YEAR-TO-YEAR VARIATIONS IN THE PLANKTOLOGY OF THE OREGON UPWELLING ZONE

William T. Peterson and Charles B. Miller[1]

ABSTRACT

Sampling results from Oregon coastal waters show that plankton abundance in 1971, a year of reduced coastal upwelling, was lower than in 1969 or 1970. This was correlated with greater frequency and abundance in 1971 for species usually found more offshore and with a general reduction in the number and density of the most strictly neritic species. It is proposed that these changes are related to changes in nearshore fisheries which, therefore, appear to depend upon the general stimulation of production by upwelling.

In this paper we describe the nearshore zooplankton community found off the Oregon coast during the upwelling seasons of 1969, 1970, and 1971. Differences in species composition and abundance between the individual upwelling seasons will be described and related to differences in upwelling strength, hydrographic conditions, and wind patterns. Our research on coastal zooplankton is centered upon understanding the dynamics of the nearshore community found within 18 km of the beach. We have concentrated our efforts in this area because it has been shown to be the location of the most intense coastal upwelling. Effects of upwelling are present farther offshore, but the phenomenon is most pronounced within 10 km of shore (Huyer 1974). The importance of understanding coastal upwelling and its effect upon biological production is well established.

PREVIOUS ZOOPLANKTON STUDIES IN THE OREGON AREA

Distribution and abundance of Oregon coastal zooplankton has been the subject of several theses at Oregon State University. Seasonal variations in distribution and abundance along a single line of latitude have been studied by Hebard (1966) off Newport (Figure 1) and by Laurs (1967) off Brookings. Both seasonal and spatial variations were considered by Cross (1964) from data collected off Astoria, Newport, Coos Bay, and Brookings. Lee (1971) looked at samples collected from a grid of stations during one brief interval in August 1963. Both Hebard and Laurs employed plankton nets with a mesh size of 570 μm while Cross and Lee used nets with 240-μm mesh. Since the larger mesh retained only very large forms, some very different conclusions about the relative importance of zooplankton species were reached by the different authors. Hebard found that the euphausiid *Euphausia pacifica* was numerically dominant, and Laurs found that this animal dominated the zooplankton biomass. Copepods were unimportant in their studies. Conversely, Cross and Lee found that the copepods *Oithona similis*, *Pseudocalanus*, and *Acartia longiremis* were numerically dominant. A forthcoming paper by Pearcy (in litt.) will summarize the results of a

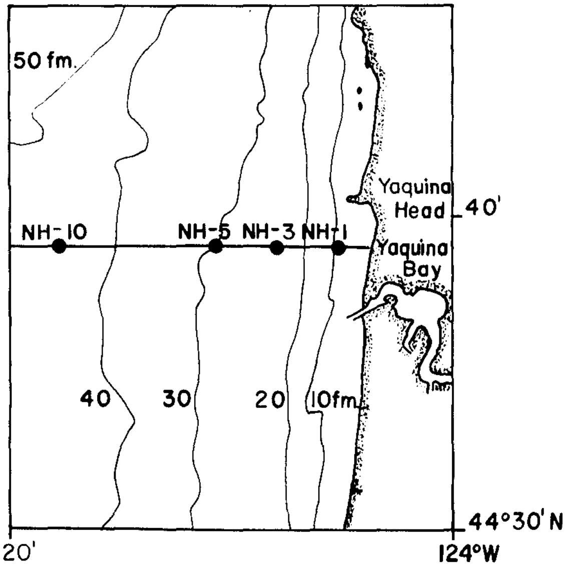

Figure 1.—Map of the study area showing the Newport hydrographic line (solid dark line) and the sampling positions.

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[1] School of Oceanography, Oregon State University, Corvallis, OR 97331.

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4-yr study of seasonal biomass cycles at distances of 28 km from shore and beyond, which employed mid-water trawls and 570-μm plankton nets.

Peterson (1972) summarized the results of 434 zooplankton samples collected off Oregon and Washington with 110-μm mesh Clarke-Bumpus nets at an irregular set of stations in 1961 and 1962. Most of the samples were taken beyond the continental shelf break. His conclusion that copepods attain larger inshore populations in winter than in summer is not in agreement with our results for the Oregon nearshore zone. We have found winter densities to be several orders of magnitude lower than summer densities. This discrepancy makes his work difficult to evaluate.

All of these studies share two shortcomings: First, few or no samples were collected within 10 km of the coast. Second, the time intervals between samplings were large, ranging from monthly (Hebard 1966) to quarterly and longer (Cross 1964; Laurs 1967; Peterson 1972). Under such sampling programs the authors could only document large scale phenomena, such as faunal changes associated with seasonal hydrographic changes, and faunal differences between nearshore and offshore stations.

THE COASTAL ENVIRONMENT OF OREGON

Aspects of descriptive physical oceanography of Oregon coastal waters can be found in Burt and Wyatt 1964; Pattullo and Denner 1965; Cross and Small 1967; Collins et al. 1968; Bourke 1972; Pillsbury 1972; Huyer 1974; and Smith 1974.

Circulation Patterns

The California Current is a slow, southward-flowing current situated within a band 300 to 800 km off the Oregon coast. Inshore of this permanent feature the circulation changes with season. During spring and summer months nearshore flow is southward, driven by northerly winds. During fall and winter months, after cessation of upwelling, flow is northward. This flow is called the Davidson Current.

Wind and Coastal Upwelling

Northerly winds predominate from April to September. They produce a generally southward transport of surface water with a component to the right of the wind away from the coastline. This offshore, near-surface transport is balanced by northward and onshore transport at depth of cool, high salinity, nutrient rich water. When northerly winds are strong and/or persistent, cold, high salinity water appears on the beach and throughout the entire water column out to about 10 km. This condition is called active or intense upwelling. When north wind stress is weak or nonexistent, this onshore deep transport is weakened and nearshore waters are warmed by solar radiation.

Intense upwelling is not a continuous process during summer, but occurs sporadically. If northerly winds blow for a day or two, upwelling will develop. If wind ceases or changes direction, upwelling ceases. During July and August northerly winds are often persistent, so that intense upwelling may continue for several weeks without interruption.

Waters offshore of 10-20 km do not experience these rapid changes. In these deeper waters, upwelling is indicated in hydrographic sections by upward sloping isolines of temperature, salinity, and density (see Smith 1974). The upward slope develops in April or May and persists until cessation of upwelling in September or October. Offshore surface waters are warm (as high as 17°C) and a mixed layer is well developed. Salinities are reduced as a result of the Columbia River plume.

Temperature and Salinity Relationships

Pillsbury (1972) has summarized all temperature and salinity data collected within the top 10 m of the water column at stations 5 and 9 km from shore during the April-September upwelling seasons of 1960 through 1970, a total of 188 observations. Pillsbury used the modal cell technique of Pattullo and Denner (1965) to summarize the data. The portion of a temperature-salinity plot containing the most data points was one bounded by 8.1°-9.0°C and 33.1-34.0‰. That "cell" accounted for 28% of the data. Pillsbury identified two general water types that occur at the two stations: 1) cold-upwelled water (7.5°-8.5°C and 33.5-34‰) and 2) warm, low salinity water (11.0°-12.0°C and 30.5-31.5 ‰) which is a mixture of Columbia River plume water and surface oceanic water.

MATERIALS AND METHODS

Zooplankton were collected along the Newport Hydrographic (NH) line, lat. 44°40′N. We chose this line because extensive hydrographic data are available from cruises made since 1960. Station labels NH 1, NH 3, NH 5, and NH 10 refer to distances in nautical miles from shore and are approximately 2, 5, 9, and 18 km from the beach. Figure 1 is a map of the study area.

Zooplankton samples were collected with 20-cm "Bongo" nets without an opening-closing mechanism. To construct the net frame, two 20-cm diameter × 30-cm PVC (polyvinyl chloride) cylinders were bolted to either side of a pivoting wire clamp. When mounted on the towing cable the net frame was free to move in the vertical plane about 120° of arc, and it could rotate horizontally about the towing cable.

The two plankton nets were 145 cm long and were constructed of NITEX[2] nylon with mesh aperatures of 505 and 240 μm. The ratio of net mesh area to net mouth area was about 11.5:1 for the 240-μm net. The cod ends were 9-cm diameter × 16-cm PVC buckets with stainless steel mesh screens cemented to laterally positioned filtering windows. The two cod ends were fastened about 15 cm apart with a stainless steel strap which kept the nets from wrapping about the cable while being towed. Tsurumi-Seiki Kosakusho flowmeters were mounted off-center in each net mouth. Tows were made obliquely over the entire water column using either a V-fin or Kite-Otter depressor. A time-depth recorder was used to record the towing track. Samples were preserved with 10% buffered formaldehyde solution.

In the laboratory, samples were poured into 500-ml pharmaceutical graduates and allowed to settle. Several hours later the settled volume was read. Water was then decanted off or added to make a diluted volume of five times the settled volume. Aliquots for counting were removed from this volume with a 1-ml Stempel pipette, after the animals were suspended by agitation with a small spatula.

Animals were enumerated with the aid of a binocular dissecting microscope at 25× magnification. Five aliquots were drawn from each sample. Taxa were counted in the first and successive aliquots until 50 in a category were enumerated. These counts were multiplied by appropriate factors to arrive at a number of individuals in a category per five aliquots. A computer was used to convert these raw data into number of individuals per cubic meter and to carry out much of the summary data analysis.

All adult copepods were divided by sex and identified to species. Two morphs of the genus *Metridia* were seen and were separated on the basis of shape of the prosome in lateral view. The *Metridia pacifica* type is more robust and has a steeply sloping forehead, while the *M. lucens* type has a much less sloping forehead. Detailed morphological study of the two types has not been done. Copepodite stages were identified for all species except those of *Clausocalanus*. Only the nauplii of *Calanus* sp. were distinguished. Both euphausiids and cladocerans were identified to species. All other holoplanktonic taxa were grouped (e.g., amphipods, ostracods, medusae, ctenophores, chaetognaths, etc.). Meroplankton were counted as general categories: barnacle nauplii, crab zoea, bivalve veligers, etc. The crab larvae were not counted because they are being studied by R. Gregory Lough, School of Oceanography, Oregon State University.

Surface temperature was measured at all stations and a surface salinity sample was gathered at nearly all stations. Bottom salinity samples were taken on many cruises. Bathythermograph traces were taken at most stations.

Hourly wind data were supplied by William Gilbert, School of Oceanography, Oregon State University. They were gathered by the National Weather Service, NOAA (National Oceanic and Atmospheric Administration) from a recording anemometer located on the south jetty off Newport, Ore., and are stored on magnetic tapes as north-south and east-west components. We determined the resultant vector from the daily mean components and constructed progressive vector diagrams (PVD's) for each upwelling season.

RESULTS

Hydrography and Wind Data

We have compared our surface temperature and salinity data to Pillsbury's modal cell. Data collected during the upwelling seasons 1969-71, from NH 1, NH 3, and NH 5 are shown in Figure 2. None of our observations were part of Pillsbury's data. Striking differences between upwelling

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[2] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

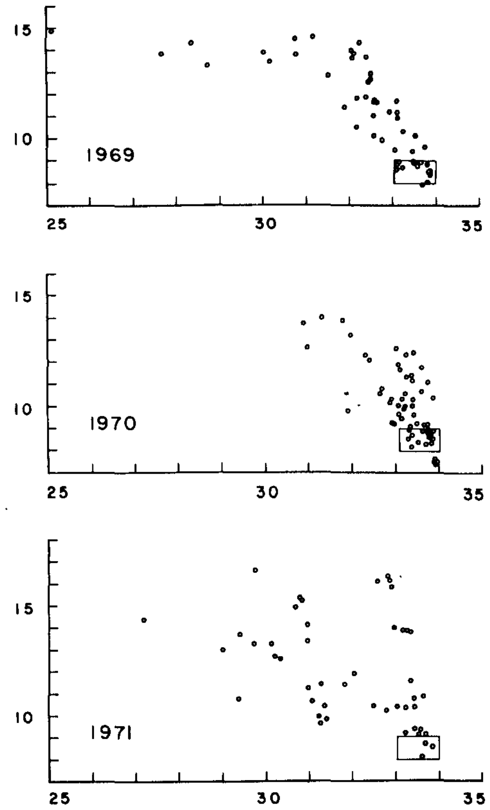


FIGURE 2.–Temperature-salinity diagrams for NH 1, NH 3, and NH 5 in 1969, 1970, and 1971 between April and September.

seasons are seen. About 26% of the 1969 and 1970 data fell within the limits of the modal cell (8.1°-9.0°C and 33.1-34.0 ‰). Only 6% of the 1971 data fell within the limits. Water was generally warmer and of a lower salinity during most of the 1971 upwelling season. Higher temperatures and lower salinities indicate the presence of mixed Columbia River plume water and surface oceanic water. Both the modal cell and surface temperature observations indicate that upwelling was weaker in 1971 than in 1969 or 1970.

Wind data supports the conclusion that the upwelling season of 1971 was a weak one. The PVD's (Figure 3) illustrate the pattern of the wind from 1 May through 30 September for the years 1969-71. They give an indication of amounts of upwelling-inducing northerly winds during a given season, and are useful for comparing different seasons. The axes of the PVD's are wind-miles (i.e., miles per hour multiplied by hours). The northerly component of the wind extends positively down the ordinate and westerly component extends positively along the abscissa. The seasonal pattern for 1971 is quite different from 1969 and 1970. Northerly wind miles are low while westerly wind miles are exceptionally high. Therefore, upwelling should have been relatively weak. This explains the low frequency of temperature and salinity observations in the modal cell in 1971, compared to 1969 or 1970. The 1969 and 1970 wind patterns are similar; 1969 had about 2½ mo of persistent northerlies, while 1970 had about 4 mo of persistent northerlies. A higher total northerly component was achieved in 1970 than in 1969.

The upwelling index data of Bakun (1973) show 1969 and 1970 to have been close to average years compared with the years 1946 to 1971, while 1971 was far below average. These monthly indices estimate the magnitude of the offshore component of the Ekman transport and are calculated from an estimate of the mean monthly sea surface wind stress, which is based in turn on a geostrophic wind calculation from pressure field data. The anomalies of the index at lat. 45°N, long. 125°W for the periods of interest in our study are:

Month	*25 yr mean index for month*	*1969*	*1970*	*1971*
May	34	-22	-1	+32
June	48	+13	-2	-36
July	74	+32	-3	-9
Aug.	51	-5	+23	-27
Sept.	17	-11	-5	-8
Total		+7	+12	-48

Bakun's indices were derived from different data than the PVD's and comparisons between years would not be expected to be in exact agreement.

Total Zooplankton

Table 1 is a list of the sampling dates and total zooplankton abundance at stations NH 1, 3, 5, and 10. The 1972 data set is shown, but since so few samples were taken relative to the number gathered in other years, we have eliminated these data from comparative discussions. One can see several patterns in Table 1. Abundances are usually highest at the station nearest the shore (2 km from the beach). Abundances grade to lows at the station 18 km from shore. They continue to decrease farther from shore (Cross 1964). There is

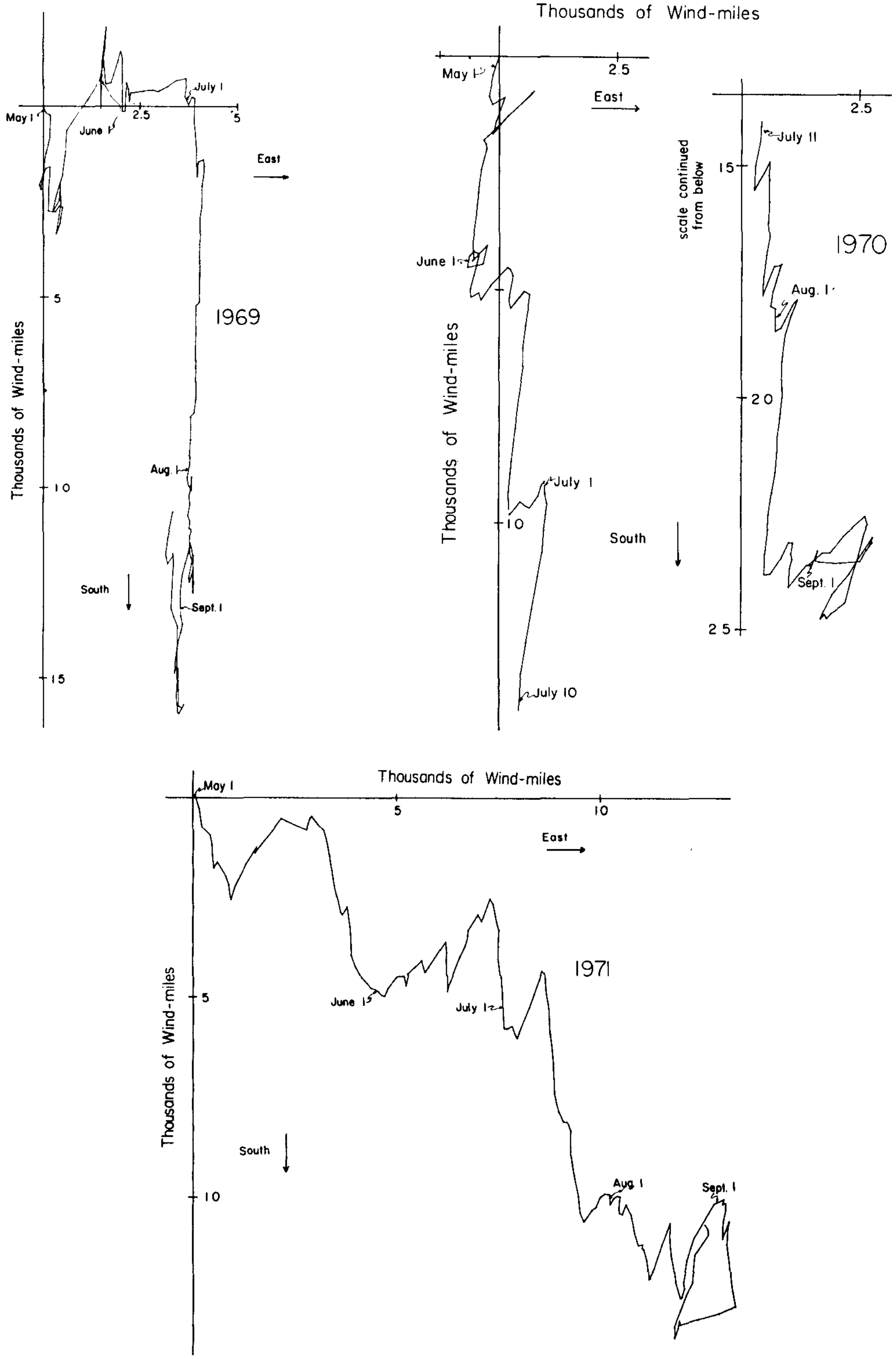


FIGURE 3.—Progressive vector diagrams for the wind at the Newport jetty between May 1 and September 30 in 1969, 1970, and 1971.

TABLE 1.—A list of sampling dates and total zooplankton catch (individuals/m^3) at stations NH 1, 3, 5, and 10. These stations are approximately 2, 5, 9, and 18 km from shore.

Date	NH 1	NH 3	NH 5	NH 10
1969:				
22 June	15,305	2,780	2,375	553
29 June	—	3,712	—	3,895
10 July	15,097	—	8,016	—
18 July	44,782	3,442	10,131	766
25 July	16,277	30,633	1,042	1,334
6 Aug.	9,531	7,482	2,940	—
26 Aug.	—	—	1,721	90
30 Aug.	9,069	6,150	3,141	998
3 Sept.	4,344	3,051	4,756	3,058
14 Sept.	—	5,707	4,447	—
28 Sept.	—	3,457	3,368	—
1970:				
27 Apr.	105	606	767	797
6 May	1,393	872	—	158
22 May	1,166	1,793	1,739	178
4 June	5,375	614	1,185	—
23 June	51,372	1,118	59	434
2 July	30,952	3,633	3,172	2,136
16 July	6,495	4,195	1,935	1,508
29 July	—	4,198	3,179	1,833
13 Aug.	4,135	—	2,202	108
23 Aug.	5,846	4,070	1,264	1,846
11 Sept.	3,121	9,307	322	2,406
25 Sept.	11,450	5,806	6,263	4,349
1971:				
3 May	1,153	1,820	933	927
14 May	967	1,660	1,292	1,679
29 May	4,691	741	1,410	1,715
2 June	—	2,721	—	—
12 July	8,276	4,075	2,086	2,385
28 July	6,737	973	765	—
6 July	3,638	313	674	1,482
21 July	9,577	1,236	1,069	760
2 Aug.	4,276	1,370	2,940	886
19 Aug.	1,559	1,165	531	388
23 Sept.	1,023	896	565	613
1972:				
20 Apr.	1,123	—	1,131	1,057
22 May	2,553	1,652	164	194
11 June	1,242	952	2,578	913
28 June	3,108	1,293	1,090	1,606
21 July	1,372	886	1,071	1,835
5 Aug.	2,589	—	338	575

a seasonal pattern in total zooplankton abundance. Low abundances always occur in April, May, and early June. Low abundances occur at various times during summer and fall as well. Peak abundances occurred in late June and July during 1969 and 1970. No such peak developed in 1971. As a result, standing stocks in 1971 were much lower than other years. There is some indication that 1972 may have had low standing stocks as well.

Table 2 shows the average catch at each station for three seasons. The 1969 data are biased since there are no samples for spring months. To make the average catch data comparable, samples averaged for 1970 began with 23 June and for 1971 began with 12 June. As with temperature-salinity and wind data, 1971 is markedly different from 1969 and 1970, particularly close to shore. This inference was tested by the Kruskal-Wallis sum of ranks test. Medians for the 3 yr were found to be significantly ($P < 0.05$) nonhomogeneous at all of the stations except NH 10.

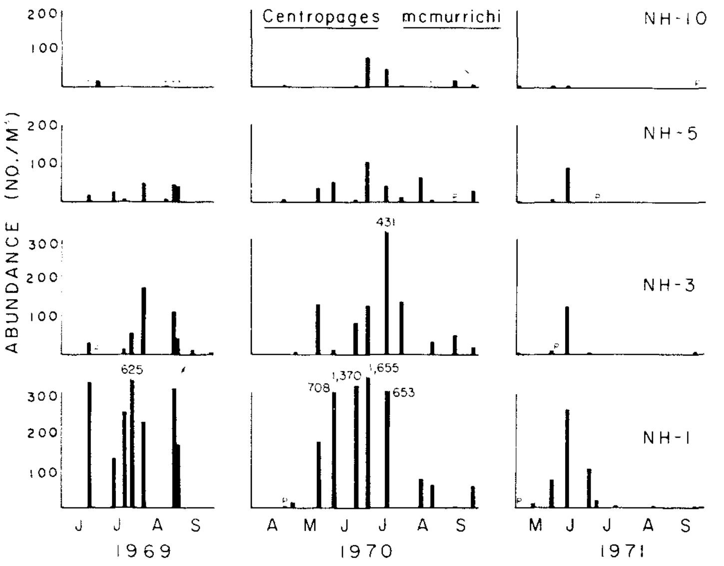
TABLE 2.—Average catch of zooplankton at stations NH 1, 3, 5, and 10 for each upwelling season. Not all sampling dates are included in the mean because the 1969 data are biased since the first samples were collected on 22 June. Therefore, to make all data sets comparable, only samples taken from 23 June through September 1970 and 12 June through September 1971 were used.

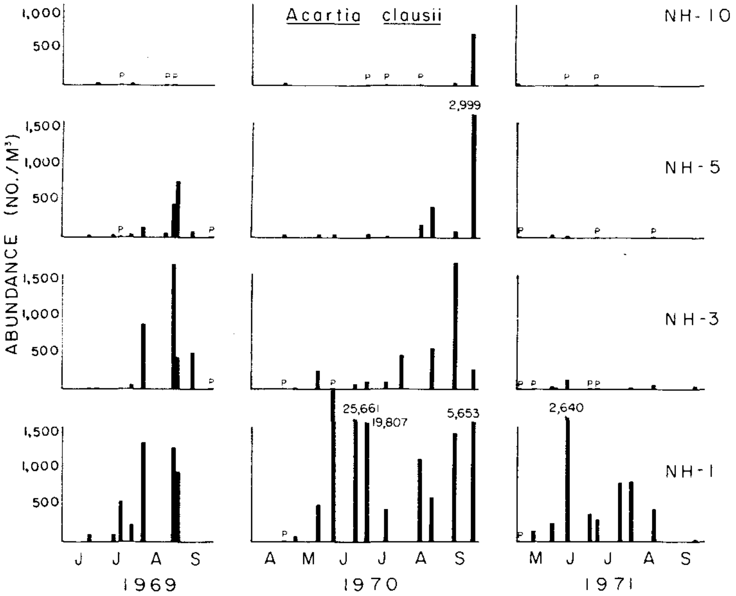
Year	NH 1	NH 3	NH 5	NH 10
1969	16,344	7,379	4,090	1,528
1970	16,196	4,618	2,300	1,828
1971	5,012	1,433	1,233	1,086

Zooplankton Species

Copepods are the dominant zooplankters in our samples. In 100 of 137 samples collected 1969-72, they account for more than 90% of the total catch. In the remaining samples they made up at least 50%. Several species of copepods were individually dominant or shared dominance: *Calanus marshallae* Frost (1974), *Pseudocalanus* sp., *Centropages abdominalis* Sato (= *C. mcmurrichi* Willey), *Acartia clausii* Giesbrecht, *A. longiremis* Lilljeborg, and *Oithona similis* Claus. These copepods are responsible for the patterns of seasonal and spatial abundance seen in Table 1. Individual species patterns are illustrated in Figures 4 and 5. *Pseudocalanus* sp., *A. clausii*, and *C. abdominalis* are grouped in Figure 4 because they are most abundant at the station nearest the beach. Figure 5 contains *A. longiremis* and *Calanus* sp. because they are usually more abundant farther offshore. *Oithona similis* abundance has no certain relationship to distance offshore within 18 km of the coast. Other species exhibit similar abundance gradients but they will not be discussed in this paper.

Table 3 lists relative density and frequency of occurrence of all copepod species. Relative density is the average number of individuals in samples in which the species occurred. The values in the table are sums of relative densities at the four stations for individual years. Table 4 lists relative density and frequency of occurrence of other holoplanktonic taxa and of the meroplankton. The taxa that occurred most frequently or were abundant include chaetognaths (*Sagitta elegans* Verrill predominantly), bivalve veligers, barnacle nauplii, euphausiid eggs, and small round eggs which are probably *Calanus* eggs.





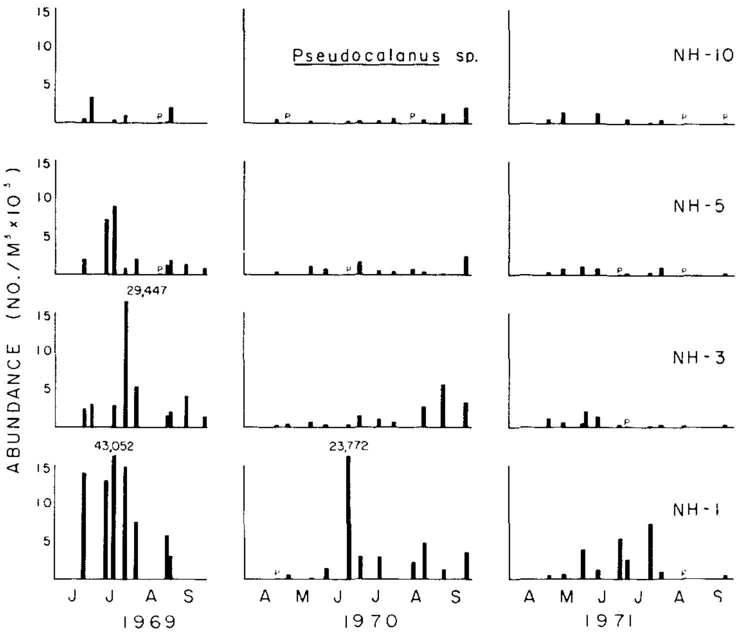


FIGURE 4.—Density of *Pseudocalanus* sp., *Acartia clausii*, and *Centropages mcmurrichi* (= *C. abdominalis*) at NH 1, NH 3, NH 5, and NH 10 in the upwelling seasons of 1969, 1970, and 1971.

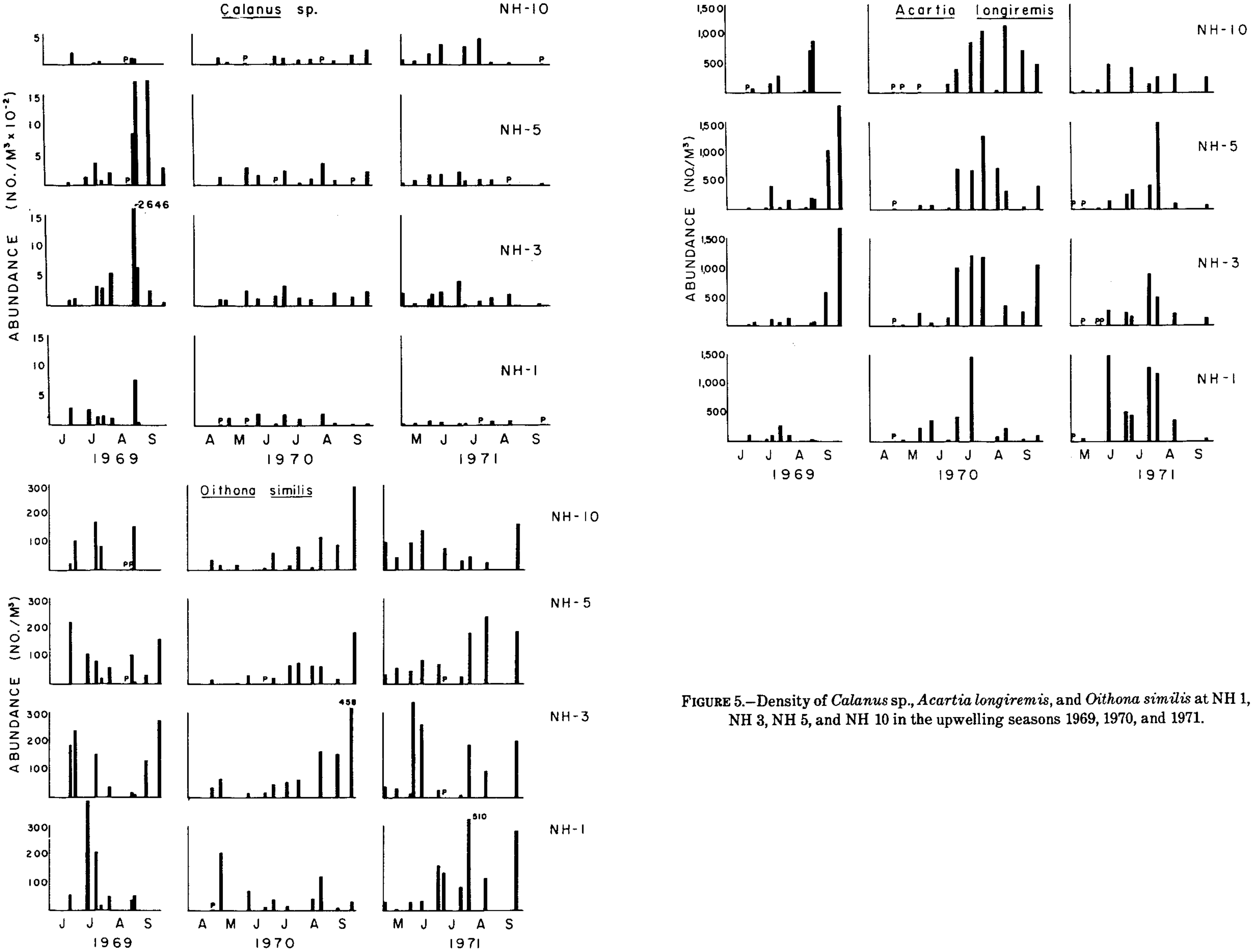


FIGURE 5.—Density of *Calanus* sp., *Acartia longiremis*, and *Oithona similis* at NH 1, NH 3, NH 5, and NH 10 in the upwelling seasons 1969, 1970, and 1971.

TABLE 3.—Total relative density and frequency of occurrence of the copepod species taken within 18 km of the Oregon coast, during 1969, 1970, and 1971. Relative density is average number of individuals per cubic meter in samples in which the species occurred. The table entries represent the sums of relative density at each of four stations. A total of 33 samples were collected in 1969, 44 in 1970, and 40 in 1971.

	Total relative density			Frequency		
Species[1]	1969	1970	1971	1969	1970	1971
Calanus sp.	1,475.2	482.5	436.1	32	44	40
C. tenuicornis	1.3	5.1	7.9	1	4	14
Eucalanus bungii	21.1	3.1	9.0	13	10	15
Paracalanus parvus	80.7	147.3	16.8	29	21	20
Pseudocalanus sp.	23,776.3	6,682.4	3,994.5	33	44	40
Microcalanus pusillus	2.2	18.5	1.8	4	17	2
Clausocalanus arcuicornis	0	1.4	4.0	0	3	7
C. pergens	20.2	5.9	6.6	5	5	9
Clausocalanus immatures	0	0.5	2.1	0	5	2
Ctenocalanus vanus	4.8	31.0	11.0	5	7	16
Aetideus pacificus	1.5	2.3	2.7	4	4	1
Gaidius immatures	2.5	3.4	3.7	3	3	2
Racovitzanus antarcticas	0.6	2.1	1.3	1	2	2
Scolecithricella minor	9.3	4.6	16.0	7	14	16
Metridia lucens	21.4	16.3	48.6	18	29	26
M. pacifica	6.7	2.9	3.7	2	5	6
Lucicutia flavicornis	0	0.4	2.0	0	1	9
Centropages abdominalis	371.8	686.2	110.7	29	42	23
Epilabidocera longipedata	2.9	10.8	0	5	6	0
Acartia clausii	1,178.1	6,045.1	414.9	31	37	29
A. longiremis	1,078.2	1,509.2	1,331.1	33	44	38
A. tonsa	130.7	27.5	0	31	19	0
Tortanus discaudatus	17.5	12.3	0	3	10	0
Oithona similis	369.9	275.0	416.2	32	42	40
O. spinirostris	19.9	16.0	55.5	19	28	31
Corycaeus anglicus	2.8	8.0	3.6	2	10	3

[1] The following species were found in less than five samples: *Calanus plumchrus*, *Gaetanus* immatures, *Paraeuchaeta japonica* immatures, *Candacia bipinnata*, *Eurytemora thompsoni*, *Rhincalanus nasutus*, *Oncaea borealis*, *O. tenella*, *O. media hymena*, *O. mediterranea*, *Sapphirina* sp., and *Microsetella* sp.

TABLE 4.—Total relative density and frequency of occurrence of other holoplanktonic taxa and meroplankton taken within 18 km of the coast during 1969, 1970 and 1971 upwelling seasons. Entries are sums of average abundances at each of four stations.

	Total relative density			Frequency		
Species	1969	1970	1971	1969	1970	1971
Calanus nauplii	119.5	695.5	172.7	21	40	28
Other Copepod nauplii	43.1	68.1	52.3	10	20	20
Amphipods	8.5	18.5	15.7	5	15	14
Euphausiid nauplii	46.3	85.9	84.0	5	26	18
Euphausiid calyptopis	13.3	14.5	17.2	4	17	11
Euphausiid furcilia	30.2	13.6	17.7	14	20	10
Thysanoessa spinifera	35.4	4.0	87.3	2	7	11
Evadne nordmanni	73.7	58.9	9.8	17	26	2
Podon leukarti	2.8	115.3	5.2	2	12	1
Pteropods	10.2	24.6	60.6	11	22	35
Chaetognaths	89.4	50.3	30.8	25	33	34
Oikopleura	69.2	85.7	66.5	11	15	21
Ctenophores	6.0	2.5	34.9	7	5	19
Scyphomedusae	22.9	70.9	22.8	13	28	22
Decapod shrimp mysis	142.7	52.6	45.3	16	24	22
Barnacle nauplii	59.3	168.3	231.4	8	32	23
Barnacle cypris	4.4	64.0	8.3	2	19	10
Polychaete post-trochophores	16.2	20.1	21.4	5	23	15
Bivalve veligers	170.5	258.9	68.3	20	40	27
Gastropod veligers	28.9	79.2	42.2	16	33	23
Hydromedusae	6.1	3.2	10.3	2	2	11
Unidentified annelid without parapodia	8.2	23.1	35.8	3	3	16
Pluteus	0	16.0	117.6	0	5	11
Large round eggs (fish)	36.8	25.0	17.8	11	13	12
Small round eggs	[1]870.1	168.7	226.1	10	28	25
Euphausiid eggs, early	55.0	686.1	449.6	11	29	24
Euphausiid eggs, late	70.0	57.5	39.6	2	16	14
Other fish eggs	19.1	35.1	34.3	12	18	18

[1] Biased by a single observation of 760 individuals/m^3.

Only a few of the taxa in these tables had similar average abundances in each season. Some of the taxa can be assigned "good" and "bad" years on the basis of either their abundance or frequency of occurrence in samples. Others cannot be assigned with much confidence. Accordingly, on the basis of frequency of occurrence, 1971 was the "best" year for the following copepods: *Calanus tenuicornis* Dana, *Clausocalanus arcuicornis* Dana, *Ctenocalanus vanus* Giesbrecht s.l. and *Lucicutia flavicornis* Claus. On the basis of abundance, the following categories can be added to the list: *Metridia lucens* Boeck, *O. spinirostris* Claus, the euphausiid *Thysanoessa spinifera* Holmes, the pteropod *Limacina helicina* (Phipps), ctenophores, hydromedusae, echinoderm pluteus larvae, and unidentified annelids. Using the same criteria, 1971 was the poorest year for the copepods *Paracalanus parvus* Claus, *Pseudocalanus*, *Aetideus pacificus* Brodskii, *Centropages abdominalis*, *Acartia clausii*, *A. tonsa* Dana, *Tortanus discaudatus* Thompson and Scott, and *Epilabidocera longipedata* Sato (= *E. amphitrites* McMurrich). Also poorly represented in 1971 were the cladoceran *Evadne normanni* (Loven) and bivalve mollusc veligers.

A definite pattern emerges from the above classifications. All of the copepod species having their best year in 1971 are basically offshore, warmwater species that can always be found well off the Oregon coast (Peterson and Anderson 1966; Peterson 1972) and which seem to have their highest abundances to the south (Fleminger 1967). Those species which had their poorest year in 1971 are all nearshore, coastal species. In fact, some of the neritic species which had their "best" years in 1969 or 1970 did not even occur in 1971 (*Epilabidocera longipedata*, *T. discaudatus*, and *A. tonsa;* see Figure 6). Fleminger (1967) listed *Paracalanus parvus* and *A. tonsa* as temperate-subtropical neritic, and *Pseudocalanus*, *A. clausii*, *T. discaudatus*, and *E. longipedata* as boreal-temperate neritic. *Centropages mcmurrichi* is also a boreal neritic species (Cameron 1957). The attribute shared by each of the animals having a "poor" year in 1971, is restriction to the neritic zone. Warmwater or cold-water affinities seem unimportant. Even though surface temperatures were much higher in 1971, two important animals with norther affinities and not narrowly restricted to the neritic zone, maintained the same level of abundance as they had in 1969 and 1970: *A. longiremis* and *O. similis*.

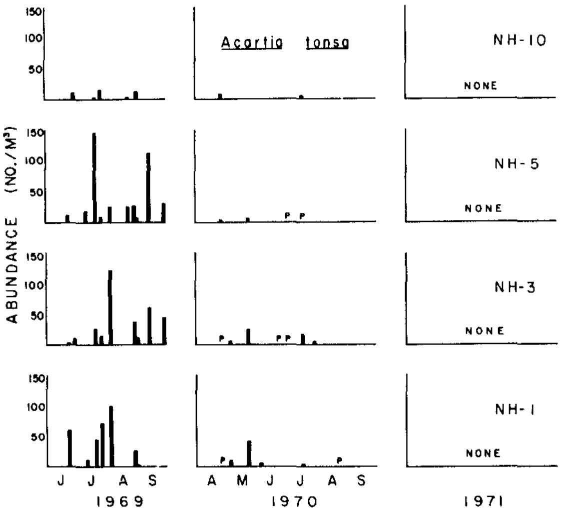


FIGURE 6.—Density of *Acartia tonsa* at NH 1, NH 3, NH 5, and NH 10 in the upwelling seasons of 1969, 1970, and 1971.

There are important differences between the good upwelling years of 1969 and 1970. A number of taxa were very abundant only in 1970: the copepods *Microcalanus pusillus* Sars and *A. clausii*, *Calanus* nauplii, the cladoceran *Podon leukarti* (Sars), barnacle cypris, and gastropod veligers. The year 1969 was the better year for two dominant copepod species (*Calanus* sp. and *Pseudocalanus* sp.), for the copepods *Eucalanus bungii* Giesbrecht and *A. tonsa*, and for shrimp larvae. We do not fully understand these observations.

The greatest share of the taxa listed in Tables 3 and 4 seem to be either equally abundant over all three upwelling seasons (copepod nauplii, euphausiid life history stages, *Oikopleura* sp., polychaete post-trochophores, small round eggs, euphausiid eggs, and fish eggs), or have uncertain or no relationship to the upwelling seasons. These animals include the copepods *Clausocalanus pergens* Ferran, *Scolecithricella minor* Brady, *Metridia pacifica* Brodskii, *Racovitzanus antarcticus* Giesbrecht s.l., *Gaidius* sp., and chaetognaths, barnacle nauplii, and scyphomedusae.

DISCUSSION

Upwelling along the Oregon coast was relatively weak in 1971. It was seldom strong enough to create the low temperature-high salinity conditions close to the beach that are characteristic of the process. This occurred because there were no sustained periods of southward wind in 1971. There were only four "upwelling events": 2-10 May, 16-25 May, 20 June-2 July, and 10-24 July. Each of these events was unusual compared to those of other years in that the wind also had a substantial eastward component. There were also four storms from the southwest of the sort that characterize the winter period on the Oregon coast: 11-15 May, 16-23 June, 7-9 July, and 27-31 August. It is expected that under these conditions surface waters from offshore would have been more prevalent in the nearshore zone in 1971 than in other years. The composition of the plankton observed in 1971 within 18 km from shore is in agreement with that hypothesis.

Comparison of onshore-offshore hydrographic sections for upwelling events and for intervals of low southward winds (Smith 1974) suggests an explanation for the fact that NH 10 does not show the same degree of year-to-year variations as stations nearer shore. During the upwelling season all isopycnals below 15 m slope upward toward the shore at least as far seaward as 30 km. Upward sloping extends to the shore during upwelling events, but during lapses of the southward wind the isopycnals come to slope downward toward shore from 10 km seaward to the beach. Seaward of 10 km they continue to slope upward despite prolonged lapses. It seems likely that coastal upwelling only takes the form of pulsed events in this most inshore zone. Thus it is reasonable that the low frequency and amplitude of upwelling events in 1971 only had a pronounced effect on the planktology at stations less than 10 km from shore. On the other hand, Hubbard and Pearcy (1971) demonstrated marked changes in the species composition of the salp fauna off Oregon at distances beyond 28 km from shore in 1963, another year of anomalously low coastal upwelling (Bakun 1973). The detailed relationship between inshore and offshore plankton changes as correlated with year-to-year weather variations cannot yet be deduced. The length, frequency, and spatial extent of the data set necessary to deal with this problem probably puts it beyond our reach.

There is a suggestion in the data that intense upwelling events rather immediately result in high zooplankton abundance at the NH 1 and NH 3 stations. Huge population peaks on 10, 18, and 25 July 1969 and 23 June and 2 July 1970 were associated with periods of intense upwelling. The high density found on 22 June 1969, however, followed a 41-day period of little or no north wind. It seems most likely that peak densities are simply reached at about the same time each year, namely late June and early July. We do not as yet know the relationship between copepod developmental schedules and the seasons in this area well enough to decide this issue with any certainty. Further analysis of our data as it bears on this point is planned.

Summers of below average upwelling like 1971, together with the resultant reductions in primary and secondary production, probably have important effects upon nearshore fisheries. A statistical link exists between summer upwelling strength and Dungeness crab production (Peterson, 1973). A strong upwelling season results in a heavy crab catch 1½ yr later. The Dungeness crab catch for the 1972-1973 season was one of the lowest on record.

Other fisheries seem to have been similarly affected. The Fish Commission of Oregon has documented 1971 as a poor growth year for the shrimp *Pandalus jordani* (Robert L. Demory, Oregon Fish Commission, Newport, Ore., pers. commun.), coho salmon, *Oncorynchus kisutch* (Paul H. Reed, Oregon Fish Commission, Newport, Ore., pers. commun.), and razor clams *Siliqua patula* (C. Dale Snow, Oregon Fish Commission, Newport, Ore., pers. commun.). The shrimp data are mean carapace length of Age I animals from the Coos Bay, Ore. area (lat. 43°15′N) and are as follows: 1969, 16.45 cm; 1970, 16.76 cm; and 1971, 15.87 cm. Averaged dressed weights of coho salmon were 2.59 kg in 1969, 3.41 kg in 1970, and 2.68 kg in 1971. Razor clam lengths averaged 75.4 mm in 1969, (no data for 1970), 69.4 mm in 1971, 78.5 mm in 1972, and 83.5 mm in 1973. Some of these data may be better interpreted in terms of good growth years. As shown by the wind data (Figure 3), 1970 had many more days of upwelling inducing winds than 1969. Primary and secondary production should have been greater in 1970. Both shrimp and coho salmon were larger in 1970. Unfortunately no razor clam data were taken in 1970, but data for other years support the conclusion that 1971 was a poor growth year.

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