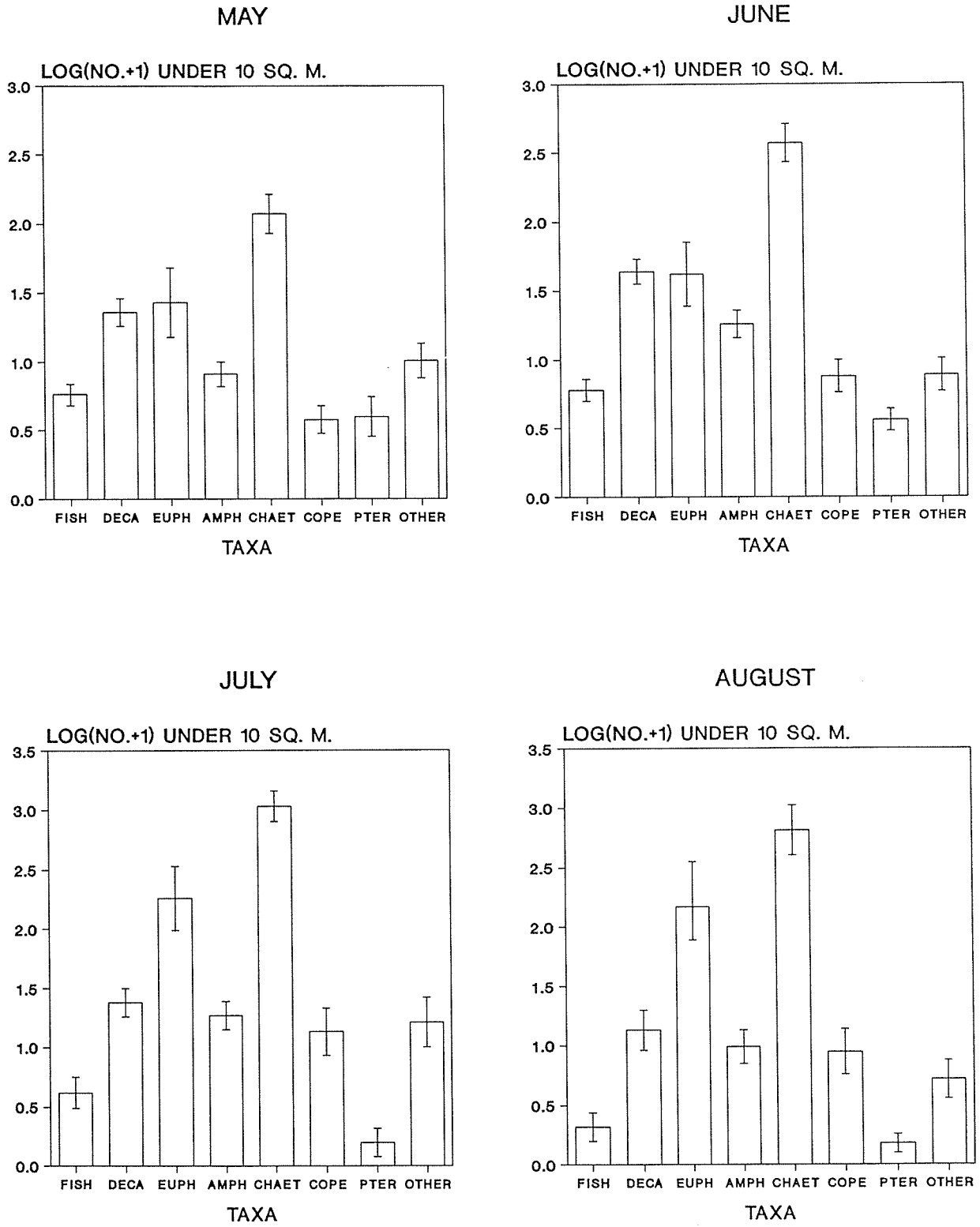
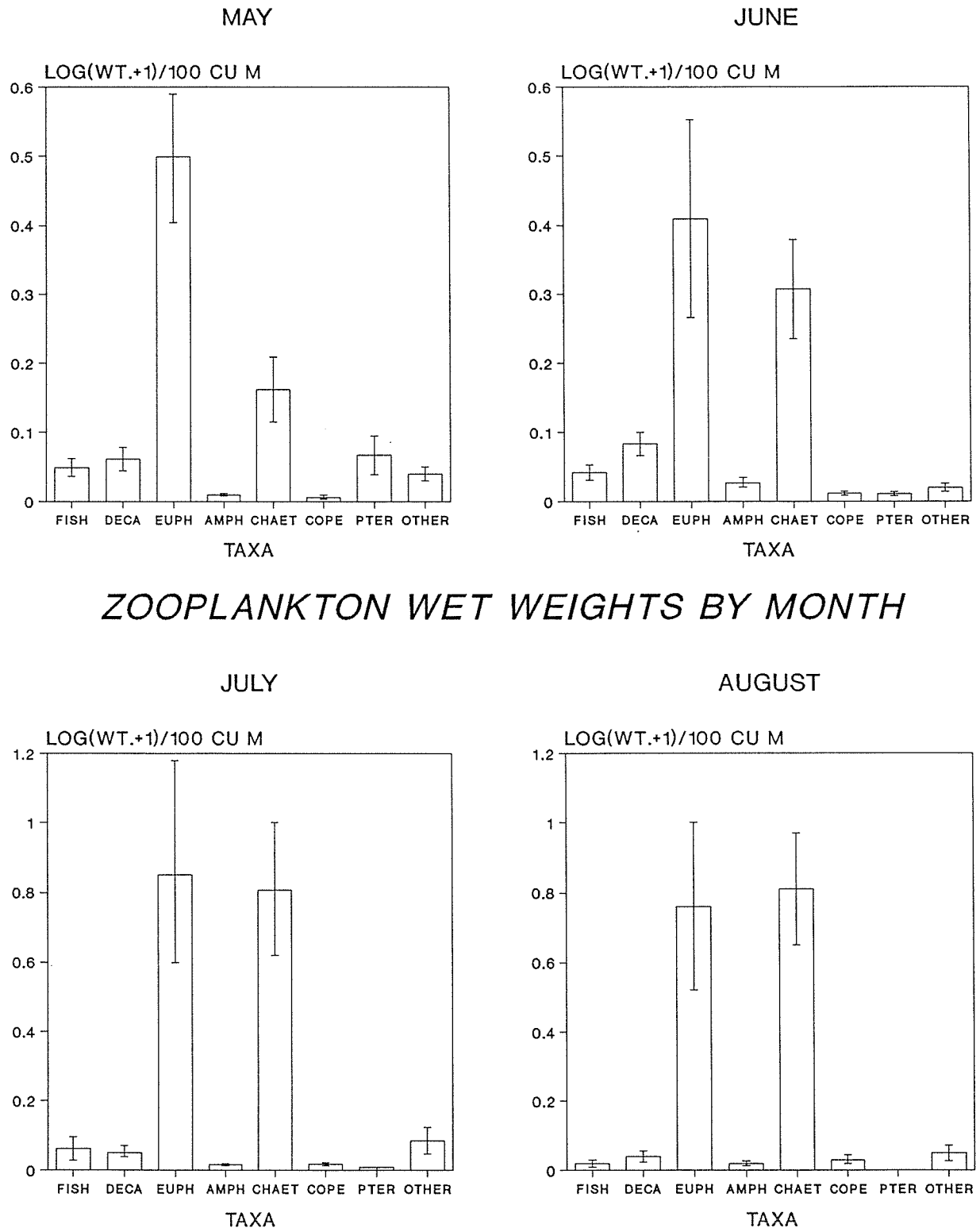


Figure 5. Means (bar) and \pm standard errors (vertical bars) of the abundance under 10 m² of sea surface area for the dominant taxonomic categories collected during each cruise.



ZOOPLANKTON WET WEIGHTS BY MONTH

Figure 6. Means (bar) and \pm standard errors (vertical bars) of the wet weight per 100 m³ of water filtered for the dominant taxonomic categories collected during each cruise.

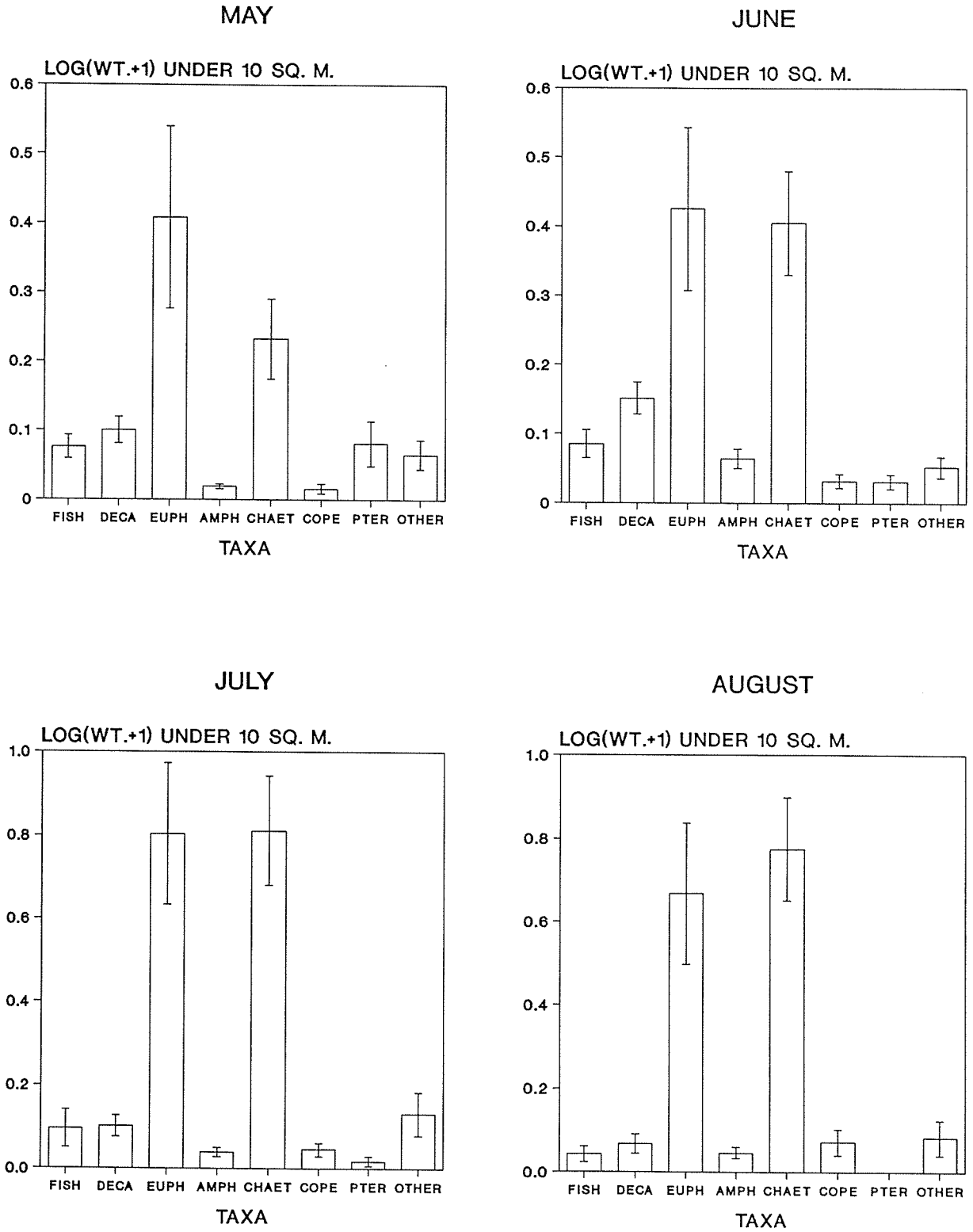


Figure 7. Means (bar) and \pm standard errors (vertical bars) of the wet weight under 10 m² of sea surface area for the dominant taxonomic categories collected during each cruise.

ZOOPLANKTON DISTRIBUTIONS

Total abundance and biomass distributions varied somewhat among the cruises although direct comparisons were difficult since the same stations were not sampled each time. Highest abundances in May and June tended to be found mid-shelf off the Columbia River and closer inshore off Yaquina Bay (Fig. 8). Abundances were more uniformly distributed during July and August. Biomass peaks occurred further offshore than the numerical abundance peaks (Fig. 9) but otherwise followed the same general patterns.

Euphausiid distributions were examined in detail since they contributed so substantially to the total abundance and biomass. Abundances were the highest in the vicinity of the Columbia River during all cruises and off southern Oregon in June and Yaquina Bay in August (Fig. 10). Euphausiids were absent from several inshore stations. Biomass generally peaked in mid-shelf regions and was low at most of the inshore stations (Fig. 11).

DIEL VARIATIONS

A diel series of tows (stations KG02-08 [see Appendix Table 1]) was made in the same general area off Yaquina Bay, Oregon (Fig. 1) to examine diel variability in zooplankton composition. Pteropods and chaetognaths were the most abundant of the major taxa during most collection periods and also showed the greatest variability (Fig. 12). Euphausiids were not abundant during all these collections despite their high abundances found in the sampling overall. Abundances of all taxonomic groups were generally higher during daylight hours than during the evening. The biomass patterns were dominated by high weights of pteropods collected during the late afternoon and early evening. Fish biomass was higher at night than during the day, suggesting that some of the larger fish were able to avoid the nets during daylight hours.

RELATION TO ENVIRONMENTAL VARIABLES

Although most of the taxonomic categories showed significant relationship with one or two environmental variables (Table 4), the overall relationships were weak (all coefficients of determinations <0.17). Euphausiids showed a positive association with depth (increase in abundance in deeper water) and a negative association with light. Decapod larvae showed the same association with light but were found closer to shore. Chaetognaths were positively associated with temperature and chlorophyll, which would indicate an association with Columbia Plume water. Copepods were positively related to both depth and temperature, suggesting that they are associated with offshore, warm water. Pteropods were negatively related to temperature, which may indicate an association with upwelled water. Finally, both the total and >5 mm zooplankton were positively related to distance from shore, suggesting that zooplankton volumes increased offshore.

TOTAL MACROZOOPLANKTON ABUNDANCE

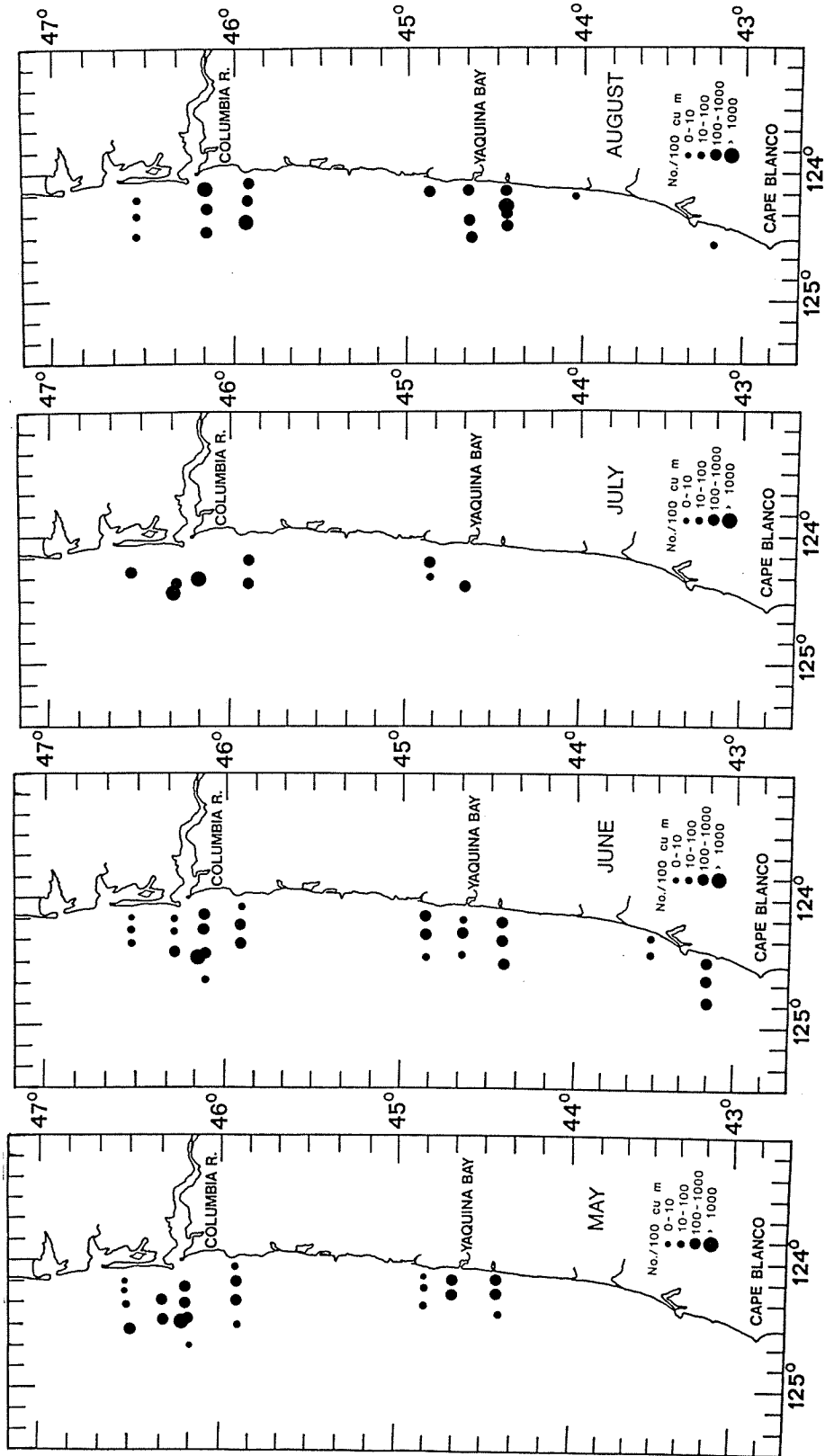


Figure 8. Total abundance (numbers per 100 m³) of the sorted zooplankton for each cruise.

TOTAL MACROZOOPLANKTON BIOMASS

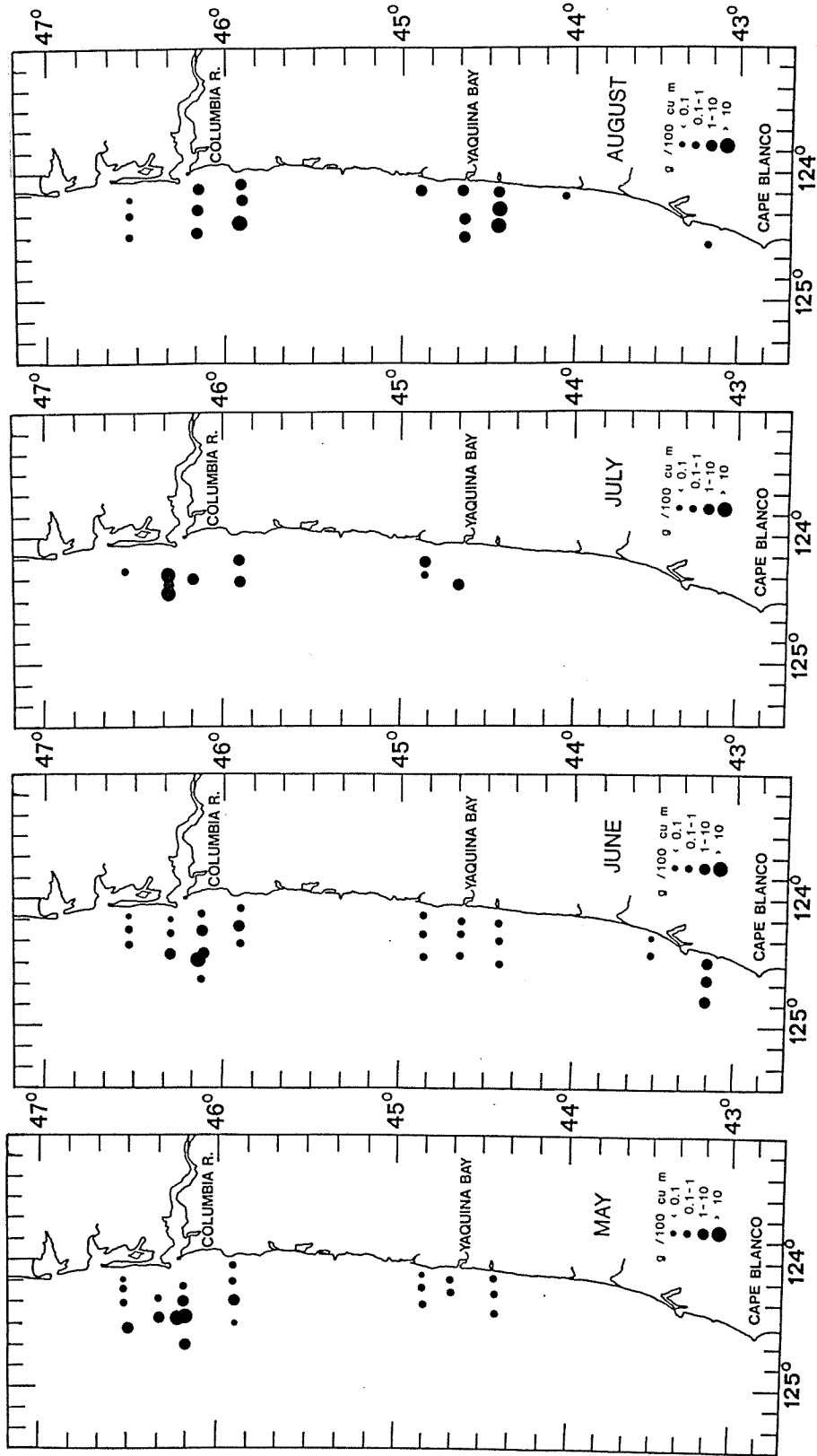


Figure 9. Total biomass (wet weight per 100 m³) of the sorted zooplankton for each cruise.

EUPHAUSIID ABUNDANCE

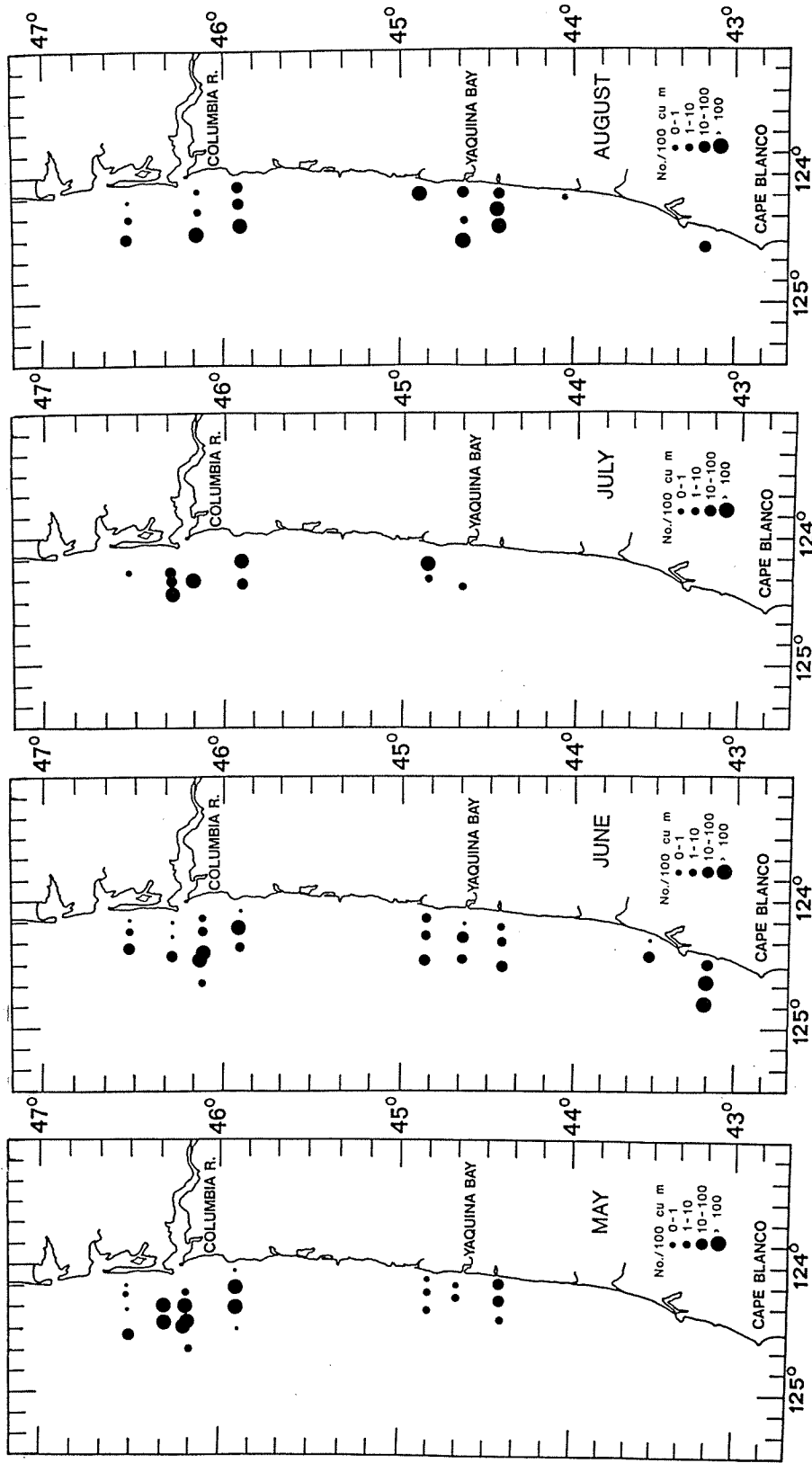


Figure 10. Total abundance (numbers per 100 m³) of all euphausiid species for each cruise. The smallest dots represent stations where no euphausiids were caught.

EUPHAUSIID BIOMASS

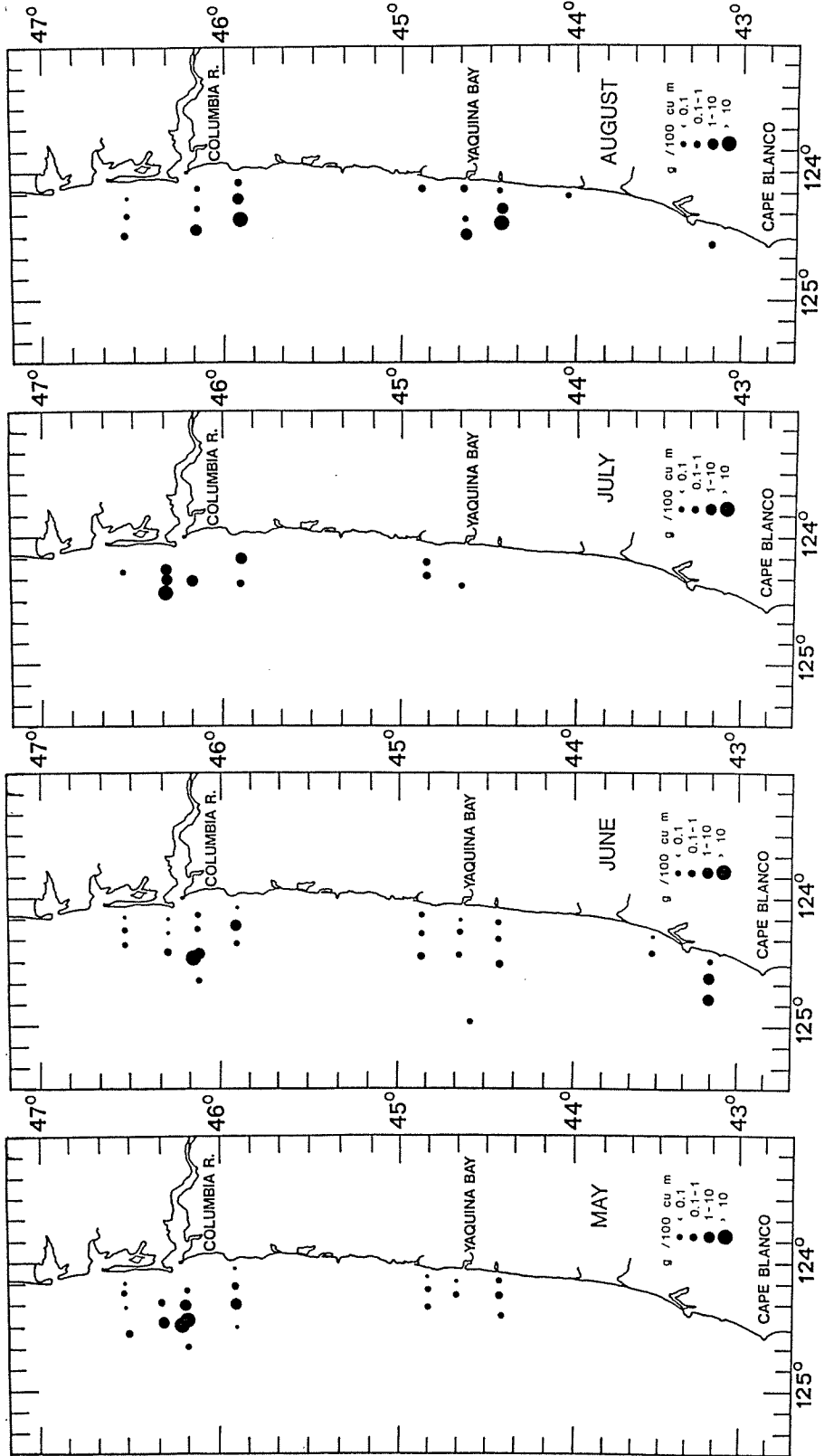


Figure 11. Total biomass (wet weight per 100 m³) of all euphausiid species for each cruise. The smallest dots represent stations where no euphausiids were caught.

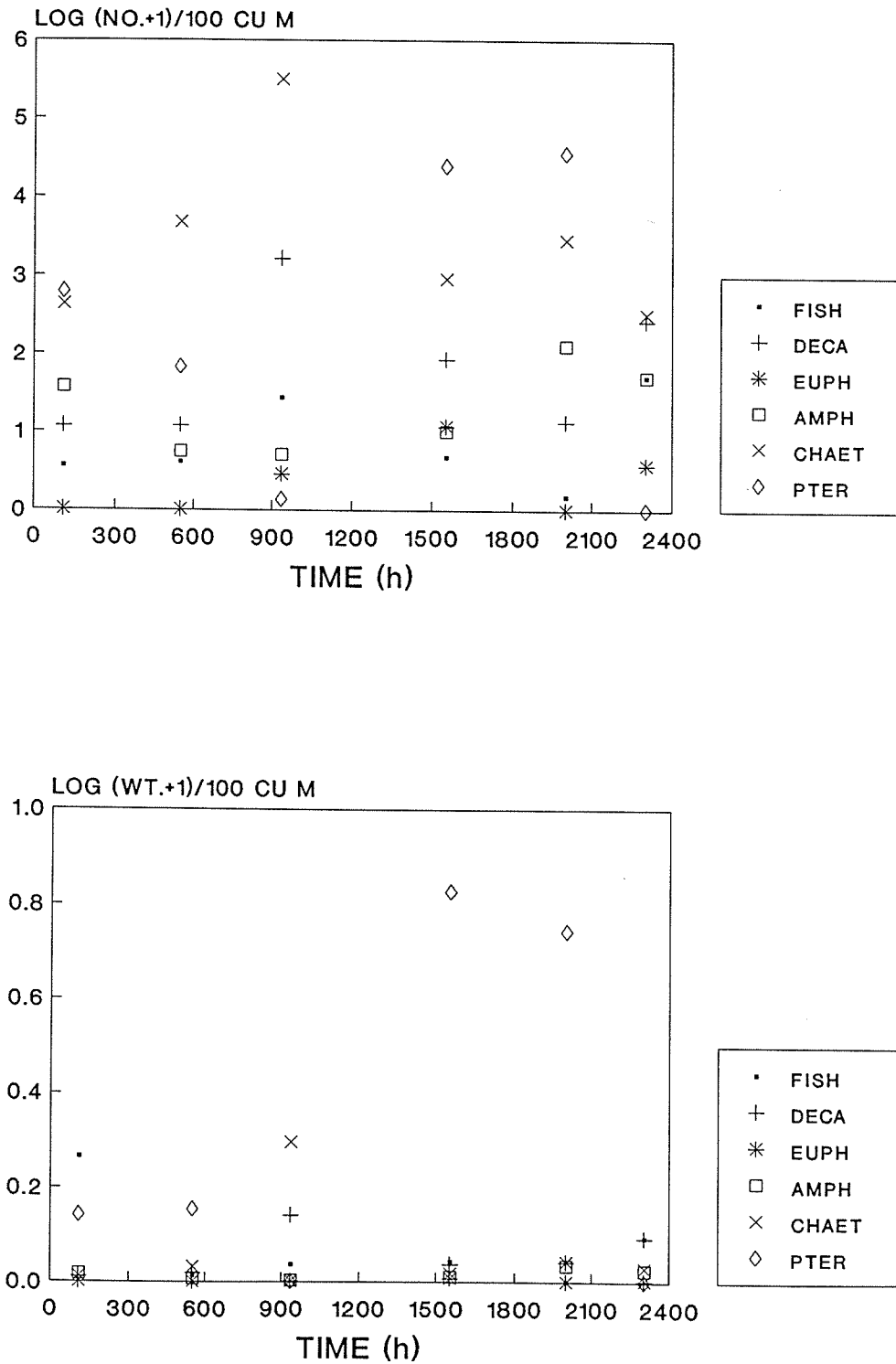


Figure 12. Diel variations in numbers (top) and weight (bottom) of the major zooplankton taxa collected during the diel series. Note that both abundances and weights are shown in log scale.

Table 4. Environmental and station correlates of abundances of major taxonomic categories (see Table 1 for abbreviations). Results are final multiple regression model including only the variables considered significant.

Dependent variable	R ²	Independent variables	Coefficient	Standard errors	Significance
EUPH	0.11	Constant	-11.91	12.37	0.34
		DEPTH	6.00	2.68	0.03
		LIGHT	-1.06	0.50	0.04
DECA	0.11	Constant	6.47	1.20	0.00
		DIST	-0.73	0.34	0.03
		LIGHT	-0.25	0.09	0.01
CHAET	0.13	Constant	-13.78	10.18	0.18
		TEMP	1.51	0.72	0.04
		CHLOR	3.75	1.29	0.01
COPE	0.17	Constant	-5.39	1.70	0.00
		DEPTH	0.60	0.27	0.02
		TEMP	0.31	0.10	0.00
PTER	0.06	Constant	5.34	1.81	0.00
		TEMP	-0.29	0.12	0.02
TOTZ	0.15	Constant	1.69	0.18	0.00
		DIST	0.24	0.06	0.01
SORZ	0.09	Constant	1.52	0.21	0.00
		DIST	0.22	0.07	0.01

DISCUSSION

The general increase in zooplankton biomass and abundance through the summer corresponded with and was probably related to the seasonal increase in chlorophyll concentration. May and June were below the long-term average upwelling intensity at 45°N whereas July was substantially above this average (Brodeur and Pearcy 1986). Chlorophyll concentrations observed during 1981 were below the levels observed during the strong upwelling year of 1982 but well above 1983 and slightly above 1984 for June, the only month for which comparable data exists from the study area (Brodeur and Pearcy 1986). It is not known how the zooplankton seasonal trends during 1981 compare with other years as similar macrozooplankton studies are not available for the study area. Using smaller mesh (0.24 µm) nets and 0.2-m diameter bongo nets, Peterson and Miller (1977)

found that abundances at inshore stations off Newport, Oregon peaked during different months of the year over a 4-year (1969-72) period.

The highest biomass of total macrozooplankton occurred farther offshore than the main concentration of chlorophyll but did not appear to be associated with the Columbia River plume of low salinity water. Distance offshore (or depth, which was highly [$r = 0.76$] correlated with this parameter) was a significant variable in most of the final regression equations. Using partial correlation analysis of scyphomedusae abundance and a similar suite of environmental variables, Shenker (1984) found distance from shore to be the only variable which explained species abundance patterns.

These higher offshore biomass concentrations of zooplankton were dominated by euphausiids, mainly *Euphausia pacifica*, which are known to concentrate at the shelf break and upper slope (Hebard 1966, Percy 1976, Fulton and Lebrasseur 1984, Simard and Mackas 1989), where they feed on phytoplankton and microzooplankton advected offshore. According to Landry and Lorenzen (1989), macrozooplankton grazing in the mid-shelf region exceeds the primary production rate, which could account, in part, for decreasing chlorophyll *a* concentrations with increasing distance offshore. Their estimates suggest that most of this grazing is done by copepods with only a small contribution by euphausiids, but these estimates may be biased toward the smaller size fractions based on the sampling gear they used (pumps).

Interestingly, chaetognaths were numerically dominant during all 4 months in these collections. The majority of the individuals collected were small juvenile *Sagitta elegans*, which may account for their lesser importance by weight relative to euphausiids. This species was the most abundant macrozooplankton represented in the samples. Mackas and Sefton (1982) also found *S. elegans* to be the dominant non-copepod species in their collections off Vancouver Island. It is possible that overall chaetognath abundance was higher during 1981 than normal, since they occurred frequently in stomach contents of predators that year but not in succeeding years (Brodeur et al. 1987, Brodeur and Percy, in press).

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LITERATURE CITED

- Alton, M.S. and C.J. Blackburn. 1972. Diel changes in the vertical distribution of the euphausiids, *Thysanoessa spinifera* Holmes and *Euphausia pacifica* Hansen, in coastal waters of Washington. Calif. Fish Game 58:179-190.
- Barnes, C.A., A.J. Duxbury, and B.A. Morse. 1972. Circulation and selected properties of the Columbia River effluent at sea. Pages 41-80 in A.T. Pruter and D.L. Alverson (eds.), The Columbia River Estuary and Adjacent Ocean Waters. Univ. of Wash. Press, Seattle.
- Brodeur, R.D. and W.G. Pearcy. In press. Trophic relations of juvenile Pacific salmon off the Oregon and Washington coast. Fish. Bull.
- Brodeur, R.D. and W.G. Pearcy. 1986. Distribution and relative abundance of pelagic non-salmonid nekton off Oregon and Washington, 1979-1984. NOAA Tech. Rep. NMFS No. 46. 85 p.
- Brodeur, R.D., H.V. Lorz, and W.G. Pearcy. 1987. Food habits and dietary variability of pelagic nekton off Oregon and Washington, 1979-1984. NOAA Tech. Rep. NMFS No. 57. 32 p.
- Cross, F.A. 1964. Seasonal and geographic distribution of pelagic copepods in Oregon coastal waters. M.S. Thesis, Oregon State University, Corvallis. 73 p.
- Day, D.S. 1971. Macrozooplankton and small nekton in the coastal waters off Vancouver Island (Canada) and Washington, spring and fall of 1963. U.S. Dep. Commer., Spec. Sci. Rep. Fish. 619. 94 p.
- Fulton, J. and R. LeBrasseur. 1984. Euphausiids of the continental shelf and slope of the Pacific coast of Canada. La Mer 22:268-276.
- Hebard, J.F. 1966. Distribution of Euphausiacea and Copepoda off Oregon in relation to oceanographic conditions. Ph.D. Thesis, Oregon State University, Corvallis.
- Huyer, A. 1983. Coastal upwelling in the California Current System. Prog. Oceanogr. 12:259-284.
- Landry, M.R. and C.J. Lorenzen. 1989. Abundance, distribution, and grazing impact of zooplankton on the Washington shelf. In M.R. Landry and B.M. Hickey (eds.), Coastal Oceanography of Washington and Oregon. Elsevier Science Publ., Amsterdam.
- Laurs, R.M. 1967. Coastal upwelling and the ecology of lower trophic levels. Ph.D. Thesis, Oregon State University, Corvallis.
- Lough, R.G. 1975. Dynamics of crab larvae (Anomura, Brachyura) off the central Oregon coast, 1969-1971. Ph.D. Thesis, Oregon State University, Corvallis.
- Lorz, H. and W.G. Pearcy. 1975. Distribution of hyperiid amphipods off the Oregon coast. J. Fish. Res. Bd. Can. 32:1442-1447.
- Mackas, D.L. and H.A. Sefton. 1982. Plankton species assemblages off southern Vancouver Island: Geographic pattern and temporal variability. J. Mar. Res. 40:1173-1200.
- Pearcy, W.G. 1976. Seasonal and inshore-offshore variations in the standing stocks of micronekton and macrozooplankton off Oregon. Fish Bull. U.S. 74:70-80.
- Peterson, W.K. 1972. Distribution of pelagic Copepoda off the coasts of Washington and Oregon during 1961 and 1962. Pages 313-343 in A.T. Pruter and D.L. Alverson (eds.), The Columbia River Estuary and Adjacent Ocean Waters. Univ. of Wash. Press, Seattle.
- Peterson, W.K. and G.C. Anderson. 1966. Net zooplankton data from the Northeast Pacific Ocean: Columbia River effluent area, 1961, 1962. Univ. of Wash. Tech. Rept. 160. 225 p.

- Peterson, W. and C. Miller. 1976. Zooplankton along the continental shelf off Newport, Oregon, 1969-1972: Distribution, abundance, seasonal cycle, and year-to-year variations. Oregon State Univ., Sea Grant Coll. Prog. Publ. ORESU-T-76-002, Corvallis, OR, 111 p.
- Peterson, W.T. and C.B. Miller. 1977. Seasonal cycle of zooplankton abundance and species composition along the central Oregon coast. Fish Bull. U.S. 75:717-724.
- Peterson, W.T., R.D. Brodeur, and W.G. Pearcy. 1982. Food habits of juvenile salmon in the Oregon coastal zone, June 1979. Fish. Bull. U.S. 80:841-851.
- Peterson, W.T., C.B. Miller, and A. Hutchinson. 1979. Zonation and maintenance of copepod populations in the Oregon upwelling zone. Deep-Sea Res. 26:467-494.
- Shenker, J.M. 1984. Schyphomedusae in surface waters near the Oregon Coast, May-August 1981. Est. Coast. Shelf Sci. 19:619-632.
- Simard, Y. and D.L. Mackas. 1989. Mesoscale aggregations of euphausiid sound scattering layers on the continental shelf of Vancouver Island. Can. J.Fish. Aquat. Sci. 46:1238-1249.
- Small, L.F. and D.W. Menzies. 1981. Patterns of primary productivity and biomass in a coastal upwelling region. Deep-Sea Res. 28:123-149.
- Smiles, M.C. Jr. and W.G. Pearcy. 1971. Size structure and growth rate of *Euphausia pacifica* off the Oregon coast. Fish. Bull. 69:79-86.
- Smith, P.E. and S.L. Richardson. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fish. Tech. Paper 175, 100 p.
- Wakefield, W.W., J.P. Fisher, and W.G. Pearcy. 1981. Studies of juvenile salmonids off the Oregon and Washington coast, 1981. Oregon State Univ., Sea Grant Coll. Prog. Ref. 81-13, 51 p.

APPENDICES

Appendix Table 1. Station and environmental data for zooplankton collection in 1981.

May Cruise

Tow	Date	Latitude (N)	Longitude (W)	Dist. (km)	Depth (m)	Start Time	Temp. (°C)	Sal. (o/oo)	Chlor. (ug/l)
KG02	16 May	44 38.4	124 17.9	18.3	77	0935	12.6	26.9	1.1
KG03	16 May	44 38.3	124 24.9	28.3	67	1553	12.8	27.2	0.6
KG04	16 May	44 38.1	124 17.6	18.7	77	2000	12.4	27.5	2.3
KG05	16 May	44 38.1	124 17.7	18.9	77	2304	12.9	26.3	-----
KG06	16 May	44 37.0	124 18.1	18.5	79	0108	12.6	26.1	-----
KG07	17 May	44 38.5	124 18.0	19.1	77	0550	12.2	27.3	-----
KG08	17 May	44 38.3	124 17.8	18.9	75	0807	12.3	-----	0.6
KG09	18 May	44 25.1	124 10.8	8.0	49	1403	13.0	27.6	1.0
KG10	18 May	44 25.0	124 19.0	18.5	68	1932	12.1	29.7	5.9
KG11	18 May	44 25.1	124 26.0	28.0	79	2156	12.7	-----	0.7
KG12	19 May	44 51.0	124 08.0	7.0	60	0949	12.7	27.4	0.8
KG13	19 May	44 51.5	124 12.5	13.0	99	1151	13.2	28.8	0.3
KG14	19 May	44 50.8	124 20.2	22.8	135	1806	13.4	28.5	0.2
KG15	20 May	45 54.9	124 04.0	7.4	66	0841	13.5	25.6	1.9
KG16	20 May	45 55.0	124 08.4	13.3	81	1014	13.3	17.0	1.8
KG17	20 May	45 55.1	124 12.5	18.5	105	1238	13.2	26.2	2.1
KG18	20 May	45 55.1	124 12.5	18.5	104	1413	13.2	26.2	2.1
KG19	20 May	45 55.0	124 27.0	37.2	146	1833	13.4	27.6	1.4
KG20	21 May	46 10.0	124 28.0	38.3	130	0701	12.1	29.7	1.2
KG21	21 May	46 09.7	124 34.3	46.6	155	0945	12.4	29.2	0.1
KG22	21 May	46 10.0	124 20.1	28.1	110	1529	13.4	22.9	3.0
KG23	21 May	46 10.0	124 08.3	12.8	49	1827	13.2	24.3	1.6
KG24	22 May	46 20.0	124 25.4	27.8	130	1913	12.9	29.3	1.0
KG25	22 May	46 19.8	124 32.6	37.0	136	2201	13.0	30.8	0.1
KG26	23 May	46 35.0	124 25.6	28.0	91	1026	12.9	29.5	0.9
KG27	23 May	46 35.0	124 18.0	18.1	64	1245	12.8	24.9	3.4
KG28	23 May	46 35.1	124 13.5	12.6	45	1431	13.9	22.0	3.3
KG29	23 May	46 35.0	124 11.1	9.6	37	1642	14.2	22.6	-----
KG30	25 May	46 09.0	124 20.1	28.0	110	0221	13.7	23.4	1.5

Appendix Table 1—cont.

June Cruise

Tow	Date	Latitude (N)	Longitude (W)	Dist. (km)	Depth (m)	Start Time	Temp. (°C)	Sal. (o/oo)	Chlor. (ug/l)
KG31	9 June	46 35.0	124 11.4	9.6	39	1210	13.8	26.9	5.3
KG32	9 June	46 35.0	124 18.2	18.3	66	1645	13.2	----	1.0
KG33	9 June	46 35.0	124 25.4	27.8	95	1923	13.7	31.1	0.4
KG34	10 June	46 20.0	124 25.0	28.1	126	0937	14.2	24.9	2.0
KG35	10 June	46 20.1	124 18.3	18.5	80	1225	14.8	20.1	3.2
KG36	10 June	46 20.0	124 12.0	10.6	35	1616	15.2	14.7	4.1
KG37	10 June	46 10.0	124 07.1	9.3	37	1913	15.1	23.2	1.4
KG38	10 June	46 10.0	124 12.8	18.5	73	2300	15.0	26.7	0.6
KG39	11 June	46 09.9	124 20.3	28.1	115	0820	14.8	25.2	0.3
KG40	11 June	46 09.8	124 34.2	46.3	154	1252	14.3	29.6	0.8
KG41	11 June	46 10.0	124 19.2	26.8	104	1835	15.3	25.7	0.3
KG42	11 June	46 10.6	124 20.0	27.4	60	0034	15.1	25.5	0.3
KG43	12 June	45 55.0	124 20.0	28.5	135	1301	15.0	24.9	0.7
KG44	12 June	45 55.0	124 12.5	18.9	103	1513	15.2	25.5	0.5
KG45	12 June	45 55.0	124 03.8	7.2	66	1922	15.2	27.4	0.5
KG46	13 June	44 51.4	124 08.1	7.0	62	1531	14.8	29.5	0.2
KG47	13 June	44 51.5	124 16.7	18.5	122	1948	14.8	29.5	0.4
KG48	13 June	44 51.5	124 23.8	27.8	152	2231	14.7	29.7	0.3
KG49	14 June	44 39.9	124 24.4	27.8	90	1114	14.9	29.2	0.2
KG50	14 June	44 38.4	124 17.5	17.9	75	1314	15.7	28.4	0.4
KG51	14 June	44 38.4	124 13.4	13.0	64	1647	15.4	28.7	0.3
KG52	15 June	44 25.0	124 10.6	8.1	48	1000	14.6	29.9	1.0
KG53	15 June	44 25.0	124 18.9	18.5	68	1333	15.9	29.2	----
KG54	15 June	44 24.9	124 26.0	27.8	77	1531	15.9	29.4	1.1
KG55	16 June	43 11.3	124 44.5	27.8	247	0840	15.4	30.0	0.1
KG56	16 June	43 11.3	124 37.5	18.5	123	1122	14.8	30.2	0.2
KG57	16 June	43 11.4	124 29.6	6.9	60	1558	12.8	31.4	6.0
KG58	17 June	43 31.7	124 15.8	1.8	22	1137	13.3	30.7	3.8
KG59	17 June	43 31.5	124 24.5	13.3	110	1348	13.4	31.0	1.0

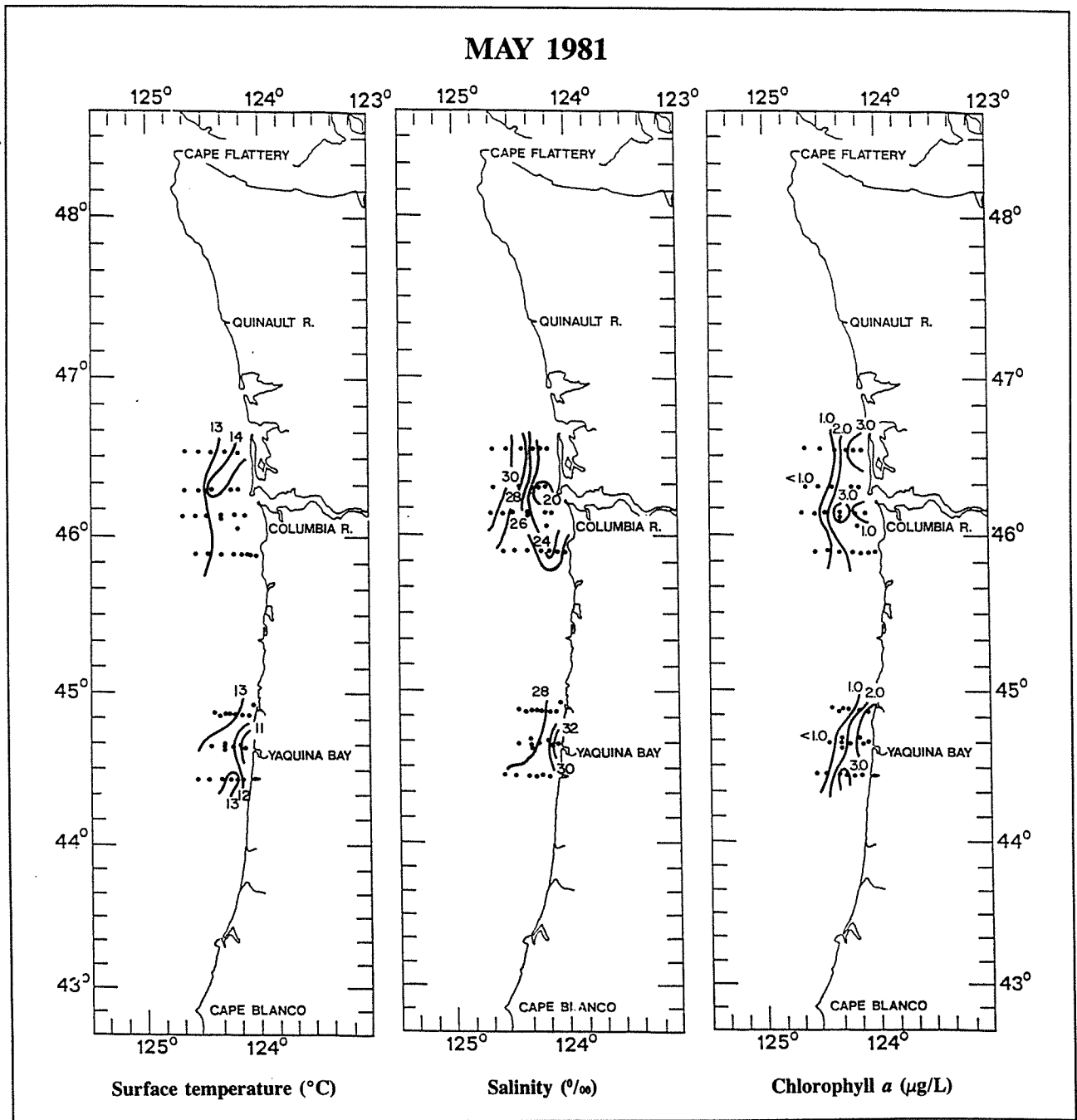
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July Cruise

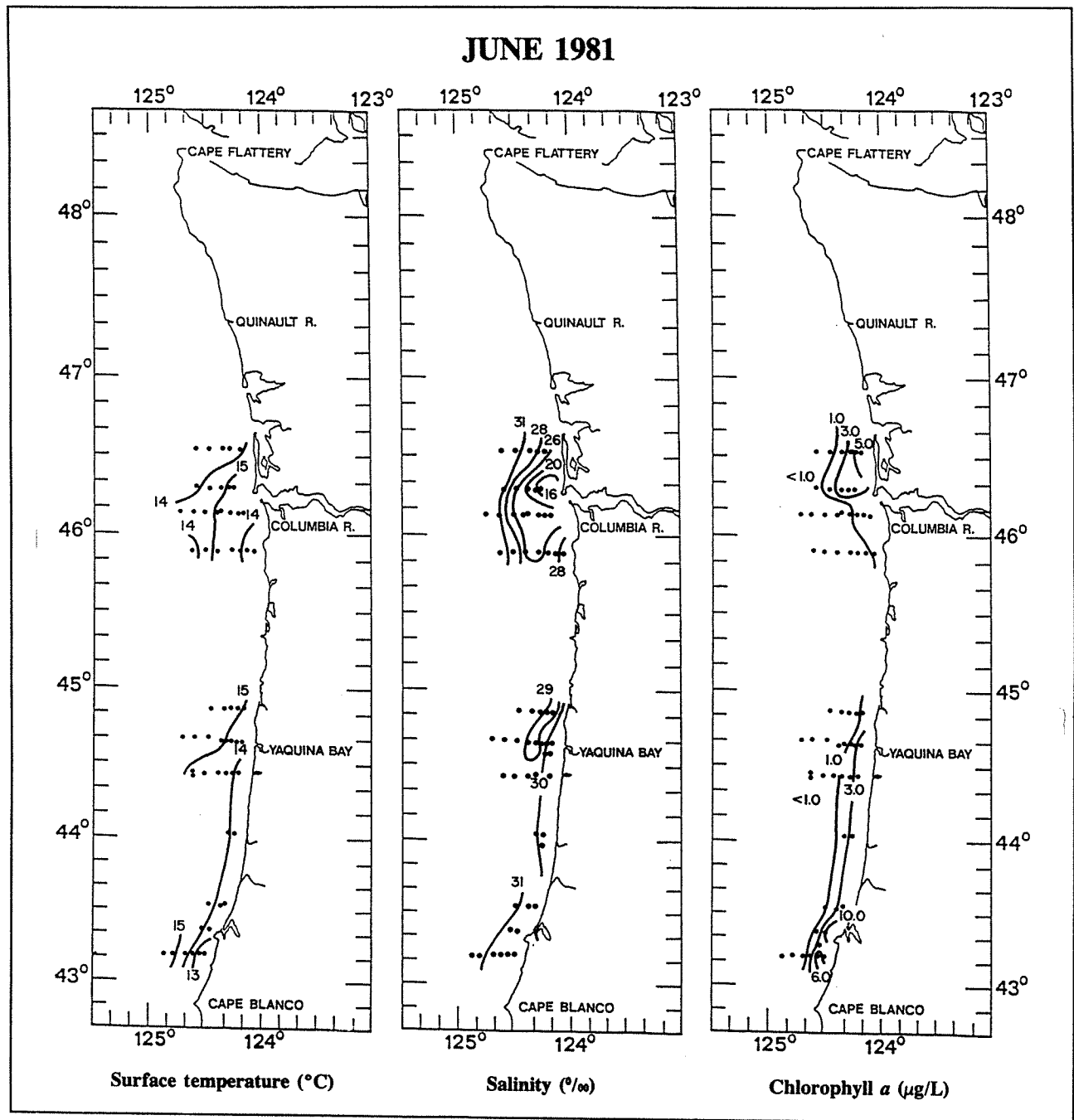
Tow	Date	Latitude (N)	Longitude (W)	Dist. (km)	Depth (m)	Start Time	Temp. (°C)	Sal. (o/oo)	Chlor. (ug/l)
SF01	9 July	46 35.0	124 19.8	19.4	68	1530	14.7	31.4	0.7
SF02	11 July	46 09.8	124 12.4	18.3	73	1657	14.6	26.3	5.5
SF03	12 July	46 20.7	124 25.7	28.3	117	1006	15.4	13.3	4.0
SF04	12 July	46 20.4	124 18.2	18.5	75	1124	16.2	14.6	3.0
SF05	12 July	46 20.1	124 18.4	18.5	81	2310	15.0	17.1	-----
SF06	13 July	46 19.9	124 18.5	18.7	81	0430	15.1	17.6	-----
SF07	14 July	45 55.3	124 12.5	18.1	104	0701	14.9	23.3	5.0
SF08	14 July	45 55.0	124 20.2	28.5	137	0823	15.8	17.4	2.9
SF09	17 July	44 38.3	124 18.0	18.9	77	1020	11.6	32.3	7.5
SF11	18 July	44 51.2	124 16.3	18.0	126	1048	15.1	31.0	0.5
SF12	18 July	44 51.2	124 12.8	13.3	104	1140	14.4	30.9	1.0

August Cruise

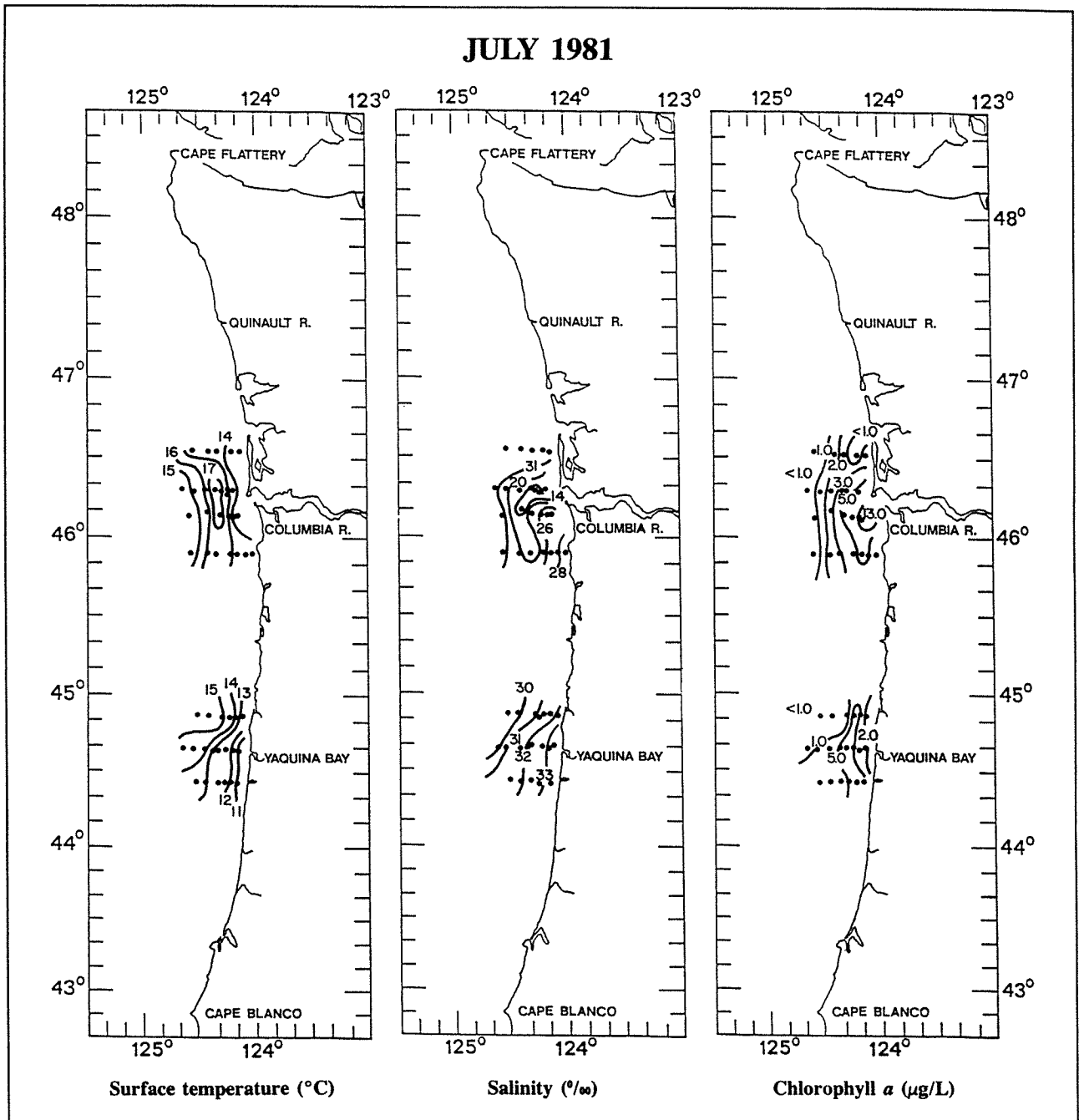
Tow	Date	Latitude (N)	Longitude (W)	Dist. (km)	Depth (m)	Start Time	Temp. (°C)	Sal. (o/oo)	Chlor. (ug/l)
SF13	11 Aug	46 35.3	124 25.5	27.9	97	1320	15.0	32.7	1.4
SF14	11 Aug	46 35.0	124 18.5	18.9	64	1550	14.1	32.7	7.7
SF15	11 Aug	46 35.1	124 11.1	9.4	37	1820	13.4	32.7	6.5
SF16	12 Aug	46 09.5	124 19.3	27.4	108	1257	15.6	22.2	10.0
SF17	12 Aug	46 09.9	124 12.5	18.1	73	1610	16.5	22.2	13.1
SF18	12 Aug	46 09.5	124 06.4	10.7	37	1935	14.7	24.8	7.4
SF19	13 Aug	45 55.2	124 19.7	27.2	135	1114	15.4	25.1	8.0
SF20	13 Aug	45 55.3	124 12.8	18.7	104	1434	14.5	31.0	2.7
SF21	13 Aug	45 55.0	124 04.2	7.8	70	1922	14.6	32.1	1.3
SF22	15 Aug	44 38.2	124 07.3	4.6	46	1305	13.3	33.1	1.0
SF23	15 Aug	44 38.4	124 18.2	19.2	81	1538	12.5	33.0	10.1
SF24	15 Aug	44 38.2	124 24.7	27.6	66	1741	13.9	32.3	3.3
SF25	16 Aug	44 51.6	124 08.8	8.0	64	1610	12.9	33.0	1.9
SF26	17 Aug	44 25.0	124 19.6	19.1	70	1425	13.2	32.6	2.8
SF27	17 Aug	44 25.1	124 14.7	13.0	66	1602	13.3	33.4	0.7
SF28	17 Aug	44 25.2	124 10.3	7.2	49	1735	13.1	33.4	2.1
SF29	18 Aug	43 11.6	124 33.0	12.4	81	1202	13.3	32.8	1.8
SF30	19 Aug	44 01.0	124 10.2	2.6	39	1206	13.1	32.8	1.0



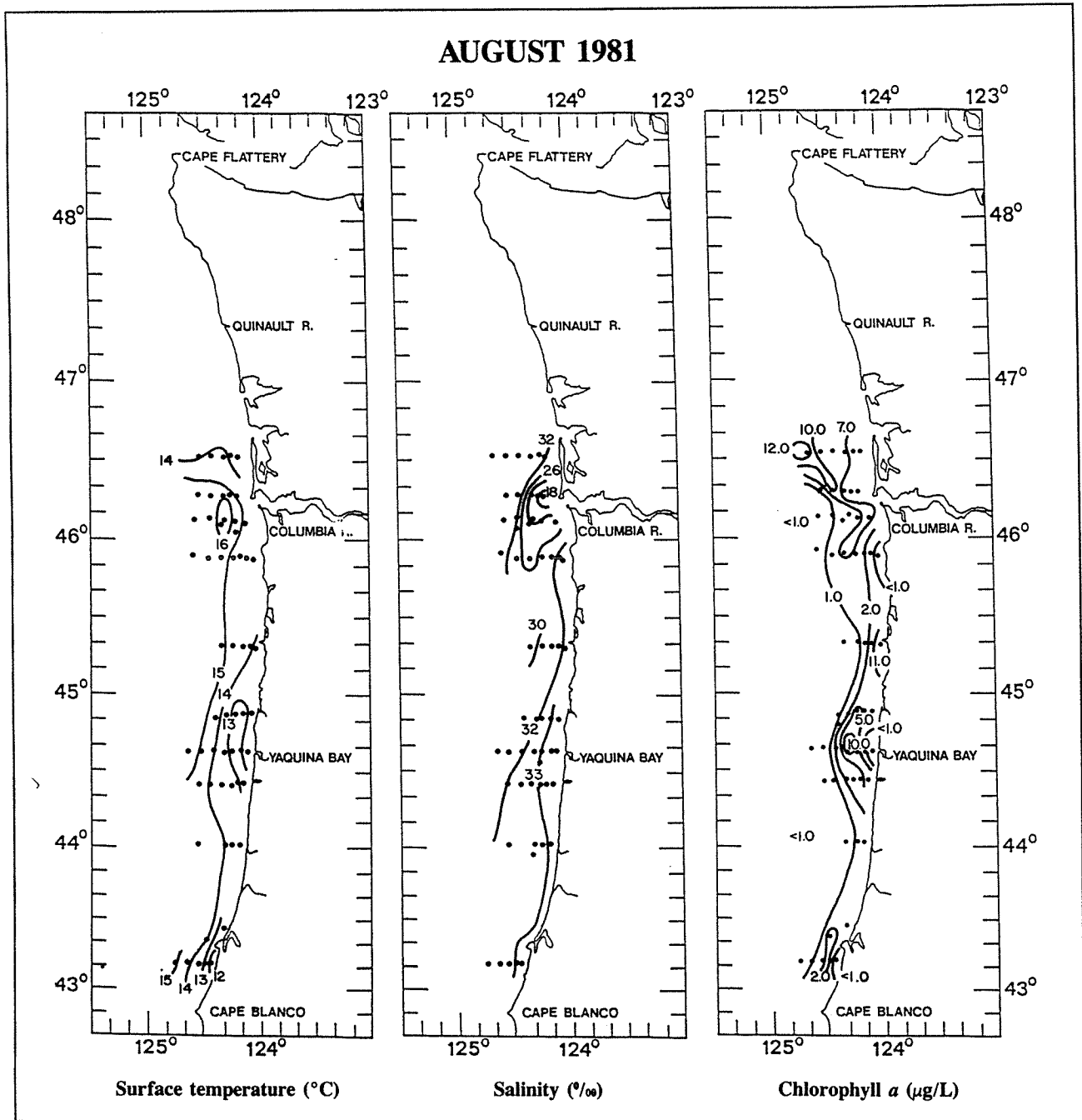
Appendix Figure 1. Distribution of surface temperature, salinity and chlorophyll *a* in May based on 1981 sampling at each purse seine station (taken from Brodeur and Percy 1986).



Appendix Figure 2. Distribution of surface temperature, salinity and chlorophyll *a* in June based on 1981 sampling at each purse seine station (taken from Brodeur and Pearcy 1986).



Appendix Figure 3. Distribution of surface temperature, salinity and chlorophyll *a* in July based on 1981 sampling at each purse seine station (taken from Brodeur and Pearcy 1986).



Appendix Figure 4. Distribution of surface temperature, salinity and chlorophyll *a* in August based on 1981 sampling at each purse seine station (taken from Brodeur and Percy 1986).