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Title SEA WATER TEMPERATURE AND SALINITY CHARACTERISTICS OBSERVED AT OREGON COAST STATIONS IN 1961.

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Measurements of sea water temperature and salinity taken at coast stations along the Oregon coast during 1961 are analyzed. The frequency distributions of temperature and salinity are discussed, and, for the first time, bivariant analysis is applied to coast station observations.

Marked differences are noted in the distributions obtained for the individual coast stations. χ^2 analysis shows that these differences are statistically significant at the 7.5 percent confidence level.

The differences found between stations is explained in terms of local processes. An examination of oceanographic and meteorological conditions existing along the Oregon coast is made. This leads to the conclusion that upwelling and the local supply of fresh water are two major factors altering the characteristics of the waters supplied to the coastal region from offshore.

SEA WATER TEMPERATURE AND SALINITY CHARACTERISTICS OBSERVED AT OREGON COAST STATIONS IN 1961

by

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INTRODUCTION

The Coastline

In general the earth may be thought of as consisting of matter in three states which are separated by three interfaces. The states are the solid, liquid and gaseous portions of the planet, known respectively as the lithosphere, hydrosphere, and atmosphere. The interfaces are the water-basin, the land-air, and the ocean-air interface.

For all practical purposes, the hydrosphere is the ocean. The physical conditions which exist in the ocean are a result of the physical-chemical properties of the water and its interaction with the other states, the atmosphere and the lithosphere. Of particular interest is the region of intersection among all three states, where ocean, atmosphere, and land meet. This is the coastline.

Although oceanic conditions can be described in terms of many variables, two have become particularly popular. The two variables most commonly measured in oceanography are the temperature and salinity of the water. In some regions of the ocean these quantities are quite constant, while in other regions they are far from constant. The coast region of the ocean is a region of maximum variability.

However, since the oceanographer is interested in all the ocean including its boundary interfaces, the region of high variability must be studied. One approach to the study of this region is to measure the parameters of temperature and salinity from the shore. Stations established for this purpose are commonly called coast or shore stations.

Coast Station Programs

Coast stations offer several distinct advantages over ship-based operations for study of the nearshore waters. One of the most important is the high cost of oceanographic vessel operation. Depending on the size of the ship, daily operation costs range from hundreds to thousands of dollars per day. Coast stations, on the other hand, can be operated for dollars per day or less. In addition, through use of coast stations as a foundation for studying the nearshore region, oceanographic vessels can be released, at least to some extent, for deep ocean work. Shore station observations can be made conveniently and accurately in exactly the same location each time. It requires considerable effort to achieve these conditions on oceanographic vessel surveys.

Many different groups establish and operate coast stations all over the world. In fact, coast stations have been established in most of the countries bordering the sea.

Lisitzin (13, p. 4) reports that observations are made at lighthouses in the northern Baltic.

The Japanese also have an active coast station program in conjunction with observations at meteorological observatories. (7, p. 123).

Particularly active in this hemisphere is the United States Coast and Geodetic Survey, hereafter called USCGS. This agency has established and supervised stations all along the coastline of the United States. Also, in cooperation with the Inter-American Geodetic Survey, they act as a clearing agency for stations in Central and South America, and around the Caribbean (27, p. 1).

Marine laboratories, often associated with universities, have also conducted coast station programs. Scripps Institution of Oceanography has summarized data from stations in California (26, p. 1).

The Canadian coast station program is extensive along the Pacific coast of Canada (10, p. 705). The program has been in operation since 1914, and now consists of 14 stations which have been in operation since 1933. Both oceanic and atmospheric conditions are observed at each station. The stations have been established in regions with differing exposure to the ocean; open ocean, protected coastal, and seaways. The Canadian coast station program is an integral part of the oceanographic program. Tully and Bennett (25, p. 1-2) have shown that offshore conditions can often be inferred from coast station records.

Since 1959 a program of coastal observations has been pursued by the Department of Oceanography at Oregon State University, hereafter called OSU. These stations serve two purposes. First, they fill the gap between offshore observations and the beach. Second, they provide an indication of offshore conditions in periods when no offshore data are available. The results of this program indicate that such studies have value not only to students of coastal oceanography and climatology, but may well be related to large scale features of oceanic circulation.

Classification of Coast Station Data

A number of different methods have been used in the past to classify coast station data and a review of these is in order.

Tabata (24, p. 191-197) has suggested a method of classification of offshore station data, if a large number of observations are available to be classified. Using 15 years of daily observations from five Canadian coast stations, for the period 1940 through 1954, he classified the data in terms of departure from the long time mean of the same period. He grouped the data in terms of monthly standard deviation from the means for both temperature and salinity. He used a block diagram to show the results of the classification for all 15 years data. He pointed out that this approach requires a long series of observations in order that one may compute the statistical parameters with a high degree of confidence.

Hishida (7, p. 123-128) also used a standard deviation approach for classification of the "standard specific gravity" of sea water (σ_{15}) at many Japanese coast stations. He used three parameters, the mean, the standard deviation, and the frequency distribution to classify

12 coastal stations along the coast of Japan into three groups. Hishida further concluded that only in one group could he infer oceanic conditions directly from conditions along the coast. Therefore he introduced a term he called the "oceanic factor." He determined the "oceanic factor" for each station in all groups on the basis of an empirical formula to be fitted to the frequency distribution for each station.

His approach seems well suited to the determination of the relationship between oceanic conditions and coastal conditions. However, this method of classification also requires a large sample, which is simply not yet available from stations along the Oregon coast.

In 1956 Hishida (8, p. 1-4) published another paper on the relationship between coastal and oceanic water in which he used observations taken at 35 Japanese coast stations. He classified each station in each of the four seasons of the year. The classification in each season was based on the number of observations falling between $\sigma_{15} = 0$ and $\sigma_{15} = 24$. In this way he found that some stations represent oceanic conditions in some seasons of the year and not in others.

In a third paper he attempted classification using harmonic analysis (9, p. 5-10). Again he was able to classify the coast stations into three groups. His new classification corresponded well to his earlier classification in terms of the oceanic factor b. Expressions are given relating the coastal water temperatures to oceanic and meteorological conditions.

In all the approaches taken by Hishida, many years of daily observations were used. This makes his approaches unsuitable for classification of conditions off the coast of Oregon.

The Bivariant Diagram and Its Application to Coast Station Data

Many studies of the distribution of surface temperature have been made by Murry (16, p. 34-51), Spilhaus (21), Robinson (19, p. 1-98), and others, but much less has been done on the covariation of temperature and salinity. Helland-Hansen (6, p. 1-76) used T-S diagrams to correlate temperature and salinity from serial observations. T-S diagrams, as temperature-salinity diagrams are referred to in oceanography, were also used by Montgomery (14) in 1955 to discuss the frequency distributions of these variables at Weather Station J.

My approach is similar to one suggested by Cochrane (3, p. 45-53; 4, p. 111-127) on the temperature-salinity distributions in the Pacific. The method has also been used by Montgomery (15) and Pollak (20). The method involves the use of temperature-salinity diagrams to study the distribution of paired values of these characteristics in the ocean.

The following approach was taken by Cochrane (3, p. 45-53) in 1956 to study surface temperature and salinity distributions in the Pacific Ocean. He first chose what he defined as his "characteristic" class interval. This was a small area of the T-S diagram, bounded on two sides by values of temperature and on two sides by values of salinity. His class intervals were 2°C and 0.4 o/oo. The frequency of temperature-salinity readings falling in a given characteristic region is then the prevalence of that interval.

To obtain temperature and salinity values to plot, he divided data from the Pacific Ocean by area into a grid of 5 degrees of latitude and 5 degrees of longitude. Then for each of the areas of the grids a temperature and salinity were obtained from surface charts of these values. This was done for the months of February and August, to represent winter and summer conditions. The surface area distribution of temperature and salinity for winter and summer were then determined by summing all the areas falling in a particular characteristic class on the T-S diagram. From this an estimate of the average distribution was obtained. Cochrane (3, p. 97) noted that it was particularly instructive to enclose with isopleths the prevalent characteristic regions on the diagram.

The yearly distribution of characteristics for the North Pacific, found by Cochrane is shown in Figure 1. The shape of the distribution, as indicated by the lower frequency isopleths, is that of the number seven. That is, there are two high frequency ridges that meet at an acute angle on the T-S diagram. The highest frequency occurred at high salinity and high temperature, where the ridges meet.

Cochrane (4, p. 111-127) used the same procedure in a paper published in 1958 using potential temperature and salinity. In this paper, instead of dividing the ocean surface into a grid and determining a mean pair of characteristics of each area of the grid, he associated a pair of characteristics with a certain volume of the

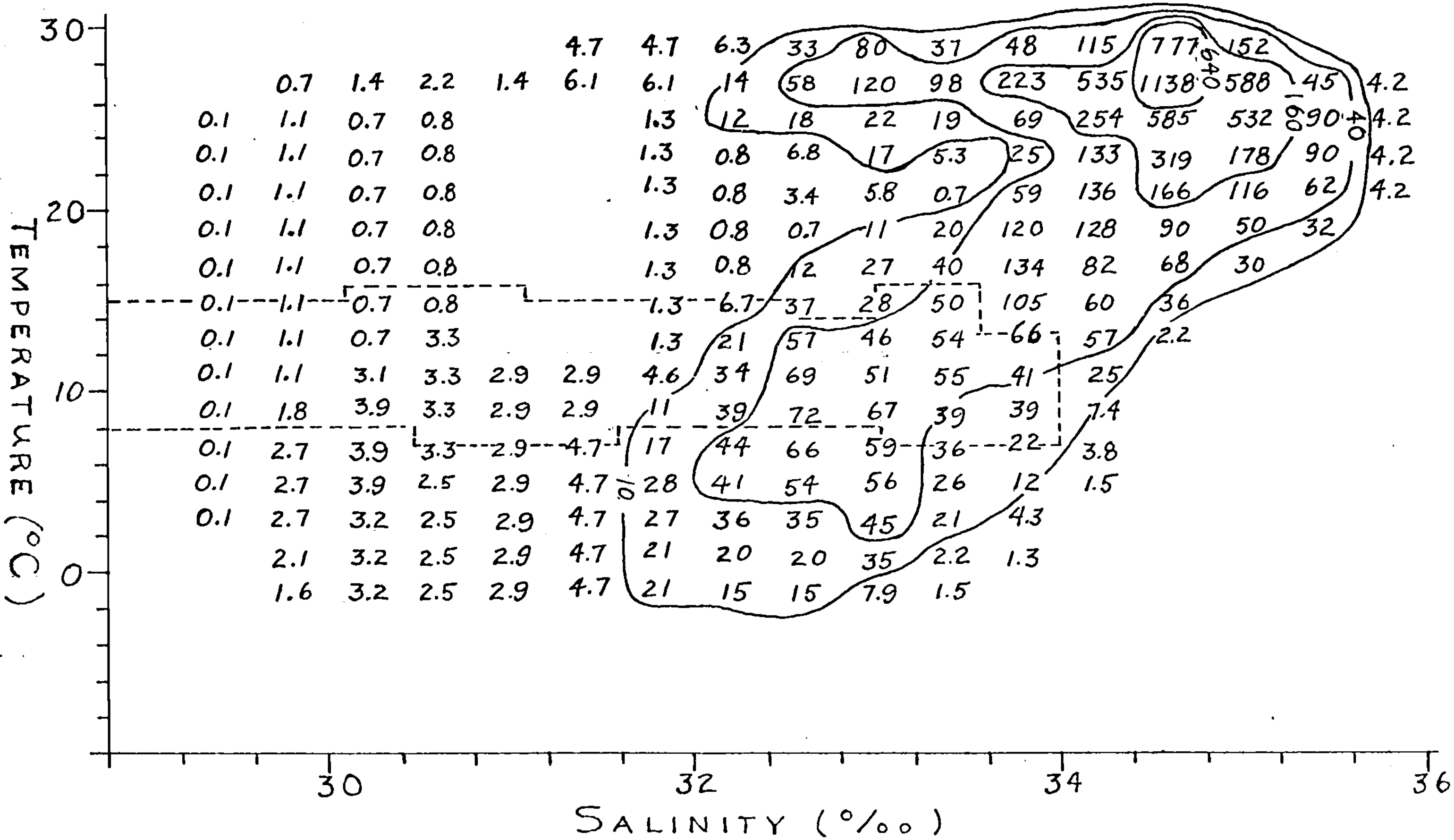

Figure 1. The frequency distribution of surface water characteristics in the North Pacific Ocean, according to Cochrane (after 3, p. 50).

ocean. Therefore, the frequency in a characteristic region of the T-S diagram represented the volume of water in the Pacific Ocean having the characteristics of that region.

Use of bivariant diagrams in oceanography has been only partially explored to date. The chief limitation of the method at present is the amount of data available. In this paper, bivarient diagrams are applied to the data collected at OSU coast stations and to other data of interest collected in the same general area.

THE DATA AND METHODS OF CLASSIFICATION

Sources of Data

Three sources of coast station data were used in this analysis: (1) Observations taken weekly at seven OSU coast stations during 1961. (2) Observations taken daily during the winter of 1961-1962, under the supervision of the author. (3) Observations taken daily at eight tide gauge stations of the USCGS in 1933 and 1934.[1] Also, offshore observations of temperature and salinity made during 1961 within 25 miles off the coast were used.

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[1]Unpublished data, taken at tide gauge stations along the Oregon-California coast in 1933 and 1934. These data were obtained from original records of the USCGS.

Location and Description of Coast Stations

The location of all the coast stations used in this study are shown in Figure 2. The latitude, longitude, type of station, name of the observer, and the total number of observations for each station are given in Table 1.

The second group of data will be referred to as OSU special data. Two stations were begun, on a trial basis, to determine the value of taking samples at closer intervals than weekly. As interest in this type of program was shown by elementary and secondary science classes, two groups at schools near the ocean were selected for the study. The two special stations are located at Newport and Oceanlake, Oregon, and are about 20 miles apart on the Oregon coast. At Newport the observations were taken under the direction of Mr. Harry McAdams by his senior biology class at Newport High School. At Oceanlake the observations were taken under the direction of Mrs. Marjorie Boetger by her seventh and eighth grade science class at Oceanlake Grade School.

A total of 17 coast stations were used in this study. Each station represents considerable personal effort by the observer, and the author is well aware of his indebtedness to the observers.

For comparison with conditions offshore, surface temperature and salinity data collected on oceanographic cruises were analyzed in the same manner as the coast station data (as described in a following section). These data are on file in manuscript form in

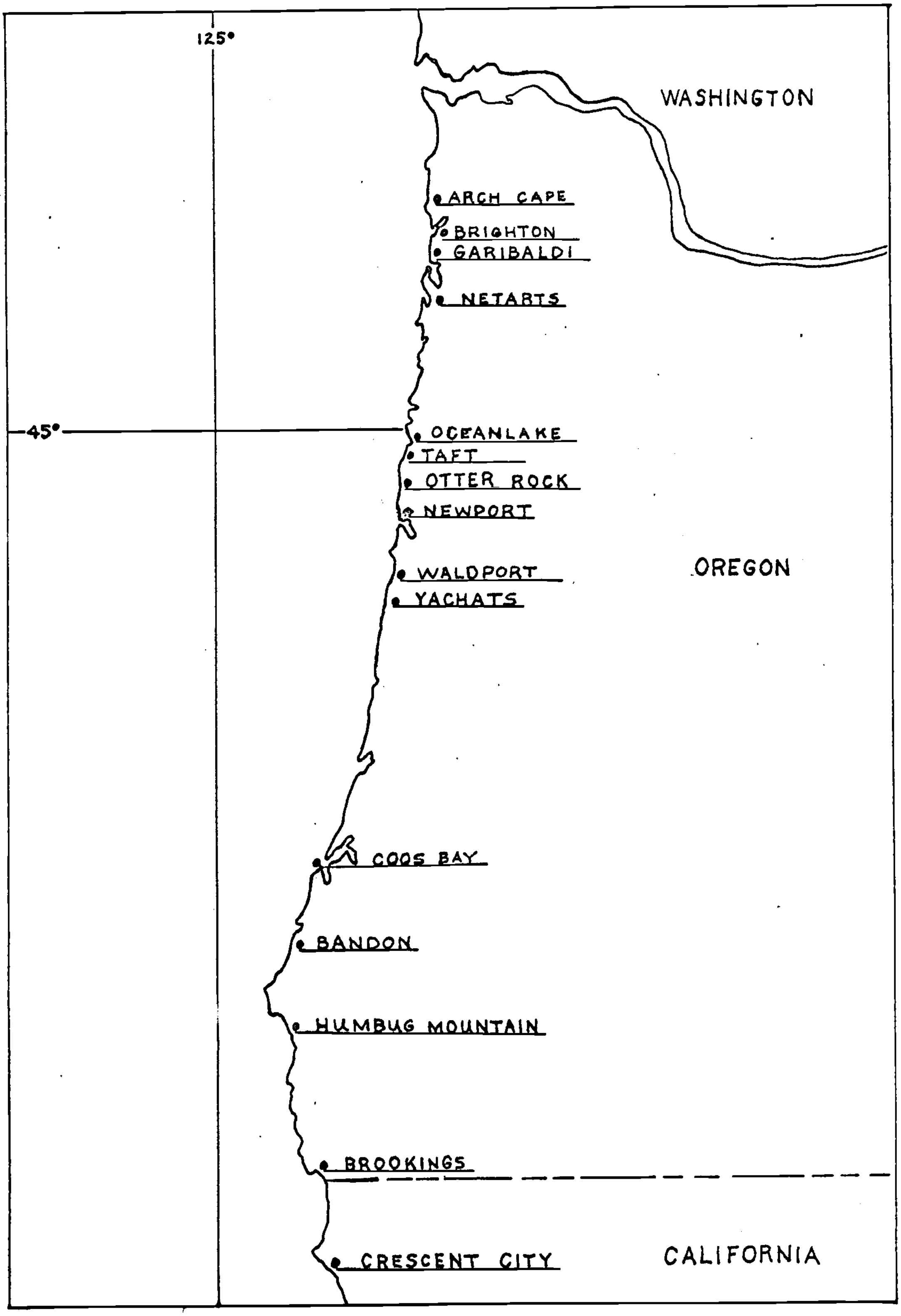

Figure 2. The location of coast stations.

TABLE 1. List of Coast Stations

Station Identification and Location	Description	Observer
OSU Stations		
Arch Cape 45°48.0'N 123°58.0'W	In the surf on a sand beach	Mrs. Berkely Snow Mr. John Markham
Netarts 45°26.1'N 123°58.0'W	Boat ramp at the entrance of Netarts Bay	Mrs. Virginia Cornette
Otter Rock 44°44.6'N 124°58.0'W	Off the rocks	Mr. Robert Troxel
Yachats 44°18.5'N 124° 4.0'W	Off the rocks	Mr. Eugene Hanson
Bandon 43° 7.0'N 124°25.5'W	Off the rocks	Miss Lura Morgan Mr. George Anthony
Humbug Mountain 42°36.6'N 124°24.0'W	Off the rocks	Mr. E. V. Nelson
Brookings 42° 4.1'N 124°18.8'W	Off the rocks	Mr. Morton W. Phillips
OSU Special Stations		
Newport 44°38.0'N 124° 3.5'W	Off the rocks	Mr. Harry McAdams and Students
Oceanlake 44°59.0'N 124° 1.0'W	Off the rocks	Mrs. Marjorie Boetger and Students

(Table 1 cont'd)

Station Identification and Location	Description	Observer
USCGS Stations - 1933-1934		
Brighton 45°40.2'N 123°55.5'W	None Available	Mr. W. A. Rowe
Garibaldi 45°33.3'N 123°54.4'W	None Available	Mr. W. M. Davis
Taft 44°55.6'N 124° 1.2'W	None Available	Mr. C. T. Dewey
Newport 44° 37.8'N 124° 3.3'W	None Available	Mr. M. E. Simmons
Waldport 44°26.1'N 124° 3.5'W	None Available	Mr. C. R. Evans
Coos Bay 43°20.9'N 124°19.3'W	None Available	Mr. A. E. Holst
Bandon 43° 7.5'N 124°24.8'W	None Available	Mr. J. E. Walstrom
Crescent City 41°44.8'N 124°11.8'W	None Available	Mr. L. W. Viemann

the Department of Oceanography, Oregon State University.[2]

Sampling Procedure

It was unavoidable that the sampling procedure differed at the different types of stations. At the OSU regular coast stations an attempt is made to make sure that all the samples are comparable and that the results are accurate. This is achieved by having a standard procedure used by all observers. The water for salinity determinations are taken in rubber-stoppered citrate bottles with a volume of 300 ml. The observer is asked to rinse the bottle twice before filling it with the sea surface sample. At the same time as the sample is taken the water temperature is taken with a bucket thermometer. The observers are asked to take the samples at high tide if possible. This is a considerable inconvenience to the observers, since it requires a different time for successive observations, and in many cases is not possible.

The samples were analyzed for salt content by titration using the modified Mohr method, which is considered to have an accuracy of 0.02 o/oo. This is computed from the formula given by Strictland and Parsons (22, p. 12).

The temperatures were read to the nearest 0.1°C. The recorded temperatures were corrected at the university from the calibration

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[2]These data are from two sources: (a) Unpublished data of the University of Washington, taken on cruises of the BROWN BEAR in 1961. (b) Unpublished data of OSU, taken on cruises of the R/V ACONA in the same year.

curve of the thermometer. The correction was usually less than 0.2°C for the thermometers used in this study.

The same procedure was followed with the OSU special coast stations with two exceptions. No effort was made in this case to take the samples at high tide, and the temperature readings are not corrected.

The procedure followed in collection of the USCGS data is given in their special publications number 280 and 281 (27, p. 1; 26, p. 1). Water samples were obtained in a bucket from two or three feet below the surface and the temperature was measured with a mercury thermometer. No discussion of the accuracy is given in the reports. From examination of the USCGS data the author feels that the accuracy of the temperature measurements is less than that of the OSU stations.

The density of the water was measured with a hydrometer, and the hydrometer readings were later converted to salinities. No effort was made to take the samples at any special phase of the tidal cycle. These observations were made at tide gauge stations, located in estuaries or bays to protect them from wave action. Therefore, these data may not be directly comparable to the other two groups with open ocean exposure.

Analysis

The data collected at the coast stations listed in Table 1 were plotted on T-S diagrams. After consideration of the data from each group separately, class intervals were defined for both temperature and salinity. These class intervals formed unit regions on the T-S diagram. These regions represent what Cochrane defined as "characteristic" classes for the water (3, p. 46).

Data from all stations were plotted on T-S diagrams. A unit region, with sides of 1.0°C for temperature and 0.5 o/oo for salinity, was used in the T-S analysis. As is common in statistical work, the class intervals were selected at one decimal beyond the accuracy of the variable determination. This avoids rounding of the values falling directly on a class interval limit. For example, one temperature interval is 9.01°C to 10.01°C and one salinity interval is 30.001 o/oo to 30.501 o/oo. For the sake of brevity, in the remaining sections of this thesis only the unit portion of the class interval limits will be used to designate a class interval.

The number of values falling in a characteristic region is determined and this total is entered on a T-S diagram. These distributions are shown in the top portions (a) of Figures 3 through 12.

In addition, by summing the number of observations in a given salinity class interval over all temperatures and dividing by the total number of observations at the station, the relative frequency of occurrence of salinities within that class interval is determined. Applying this same procedure to each class interval leads to a frequency distribution of salinity. These distributions are found in Figures 3b through 12b. A class interval of 1 o/oo was used in this part of the analysis. If the same procedure is followed for temperature over all salinities, the frequency distribution of temperature is obtained. These distributions are found in Figures 3c through 12c. The cumulative frequencies for both salinity and temperature are represented as curves. Also, included in Figures 3 through 10 are the number of observations taken in any given month, so that seasonal weighting of the distributions can be evaluated qualitatively.

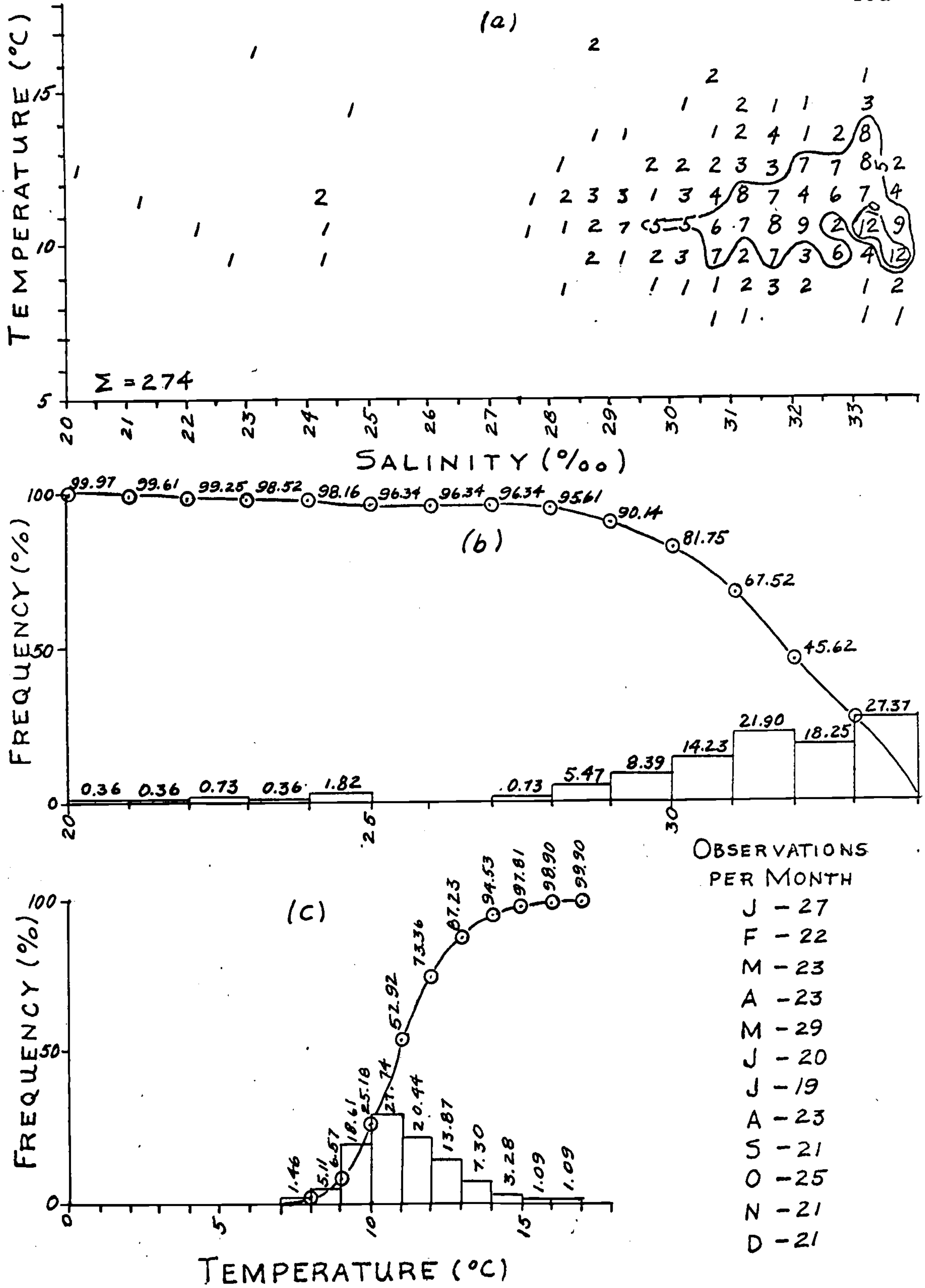
Figures 4 through 10 represent that data for the seven OSU regular stations, while 3 is derived from the sum of the observations at all these stations.

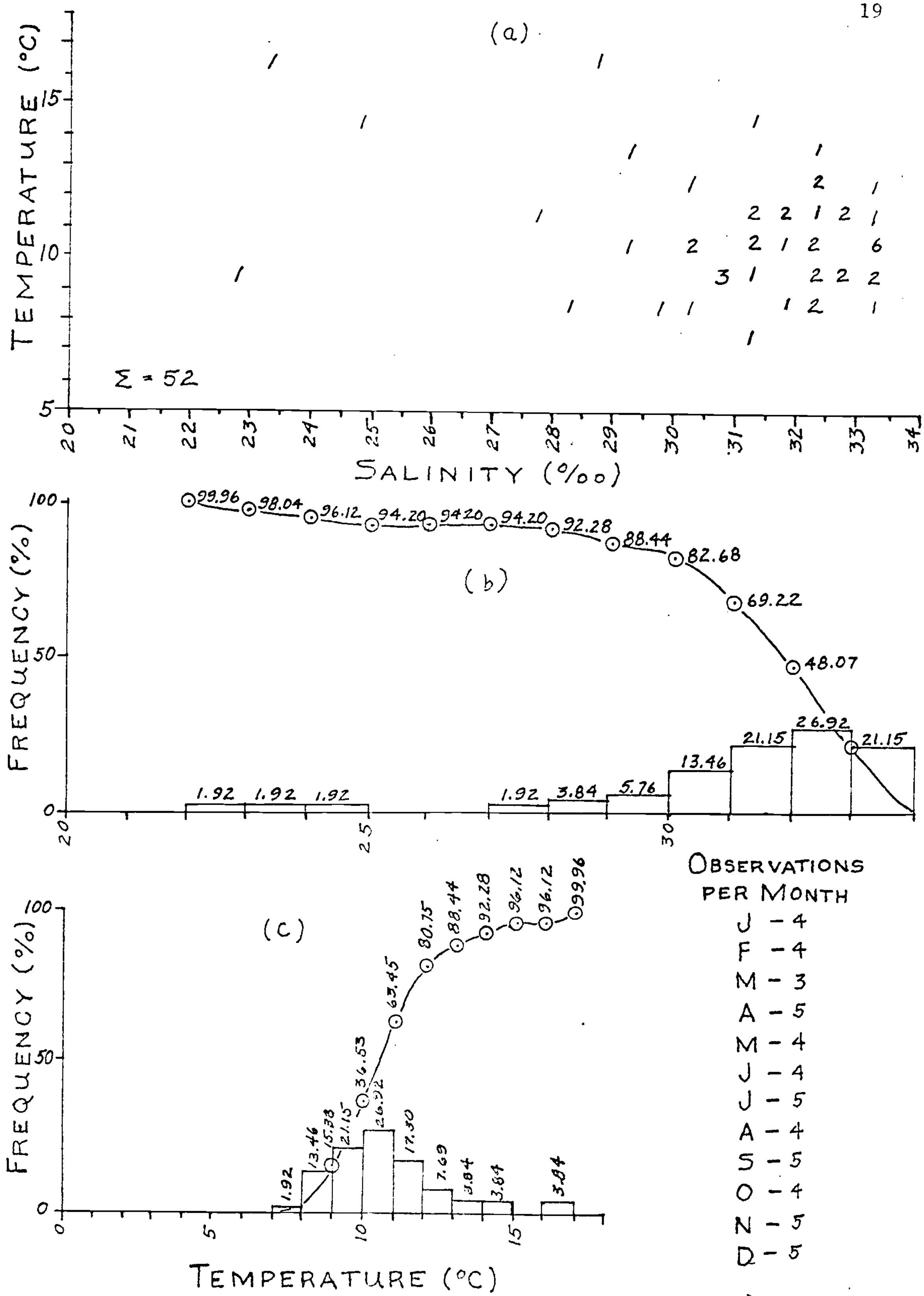
The USCGS observations are not considered to be as accurate as OSU regular observations. Therefore, the data from all USCGS stations are combined, forming one distribution. As salinities less than 20 o/oo occur in the ocean, only on rare occasions they are neglected in consideration of these data. Figure 11 shows the distribution of these data.

In Figure 12 are distributions for offshore surface observations taken during 1961. All the 264 observations were taken within 25 miles from shore. The latitudinal range for these observations is from 41°00'N to 46°30'N.

Figures 13a and 13b are T-S distributions for OSU special stations. Further analysis was notcarried out because of the seasonal limitation of these data. Figure 13a is the distribution of observations taken at Oceanlake, while 13b is the distribution for Newport.

Figure 3. The frequency distribution of surface water characteristics observed at all OSU coast stations in 1961.
(a) bivariant distribution of temperature and salinity
(b) frequency and cumulative frequency distribution of salinity
(c) frequency and cumulative frequency distribution of temperature


(a)
TEMPERATURE (°C)
Σ = 274
SALINITY (°/oo)
(b)
FREQUENCY (%)
99.97
99.61
99.25
98.52
98.16
96.34
96.34
96.34
95.61
90.14
81.75
67.52
45.62
27.37
0.36
0.36
0.73
0.36
1.82
0.73
5.47
8.39
14.23
21.90
18.25
(c)
FREQUENCY (%)
TEMPERATURE (°C)
OBSERVATIONS PER MONTH
J - 27
F - 22
M - 23
A - 23
M - 29
J - 20
J - 19
A - 23
S - 21
O - 25
N - 21
D - 21


(a)
TEMPERATURE (°C)
SALINITY (‰)
Σ = 52
(b)
FREQUENCY (%)
99.96 98.04 96.12 94.20 94.20 94.20 92.28 88.44 82.68 69.22 48.07
1.92 1.92 1.92 1.92 3.84 5.76 13.46 21.15 26.92 21.15
(c)
FREQUENCY (%)
1.92 13.46 15.38 21.15 36.53 26.92 63.45 17.30 80.75 88.44 92.28 96.12 96.12 99.96 7.69 3.84 3.84 3.84
TEMPERATURE (°C)
OBSERVATIONS PER MONTH
J - 4
F - 4
M - 3
A - 5
M - 4
J - 4
J - 5
A - 4
S - 5
O - 4
N - 5
D - 5

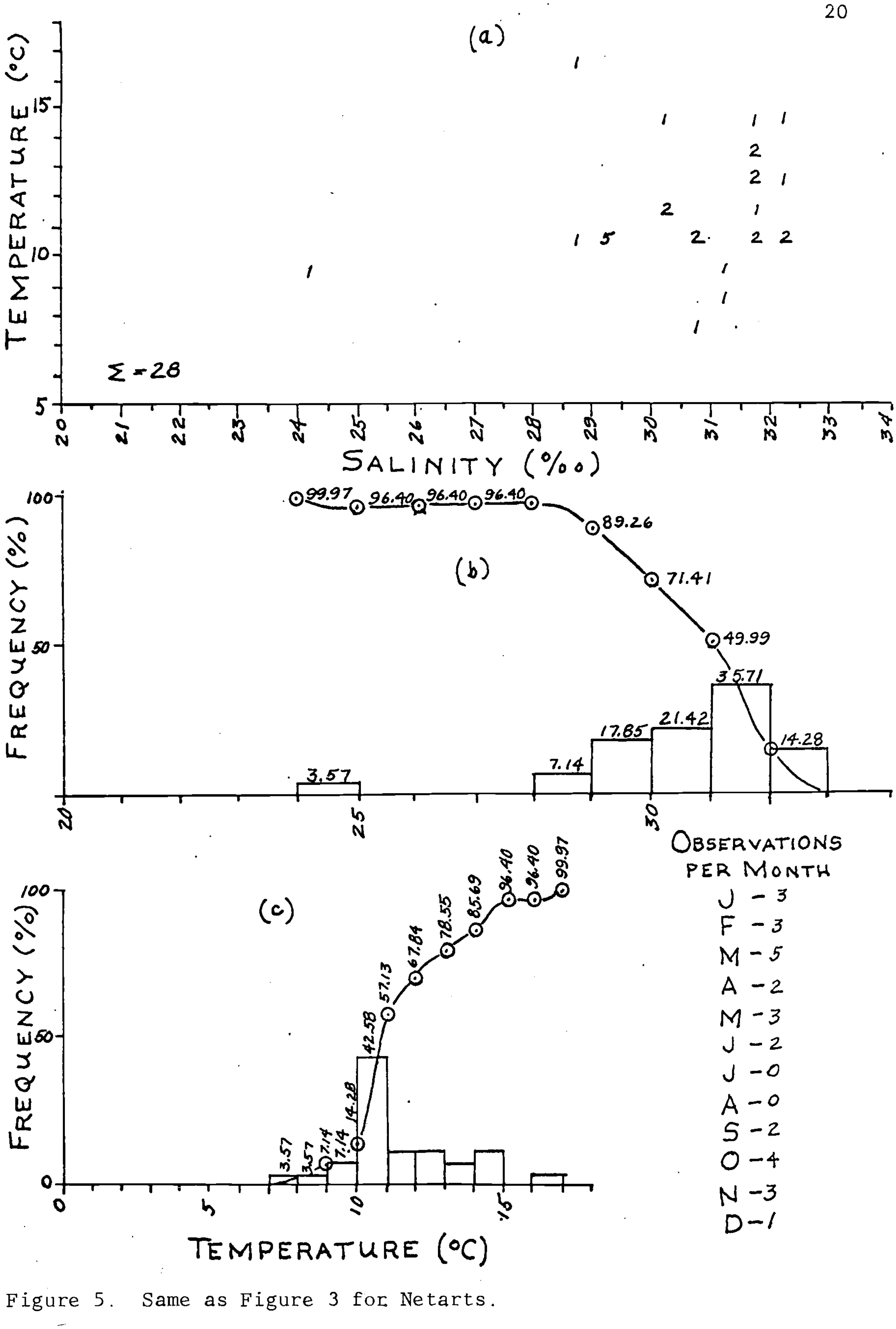


Figure 5. Same as Figure 3 for Netarts.

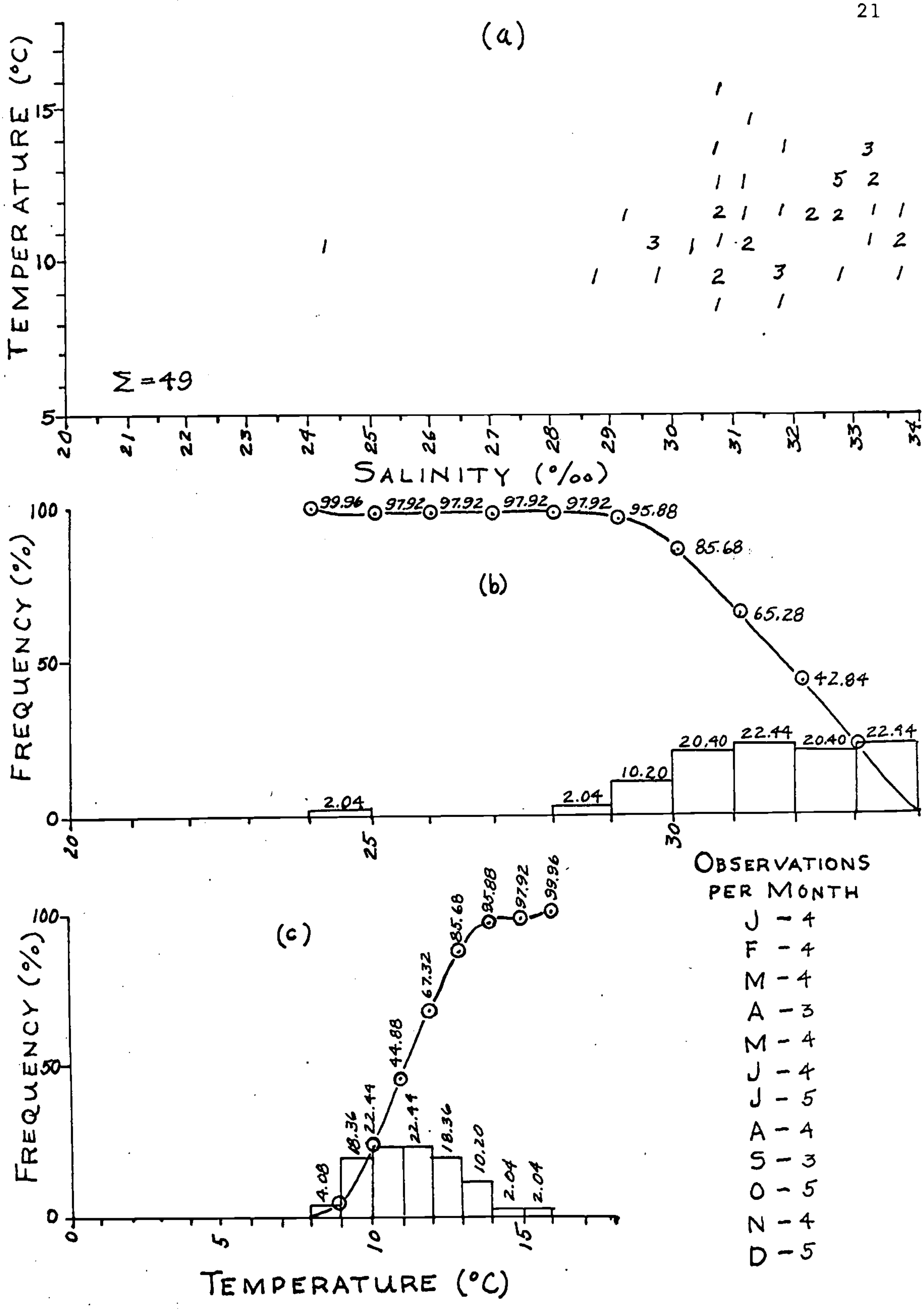


Figure 6. Same as Figure 3 for Otter Rock.

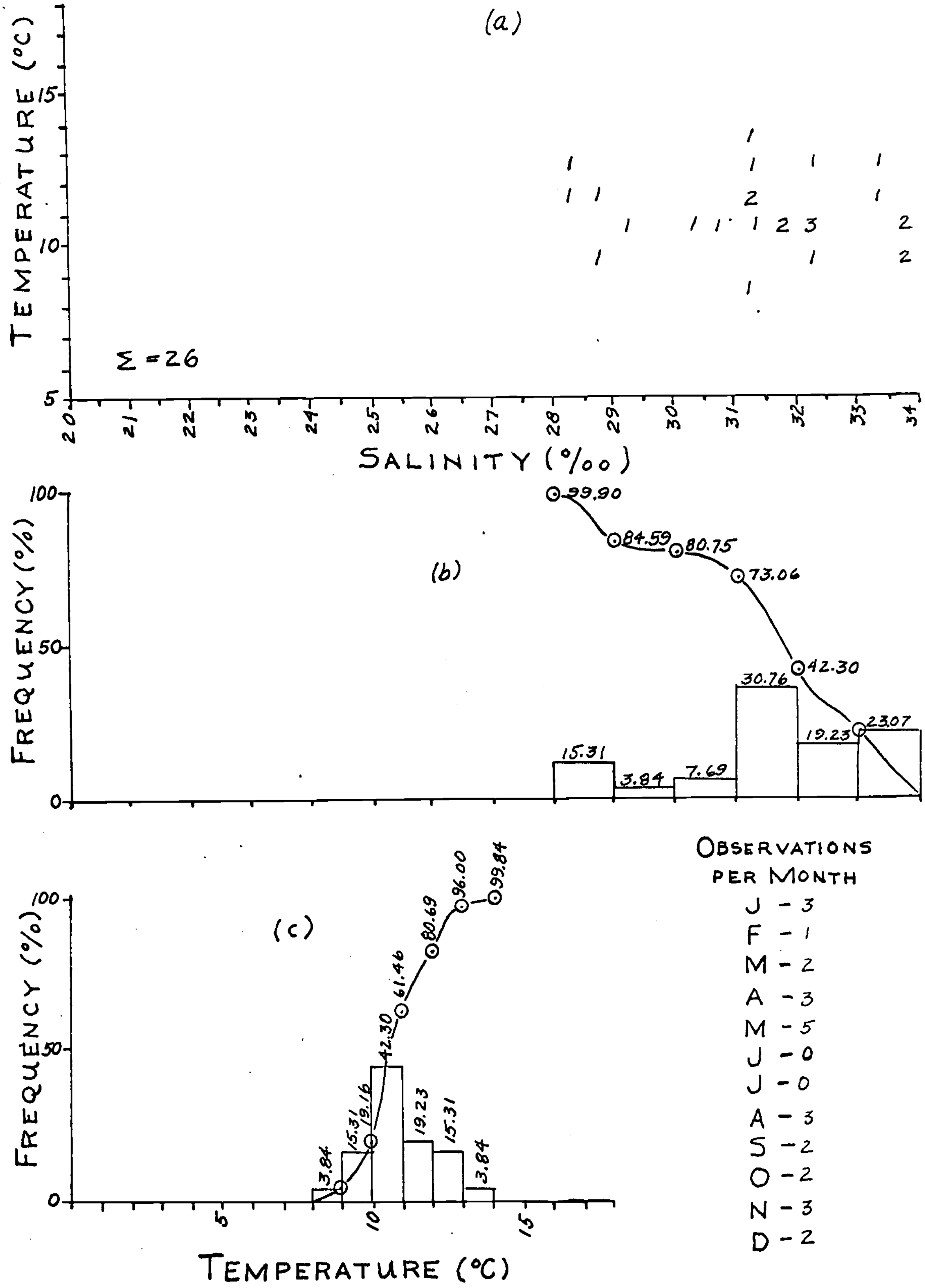


Figure 7. Same as Figure 3 for Yachats.

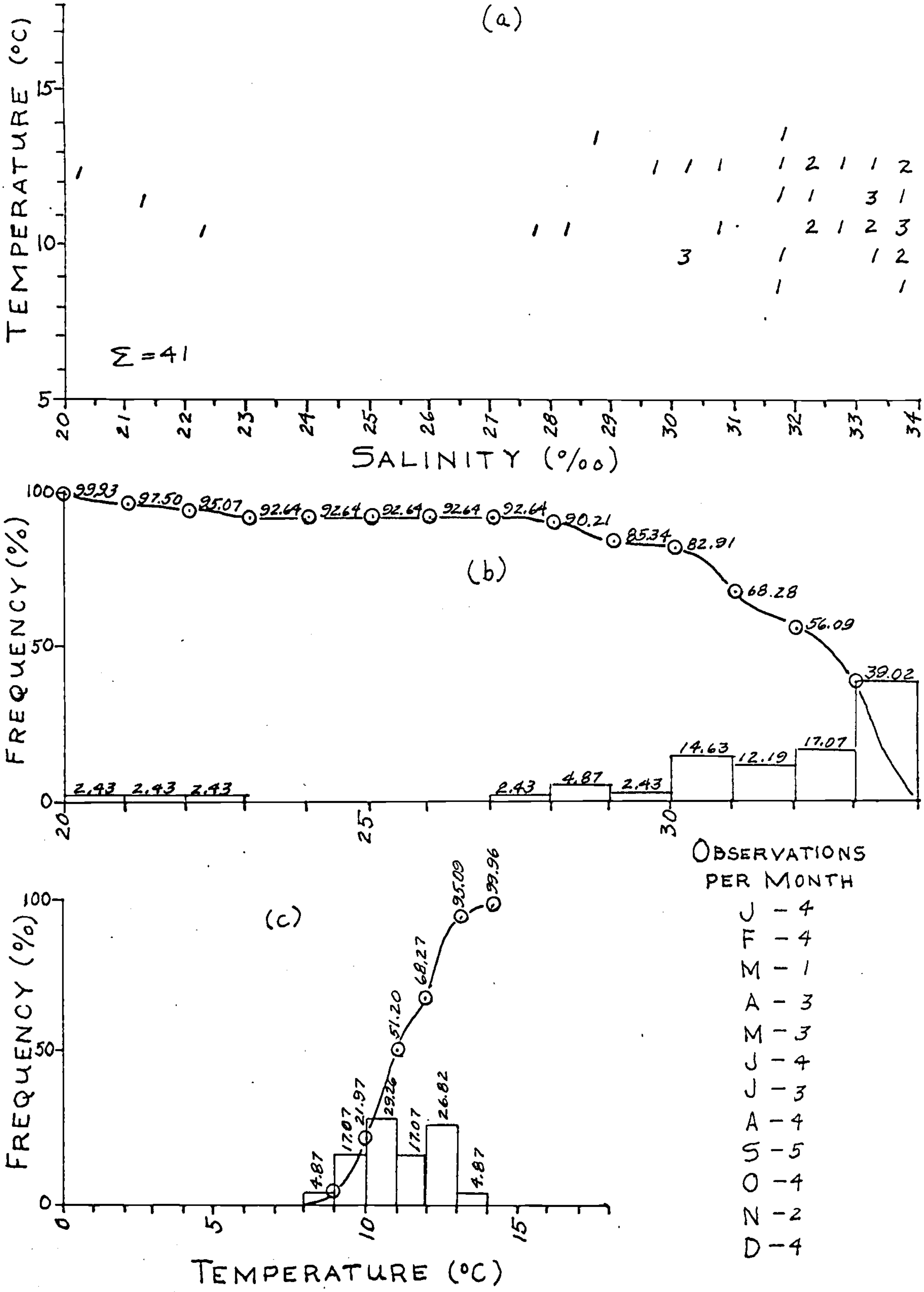


Figure 8. Same as Figure 3 for Bandon.

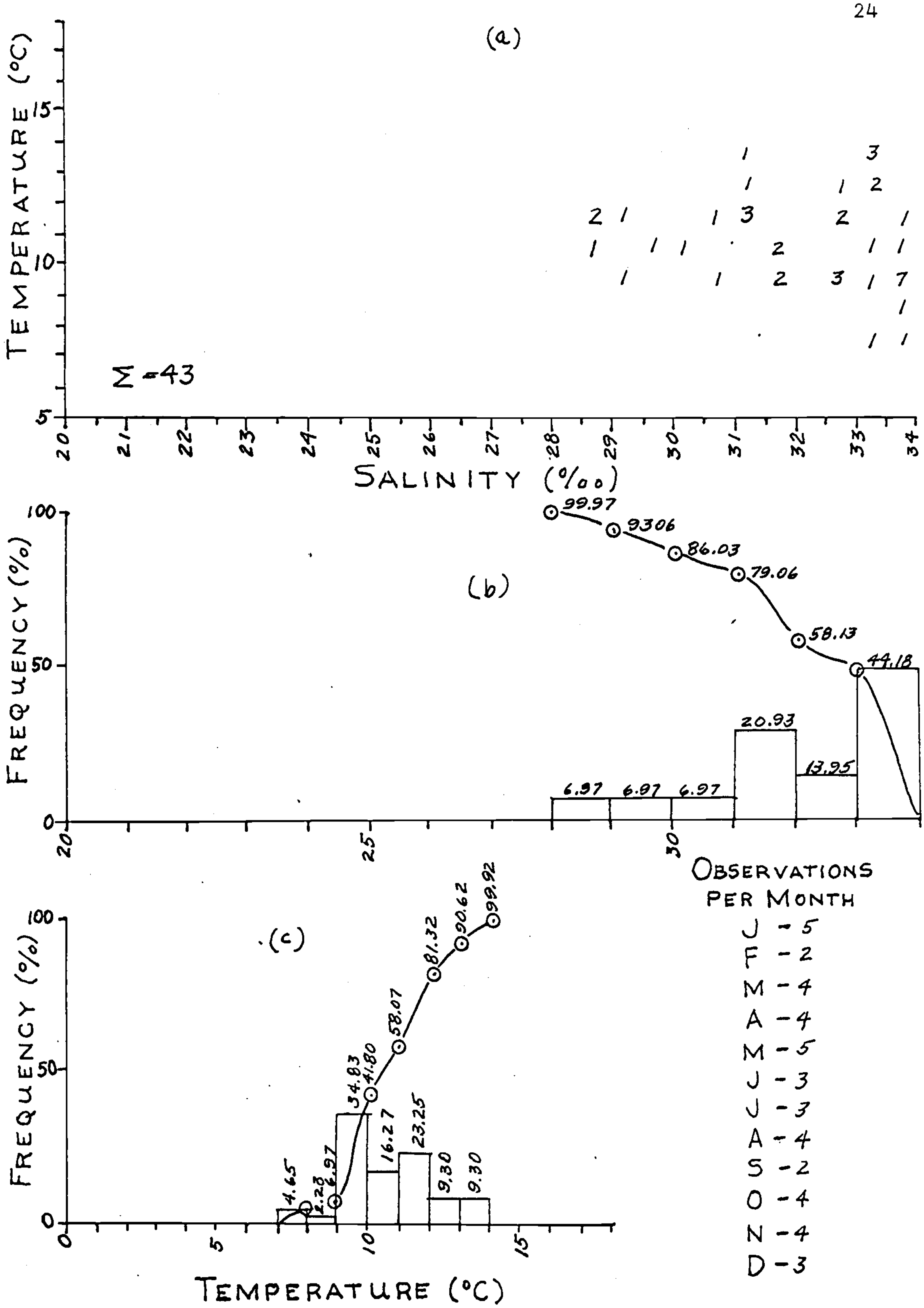


Figure 9. Same as Figure 3 for Humbug.

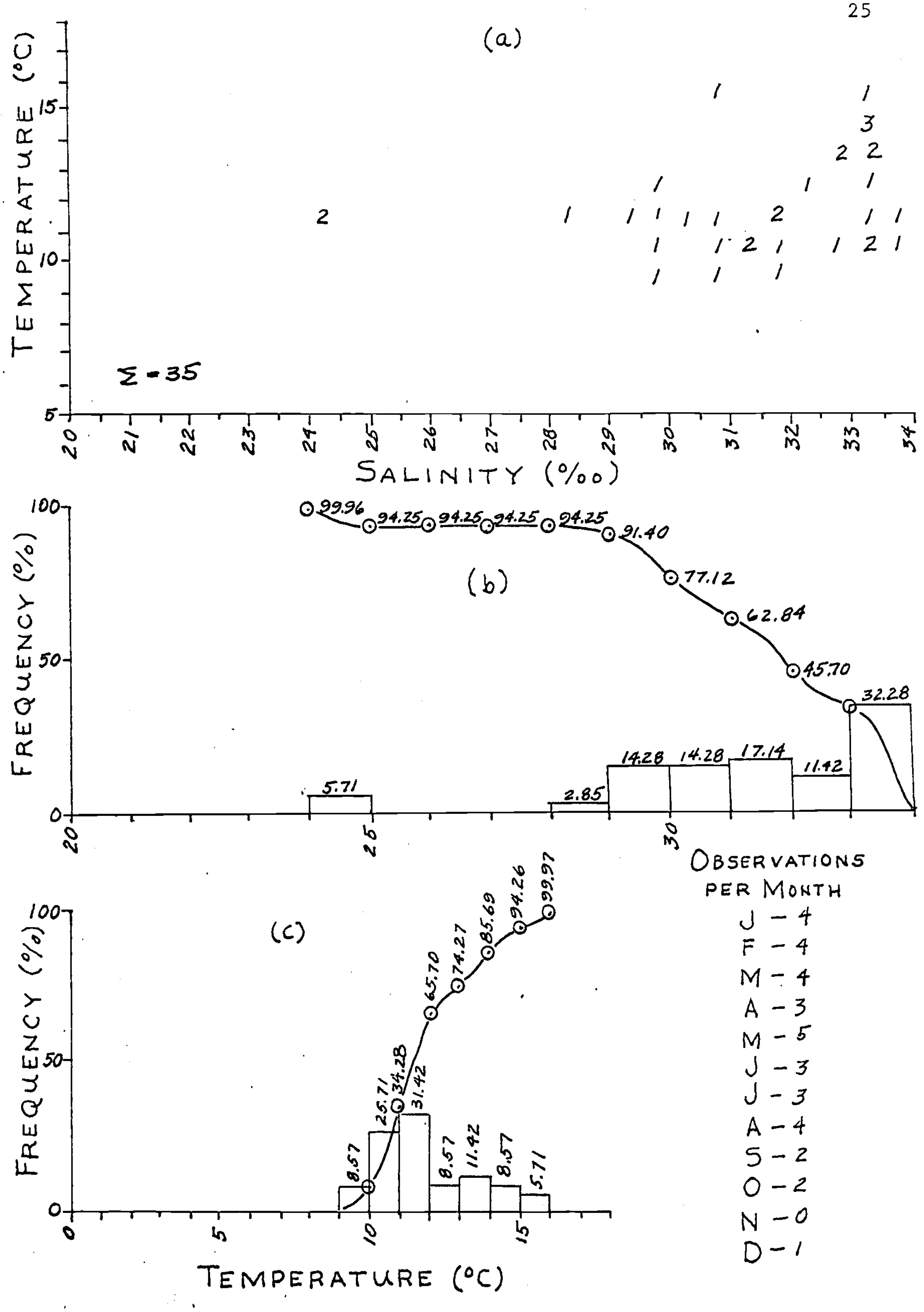


Figure 10. Same as Figure 3 for Brookings.

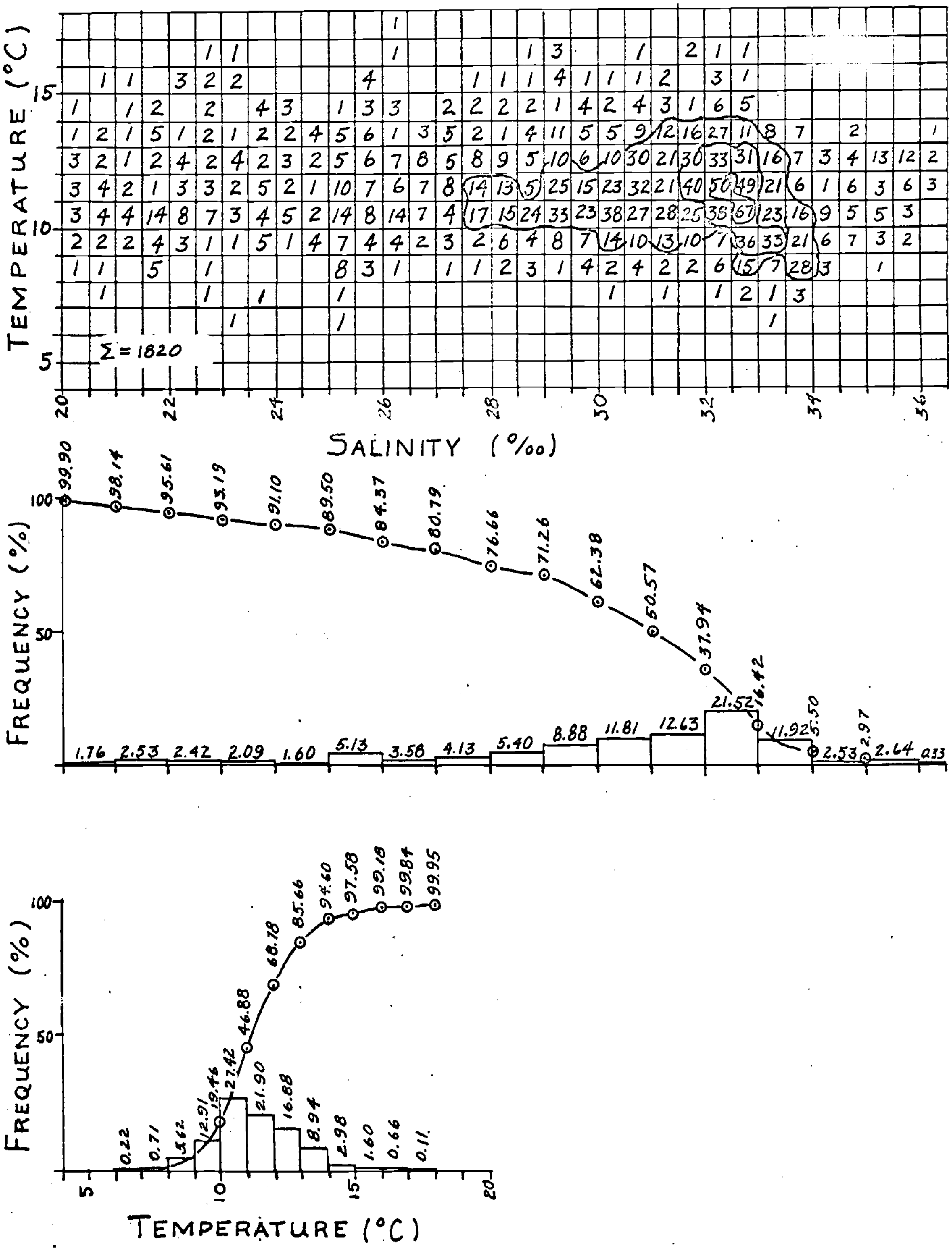


Figure 11. Same as Figure 3 for all USCGS coast stations.

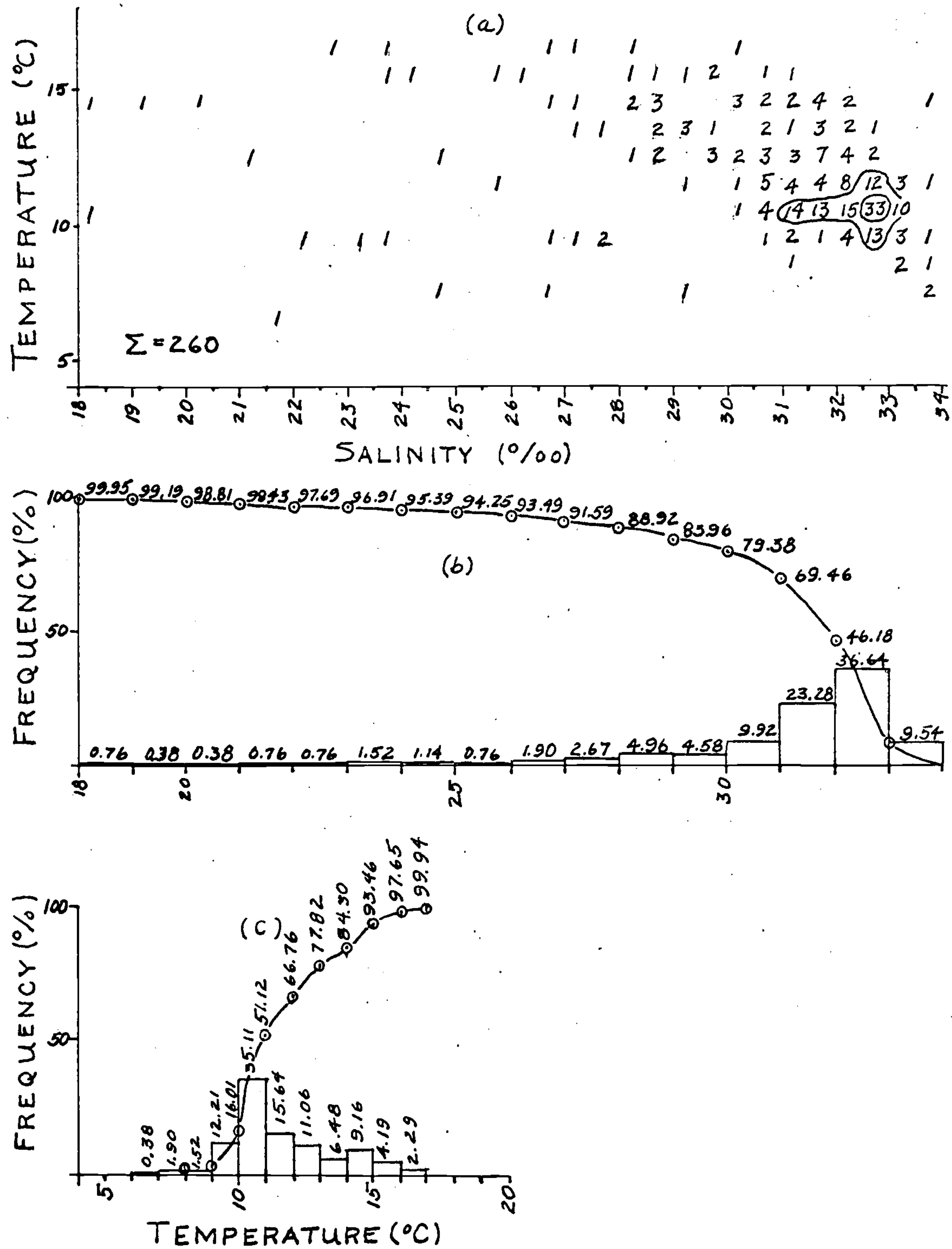


Figure 12. Same as Figure 3 for surface water characteristics within 25 miles off Oregon coast in 1961 (38, p. 18-21 and unpublished data taken on hydrographic cruises of the R/V ACONA and BROWN BEAR).

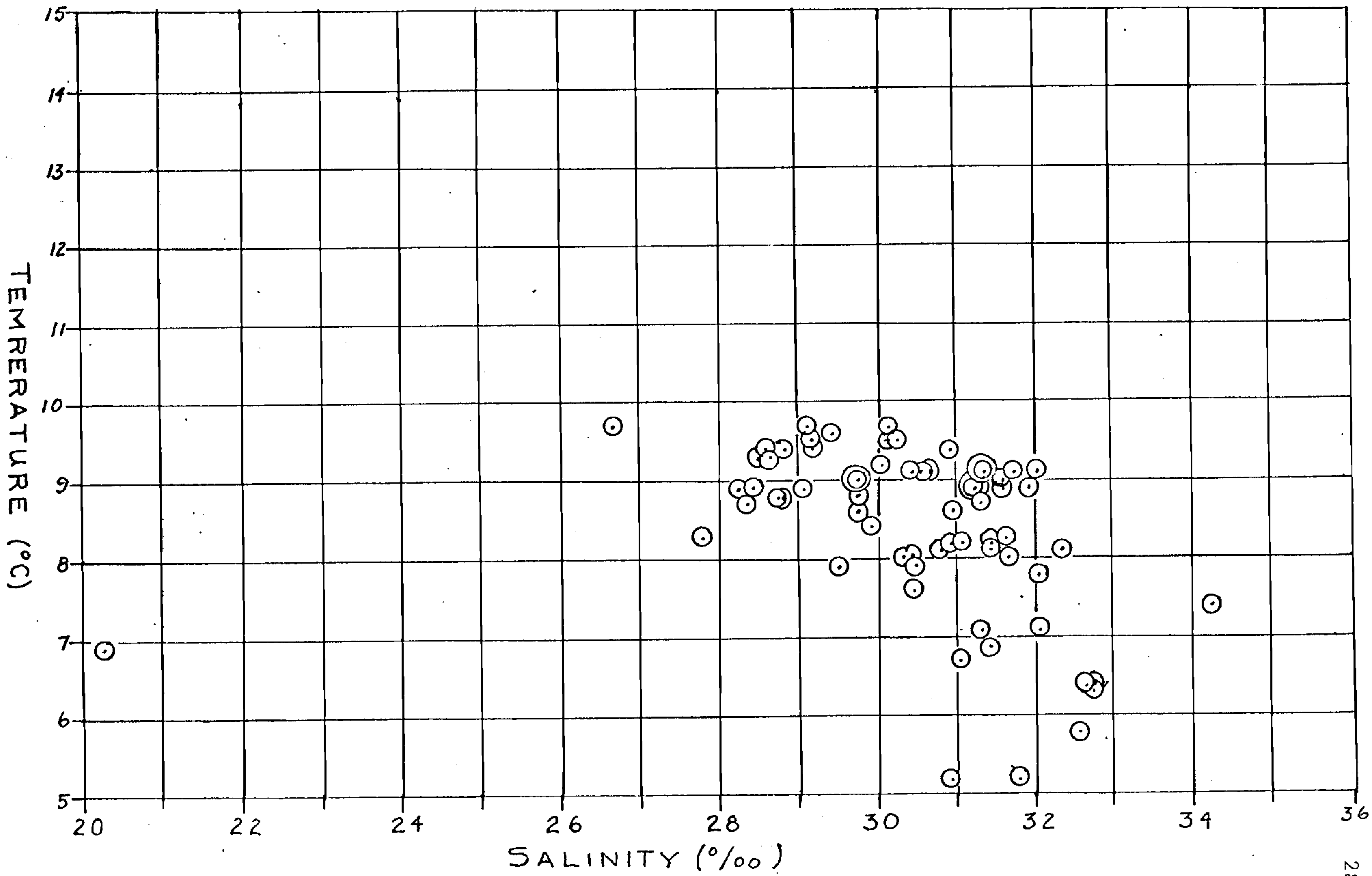


Figure 13a. The frequency distribution of surface water characteristics at Oceanlake during December 1961, February 1962, and January 1962.

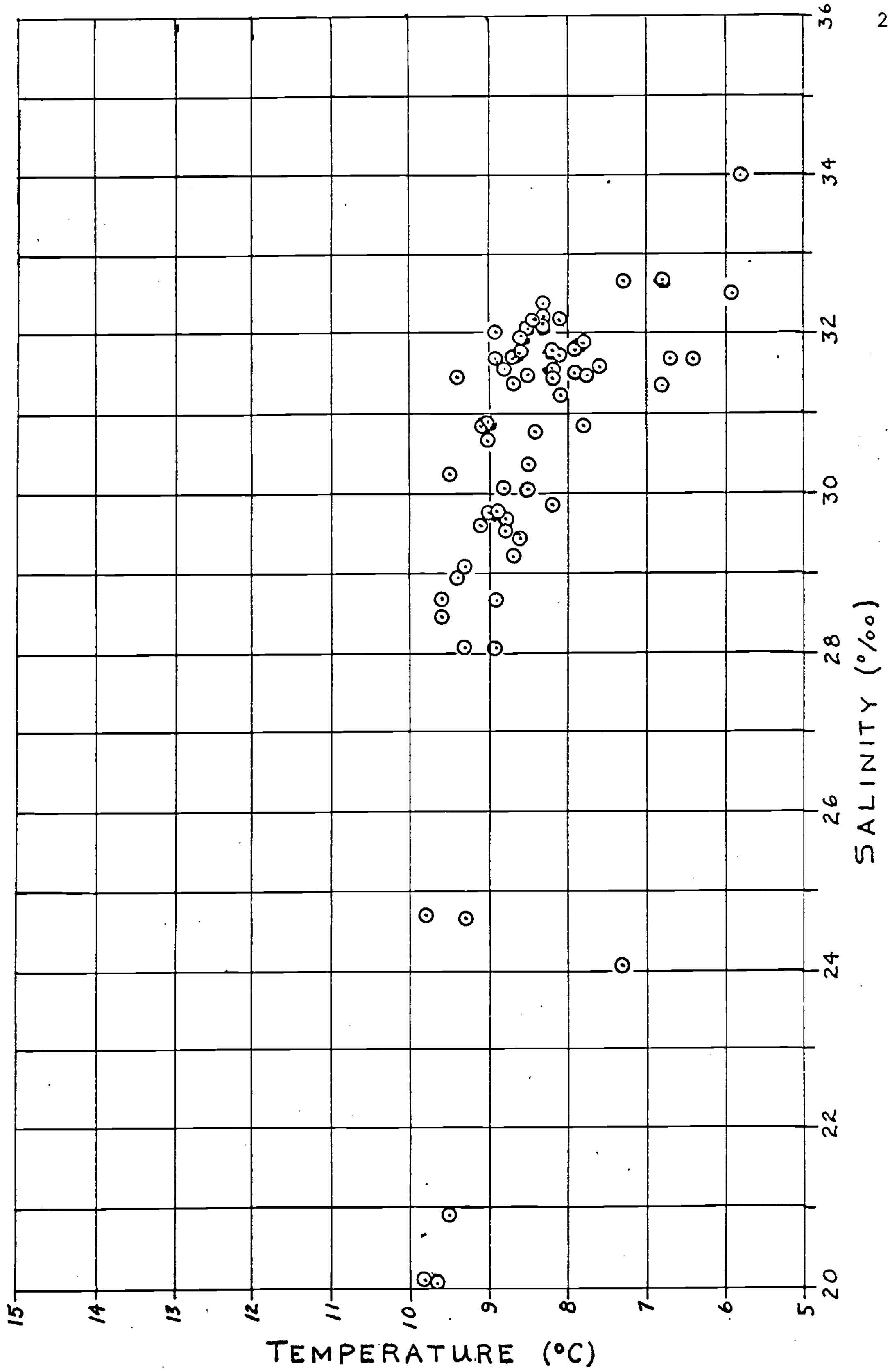


Figure 13b. Same as Figure 13a for Newport.

THE RESULTS

The Statistical Features of the OSU Distributions

Consider first the distributions in Figure 3 which represents the average for all OSU stations. The bivarient distribution is shown in part (a). The observations cluster at higher salinities. The highest number of observations to occur in a single cell is 12 and this occurred in two cells. These cells are bound by the temperature intervals between 9°C and 11°C and the salinity intervals between 33 o/oo and 34 o/oo. No marked correlation is evident between the two variables. There is some slight tendency toward negative correlation, but this is too weak to justify detailed statistical analysis.

In part (b) the frequency, in general, increases toward higher salinity, reaching a maximum in the interval 33-34 o/oo. No salinities greater than 34 o/oo were observed at any OSU stations. However, the distribution is quite flat from 31 o/oo to 34 o/oo. A few very low salinities were observed.

In the cumulative frequency curve in part (b) over two-thirds of the observations occurred between 31 o/oo and 34 o/oo.

In Figure 3c is the temperature distribution. This distribution is much more "normal" than is the salinity distribution, but is skewed slightly toward higher values. The mode occurs in the 10-11°C class interval.

From the cumulative temperature curve we note that about

81 percent of the observations occur in the class intervals between 9°C and 13°C. No temperatures less than 7°C or greater than 17°C were observed.

The distributions in Figures 4 through 10 for the individual stations differ markedly, in some cases, from the mean.

At Arch Cape (Figure 4) the highest salinity observed was between 33 o/oo and 34 o/oo and the mode occurs between 32 o/oo and 33 o/oo. The temperature distribution is almost indistinguishable from the average (Figure 3c).

At Netarts (Figure 5) no salinities greater than 32.5 o/oo were observed. The mode occurs between 31 o/oo and 32 o/oo. The temperature mode occurs in the same interval as in the average distribution, but the Netarts distribution is more sharply peaked. This may be due to the small sample.

The distribution at Otter Rock (Figure 6) is almost identical to the mean distribution.

At Yachats (Figure 7) a surprising trimodal salinity distribution occurs. This is undoubtedly due in part to the small size of the sample. There were only 26 observations recorded. However, exposure may also be a factor and this will be discussed in the next section. No temperatures above 14°C were recorded at this station.

At Bandon (Figure 8) the salinity distribution is strongly peaked at high values. Thirty-nine percent of the observations had salinities between 33 o/oo and 34 o/oo. Again at this station, as at Yachats, no temperatures above 14°C were observed. There was a total of 41 observations, evenly distributed throughout the year.

Of all the stations, Humbug (Figure 9) has the highest percentage of salinities in the highest class interval (44 percent). No salinities were observed below 28 o/oo. The temperature mode lies in the interval one degree lower than that of the average distribution or any of the other stations (9-10°C).

At Brookings (Figure 10) the salinity distribution is similar to the mean, but with a higher percentage between 33 o/oo and 34 o/oo. The temperature mode occurs one degree higher than the mode in the mean distribution. In addition, no temperatures below 9°C were observed.

The number of observations at the individual stations varies from a minimum of 26 at Yachats to a maximum of 52 at Arch Cape. The total number of observations are shown in each figure at the lower left hand corner of the T-S distribution. As we would expect, the larger the number of observations the "smoother" the frequency distribution. Both Netarts and Yachats with less than 30 observations show a marked unevenness, while Arch Cape, Otter Rock, Humbug, and Bandon, with more than 40 observations show more regular distributions.

Some sharp differences have been noted among the distribution curves for the individual coast stations. The question arises whether or not these stations are all sampling the same population.

The χ^2 Test for Homogeneity of Oregon Coastal Waters

That some of the stations do differ markedly is evident from the frequency distributions. However, the computation of a statistic showing that this difference is real is appropriate. The statistic selected to examine this is the χ^2 test for independence (12, p. 410). This test determines (to a selected level of confidence) whether or not a group of samples are taken from a homogeneous population.

To perform this test the frequencies in all the class intervals are formed in an array with the stations. The array of temperature frequencies for each of the OSU regular stations is shown in Table 2. Also, included in the table are the hypothetical frequency and the computed χ^2 for each cell. These two quantities are computed from the following formulas:

$$\text{Hypothetical frequency} = \frac{\text{row total x column total}}{\text{grand total}}$$

$$\chi^2 = \sum^{rc} \frac{(\text{observed frequency - hypothetical frequency})^2}{\text{hypothetical frequency}}$$

The total χ^2 for the distribution is the sum of the χ^2 contributions from all the cells.

The results of this computation gives a χ^2 of 58.36 for the temperature distribution. The number of degrees of freedom in this computation is given by the number of rows minus one, multiplied by the number of columns minus one. In this case the number of degrees of freedom in the distribution are 36. In the χ^2 table 36 degrees of freedom has a 5 percent confidence level of 50.96 (12, p. 518). This indicates that the stations are indeed not sampling the same population, at least the probability is less than 5 percent that they are.

Station	Frequency 8	9	10	11	12	13	14	15	Σ
Arch Cape	Observed	8	11	14	9	4	2	4	52
	Hypothetical	3.42	9.68	14.42	10.63	7.21	3.80	2.85	52.01
	χ^2	6.15	0.18	0.01	0.25	1.43	0.8	0.47	9.34
Netarts	Observed	2	2	12	3	3	2	4	28
	Hypothetical	1.84	5.21	7.77	5.72	3.88	2.04	1.53	27.99
	χ^2	0.01	1.98	2.31	1.30	0.20	0.00	3.97	9.77
Otter Rock	Observed	2	9	11	11	9	5	2	49
	Hypothetical	3.22	9.12	13.59	10.02	6.80	3.58	2.68	49.01
	χ^2	0.46	0.00	0.49	0.10	0.72	0.57	0.17	2.51
Yachats	Observed	1	4	11	5	4	1	0	26
	Hypothetical	1.71	4.84	7.21	5.31	3.61	1.90	1.43	26.01
	χ^2	0.29	0.14	2.00	0.02	0.04	0.42	1.43	4.34
Bandon	Observed	2	7	12	7	11	2	0	41
	Hypothetical	2.70	7.63	11.32	8.38	5.69	2.99	2.24	40.95
	χ^2	0.18	0.05	0.04	0.23	4.97	0.33	2.24	8.03
Humbug	Observed	3	15	7	10	4	4	0	43
	Hypothetical	2.82	8.00	11.93	8.79	5.96	3.14	2.35	42.99
	χ^2	0.01	6.12	2.03	0.17	0.65	0.24	2.35	11.56
Brookings	Observed	0	3	9	11	3	4	5	35
	Hypothetical	2.30	6.52	9.71	7.15	4.85	2.56	1.92	35.01
	χ^2	2.30	1.90	0.05	2.07	0.71	0.82	4.96	12.80
	$\Sigma \chi^2$	9.41	10.37	6.93	4.12	8.74	3.22	15.60	58.36

TABLE 2. χ^2 computation for temperature.

The same analysis can be applied to the salinity frequency distributions. We cannot assume without analysis that the salinity distribution should not show independence, just because the temperature distribution gave a nonconfidence result for independence. The array of observed frequencies, hypothetical frequencies, and individual cell χ^2 computations are shown in Table 3 for the salinity distributions. In this computation of χ^2 there is a 6 by 7 array of cells leading to a value with 30 degrees of freedom. Because of a low observed frequency in class intervals below 29 o/oo, the observations below this level were combined forming one class for the χ^2 computation. At the 5 percent confidence level for 30 degrees of freedom the χ^2 value is 43.77 (12, p. 518). From Table 3 a χ^2 of 41.76 is attained for the salinity distribution. This is only slightly less than the 5 o/oo value from the χ^2 table for 30 degrees of freedom. This indicates that the salinity population sampled at the coast stations is homogeneous at the 5 percent level as far as we can determine from the data. It is not homogeneous at the 7.5 percent confidence level. A larger sample of data is needed to improve the reliability of the results. At this time this is not available.

Many interesting features of the χ^2 tables (Tables 2 and 3) can be noted. Cells contributing high χ^2 values are found at Arch Cape, Netarts, Bandon, Humbug, and Brookings. Otter Rock and Yachats make much smaller χ^2 contributions to the total χ^2. The interesting features of these arrays are discussed in the following section of this thesis.

Station	Frequency	29	30	31	32	33	34	Σ
Arch Cape	Observed	6	3	7	11	14	11	52
	Hypothetical	5.12	4.36	7.40	11.39	9.49	14.23	51.99
	χ^2	0.15	0.42	0.02	0.01	2.14	0.73	3.47
Netarts	Observed	3	5	6	10	4	0	28
	Hypothetical	2.76	2.35	3.99	6.13	5.11	7.66	28.00
	χ^2	.02	2.99	1.01	2.44	.24	7.66	14.36
Otter Rock	Observed	2	5	10	11	10	11	49
	Hypothetical	4.83	4.11	6.97	10.73	8.94	13.41	48.99
	χ^2	1.66	.19	1.32	.01	.13	.43	3.74
Yachats	Observed	4	1	2	8	5	6	26
	Hypothetical	2.56	2.18	3.70	5.69	4.74	7.12	25.99
	χ^2	.81	.64	.78	.94	.01	.18	3.36
Bandon	Observed	6	1	6	5	7	16	41
	Hypothetical	4.04	3.44	5.84	8.98	7.48	11.22	41.00
	χ^2	.95	1.73	.01	1.76	.03	2.04	6.52
Humbug	Observed	3	3	3	9	6	19	43
	Hypothetical	4.24	3.61	6.12	9.42	7.85	11.77	43.01
	χ^2	.36	.10	1.59	.02	.44	4.44	6.95
Brookings	Observed	3	5	5	6	4	12	35
	Hypothetical	3.45	2.94	4.98	7.66	6.39	9.58	35.00
	χ^2	.06	1.44	.00	.36	.89	.61	3.36
	$\Sigma \chi^2$	4.01	7.51	4.73	5.54	3.88	16.09	41.76

TABLE 3. χ^2 computation for salinity.

The Statistical Features of the USCGS Distributions

The distribution of temperature and salinity observations at the USCGS tide gauge stations listed in Table 1 are shown in Figure 11. Since in this study only oceanic conditions are of interest, only observations with salinities greater than 20 o/oo are included in this distribution. Due to the estuarine location of these stations many values below this limit were recorded. However, the values above 20 o/oo are seen to cluster around higher salinities as is shown in part (a) of Figure 12. The highest frequency cells occur at lower salinity and higher temperatures than the high frequency cells in the OSU data.

Salinity values greater than 36 o/oo were recorded in this data. The salinity distribution (Figure 11b) has a single mode between 32 o/oo and 33 o/oo.

The temperature frequency distribution (Figure 11c) is slightly skewed toward lower temperatures. The mode occurs in the interval 10°C to 11°C, this interval containing greater than 27 percent of the observations.

The Statistical Features of the Offshore Distribution for 1961

The T-S distribution of offshore observations within 25 miles off the coast are shown in Figure 12. The highest frequency cell in this distribution is found between 10°C and 11°C and 32.5 o/oo and 33 o/oo. There are 33 observations in this cell and the next highest cell frequency is only 15. The observations again cluster around higher salinities.

The salinity distribution has a sharp peak between 32 o/oo and 33 o/oo with greater than 36 percent of the observations in this interval. Only a few values are found in the 33 o/oo to 34 o/oo interval. The salinity distribution is skewed toward lower salinity.

The temperature distribution is also sharply peaked in the class interval 10°C and 11°C. This interval contains about 35 percent of the observations. The distribution is skewed toward higher temperature.

<u>The Distribution of Daily Observations at Oceanlake and Newport</u>

The T-S distributions of daily observations at Oceanlake and Newport are shown in Figures 13a and 13b respectively. In these distributions the tendency toward negative correlation is more prominent. However, large variability is observed. The observations at both stations group around the same area of the plot. The majority of the salinities are found between 28 o/oo and 32 o/oo. Some very low temperatures were recorded in these diagrams. In general the low temperatures are associated with high salinities. This is an important point and will be discussed in the next section of this thesis.

DISCUSSION

The major statistical features of the distribution of temperature and salinity off the Oregon coast have been described in the previous section. In summary, the salinity distribution is highly skewed toward low values. The largest percentage always occurred at high salinities with a sharp cutoff at 34 o/oo. The temperatures are quite uniform in space and time. The χ^2 computations show that at least some of the differences between stations are real. Any attempt to explain these features requires knowledge of oceanic conditions occurring along this coast.

The most important factors influencing the temperature and salinity of water sampled at coast stations are the local climatological and oceanic conditions. The lithosphere, of course, influences both of these conditions. The oceanic conditions influencing coast station waters will be discussed first.

The General Oceanography of the Northeast Pacific

Oceanic circulation is a primary factor determining the water found at stations along the open coast. For this study the circulation can be discussed on the basis of size and persistence. Much of the water found off the Oregon coast has characteristics it acquired in other areas of the Pacific Ocean. The general areas of water mass and type formation have been reasonably well studied and charted for the Northeast Pacific Ocean.

Three separate water masses are believed to exist in the eastern North Pacific: Equatorial Pacific (EP); Eastern North Pacific Central (ENPC); and Subarctic North Pacific (SANP) (23, p. 740). Areas occupied by these water masses are shown in Figure 14. Only two of

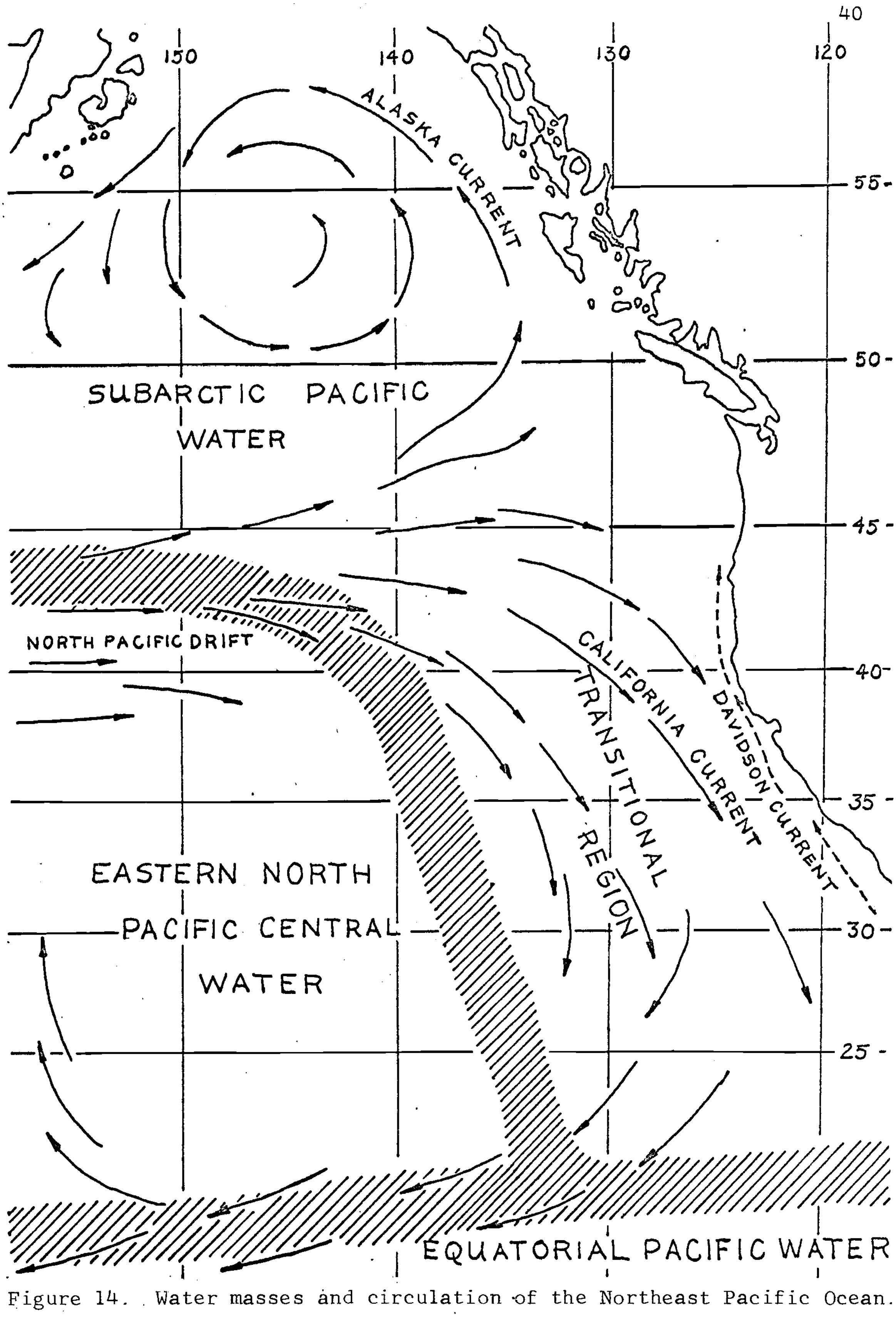


Figure 14. Water masses and circulation of the Northeast Pacific Ocean.

these water masses are believed to make major contributions to the waters off the Oregon coast, forming a "transitional zone" (23, p. 740). The two major water masses are the EP and the SANP, with the major contributor being the latter, especially in the upper layers of the sea.

SANP is found in the North Pacific at latitudes greater than 45°N, from North America to Asia. This water is very cold with winter surface temperatures as low as 2°C. The salinity in the surface waters may be as low as 32.0 o/oo.

EP is found in the North Pacific extending north to about latitude 20°N. EP extends completely across the Pacific Ocean from Central and South America. This water mass is very warm with temperatures greater than 17°C in the surface layers. It is also characterized by high salinities, which may be greater than 35.0 o/oo.

The major features of the large scale circulation in the northeast Pacific are also shown in Figure 14. The most important contribution to the surface water supply off the Oregon coast is provided by the North Pacific Drift. This is a current flowing east about latitude 40°N. When this current approaches the North American continent it divides, with a portion passing north as the Alaska Current and a portion passing south as the California Current. The water transported south by the California Current is mainly SANP. It is believed that there is a counter current, at depth, of EP water (23, p. 726-727). Mixing between the two currents leads to the formation of water found in the transitional zone (20, p. 41). Many other processes operate to modify the waters of the transitional zone, particularly in the surface layers. These are the smaller scale features of the circulation, and the local meteorological conditions. Little research on these features has been conducted, yet what is known is very important to this study.

The Currents Along the Oregon Coast

The California Current flows during all seasons of the year, off the Oregon coast. Sverdrup characterizes this current as a wide body of water moving sluggishly to the southeast along the west coast of North America (23, p. 724). It extends from the coast to about 700 kilometers offshore. In a study of coastal oceanography the smaller scale currents found near the shore must also be considered.

Sverdrup describes a current which is observed to flow north nearshore, counter to the California Current, during the fall and winter of the year (23, p. 725-726). This current is known as the Davidson Current. Its months of prominence are November, December, and January, while the limit of northerly circulation is about 48°N (23, p. 726-727). Thus, during the winter months, the Davidson Current, along with the subsurface counter current, forms a nearshore northward flow which exists all the way from the surface to the bottom. During spring and early summer inshore currents become southerly and are accompanied by intense "upwelling" at certain regions along the coast.

We must note that Sverdrup's discussion of the seasonal changes apply to the California coast. The conditions can be expected to be somewhat different along the Oregon coast.

Study of the nearshore currents was begun by the Department of Oceanography, Oregon State University, in 1959. The data indicate that the flow is highly variable. This is particularly true in the surface layers.

Summaries of ship's drift from many years of observations indicate currents similar to those inferred from drift bottle returns (29, p. 1-12; 32, p. 26-27). The observations show a seasonal reversal of the north-south circulation pattern near the Oregon coast. However, observations indicate that the offshore or onshore components may also be significant.

As offshore currents move on to the continental shelf, the effects of shoaling and irregular topography cause considerable changes in their velocity, both in speed and in direction (5, p. 428-431). Upon the continental shelf the vertical extent of the current may approach the depth of the water. When this occurs the bottom will exert frictional stresses on the current. Furthermore, the depth of the bottom seldom decreases uniformly as the shore is approached. The effect of of irregular topography on the nearshore currents is to cause a wide variety of flow patterns. For example, Liepper (11, p. 234-252) studying variations in surface temperatures related to the passage of tidal currents in an irregular shoaling area, concluded that parts of the current break up to form vorticies. The vorticies then moved up or down the nearshore region in response to the prevailing nearshore currents.

The Hydrography of Oregon Coastal Waters

Characteristics of the water in the transitional zone off the coast of Oregon has been studied by the Department of Oceanography of Oregon State University since 1958. The data collected have yielded considerable information of conditions in the upper 200 meters of water (33, p. 1-77). Only a brief description of the prevailing conditions will be given here.

The temperature at the surface varied from a low of 7°C in the winter to a high of 17°C in the summer. The salinity at the surface varied from 31.0 o/oo in the winter to 33.5 o/oo in the summer. The distribution of temperature and salinity with depth show marked variation with season in this layer. These changes are illustrated in Figures 15a and 15b for the months of September, 1960 and January, 1961, respectively. Many important features can be noted in these figures. First, a change occurs in the slope of the isotherms and isohalines between the two months represented. During the winter these lines slope down toward the coast. Second, the waters in the upper layers are relatively homogeneous in the winter. This is not the case in the month of September, where the temperature decreases and the salinity increases markedly as the coast is approached.

Within the body of the oceans, temperature and salinity are considered conservative properties (23, p. 158). Therefore, the upward slope of the isotherms and isohalines toward the shore in the summer

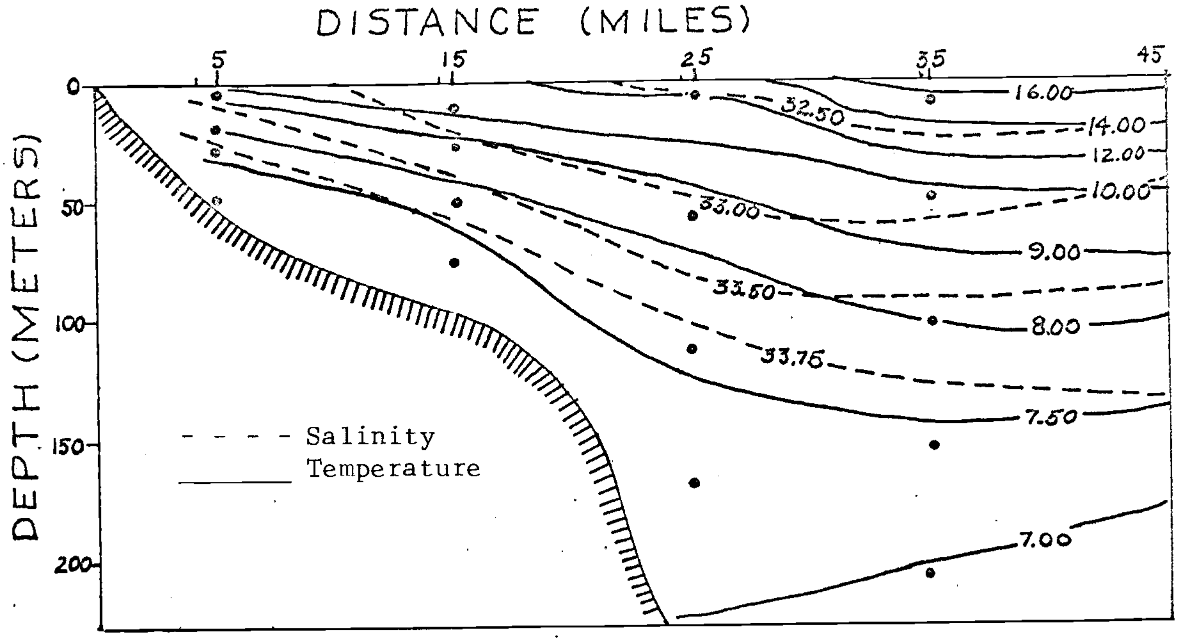


Figure 15a. Temperature and salinity distribution in upper 200 meters off Newport, September 11, 1960 (after 33, p. 40).

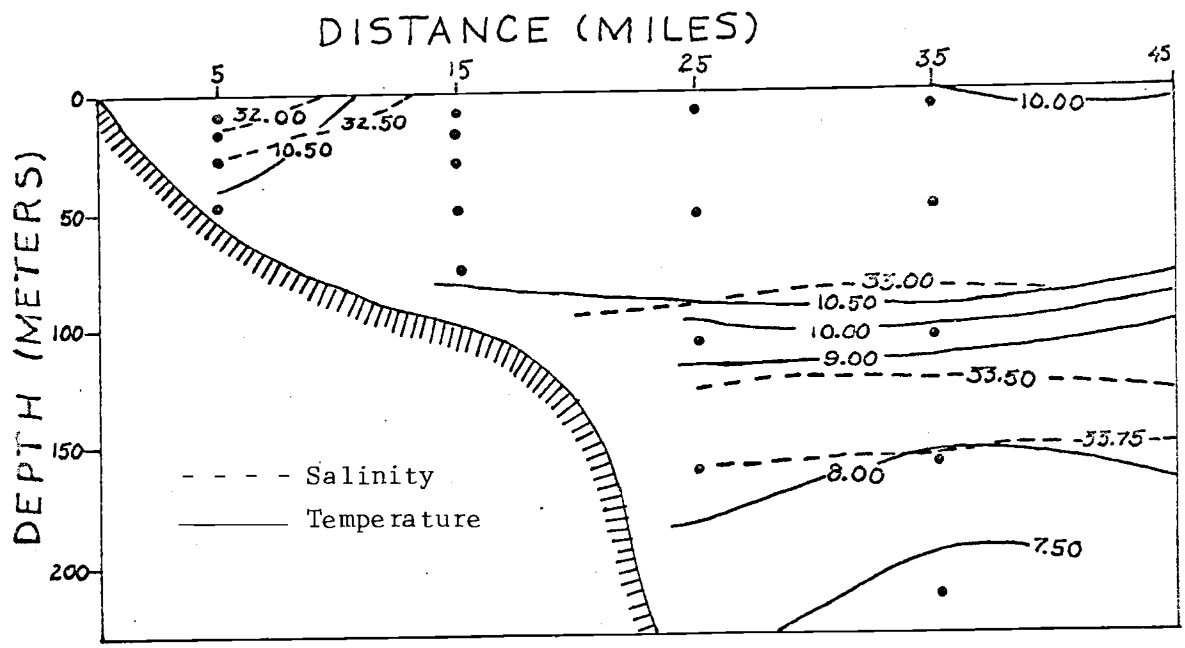


Figure 15b. Same as 15a for January 20, 1961 (after 33, p. 58).

months is associated with upwelling. Upwelling is the transport of surface waters away from the coast and replacement by waters from depth. Subsurface waters can ordinarily be recognized by their low temperature and high salinity.

The Oregon coast is oriented in a predominantly north-south direction. Because of the rotation of the earth, winds blowing from the north or east will move surface waters offshore (5, p. 642-656). These surface waters are replaced by subsurface waters through vertical convection. The magnitude or extent of the upwelling is dependent on the strength of the winds and the length of time they blow.

Upwelling along the California coast appears to occur in large patches rather than all along the coast (23, p. 724). The patchy nature of the upwelling along the Oregon coast is particularly well shown in Figure 16. In Figure 16 a patch of upwelling is delineated by the tongue of cold and highly saline water extending offshore south of Cape Blanco.

One other advective process may enter into the supply system of some of the coastal regions. This is the supply of fresh water from coastal rivers.

Oregon Estuaries

Large amounts of fresh water are supplied to the Pacific from Oregon estuaries. This fresh water plays an important role in the waters found off this coast. To gain an understanding of the

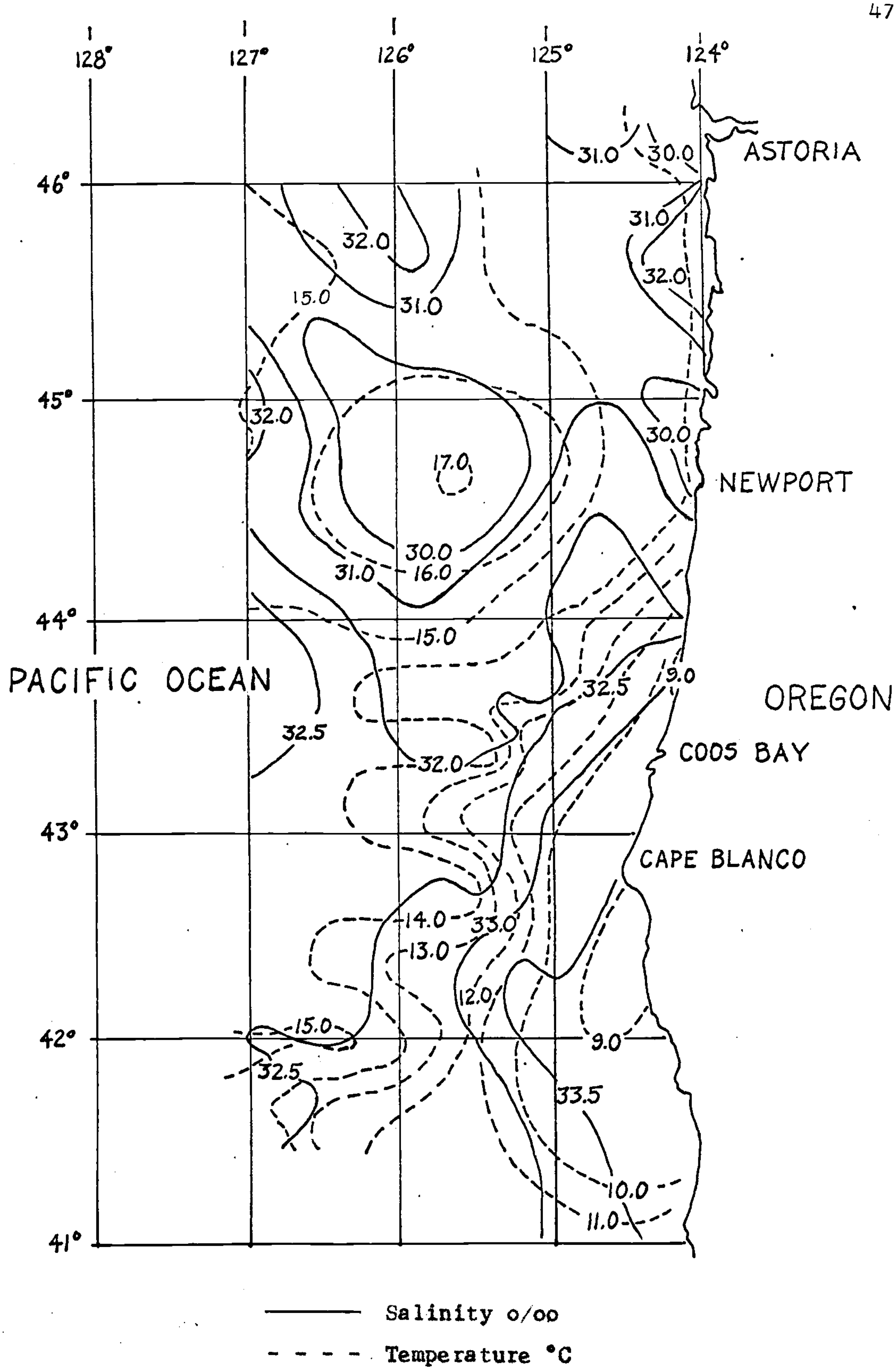


Figure 16. Contours of surface temperature and salinity, June 28 to July 14, 1960 (after 33, p. 28, 32).

amount of fresh water supplied to the coastal waters and the periods of maximum runoff the monthly gaugings for several Oregon estuaries are shown in Table 4.

The largest source of fresh water is the Columbia River, with an annual runoff exceeding 150,000,000 acre-feet per year. (One acre-foot is one acre of water, one foot deep and is equal to 1,236 cubic meters.) However, depending on the location sampled along the coast, any one of the lesser rivers could have significant effects on the water samples. It should be noted that many of the rivers were gauged at some point upstream from the mouth.

Along the Oregon coast all the estuaries have their peak runoff in either February or March, except the Columbia, which has its peak in June. This is explained by the fact that the Columbia reaches its peak during the snow melt, while the smaller rivers follow the periods of local precipitation. To illustrate this feature, the monthly runoff of the Columbia is plotted along with the sum of the runoff for all the other rivers listed in Table 4. These results are shown in Figure 17.

The large discharge of the Columbia River must be considered in any study of the coastal oceanography of this area. The Department of Oceanography at the University of Washington has expended considerable effort in studying the effluent of the Columbia (1, p. 1-17; 2, p. 1-99). To follow the effluent from the mouth they use salinity as an indicator, arbitrarily defining the effluent as water of less than 32.5 o/oo. The limits of the plume defined are found to depend

River	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Columbia	10,750	9,681	8,795	7,218	7,204	8,145	15,550	18,400	22,980	17,680	9,307	6,098
Nehalem	114	222	242	200	437	278	282	153	46	14	10	7
Wilson	91	100	98	84	161	106	104	70	21	8	7	5
Siletz	104	101	118	113	225	140	130	89	28	10	8	6
Yaquina	1	1	1	1	3	2	2	1	0.4	0.1	0.1	0.1
Alsea	32	41	70	99	264	177	192	104	36	14	8	6
Umpqua	117	99	137	374	1,014	1,110	751	635	242	92	72	67
Coos	10	7	12	22	41	35	18	22	3	0.8	0.4	0.3
Coquille	5	5	18	65	137	111	58	74	13	4	2	1
Rogue	80	70	72	92	196	251	234	217	158	83	71	61

TABLE 4. Mean monthly runoff from coastal rivers in 1,000 acre-feet from October 1959 to September 1960 (28, p. 76, 217-288).

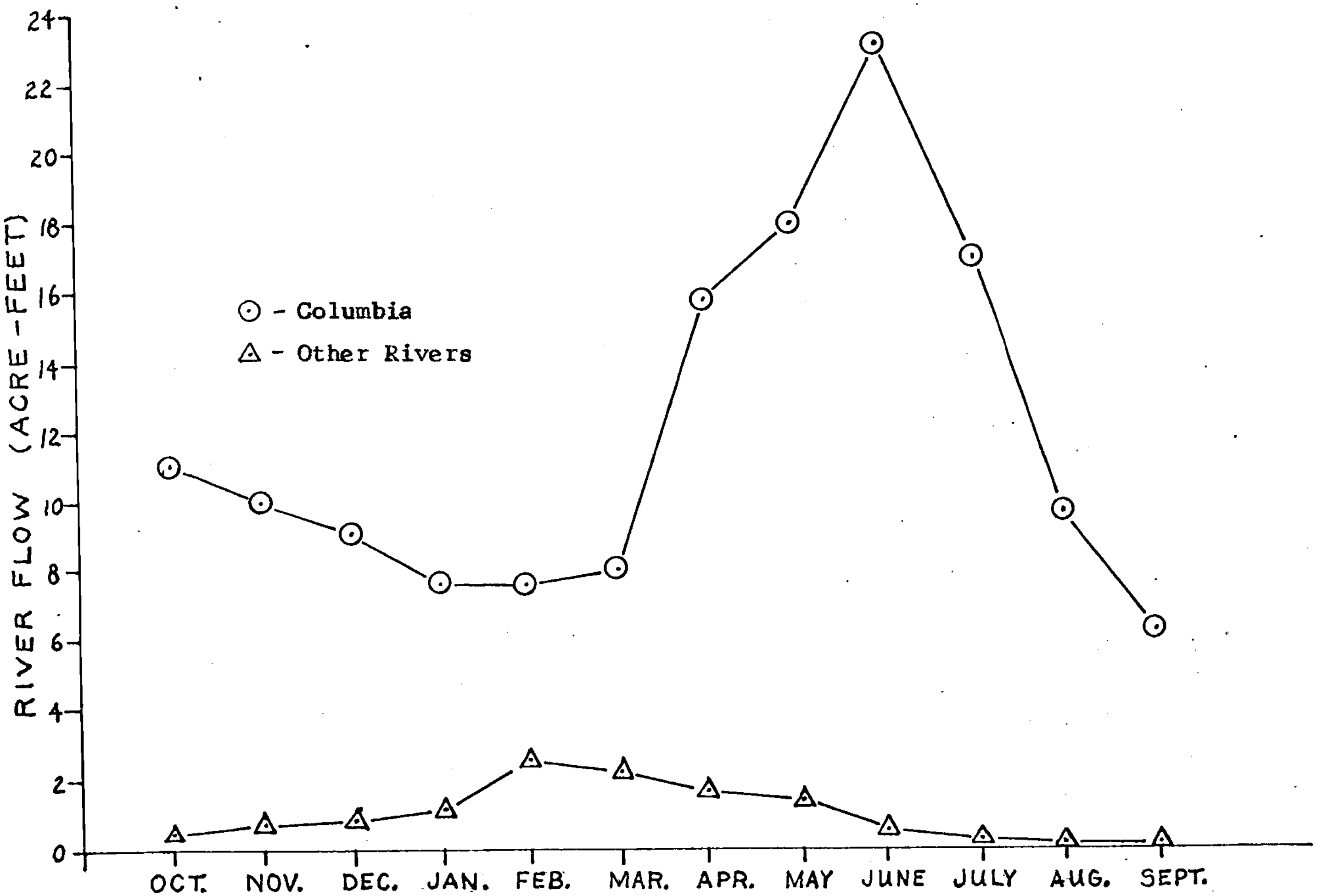


Figure 17. Mean monthly runoff in Columbia and in all other rivers listed in Table 4.

on several factors. Particularly important are the amount of precipitation and the local currents; the latter have already been discussed. The limits of the effluent for several months of 1961 are shown in Figure 18, after Anderson (1, p. 7). Particularly important to our study is the fact that the Columbia effluent does lower the salinity of the ocean adjacent to the Oregon coast.

Climatology of the Oregon Coast

In the surface layers oceanic conditions are primarily determined by meteorological conditions. Meteorological variables are measured at 22 U. S. Weather Bureau stations along the Oregon coast (31). The mean monthly values of air temperature and precipitation at these stations for 1961 are represented in Figures 19 and 20, respectively.

Figure 19 shows that the months of January, February, March, November, and December, were cold months in 1961. The minimum temperature was reached in December. The maximum occurred in July and August.

Figure 20 shows that February was the month of maximum precipitation in 1961. June through September were months of low precipitation.

The winds along the coast play an important role in determining the surface circulation. Figure 21 is a wind rose of offshore surface winds measured at a weather ship positioned at about 38°N, 129°W. The arrows in the rose point in the direction that the wind is blowing. The arrows represent the percentage of the time that the wind blew

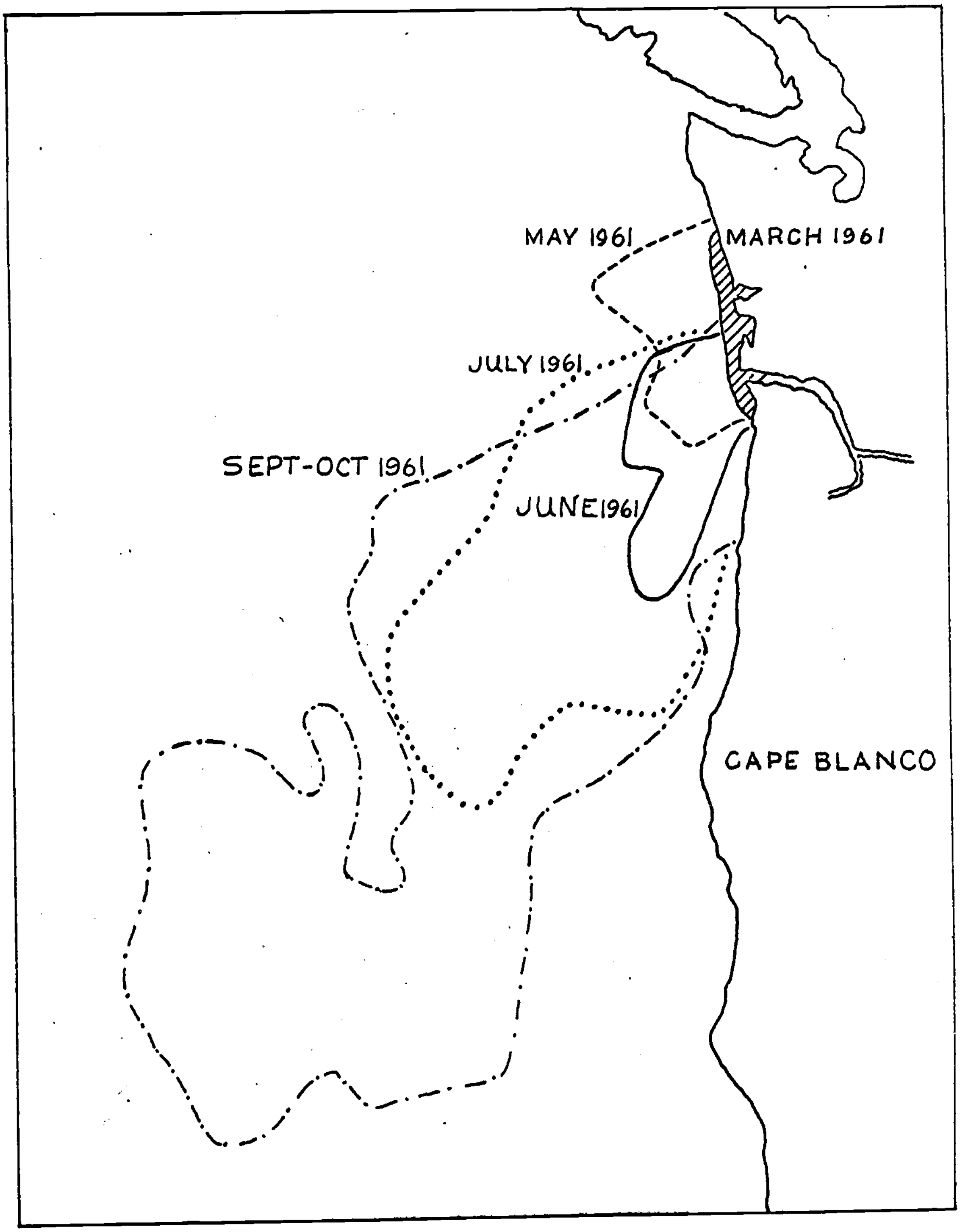
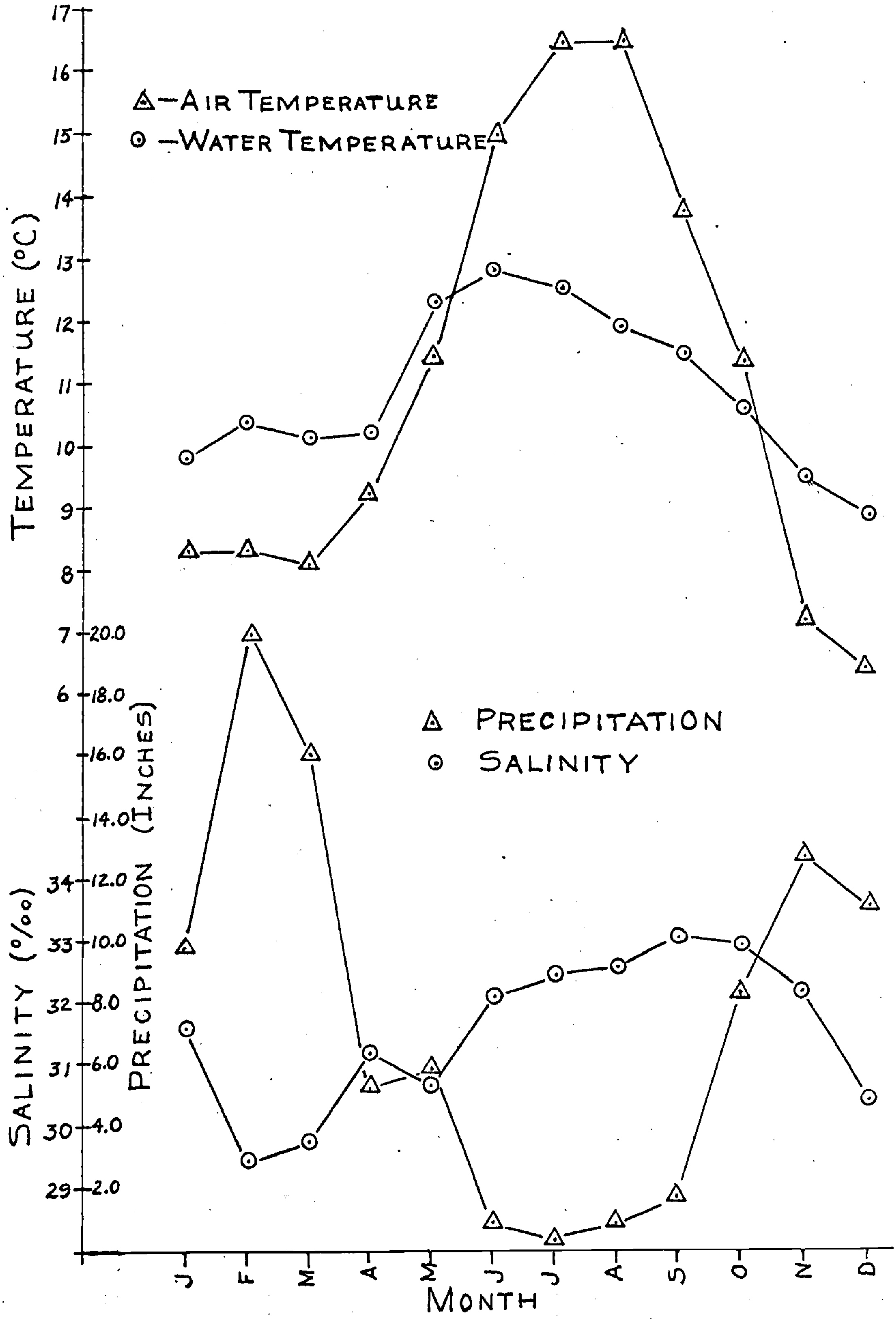


Figure 18. The limits of the Columbia effluent for several months in 1961 (after 1, p. 7).

Figure 19. Mean monthly air temperature and water temperature along the Oregon coast in 1961.

Figure 20. Mean monthly precipitation and salinity along the Oregon coast in 1961.



Δ—AIR TEMPERATURE
⊙ —WATER TEMPERATURE
TEMPERATURE (°C)
17
16
15
14
13
12
11
10
9
8
7
6
Δ PRECIPITATION
⊙ SALINITY
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
PRECIPITATION (INCHES)
SALINITY (°/oo)
34
33
32
31
30
29
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

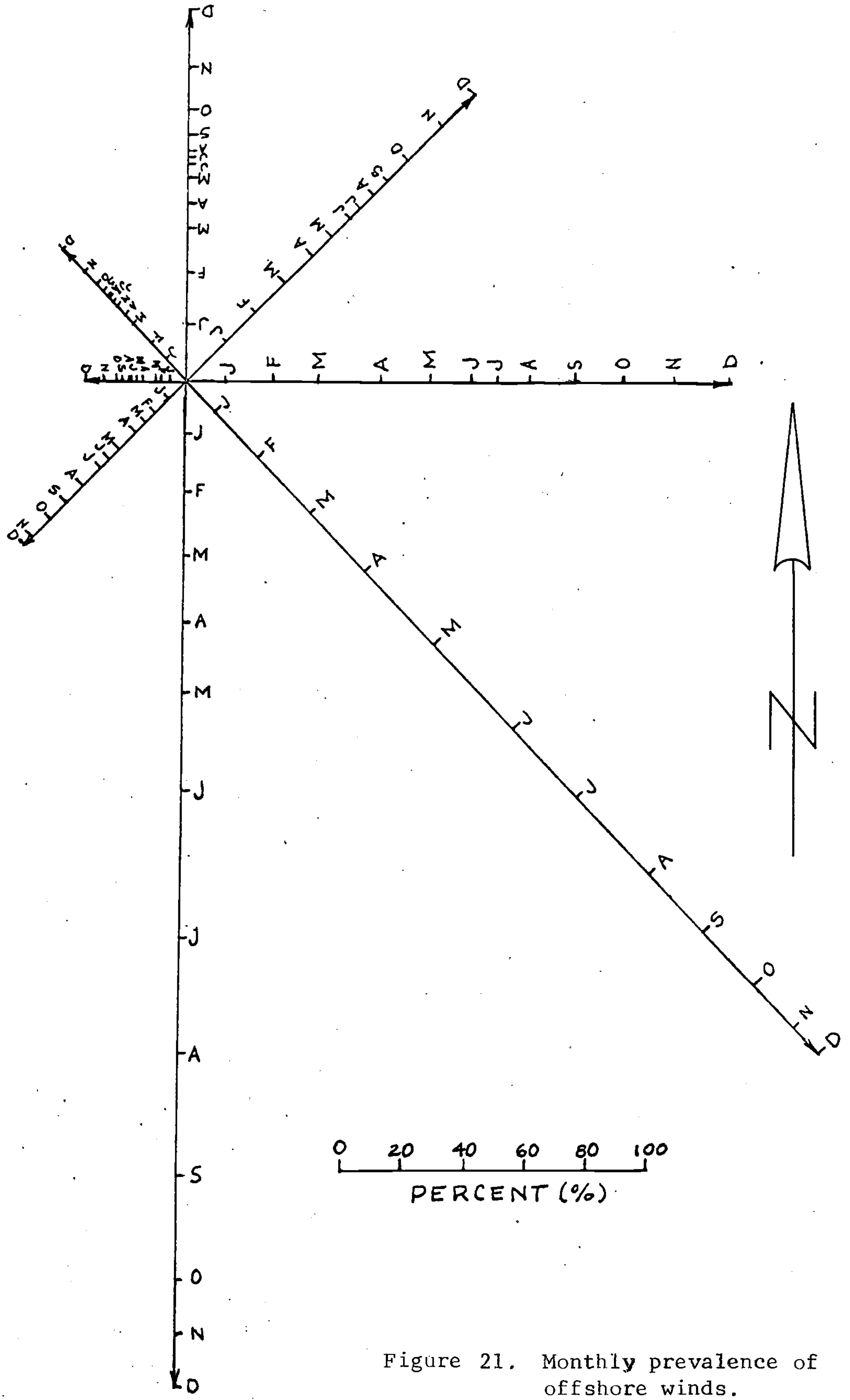


Figure 21. Monthly prevalence of offshore winds.

from a particular direction. Each arrow is divided into 12 segments, each segment representing the percentage of time the wind blew in that direction for a given month. The predominant winds are the north winds, with prevalence decreasing, generally, counter clockwise. East winds occur the least often. North winds predominate during each month of the year with the exception of January and December when south winds predominate, and November when northwest winds are prominent. The large percentage of north winds from June through September coincides with the season of upwelling described earlier.

The Relationships Between Meteorological and Oceanic Variables

The meteorological variables described in the section on climatology greatly influence the oceanic variables of temperature and salinity. In Figures 19 and 20 the mean monthly values of temperature and salinity for all OSU coast stations are plotted. In Figure 19 it can be seen that there was considerable similarity between the water temperatures and air temperatures. However, as might be expected, the range of air temperatures is approximately twice the range of monthly mean sea water temperatures. Furthermore, the times of maxima do not coincide. The air temperature reached its peak in July and August, with a value of 16.7°C for both months. The water temperature reached its peak in June with a temperature of 13.1°C. During the months of January through May and again in November and December, the water temperature was greater than the air temperature. In June through September, the air temperature rose above the water temperature.

The salinity varies approximately inversely with precipitation (Figure 20). However, as in the temperature comparison, the summer extrema do not coincide. The salinity reaches its peak in September with a value of 33 o/oo, while the precipitation reaches a minimum in July at 0.3 inches.

We have at this time no adequate information of evaporation from coastal waters during 1961, and this process certainly affected both the temperature and salinity of the water. This makes it impossible to make a quantitative comparison between factors affecting the atmosphere and the sea. Nevertheless, the peculiar displacement of the summer maxima (in both figures) can be explained by the occurrence of upwelling. From July through September, 1961 water temperatures fell and salinity rose. This is exactly what one expects in the presence of upwelling during these same months.

In the discussion of the temperature and salinity distributions at the individual stations (Figures 4 through 10, parts b and c), many differences were noted. Also, in the discussion of upwelling (page 46) it was noted that upwelling generally occurs in patches. Therefore, let us examine the individual stations in detail, particularly with respect to evidence for the presence or absence of upwelling.

The monthly mean water temperatures at three OSU coast stations is shown in Figure 22. Also, the monthly mean insolation at Medford, Oregon, is shown; the only standard station in Oregon that reports insolation. One would not expect high correlation between insolation at Medford (80 miles from the coast) and coastal air and water temperatures. Nevertheless, note the similarity between the insolation

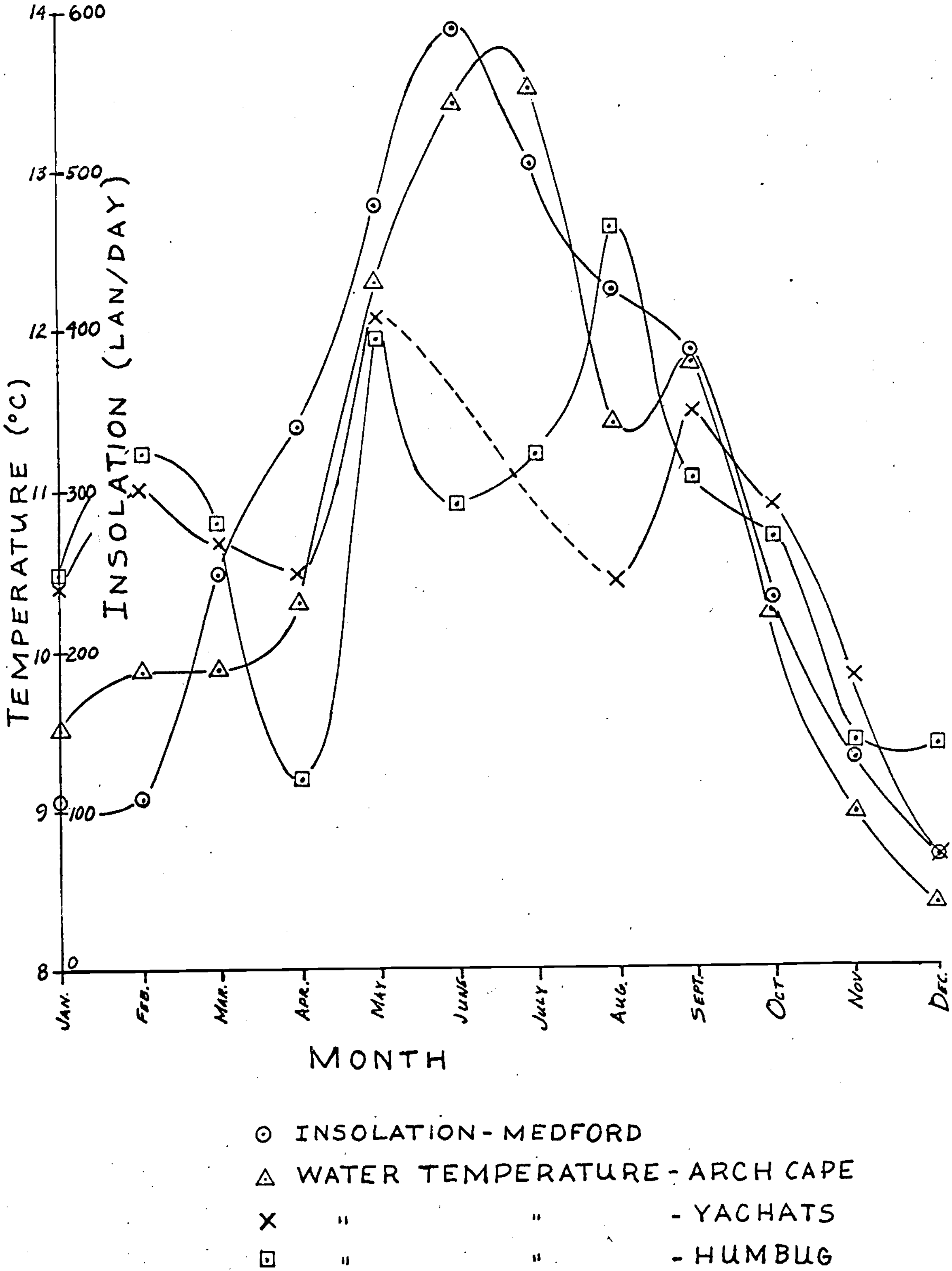


Figure 22. Mean monthly insolation at Medford, Oregon, and mean monthly water temperature at Arch Cape, Yachats and Humbug in 1961 (30, vol. 12; 17, p. 14-16).

and the average air temperature curve shown in Figure 19. Also, note the similarity between the water temperature at Arch Cape and the insolation curve. However, the sea temperatures at Humbug and Yachats are strikingly different from those at Arch Cape. The mean monthly water temperature does not follow the level of insolation, but shows two prominent minima. Both of these anomalies have undoubtedly resulted from upwelling. The fact that about 44 percent of the salinities at Humbug were greater than 33 o/oo (Figure 9, part b) supports this explanation.

Thus, it can be said that a very important factor in determining the water temperature is the solar insolation, but the temperature may be modified appreciably by advective processes, especially upwelling.

Further evidence for the location and patchy character of upwelling is given in Figures 23a and 23b. The mean values of temperature and salinity for four summer months, June through September, and for four winter months, November through February, are plotted against latitude. In Figure 23a the winter temperature means form almost a straight line, indicating that conditions along the coast were very uniform. However, in the summer a marked nonuniformity is found with low temperatures from Humbug to Yachats. Although these temperatures are not as low as those normally used to identify upwelling, it should be remembered that these are average conditions for the summer months. Since upwelling is not thought to be a continuous process, some higher temperatures and therefore higher means are to be expected.

In Figure 23b neither summer nor winter conditions are uniform,

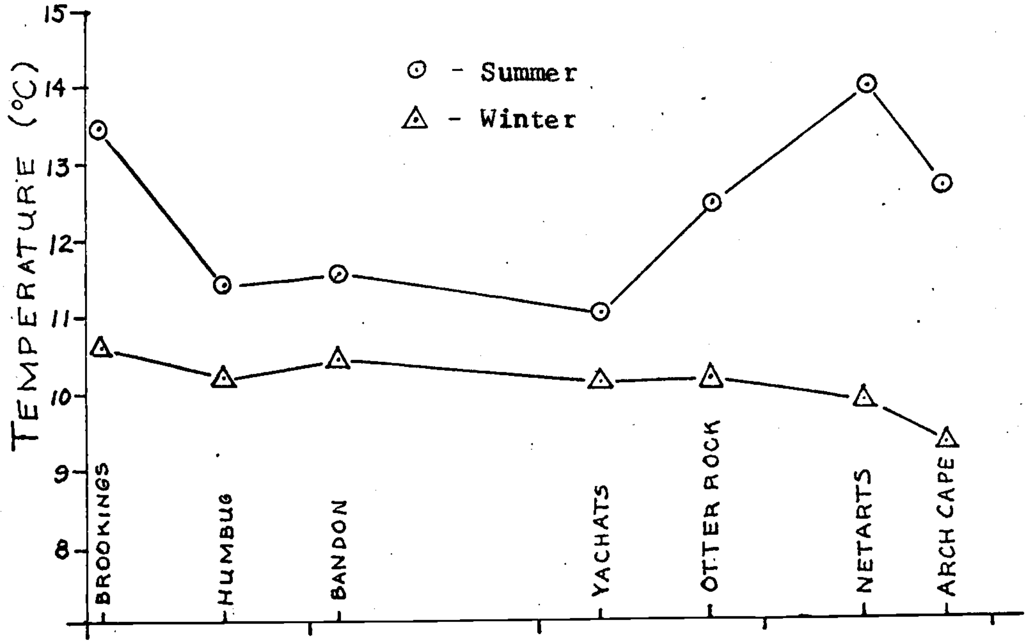


Figure 23a. Mean temperature for four summer months (June, July, August, September) and four winter months (January, February, November, December) at OSU coast stations in 1961.

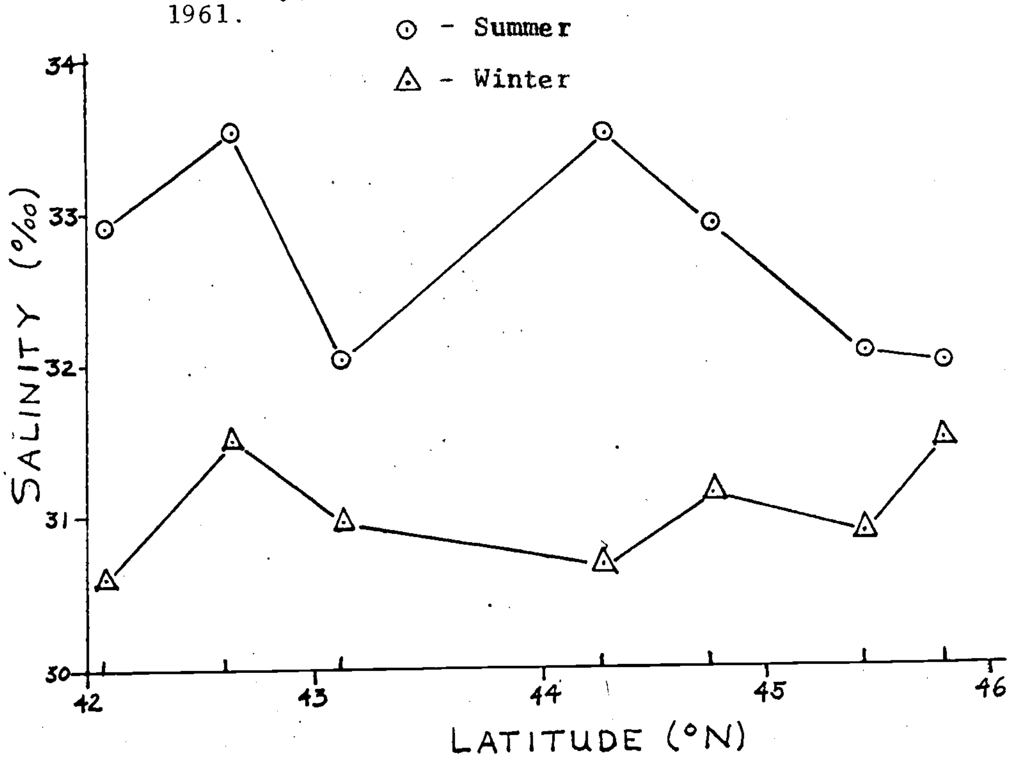


Figure 23b. Same as Figure 23a for salinity.

but the salinity variation with latitude in the winter is less than that observed for the summer. In the summer months high salinities are observed at both Humbug and Yachats, and these, combined with the low temperatures also observed at these stations, definitely indicate upwelled water. The low salinity at Bandon does not support this conjecture and must be explained in other terms. The Coquille River enters the Pacific at Bandon, and the Coos River enters only 18 miles to the north. It is possible that one or both of these rivers supplied enough fresh water to the region of the station to reduce the salinity to the value observed.

These figures indicate that individual patches of upwelling were confined within a few degrees of latitude, and that one may be centered around 43°N. To our knowledge this is the first time that this center has been explicitly defined. The fact that coast stations show the presence of upwelling so well makes these stations of substantial value in any coastal oceanography program. The fact that one station shows the presence of upwelled water, while an adjacent station does not, has not been satisfactorily explained. Part of the explanation may lie in the effects of topography both on the wind field and/or the oceanic circulation.

We are now able to explain some of the interesting features of the χ^2 tables (Tables 2 and 3). At Arch Cape the first cell in the temperature distribution gives the largest single contribution to the χ^2, 6.15. In this cell, which represents observations of temperature less than 9°C, the observed frequency is 8. However, the hypothetical frequency is only 3.42. That is, the sample at this station indicates colder conditions than are observed at other stations. This is apparently not due to upwelling, since there is no similar contribution to the salinity χ^2 in the highest salinity cell.

At Netarts the largest contribution to the salinity χ^2 is found in the last cell (33 to 34 o/oo). Small but appreciable contributions are also found in the 29 to 30 o/oo cell and 31 to 32 o/oo cell. An examination of all six cells reveals that at Netarts higher than average frequency occurred at all low salinity values (less than 32 o/oo) and lower than average frequency occurred in the high salinity classes. This is the only station for which this statement can be made. These facts indicate that there is a large supply of fresh water to this station. In fact, this station has more low salinity observations than Arch Cape which is closer to the Columbia River. Although there are many possibilities for error, this would indicate that the Columbia effluent comes in to the coast in this region, that is at some distance south of the mouth.

Otter Rock and Yachats do not have any cells which make large contributions to the total χ^2.

Bandon has a large observed frequency in the highest salinity cell, but the χ^2 contribution is only moderate at 2.04. This cannot necessarily be associated with upwelling, as no large χ^2 contribution is found in a low temperature cell. In fact, the only large contribution to χ^2 is found in the 12 to 13°C cell with higher frequency than expected.

The effects of upwelling on the homogeneity of the population are shown in both χ^2's from Humbug. A large contribution to the temperature χ^2 occurs between 9 and 10°C and a large contribution to the salinity occurs between 33 and 34 o/oo. This is a definite indication of upwelling.

At Brookings the combined effects of both upwelling and increased solar radiation apparently contribute to nonhomogeneity of the population. At this station a high observed frequency is found in the highest salinity cell. However, only moderate contributions are found in the low temperature cells. On the other hand, a high contribution is present in the highest temperature cell. Therefore, the large number of observations in the high salinity cell may be due in part to upwelling and in part to an increase in salinity with passage south along the coast.

In summary then, detailed study of observations made at coast stations, along with local meteorological data, allow us to recognize more clearly the important processes in the nearshore waters. Many different pieces of evidence have been given to show that upwelling was a patchy phenomenon along the Oregon coast. The evidence centers around the fact that low temperatures and high salinities were observed at some stations and not at others. These values cannot be accounted for in terms of meteorological variables.

<u>The Comparison Between USCGS and OSU Distributions</u>

The only other data from coast stations along this coast were taken by the USCGS in 1933 and 1934. The frequency distribution for this group of observations is shown in Figure 11. Because these data were not taken in areas of maximum exposure to the ocean they are considered less representative of conditions along the coast. In spite of probable error in these data, the distributions are similar to those obtained for OSU data. However, some differences can be noted. The temperature frequency peak occurs at higher temperatures than does the peak in the OSU distribution (10 to 12°C as compared to 9 to 11°C).

The salinity range is much greater in the USCGS data and only the distribution in the upper ranges will be considered (salinities greater than 20 o/oo). Some salinities greater than 34 o/oo are recorded in these data. As indicated earlier, salinities of this value and greater are found at depth in the ocean. The fact that a station further south is included could also explain some of these salinities. However, the cells of maximum frequency in this distribution occurred at lower salinities than the cells of maximum frequency in the OSU distribution. The peak salinity frequency occurs in the 32.5 to 33.0 o/oo interval. This is one class interval lower than the peak in the OSU distribution, and is probably due to the estuarine location of the stations. However, an alternate explanation is that upwelling was more prominent in 1961 than in

1933-1934. We have no independent data to support or disprove this possibility at this time.

A Comparison of Coast Stations and Offshore Conditions in 1961

Since all the OSU coast stations had good exposure to the open ocean, the distribution of sea surface properties at nearshore oceanographic stations should be similar to the distribution at the coast stations. The frequency distribution of offshore surface temperature and salinity are found in Figure 12. In this figure only observations made within 25 miles off the Oregon coast are included. However, two features concerning the frequency distribution are notable. First, one cell dominates the distribution. This cell is bounded by 10 to 11°C and 32.5 to 33.0 o/oo. This cell contains 33 out of a total of 260 observations. In the same cell at the coast stations only 9 observations out of a 274 total are found. If both are samples of the same population, the most frequent cell in one distribution should be the most frequent in the other. This does not occur; the higher salinities are more numerous in the coast station data. This would indicate that upwelling occurred very near-shore in 1961 and was not equally effective at all points out to 25 miles from shore. The presence of Columbia effluent could also account for the lower salinities in offshore waters.

Daily Coast Station Observations at OSU Special Stations

The value of coast station observations in any coastal oceanography program has been illustrated in this thesis. Even more information could be gained through more frequent observations. This is shown in the daily observations represented in Figures 13a and 13b. These distributions are representative of winter conditions at two stations (Newport and Oceanlake), and some interesting features can be noted at both stations. The distributions are very similar. Both distributions show very high and very low salinities. The low salinities are probably due to precipitation. Of more significance are the high salinities that occurred, particularly in conjunction with very low temperatures. These high salinities may be due to upwelling even though this process is generally not thought to occur in this season. It has been assumed in most of the literature that upwelling occurs off this coast only in the summer months. However, there is no physical reason why upwelling should not occur in the winter months if the proper winds are present. Under this discussion it appears that upwelling does occur off this coast during the winter months of the year, but that this may be of limited extent and short-lived. Daily observations at coast stations would be invaluable in providing monitoring information on such coastal processes as upwelling.

Comparison Between Coast Stations and North Pacific Distributions

It is interesting to compare the distribution of characteristics found at the OSU stations with the distribution of these same characteristics in the whole North Pacific as reported by Cochrane, (Figure 1).

The dashed line in Figure 1 encloses all the T-S pairs observed at the OSU stations with the exception of a few of very low salinity.

The characteristics observed at OSU stations occupies only a portion of the distribution given by Cochrane. There is considerable difference in the modes. The mode in the OSU distribution is centered around 10°C and 33.5 o/oo, which is within one of the ridges of higher frequency described by Cochrane. However, the mode for the entire North Pacific occurs at a much higher temperature (27°C) and salinity (34.6 o/oo).

The most striking peculiarity of the Oregon region in comparison to the Pacific as a whole is the very small range of temperatures in the face of a very large range in salinity. A principle reason for this low temperature variability is the limited area represented in the OSU distribution. However, summer upwelling and winter flow from the south undoubtedly play a role in moderating the temperature variation.

The wide range in salinity (some values observed were lower than any given by Cochrane) has been explained. Once again this range is due to the supply of high salinity waters by upwelling and low salinity waters by runoff and precipitation.

SUMMARY AND CONCLUSIONS

After consideration of many approaches taken in the past to classify coast station observations, the application of bivarient diagrams was selected to analyze observations from 18 coast stations along the Oregon coast. This is the first time, to our knowledge, that the T-S diagram, applied widely in deep-water oceanography, has been used in this application.

Using T-S diagrams the prevalent characteristics of nearshore waters were determined. The most prevalent characteristics in 1961 occurred in two cells, each with a frequency of 12 observations. Specifically, one cell is bound by salinities of 33.0 o/oo and 33.5 o/oo, with temperatures between 10°C and 11°C, while the other occurred between salinities of 33.5 o/oo and 34.0 o/oo and temperatures between 9°C and 10°C.

In addition, frequency distributions of both temperature and salinity were computed and used in detailed discussion of conditions found along the coast.

Two stations, Otter Rock and Yachats, were found most representative of mean conditions. These lie approximately in the geographical center of the latitudinal range for the stations. Some of the deviations at the other stations are undoubtedly due to latitudinal differences in climatic conditions. However, the latitudinal trends do not explain some of the most striking differences.

At Netarts a very large percentage of fresh water is found.

It is suggested that this is Columbia River water brought in to shore.

At Humbug high salinity and low temperature conditions predominate. These characteristics are usually associated with upwelling along the coast. Other stations near Humbug showed low mean temperatures and high mean salinities during the summer months of 1961. As a result it was concluded that a center of upwelling occurred around 43°N in this year.

Brookings, also, had a high frequency of observations at high salinities. However, these did not correspond to low temperatures. It is possible that upwelling occurred at this station, but greater solar insolation in this region heated the upwelled waters rapidly. It seems more likely, however, that these are natural characteristics of the waters in the region of this station. That is, temperature and salinity may both be higher, at this southerly station, than at stations to the north.

As the characteristics found at individual coast stations showed marked differences, it was suggested that the waters along the coast are not homogeneous. The χ^2 test of homogeneity was applied to both temperature and salinity to test this hypothesis. The results yield non-homogeneity (at the 7.5 percent confidence level).

Both oceanic and meteorological conditions were considered in an attempt to evaluate those processes making the largest contribution to non-homogeneity. The processes felt to be most important were upwelling and river runoff. However, many other processes may prove to be important upon further analysis.

Observations of surface temperature and salinity taken within 25 miles from shore, on standard hydrographic cruises during 1961, were analyzed in the same manner as the coast station observations. The most prevalent characteristics in these waters occurred in one cell, which had 33 out of the total 260 observations. This cell is between salinities of 32.5 o/oo and 33.0 o/oo and temperatures of 10°C and 11°C. This cell is of lower salinity than the highest frequency cells observed at the coast stations, during 1961, suggesting that upwelling is most prominent very near shore.

Thus, it appears that coast stations may be of significant importance in studying the ocean off the Oregon coast, and, in fact, a complete discussion is impossible without them.

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