THE QUALITATIVE AND QUANTITATIVE DISTRIBUTION OF PLANKTON IN THE STRAIT OF GEORGIA IN RELATION TO CERTAIN OCEANOGRAPHIC FACTORS

by

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ABSTRACT

A study of plankton communities in the Strait of Georgia was undertaken in order to determine qualitatively and quantitatively the distribution in time and space of both zooplankton and phytoplankton.

In order to gain some picture of the seasonal variations in the plankton communities two cruises were made in the Strait, one in June, 1955, and the other in November, 1955. 165 plankton collections were taken. A complete count of zooplankton organisms was made in 5cc. of each sample and the number of diatoms cells per liter was tabulated. Copepods and diatoms were analysed to species; other groups to class or genera. Surface temperatures were taken. The physical and chemical data used to account for the biological distributions were obtained largely from oceanographic data already available for the area.

The correlation of these data have resulted in a number of conclusions concerning the distribution of plankton in the Strait of Georgia. The chief factor affecting the general distribution of plankton in the Strait of Georgia is the salinity gradient. The inflow of fresh water from the Fraser River forms zones of varying properties, and leads to the development of different plankton communities. The extent to which physical and chemical factors may determine the presence or absence of certain organisms from the zones described is discussed.

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I. INTRODUCTION

The Strait of Georgia occupies a position of considerable interest for the study of plankton because within its limits it presents an unusual complexity of conditions which differ greatly from summer to winter. In summer the fresh water from the Fraser River flows into the Strait and spreads over the surface in cloud-like distribution, mixing with the saline water to form a brackish upper layer which is well differentiated from the more saline, homogeneous waters underneath. In winter the river discharge diminishes and most of the water in the Strait reaches an homogeneous state.

The Strait of Georgia itself is located between the British Columbia Mainland and Vancouver Island, and extends from Latitude 48° 50' N. to Latitude 50° 00' N. (Fig. 1). It is 120 nautical miles long and 18 nautical miles wide. It has an average area of 2000 square nautical miles and a maximum depth of 230 fathoms. The weather is generally similar over the entire area of the Strait. The precipitation is high in the fall and winter, and the summers are generally sunny and warm. Air temperatures seldom go below freezing. In winter they average 2° C. and may go as high as 10° C. In summer they average 18° C.

In accordance with the complexity of conditions, the distribution of species is intricate and their relative abundance fluctuates widely from place to place and from time to time. It has been already pointed out by Fraser (1918), that certain free-moving shore forms which occur constantly throughout the surface at Friday Harbor disappear from near the surface at Departure Bay early in summer, making the question of

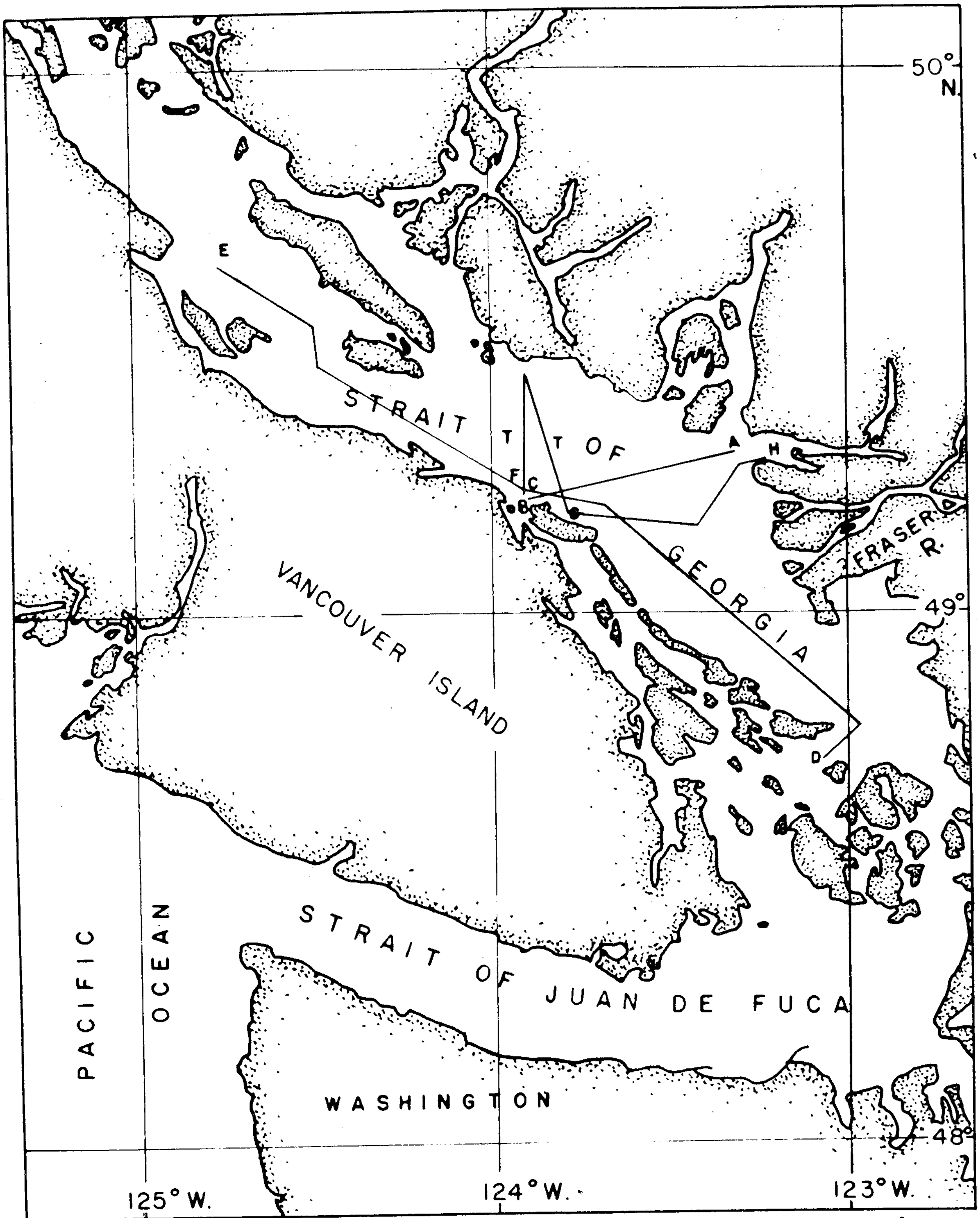


Fig. 1. Strait of Georgia showing sections made with the Hardy Recorder.

migration a matter of importance. Cameron and Mounce (1922) found that some species exhibit a difference in morphological character and rate of growth which can be traced to different physical and chemical conditions, and showed that the Fraser River was responsible for most of the conditions peculiar to these waters. Lucas and Hutchinson (1927) came to the conclusion that diatom optima exist where the Fraser River water and the sea water are mixed. They suggested the contribution of the Fraser is in the form of mineral salts containing nitrogen, phosphorous, and silica. They also stressed the important tide-diatom relationship: north of the Fraser the optimum is at the flow; south of the Fraser it is at the ebb. Hutchinson (1928) showed that the richness of the plankton flora was largely dependent on the Fraser as a source of silica and also upon the conditions which conserve this material. Hutchinson, Lucas and McPhail (1929) dealt with the seasonal variations in the chemical and physical properties of the Strait of Georgia in relation to phytoplankton. Hutchinson and Lucas (1931) studied the extent of the Fraser River's effect on temperature, salinity, currents and fish food. Again it was found that the amount of phytoplankton is greatest at the regions of water mixing. Tully and Dodimead (1954) also discuss diatom distribution in terms of dissolved oxygen, pH and dissolved nutrients. They attribute the high concentrations of dissolved phosphates to the intruding ocean waters, and the high concentrations of dissolved silicates to the Fraser River waters. They suggest that the supply of dissolved nitrates is the limiting factor in phytoplankton growth. Some preliminary work has been carried out by Campbell (1929) on the distribution of definite classes of marine organisms in the Strait of Georgia.

In this thesis an attempt is made to evaluate qualitatively and quantitatively the organisms responsible for the abundance of both phytoplankton and zooplankton and to assess the physical and chemical factors affecting their distribution.

II. DISTRIBUTION OF PHYSICAL AND CHEMICAL PROPERTIES OF THE WATERS IN THE STRAIT OF GEORGIA

a. Salinity

The range of salinities existing in the surface waters of the Strait of Georgia varies from 1 ‰ at the Fraser River estuary to 25 ‰ at the northern and southern extremities (Waldichuk, 1955). The Fraser River discharge dominates the general oceanography. The fresh water flowing into the Strait from the River spreads over the surface, mixes with the saline water, and forms an upper, brackish silty layer referred to as the "upper zone" (Tully and Dodimead, 1954). Low salinity cells exist in the southern Strait, and consistent gradients of salinity appear where the low salinity surface water mixes with the higher salinity waters brought up to the surface by tidal action. Surface salinities are lowest over the eastern portion of the Strait along the mainland. The greatest variations occur in the summer close to the mouth of the Fraser. This corresponds to the peak discharge of fresh water (Fig. 2). This peak discharge is the result of snow and ice melting in the upper reaches of the River. Small rivers entering at other points in the Strait contribute about 16% of the total fresh water. The upper zone is about 30 feet deep at the mouth of the Fraser and deepens to 80 or 90 feet as it fans out over the Strait (Waldichuk, 1952).

Isolated cells of water of varying properties are found at the surface and their position depends on the Fraser River discharge, the tidal cycle, and the wind velocity.

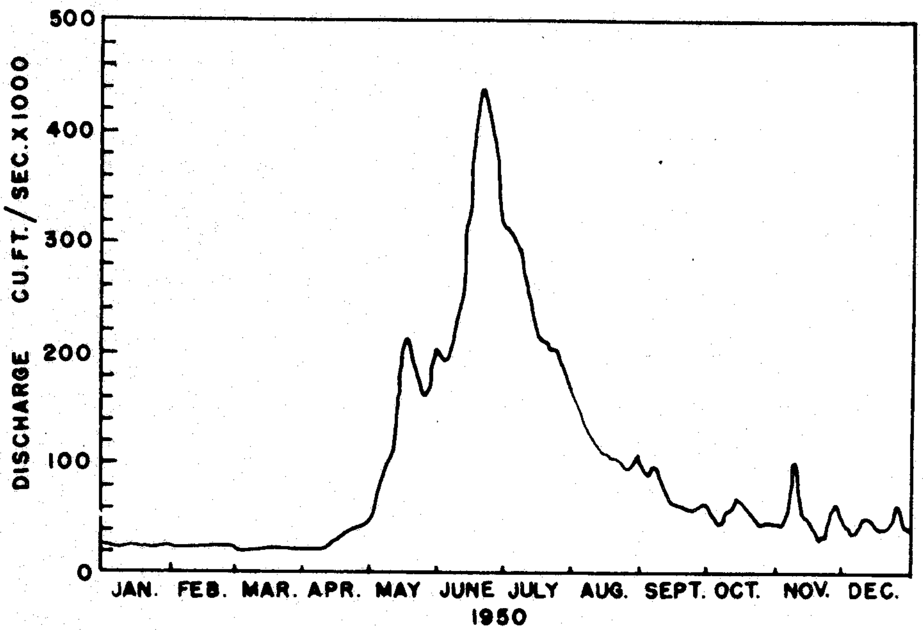


Fig.2. Seasonal variations in Fraser River discharge at Hope, B.C., 1950 (after Waldichuk, 1952).

Below the upper zone there is a layer of fairly homogeneous salinity, referred to as the "lower zone", and between the upper zone and the lower zone, there is a transition layer, referred to as the "boundary zone" (Tully and Dodimead, 1954). This boundary zone is characterised by a steep gradient of salinities.

In November the upper zone of low salinity is confined to the vicinity of the Fraser and averages 4 meters in depth (Tully, 1954). No distinct upper zone is traceable in the northern part of the Strait at this time because of the low runoff of the Fraser River.

b. Temperature

Surface temperatures in the Strait of Georgia for June, 1955, are given in Figure 3. The southern Strait exhibits the lowest temperature (12.4° C). This is produced by tidal currents in the channels mixing cold, deep water with the surface water (Waldichuk, 1953). The surface water is cold near the Fraser River estuary (12.8° C at Station 12) because the inflowing fresh water is colder than the water in the Strait. The highest temperature (15.8° C) is recorded off Gabriola Island.

Generally surface temperatures are lower in the eastern portion of the Strait along the mainland and higher in the western portion of the Strait as a result of inselation. The surface gradient over the whole area was only 3.4° C in June, 1955. The depth of heating corresponds to the upper zone which is generally less than 10 meters deep in summer (Tully and Dodimead, 1954). Below a depth of 60 meters the waters are fairly stable throughout the year, with temperatures around 7° C. The "boundary layer" is characterized by a steep gradient of temperatures.

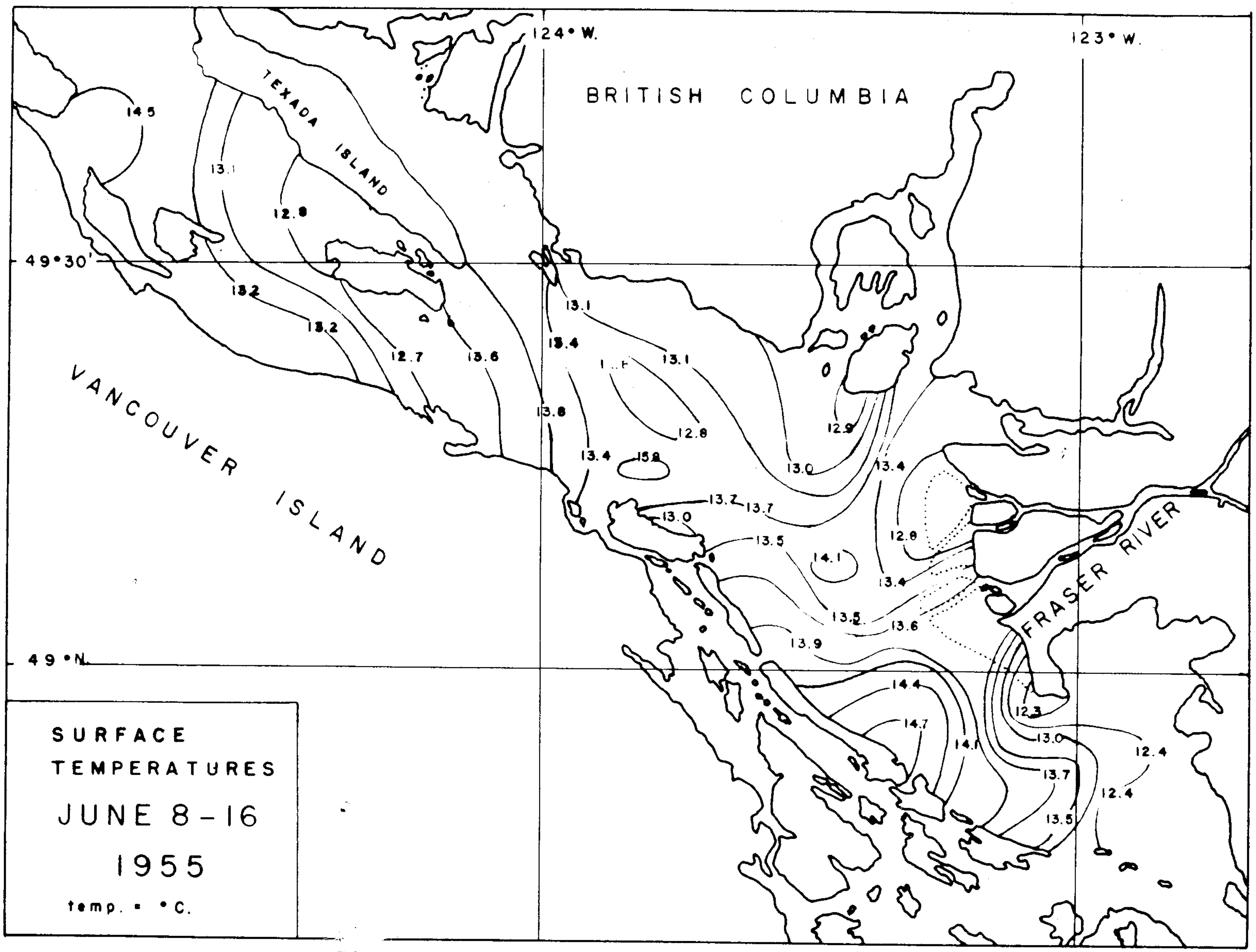


Fig. 3. Surface temperatures, June 8 - 16, 1955.

Surface temperatures in November (Fig. 4) are fairly uniform over the central part of the Strait. The northern waters, which are in the zone of minimal change, are a little warmer with a difference of temperature over the Strait of only 0.9° C (ranging from 8.5° C to 9.4° C). The effect of the Fraser River is therefore less marked in November. Loss of heat to the atmosphere takes place. In November strong winds mix the waters to great depths so that the deep waters are warmed and an isothermal state is reached (Tully and Dodimead, 1954).

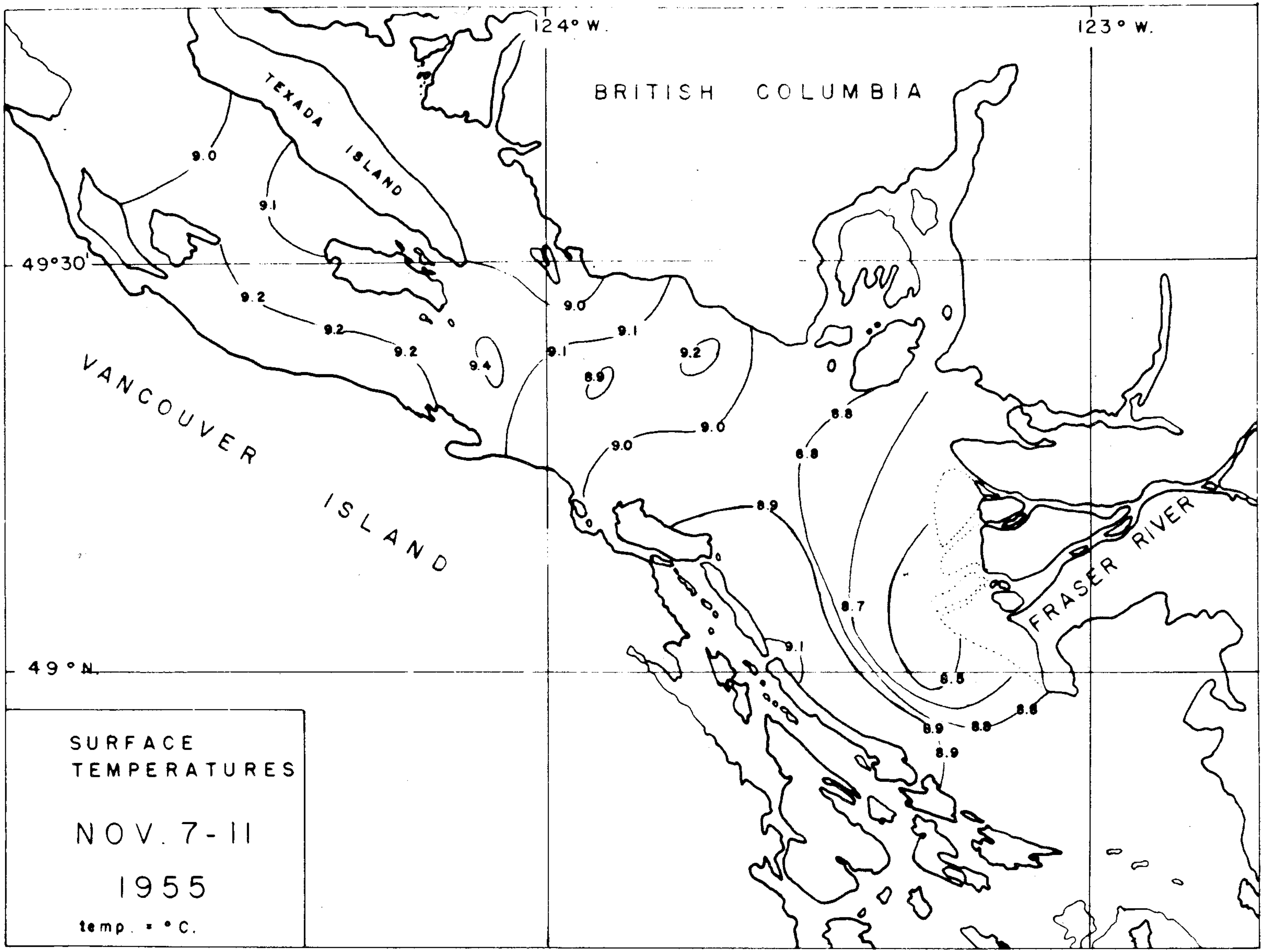


Fig. 4. Surface temperatures, November 7 - 11, 1955.

III. MATERIALS AND METHODS

a. Area covered

The data presented are based on 165 plankton collections taken in the Strait of Georgia during two cruises - one in early summer, from June 8 to 16, 1955, and one in the fall, from November 7 to 11, 1955. The first cruise covered 38 stations distributed throughout the Strait from the San Juan Islands to the northern end of Texada Island. However, as a result of bad weather conditions at the time of the fall cruise, it was possible to reoccupy only 26 of the 38 stations established on the earlier cruise. The stations occupied are distributed between latitudes 48° 48' N - 49° 40' N and longitudes 122° 50' W - 124° 45' W (Figs. 5 and 6).

At all but three stations two vertical hauls, using a plankton net (Fig. 7), were made. The first haul was always taken in one of three shallower depths (from 10, 20, or 50 meters to the surface) to prevent contaminating the net with deeper plankton species and a deeper haul was taken through strata varying from 50 to 250 meters to the surface. Surface temperatures were obtained at all stations at which plankton samples were taken. Compass bearings were taken at the start of each haul. Records of sonic depth, wind velocity, barometer readings and cloud coverage were kept. A few stations were omitted during the two cruises in order to give maximum coverage of the Strait.

In addition to the vertical hauls, horizontal sampling was carried out with the Hardy Recorder (Fig. 8) during the first cruise. The object in using the Hardy Recorder was to determine the horizontal

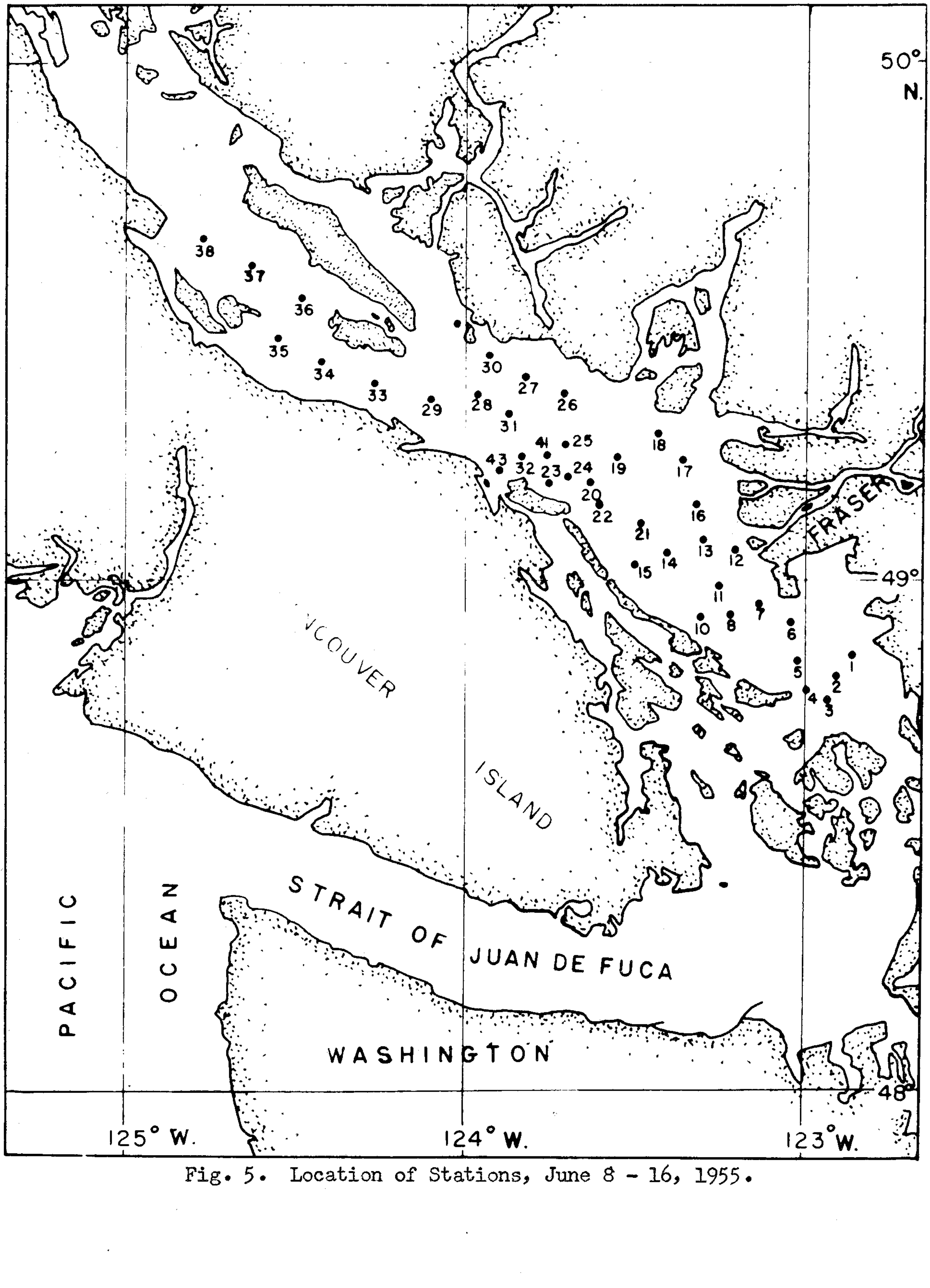


Fig. 5. Location of Stations, June 8 - 16, 1955.

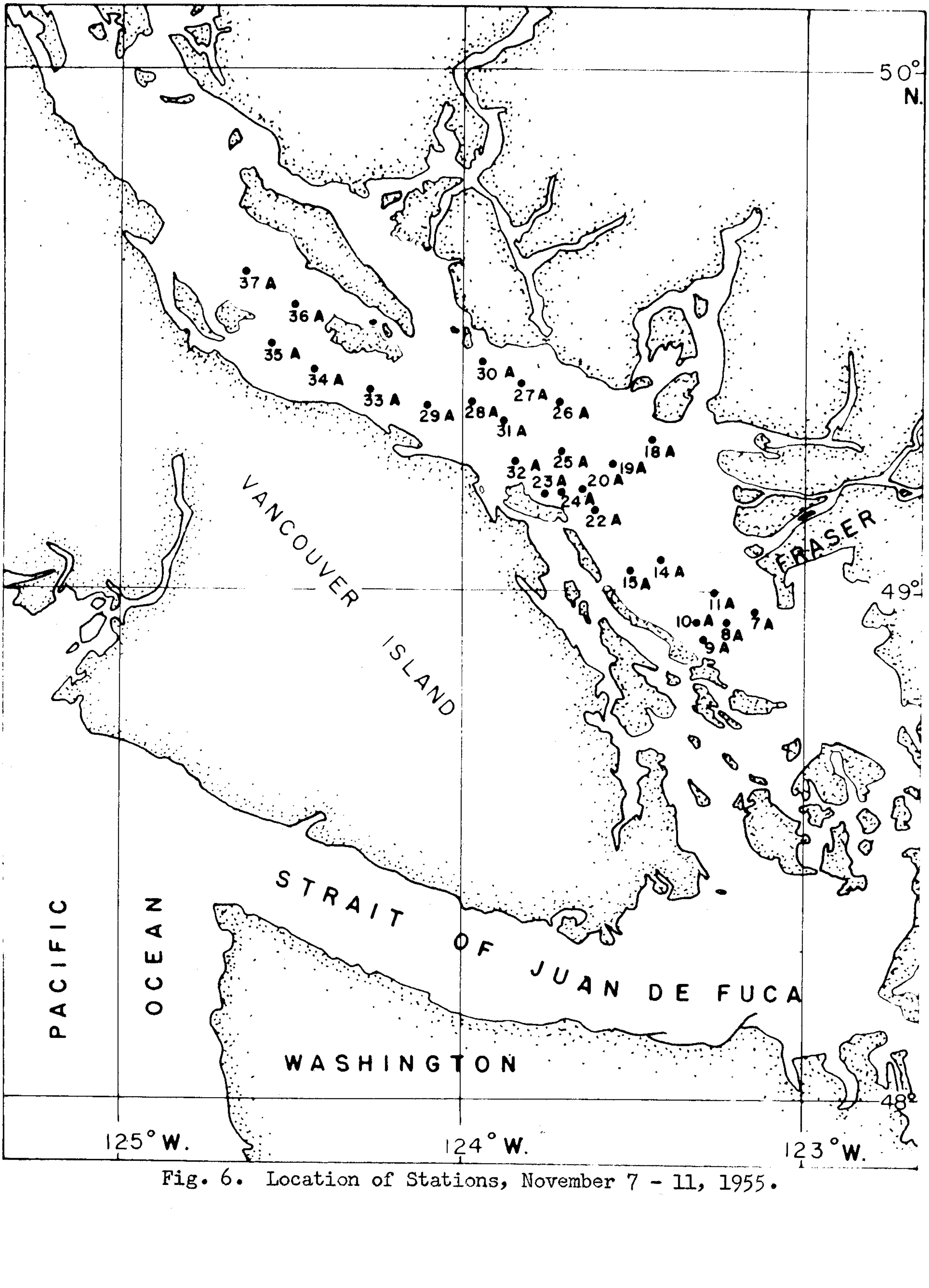


Fig. 6. Location of Stations, November 7 - 11, 1955.

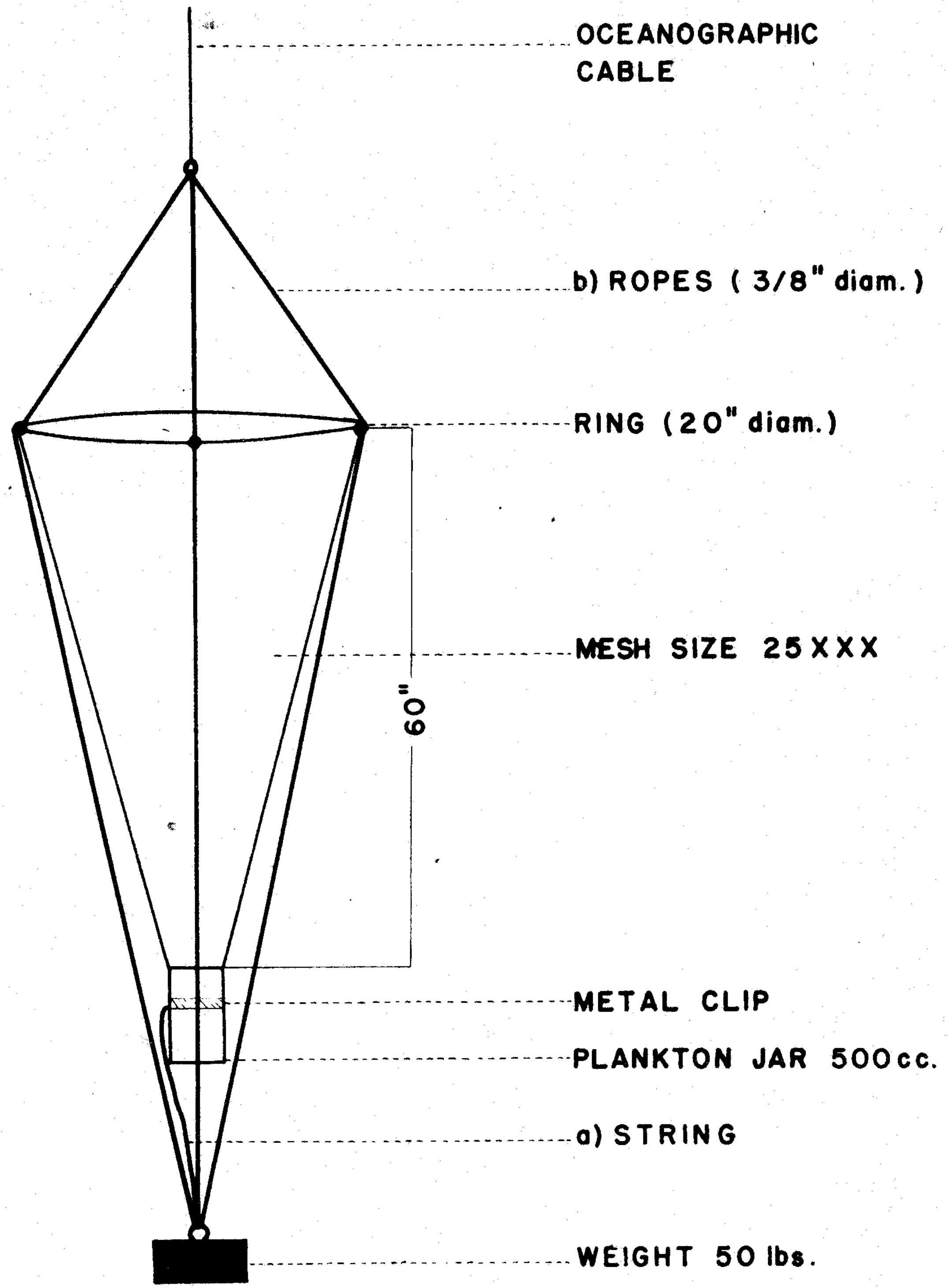


Fig.7. Diagram of plankton net used in the survey.

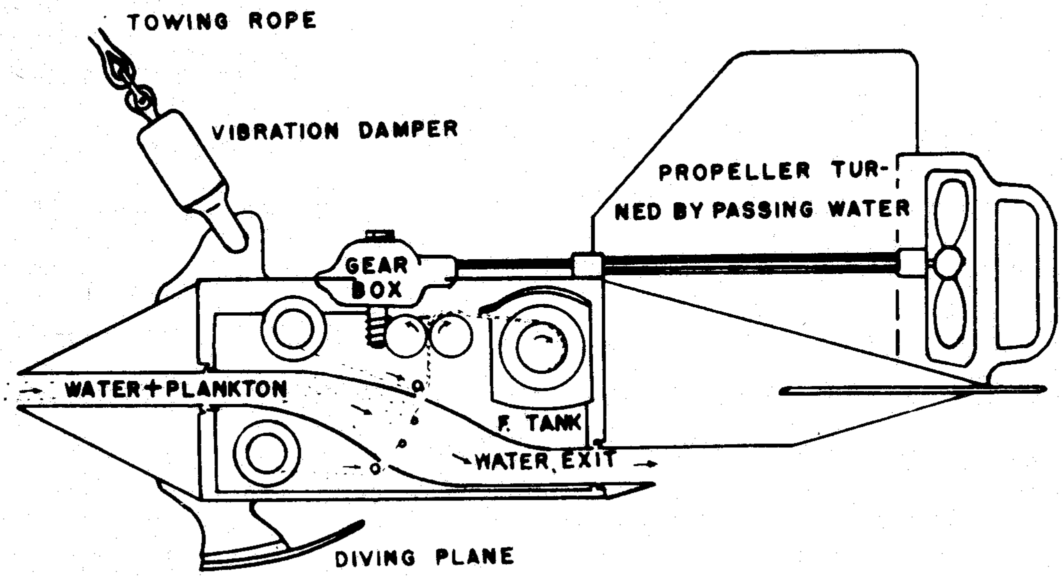


Fig.8. Diagram of Hardy Recorder in sectional view (after Hardy, 1939).

changes in the major constituents of the plankton over the areas investigated between the stations at which the vertical hauls were made.

b. Sampling Methods

In order to obtain some indication of the concentration of plankton at different depths and to trace the vertical and horizontal boundaries of distribution of the main constituents of both phyto-plankton and zooplankton, a number of sampling methods were employed.

To determine the vertical limits of distribution of the main constituents a plankton net was used (Fig. 7). The net measures 20 inches in diameter at the mouth, 60 inches in length, and 4 inches in diameter at the cod-end. A jar having a volume of 500 cc. is held tightly at the small opening by a metal clip. A string (7a) joins the metal clip to a 50-pound lead weight to keep the net from turning inside out when lowering. The weight is suspended from the lower end of three ropes (7b). These ropes, which pass alongside the net, are tied around the metal ring forming the mouth of the net, and are attached above the mouth of the net to the oceanographic cable. The net is made of bolting silk No. 25 xxx. The same net was used throughout both cruises.

1. Vertical Hauls

The shipboard procedure followed upon reaching a station involved first reversing the engine to bring the vessel to a complete stop. Some leeward motion of the ship was encountered while the sampling was being carried on, but this minor drift was disregarded.

All sampling was performed from the starboard side of the after deck. The ship was provided with a powered winch and a meter block.

The net was lowered slowly at a uniform speed and, upon reaching the desired depth it was also retrieved at a slow, uniform speed. When the net reached the surface it was lifted out of the water and while still suspended from the oceanographic boom it was washed down with three or four buckets of sea water. The plankton jar was then detached and the sample was transferred to a glass jar. The organisms clogging the net were washed free with a wash-bottle. Some formalin at 5% concentration was then added to the sample and a label was placed in the jar.

2. Hardy Recorder Tows

The instrument consists of two elements, the external torpedo-shape body weighing several hundred pounds and the internal removable mechanism. The body is fitted with two ailerons and one elevator, so that when it is towed it will dive and maintain itself at uniform depth. The depth is determined by the amount of cable played out. During the tow it is continuously sampling by filtering plankton through silk from a roll which unwinds slowly across a water tunnel by the action of a propeller turned by the passing water (Fig. 8).

When launching the Recorder the ship was stopped and the instrument was slowly lifted over the rail. This was done by using the main boom of the ship to lift the instrument and at the same time swing it clear of the stern while it was being lowered. When the Recorder touched the water the block and tackle was detached, and the towing cable played out to a mark placed on it at a point calculated to give a sampling depth of ten feet. The towing speed used varied from 8 1/4 to 8 1/2 knots, depending on the direction of the tide. At launching and at hauling the position and time were recorded. When the haul was completed the recorder was hoisted inboard and the used section of silk was removed. The silk was then transferred to a glass jar and formalin at 5% concentration was added.

c. Laboratory Methods

All the zooplankton samples were analyzed in the laboratory with a binocular microscope using a 40 X magnification, and all the phytoplankton species were identified with a compound microscope using 100 X magnification. The following treatment was used in analysing the samples:

1) the plankton sample was well shaken and 5 cc. were removed with a pipette having a length of 30 cm. and a diameter of 8 mm. A complete count of the zooplankton in the 5 cc. sample was made and tabulated as follows: all copepods to species and sex; nauplii, metanauplii, calyptopis, furcilia, cyrtopia, and adult stages of euphausids; all other major taxonomic groups including appendicularians, chaetognaths, amphipods, gastropods, ostracods, cladocerans, eggs, and larvae.

2) The qualitative analysis of the phytoplankton was made by placing a few drops of the original sample in a ruled chamber and scanning the whole field. After the entire chamber had been examined a new sample was drawn and from this chamber, which has a volume of 166 cubic millimeters, counts were made for each species. When the

quantities of phytoplankton cells were great 1/6 of the volume was counted, when they were small the number of cells in 166 cubic millimeters was counted.

3) In addition to the normal procedure outlined in section 1) and 2) a total count was made of all adult euphausids, chaetognaths and amphipods in each sample taken on the November cruise.

4) The silk taken from the Hardy Recorder was cut into sections each of which represents a horizontal haul over a distance of three to five miles. The plankton was then removed from each section. The large organisms were removed by hand, the smaller ones with a razor blade, and transferred to 100 cc. of water. A total count of all the zooplankton was made from each section of silk. The phytoplankton was analysed and counted as outlined in section 2).

IV. RESULTS

A. Composition of the Plankton

1) Zooplankton taken in the summer cruise, June 8 - 16, 1955.

Some 34 species of copepods in the following three sub-orders were taken:

Sub-order CALANOIDA

- *Acartia clausi* Giesbrecht
  - *A. longiremis* (Lilljeborg)
- *Calanus cristatus* (Krøyer)
  - *C. finmarchicus* (Gunnerus)
  - *C. tonsus* Brady
- *Candacia columbiae* Campbell

Centrogaptilus porcellus Johnson

Centropages mcmurrichi Willey

Chiridius tenuispenus Sars

Diaptomus sp. Westwood

Epilabidocera amphitrites (McMurrich)

Eucalanus bungii Giesbrecht

Euchaeta japonica Marukawa

Eurytemora hirundoides (Nordquist)

E. johanseni Willey

Gaidius pungens Giesbrecht

Metridia longa (Lubbock)

M. lucens Boeck

Microcalanus pusillus Sars

Paracalanus parvus (Claus)

Pseudocalanus minutus (Krøyer)

Scolecithricella minor (Brady)

Tortanus discaudatus (Thompson and Scott)

Sub-order CYCLOPOIDA

Ascomyzon rubrum Campbell

Corycaeus affinis McMurrich

Oithona helgolandica Claus

O. plumifera Baird

Oncaea conifera Giesbrecht

Sub-order HARPACTICOIDA

Diosaccus spinaeus Campbell

Harpacticus uniremis Krøyer

Idya furcata (Baird)

Microsetella rosea (Dana)

A few unidentified but rare species of a number of genera were met in the samples but were not identified because of taxonomic difficulties.

Several phyla were represented by many genera but not attempt was made to determine these beyond major groups. The following 26 groups were analysed in this way:

Amphipods

Annelids

Appendicularians

Barnacles : nauplius stage

cypris stage

Chaetognaths

Cladocerans

Copepods : nauplius stage

metanauplius stage

Crabs : zoea stage

metazoea stage

megalops stage

Clam larvae (early)

Eggs

Euphausids : nauplius stage
metanauplius stage
calyptopis stage
furcilia stage
cyrtopia stage

Fish larvae

Gastropods

Holothurians

Hydromedusae

Mysis

Ostracods

Coelenterate planula

Brittle star pluteus

Polychaete larvae

Pteropod larvae

Shrimp larvae

Siphonophores

Snail *(Littorina)*

Tintinnidae - observed but not analysed

Unidentified triangular egg case

Protozoans were also found in a few samples. The mesh size of the net was too coarse to retain these organisms in any quantity and no attempt was made to study their distribution. A few radiolarians were observed, but were not identified. Among the protozoans observed were:

Ceratium furca (Ehrenberg)

Dinophysis hastata Stein

Distephanus speculum var. *regularis* Lemmermann

Genyaulax spinifera (Claparede and Lachmann)

Nematodinium armatum Dogiel

Percentages, by numbers, of seven constituents of the zooplankton are given in Table I. In almost all samples copepods were the most abundant of all constituents. The appendicularians (*Oikopleura* spp.) were second in abundance, followed by euphausids, eggs, chaetognaths, gastropods and amphipods. Next, but not included in this table, were the larval stages of barnacle, crab, ostrocods, cladocerans, hydromedusae, annelids, polychaete larvae, fish larvae and other, less frequent forms. At a few stations there occurred large numbers of other specific groups, such as Siphonophores and *Littorina*, but in each case these were local populations and did not contribute to any extent to the overall distribution.

2) Phytoplankton taken in the summer cruise, June 8 - 16, 1955.

Forty-five species of diatoms were found. The following list is not complete and in a few cases the identification to species is somewhat uncertain. Some slight differences of opinion on the taxonomy of certain species are found in the literature (Gran and Angst, 1931 and Cupp, 1943) which render the identification of certain species, such as in the genus *Chaetoceros*, difficult. Nevertheless, it is possible to compare the relative abundance of most species in the area with the data available.

TABLE I

Percentages, by numbers, of seven constituents of the zooplankton,

June 8 - 16, 1955.

Stn. No.	Depth (m)	Eggs %	Cope-pods %	Oiko-pleura %	Gastro-pods %	Amphi-pods %	Chaeto-gnaths %	Euph-ausids %
1	10	12	45	36	1	1	-	1
1	50	15	68	12	-	1	-	1
2	10	7	30	46	-	1	1	4
2	80	20	48	20	3	-	-	3
4	10	10	20	58	-	-	1	2
4	100	10	61	17	4	-	-	3
5	20	3	50	23	-	-	2	2
5	200	4	82	5	4	-	-	1
6	50	5	29	32	1	-	-	7
7	10	30	33	12	1	1	1	3
7	90	25	69	2	1	-	-	-
8	50	6	67	4	4	-	-	12
8	110	3	76	7	4	-	-	5
10	10	27	11	55	-	-	-	-
10	150	11	51	26	3	-	-	2
11	10	-	69	12	-	-	-	14
11	100	4	65	14	1	1	-	9
12	10	-	64	10	-	-	-	10
12	50	12	60	15	-	-	1	2
13	10	-	88	7	-	-		-
13	50	6	72	8	-	2	-	3
14	20	5	22	64	-	-	1	2
14	200	3	63	24	3	1	-	2
15	10	5	27	58	1	-	2	1
15	150	3	58	24	6	1	-	2
16	10	-	87	4	-	1	-	7
16	100	-	80	4	3	1	-	9
17	20	5	79	6	-	1	3	3
17	150	4	78	7	4	1	-	4
18	10	-	59	8	1	1	1	22
18	150	5	73	2	12	-	-	3
19	50	3	69	10	-	1	5	1
19	200	4	77	2	2	2	-	6
20	20	17	54	15	-	-	-	4
20	250	8	71	5	2	2	-	4

TABLE I (continued)

Stn. No.	Depth (m)	Eggs %	Copepods %	Oikopleura %	Gastropods %	Amphipods %	Chaetognaths %	Euphausids %
21	20	6	64	9	-	2	-	11
21	150	3	66	8	-	1	-	13
22	10	17	31	37	-	-	-	6
22	100	2	55	23	5	-	1	2
23	10	49	37	3	1	-	1	-
23	100	17	74	2	2	-	-	-
24	20	23	54	13	-	-	-	2
24	50	18	62	9	1	1	1	3
25	10	35	49	8	-	-	1	2
25	20	17	69	5	-	-	1	2
25	50	13	67	4	3	-	1	5
25	100	13	66	5	2	-	1	6
25	150	9	65	3	2	-	1	12
26	20	7	73	5	1	1	3	2
26	150	8	80	1	2	2	1	3
27	20	1	88	1	-	3	1	1
27	50	2	82	12	-	-	1	1
28	20	1	60	4	1	-	1	27
28	230	-	82	1	3	-	1	4
29	50	7	68	1	8	1	4	3
29	150	4	78	-	5	1	1	2
30	10	3	44	3	-	11	11	17
30	150	9	74	3	1	4	1	5
31	10	2	65	11	-	-	3	8
31	100	2	68	6	3	-	2	13
32	20	9	61	11	5	-	1	2
32	100	3	77	5	6	-	-	2
33	10	9	49	27	1	1	1	8
33	200	4	62	2	3	-	-	20
34	50	-	82	5	4	-	-	5
34	150	-	81	2	5	-	-	6
35	20	1	94	2	-	-	-	-
35	100	1	82	3	4	-	-	6
36	10	10	55	5	2	3	1	12
36	100	2	58	2	9	-	-	27
37	50	7	71	5	5	-	-	10
37	100	4	74	4	5	-	-	9
38	20	5	73	8	9	-	-	2
38	100	3	71	7	12	-	-	2
41	10	16	23	33	1	1	1	3
41	200	8	56	7	5	3	1	5
43	50	38	26	24	-	-	-	2

The following diatoms were identified:

Asterionella japonica Cleve

Bacteriastrum delicatulum Cleve

Biddulphia aurita (Lyngbye) Brébisson and Godey

B. laevis Ehrenberg

B. longicruris Greville

Chaetoceros affinis Lauder

C. brevis Schütt

C. concavicornis Mangin

C. constrictus Gran

C. convolutus Castracane

C. curvisetus Cleve

C. debilis Cleve

C. decipiens Cleve

C. didymus Ehrenberg

C. lacinosus Schütt

C. lorenzianus Grunow

C. radicans Schütt

C. similis Cleve

C. teres Cleve

C. vanheurcki Gran

Corethron hystrix Hensen

Coscinodiscus excentricus Ehrenberg

C. wailesii Gran and Angst

Ditylum brightwellii (West) Grunow

Eucampia zoodiacus Ehrenberg

Fragilaria cretonensis Kitton

F. striatula Lyngbye

Grammatophora marina (Lyngbye) Kützing

Leptocylindrus danicus Cleve

Melosera moneliformis (Müller) Agardh

M. sulcata (Ehrenberg) Kützing

Navicula sp. Bory

Nitzschia sp. Hassall

Pleurosigma sp. Smith

Rhizosolenia delicatula Cleve

R. hebetata forma semispina (Hensen) Gran

R. stolterfothii Péragallo

R. styliformis Brightwell

Skeletonema costatum (Greville) Cleve

Stephanopyxis nipponica Gran and Yendo

Thalassionema nitzschioides Grunow

Thalassiosira condensata Cleve

T. decipiens (Grunow) Jørgensen

T. nordenskioldii Cleve

Thalassiothrix frauenfeldii Grunow

The dominant filamentous diatom genera found in June were Skeletonema, Chaetoceros, Thalassiosira, Biddulphia, and Nitzschia. The length of the filaments could not be approximated. The formalin solution used made the filaments very brittle and most of them broke apart when the samples were shaken.

3) Zooplankton and phytoplankton taken in the fall cruise, November 7 - 11, 1955.

Some 35 species of copepods were present in varying abundance in the samples taken in the summer, whereas only 21 species were present in November, and in very much smaller quantities in the latter instance. Some species, such as Calanus tonsus, Eucalanus bungii, and Centropages mcmurrichi, which were very abundant in June, could not be found in the samples in November, although the same depths were sampled. Deeper forms, such as Centrogaptilus porcellus, Harpacticus uniremis, and Idya furcata, could not be found in November, even though the water, at such depths, is relatively uniform in physical and chemical characteristics throughout the year. One species, Aetideus armatus, was found in the fall, but was not observed in June.

The 21 species of copepods in the following two sub-orders were taken:

Sub-order CALANOIDA

Acartia clausi Giesbrecht

A. longiremis (Lilljeborg)

Aetideus armatus (Boeck)

Calanus finmarchicus (Gunnerus)

Candacia columbiae Campbell

Chiridius tenuispinus Sars

Epilabidocera amphitrites (McMurrich)

Euchaeta japonica Marukawa

Eurytemora hirundoides (Nordquist)

Gaidius pungens Giesbrecht

Metridia longa (Lubbock)

M. lucens Boeck

Microcalanus pusillus Sars

Paracalanus parvus (Claus)

Pseudocalanus minutus (Krøyer)

Scolecithricella minor (Brady)

Tortanus discaudatus (Thompson and Scott)

Sub-order CYCLOPOIDA

Ascomyzon rubrum Campbell

Corycaeus affinis McMurrich

Oithona sp. Baird

Oncaea conifera Giesbrecht

The percentage of adult and immature individuals was found to remain quite constant in June and in November. Fifty-three percent of the summer catch was made up of adult specimens, as compared with fifty-two percent in the autumn. Many of the species found in autumn, such as *Calanus finmarchicus*, were therefore actively reproducing and not just surviving. The same is true for several other groups because immature specimens of amphipods, cladocerans, barnacles, and ostracods were found in the samples taken in November.

In addition to copepods, the main constituents of the zooplankton in November were:

Tomopteris sp.

Appendicularians

Cephalopods (egg case)

Chaetognaths

Cladocerans

Barnacles : cypris stage

Clam larvae (early)

Echinoderms (archenteric sack)

Eggs

Euphausids

Gastropods

Holothurians

Hydromedusae

Nauplii

Copepods : nauplius stage

Ostracods

Polychaete larvae

Siphonophores

Unidentified triangular egg case

Catches of chaetognaths and euphausids were made up entirely of adult specimens in November. The unidentified egg case was the next most abundant constituent of the zooplankton after the copepods. Next came the euphausids, chaetognaths, amphipods, gastropods, *Oikopleura*, ostracods, and hydromedusae. The other representatives were never abundant.

Only two species of diatoms obtained in November samples were significant. Coscinodiscus wailesii and Chaetoceros concavicornis were found in relatively large numbers. There was a dearth of all other species. A few cells of Chaetoceros affinis, Rhizosolenia semispina, and Nitzschia sp. were also encountered. Out of fifty-two samples, only thirteen gave values of more than 1 cell per liter and the maximum frequency never exceeded 10 cells per liter. No protozoans were seen in the plankton samples taken in November.

V. DISCUSSION

a. Abundance of Plankton in the Strait of Georgia

1) Abundance of zooplankton in the summer cruise, June 8 - 16, 1955.

To provide a basis for comparison of the total catch at any one locality, all quantities obtained from the 5 cc. samples quantitatively analysed were transformed into values based on a standard volume of one cubic meter. This was done by dividing the number of zooplankton per sample by the volume of water filtered. Since no device was used to record the amount of water filtered, it is assumed that the net was fishing vertically and no spilling occurred. With this assumption the number of cubic meters of water strained at each depth was then calculated. This method of calculation cannot give a complete evaluation of the zooplankton distribution with depth, but it points out with a reasonable degree of accuracy the areas of high, average, and low concentrations.

Based on the quantitative evaluation of the zooplankton obtained in the above manner three centers of different concentrations (Fig. 9; Table II) can be recognized and associated with the physical and chemical characteristics of the waters in the Strait of Georgia.

A) an area of high concentration at Stations 10, 11, 12, 13, 15, 21, and 22, with warm surface temperatures (ranging from 13.5°C to 14.7°C) and strong mixing of water masses.

B) an area of intermediate concentration at Stations 16, 17, 19, 20, 23, 24, 25, and 32, with colder surface temperatures (ranging from 12.8°C to 13.7°C) and little mixing of water masses.

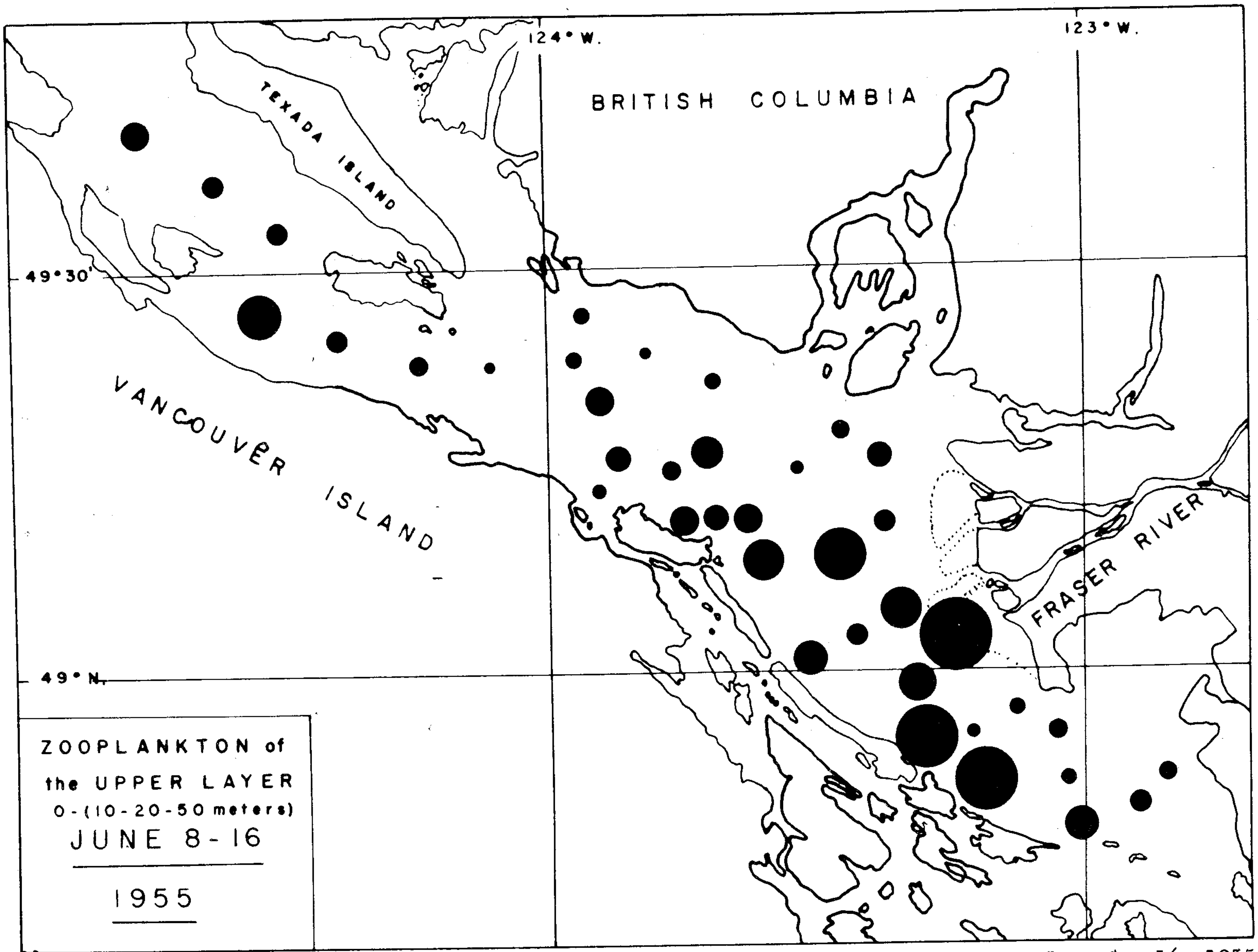


Fig. 9. Zooplankton abundance from surface to depths of 10, 20, and 50 meters, June 8 - 16, 1955.

TABLE II

Estimated numbers of zooplankton and volumes of phytoplankton collected

June 8 - 16, 1955

Stn. No.	Position Latitude	Position Longitude	Date	Time PST	Depth (m)	Water strained (m^3)	Zooplankton organisms per m^3	Phytoplankton cells per liter
1	48° 52' 00" N	122° 50' 24" W	June 13	0909	10	2.03	2154	75
1	"	"	"	0920	50	10.15	2856	546
2	48° 50' 12" N	122° 53' 30" W	"	0835	10	2.03	3220	29
2	"	"	"	0847	80	16.24	1137	22
4	48° 48' 42" N	122° 59' 00" W	"	0750	10	2.03	7252	1668
4	"	"	"	0805	100	20.39	2297	154
5	48° 52' 00" N	123° 00' 30" W	"	1023	20	4.06	1702	156
5	"	"	"	1030	200	40.58	1308	20
6	48° 56' 10" N	123° 03' 06" W	"	1130	50	10.15	2459	124480
7	48° 57' 06" N	123° 08' 00" W	"	1150	10	2.03	1599	87
7	"	"	"	1210	90	18.27	1292	54
8	48° 55' 50" N	123° 11' 30" W	"	1238	50	10.15	676	9
8	"	"	"	1243	110	22.33	958	64
10	48° 56' 00" N	123° 18' 15" W	"	1333	10	2.03	17656	26148
10	"	"	"	1341	150	30.45	710	402
11	49° 00' 00" N	123° 18' 30" W	"	1424	10	2.03	8805	347
11	"	"	"	1435	100	20.29	1845	196
12	49° 04' 20" N	123° 18' 55" W	"	1503	10	2.03	20413	1141
12	"	"	"	1510	50	10.15	3000	502
13	49° 05' 10" N	123° 21' 40" W	"	1526	10	2.03	9638	955
13	"	"	"	1534	50	10.15	5700	778
14	49° 03' 30" N	123° 26' 15" W	June 14	1117	20	4.06	3845	1084
14	"	"	"	1126	200	40.58	1326	132
15	49° 01' 50" N	123° 31' 20" W	"	1212	10	2.03	7345	2519
15	"	"	"	1221	150	30.45	829	146

TABLE II (continued)

Stn. No.	Position Latitude	Position Longitude	Date	Time PST	Depth (m)	Water strained (m^3)	Zooplankton organisms per m^3	Phytoplankton cells per liter
16	49° 10' 10" N	123° 19' 30" W	June 13	1655	10	2.03	3151	284
16	"	"	"	1705	100	20.29	1158	14
17	49° 14' 45" N	123° 20' 15" W	"	1732	20	4.06	4446	110
17	"	"	"	1744	150	30.45	1563	8
18	49° 17' 55" N	123° 25' 00" W	June 14	0740	10	2.03	2502	5564
18	"	"	"	0747	150	30.45	1006	21
19	49° 15' 30" N	123° 29' 10" W	"	0829	50	10.15	676	26
19	"	"	"	0842	200	40.58	269	5
20	49° 12' 20" N	123° 33' 15" W	"	0915	20	4.06	5605	338
20	"	"	"	0926	250	50.75	649	23
21	49° 07' 30" N	123° 25' 30" W	June 13	1605	20	4.06	14324	3872
21	"	"	"	1615	150	30.45	3906	46
22	49° 09' 15" N	123° 32' 45" W	June 14	1015	10	2.03	9314	3474
22	"	"	"	1024	100	20.29	1829	171
23	49° 11' 15" N	123° 42' 30" W	June 16	1144	10	2.03	5422	17
23	"	"	"	1153	100	20.29	1534	19
24	49° 12' 20" N	123° 39' 15" W	June 14	1336	20	4.06	4111	702
24	"	"	"	1346	50	10.15	3098	160
25	49° 16' 30" N	123° 40' 30" W	June 16	1003	10	2.03	6001	162
25	"	"	"	1009	20	4.06	4389	69
25	"	"	"	1017	50	10.15	2612	153
25	"	"	"	1028	100	20.29	1896	358
25	"	"	"	1041	150	30.45	1151	90
26	49° 21' 15" N	123° 41' 30" W	June 14	1450	20	4.06	1019	69
26	"	"	"	1505	150	30.45	410	6
27	49° 24' 10" N	123° 48' 45" W	"	1550	20	4.06	891	14
27	"	"	"	1600	50	10.15	1370	2794

TABLE II (concluded)

Stn. No.	Position Latitude	Longitude	Date	Time PST	Depth (m)	Water strained (m^3)	Zooplankton organisms per m^3	Phytoplankton cells per liter
28	49° 23' 10" N	123° 54' 15" W	June 14	1718	20	4.06	1054	20
28	"	"	"	1728	230	46.69	165	5
29	49° 22' 10" N	124° 01' 30" W	June 15	1538	50	10.15	643	9286
29	"	"	"	1548	150	15.48	344	88
30	49° 26' 45" N	123° 54' 15" W	June 14	1627	10	2.03	1460	12
30	"	"	"	1637	150	15.48	1147	29
31	49° 19' 45" N	123° 51' 15" W	June 15	1653	10	2.03	5282	2605
31	"	"	"	1701	100	20.29	742	1009
32	49° 15' 15" N	123° 49' 30" W	"	1751	20	4.06	4666	1246
32	"	"	"	1800	100	20.29	1144	528
33	49° 23' 30" N	124° 16' 00" W	"	0619	10	2.03	2456	2553
33	"	"	"	0629	200	40.58	677	78
34	49° 26' 20" N	124° 23' 00" W	"	0725	50	10.15	3690	1305
34	"	"	"	0738	150	15.48	2191	1661
35	49° 29' 30" N	124° 30' 15" W	"	0827	20	4.06	11070	5592
35	"	"	"	0835	100	20.29	3225	774
36	49° 33' 15" N	124° 27' 00" W	"	0913	10	2.03	3360	44351
36	"	"	"	0921	100	20.29	1320	594
37	49° 36' 00" N	124° 33' 45" W	"	1008	50	10.15	3880	1328
37	"	"	"	1018	100	20.29	2195	538
38	49° 40' 00" N	124° 45' 00" W	"	1124	20	4.06	5141	7650
38	"	"	"	1138	100	20.29	1072	1789
41	49° 15' 40" N	123° 42' 54" W	June 8	1320	10	2.03	2850	2293
41	"	"	"	1345	200	40.58	890	313
43	49° 13' 54" N	123° 50' 56" W	June 9	1430	50	10.15	722	777

c) an area of low concentration at Stations 18, 26, 27, 28, 29, 30, and 31, with still colder surface temperatures (ranging from 12.4°C to 13.6°C) and little mixing of water masses.

The catches made in the tows between 50 meters and the surface were more characteristic of the Strait of Georgia because they included populations inhabiting both the "upper zone" and the uppermost stratum of the homogeneous "lower zone".

The catches proved to be fairly uniform from station to station, as far as the predominant species were concerned, and thus copepods were, in most cases, the most abundant animals. However, regional differences in the relative abundance of copepods, euphausids, amphipods and chaetognaths resulted in notable differences in the plankton population from station to station.

In some instances, one or another species dominated. Thus, at Station 18, the copepod Calanus tonsus formed the bulk of the catch from 150-0 meters. Surface hauls at Stations 12, 13, 17, 35, 37, 38, yielded very large numbers of Pseudocalanus minutus. Oikopleura sp. was predominant at the surface at four stations (4, 6, 10, and 14) as were eggs at Station 10 in a haul from 10-0 meters.

2) Abundance of phytoplankton in the summer cruise, June 8 - 16, 1955.

It is impossible to state on the basis of a survey lasting only two weeks whether the conditions encountered in June 1955, are typical for this period of the year. The late spring and relatively cold June of 1955 may have affected the abundance of diatoms and delayed the period of peak abundance; according to von Hoff's Law a 10°C rise in temperature increases the rate of metabolism 2 to 3 times. Campbell (1929) found that temperature changes and plankton occurrence are definitely correlated within the limits of 10°C - 15°C. Within these limits, at least, an increase in temperature is accompanied by an increase in plankton in the Strait of Georgia.

Although absolute abundance of diatoms during the period of this study is only a measure of the standing crop it is probably indicative of a fairly productive area (Fig. 10). The maximum number of diatom cells per liter (124,480) in the Strait of Georgia does not compare with 20,000,000 cells recorded in the Clyde Sea in April 1927 (Marshall and Orr, 1927). Comparison between the maximum count obtained in June 1955 (25/100,000 vol.) and the maximum volume reported by Hutchinson and Lucas in July 30, 1927 (110/100,000 vol.) show that the values obtained on the latter date were roughly four times higher. This suggests that catches taken in June 1955 were preceding or following a period of greater abundance and that greater quantities could be expected from the area.

Few diatoms were taken at Stations 13, 16, and 17 close to the Fraser River estuary (Fig. 10). This region is characterized by a low salinity (Fig. 11) and a high turbidity. The latter greatly reduces the depth of the photic zone which in turn affects the growth of phytoplankton. In the center of the Strait the standing crop in June, 1955 was higher in the western portion than in the eastern portion; only Station 18, located at the mouth of Vancouver Harbour, where more

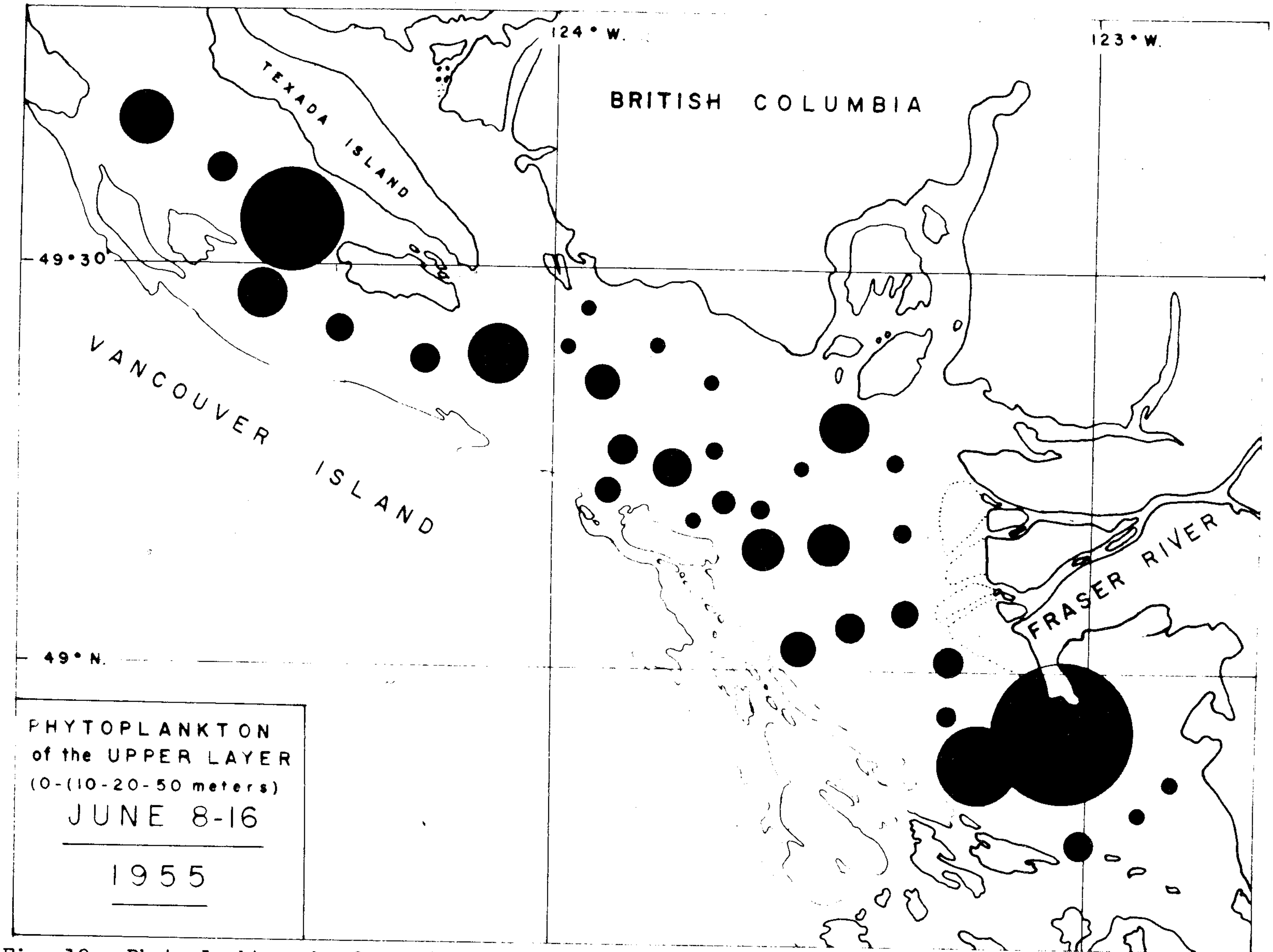


Fig. 10. Phytoplankton abundance from surface to depths of 10, 20, and 50 meters, June 8 - 16, 1955.

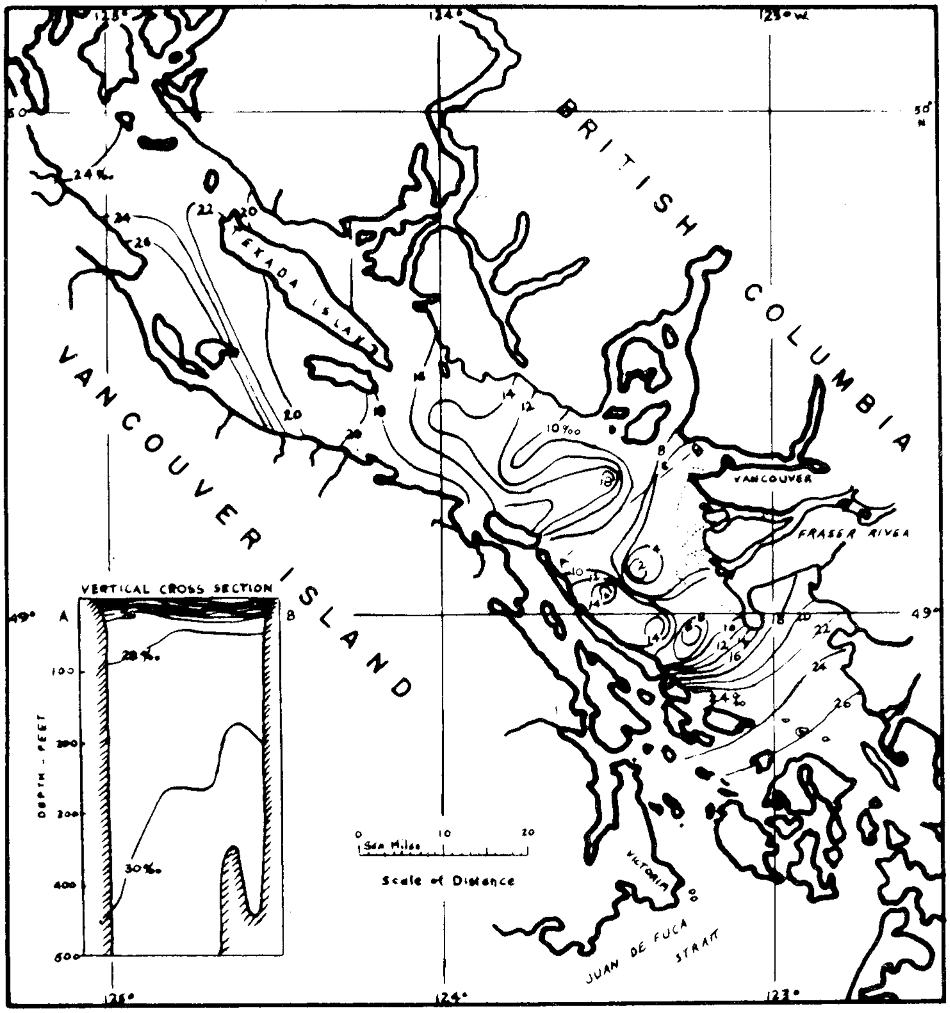


Fig. 11. Salinity at two yards depth in the Strait of Georgia from synoptic survey, June 1950 (after Waldichuk, 1952).

extensive mixing is taking place, showed a relatively high standing crop. Several authors (Hutchinson and Lucas 1931; Tully, 1932; Waldichuk, 1952) have observed a larger flow of Fraser water along the eastern portion of the Strait bringing lower salinities to the area. Temperatures are also colder in this region (Fig. 3). The salinity gradient is therefore one of the chief factors affecting the general abundance of phytoplankton in this central region of the Strait.

The standing crop of the surface waters at Stations 35, 36, and 38 in the northern area was high (Table II). Tully (1932) found a decrease of phosphate concentration during the summer and low silicate values (1 mg/l. in July) in this area. This decrease in the chemical constituents can be attributed to phytoplankton activity and since the latter region is located in the less turbulent part of the Strait (Tully, 1954) it is evident that depletion of silicates will limit phytoplankton growth. Tully (1932) suggests that other nutrients do not reach concentrations low enough to limit the development of phytoplankton.

The highest standing crop appeared south of Point Roberts at Station 6. Hutchinson and Lucas (1932) and Waldichuk (1952) found that strong physical and chemical gradients existed in this region where fresh and salt water mixing occurs. Both fresh water and sea water masses contributed certain favourable factors for the rapid growth of the phytoplankton population.

3) Abundance of zooplankton and phytoplankton in the fall cruise, November 7 - 10, 1955.

The collections taken in November present a picture of the abundance of plankton in the central and northern regions of the Strait. Since the data (Table III) were taken only during the daylight period they do not give a true quantitative value, but only an approximation of the abundance of plankton in November. Except for a region of moderate concentration (Fig. 12) at the boundary of the central and southern regions of the Strait (Stations 7A, 8A, 9A, 10A, and 11A) and three widely separated localities of moderate concentrations (Stations 18A, 19A, 20A, 30A, and 36A) the whole area of the Strait, covered in November, supported a uniformly low concentration of zooplankton. It has already be pointed out that the water reaches an almost homogeneous state in the autumn with colder temperatures than in June and a small salinity gradient. These two factors are assumed to be limiting in November. The region of moderate concentration corresponds to the zone of greater fresh water and sea water admixture off Point Roberts where a high salinity gradient exists in November.

The center of abundance for the copepods was in the 50-0 meter zone. Among the copepods, the juveniles of Calanus finmarchicus and Pseudocalanus minutus were predominant in 20-0 meters at Stations 7A, 8A, 9A, 10A, 11A, 15A, 18A, 19A, 20A, 26A, 28A, 30A, 31A, 33A, 35A, and 36A, while the adults of Calanus finmarchicus, Corycaeus affinis, Pseudocalanus minutus, Paracalanus parvus, Tortanus discaudatus, and Acartia longiremis were predominant in 50-0 meters in the area. The copepod

TABLE III

Estimated numbers of zooplankton and volumes of phytoplankton collected

November 7 - 10, 1955

Stn. No.	Position Latitude	Position Longitude	Date	Time PST	Depth (m)	Water strained (m^3)	Zooplankton organisms per m^3	Phytoplankton cells per liter
7A	48° 57' 15" N	123° 08' 00" W	Nov.9	1610	10	2.03	4102	<1
7A	"	"	"	1620	100	20.29	1028	<1
8A	48° 55' 51" N	123° 11' 30" W	"	1651	50	10.15	1148	<1
8A	"	"	"	1705	110	22.33	660	<1
9A	48° 54' 18" N	123° 16' 12" W	"	1824	20	4.06	603	1
9A	"	"	"	1830	100	20.29	408	<1
10A	48° 56' 06" N	123° 18' 16" W	"	1752	10	2.00	1460	<1
10A	"	"	"	1804	150	30.45	408	<1
11A	49° 00' 00" N	123° 18' 30" W	"	1510	10	2.03	1761	<1
11A	"	"	"	1518	100	20.29	641	3
14A	49° 03' 43" N	123° 26' 21" W	"	1400	20	4.06	313	<1
14A	"	"	"	1415	200	40.58	203	1
15A	49° 02' 00" N	123° 31' 45" W	"	1304	10	2.03	1136	<1
15A	"	"	"	1315	150	30.45	437	<1
18A	49° 18' 00" N	123° 25' 02" W	Nov.7	1335	10	2.03	1599	<1
18A	"	"	"	1348	150	30.45	621	<1
19A	49° 15' 22" N	123° 29' 00" W	"	1425	50	10.15	1037	1
19A	"	"	"	1438	200	40.58	334	<1
20A	49° 12' 20" N	123° 33' 15" W	"	1522	20	4.06	972	1
20A	"	"	"	1535	250	50.75	258	<1
22A	49° 09' 38" N	123° 32' 16" W	Nov.9	1145	10	2.03	371	<1
22A	"	"	"	1155	100	20.29	309	<1
23A	49° 11' 12" N	123° 42' 30" W	Nov.7	1645	10	2.03	278	<1
23A	"	"	"	1700	100	20.29	509	1
24A	49° 12' 22" N	123° 39' 15" W	"	1617	20	4.06	301	3
24A	"	"	"	1625	50	10.15	241	<1

TABLE III (concluded)

Stn. No.	Position Latitude	Position Longitude	Date	Time PST	Depth (m)	Water strained (m^3)	Zooplankton organisms per m^3	Phytoplankton cells per liter
25A	49° 16' 31" N	123° 40' 40" W	Nov.9	1005	10	2.03	441	1
25A	"	"	"	1015	50	10.15	407	< 1
26A	49° 21' 22" N	123° 41' 30" W	"	0859	20	4.06	451	2
26A	"	"	"	0913	150	30.45	290	< 1
27A	49° 24' 15" N	123° 48' 45" W	"	0803	20	4.06	289	1
27A	"	"	"	0814	60	12.18	301	1
28A	49° 23' 22" N	123° 54' 24" W	Nov.8	1030	20	4.06	1354	6
28A	"	"	"	1045	230	46.69	234	1
29A	49° 22' 12" N	124° 01' 30" W	"	1145	65	13.20	235	1
29A	"	"	"	1165	150	30.45	165	< 1
30A	49° 26' 45" N	123° 54' 15" W	"	0940	10	2.03	811	2
30A	"	"	"	0955	150	30.45	243	1
31A	49° 19' 45" N	123° 51' 30" W	"	0845	10	2.03	510	2
31A	"	"	"	0900	100	20.29	269	< 1
32A	49° 15' 16" N	123° 49' 30" W	"	0755	20	4.06	173	3
32A	"	"	"	0814	100	20.29	234	< 1
33A	49° 23' 38" N	124° 16' 05" W	"	1310	10	2.03	765	< 1
33A	"	"	"	1335	200	40.58	242	< 1
34A	49° 26' 10" N	124° 22' 50" W	"	1423	50	10.15	250	4
34A	"	"	"	1442	150	30.45	203	3
35A	49° 29' 22" N	124° 30' 20" W	"	1518	20	4.06	428	2
35A	"	"	"	1530	100	20.29	410	< 1
36A	49° 33' 28" N	124° 26' 50" W	"	1612	10	2.03	1390	10
36A	"	"	"	1630	100	20.29	304	1
37A	49° 36' 00" N	124° 33' 45" W	"	1713	50	10.15	500	2
37A	"	"	"	1737	100	20.29	803	2

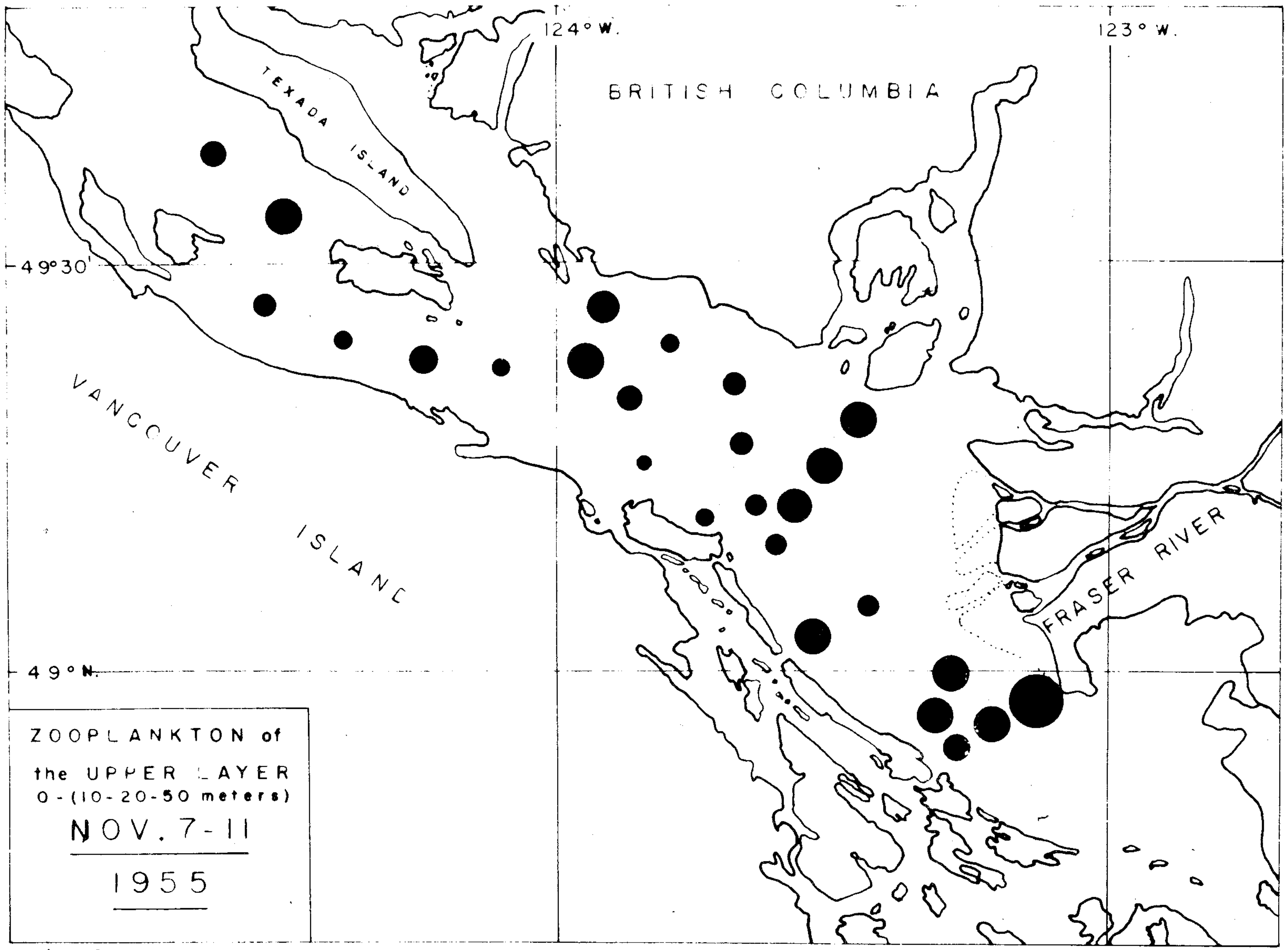


Fig. 12. Zooplankton abundance from surface to depths of 10, 20, and 50 meters, Nov. 7 - 10, 1955.

association, with Calanus finmarchicus and Pseudocalanus minutus as predominant representatives, must play an important role in the surface economy of the Strait in November.

No juvenile euphausids were caught in November and adults were found almost exclusively in the deeper hauls. The adults dominated the catch at Station 37A.

Chaetognaths and amphipods were found in small numbers at almost every station in the deeper hauls and on a few occasions in 50-0 meters.

Diatoms were so sparse in November as to be almost insignificant. Stations 28A, 34A, 36A, and 37A supported low concentrations of Chaetoceros concavicornis. Coscinodiscus wailesii was common at most of the stations visited in November.

b. Distribution of the Plankton

1) Vertical Distribution.

In comparing the abundance of the different groups of plankton in the upper 50 meters from one area of the Strait to the other, the problem of vertical distribution arises. The relative abundance of the different groups may vary depending on whether the sample came from 10-0 meters, 20-0 meters, 50-0 meters or deeper. At Station 25, for example, where hauls were made at 10-0, 20-0 and 50-0 meters, eggs were predominant from 10-0 meters, copepods from 20-0 meters, and juvenile euphausids from 50-0 meters. In order to study the vertical distribution, copepods were selected because they were the most important representatives of the plankton and contribubed many species to the community. Analysis of samples containing copepods shows that these animals fall into three distinct groups:

1. the surface forms,
2. the subsurface forms,
3. the deep forms.

When a species is common in the deep as well as in the shallow hauls, it can be said that this species inhabits the surface layer. On the other hand, if a species is never caught in the shallow haul and is abundant in the deep hauls, it is recognized as a deep form. When we compare the abundance of one species at different depths, its vertical distribution can be determined within narrow limits (Fig. 13).

Species such as Acartia clausi, Acartia longiremis, Centropages mcmurrichi, Paracalanus parvus, Tortanus discaudatus, and Epilabidocera amphitrites inhabit the surface layers (10-0, 20-0, and 50-0 meters), while Microcalanus pusillus, Euchaeta japonica, Scolecithricella minor, and Chiridius tenuispinus live in the deeper layers (250-0 meters).

Other groups of animals in the plankton also seem to follow a similar pattern of distribution. Euphausids as a group are represented by several larval stages. The nauplii and metanauplii were generally abundant at 10-0 meters, while the calyptopis, furcilia and cyrtopia stages were found deeper. Juvenile Calanus were abundant at Stations 12 and 35 in the upper 20 meters. Oikopleura was predominant at 10-0 meters, and was seldom found deeper.

2) Horizontal distribution at constant depth.

Variations in abundance at constant depth for June 8 - 16, are

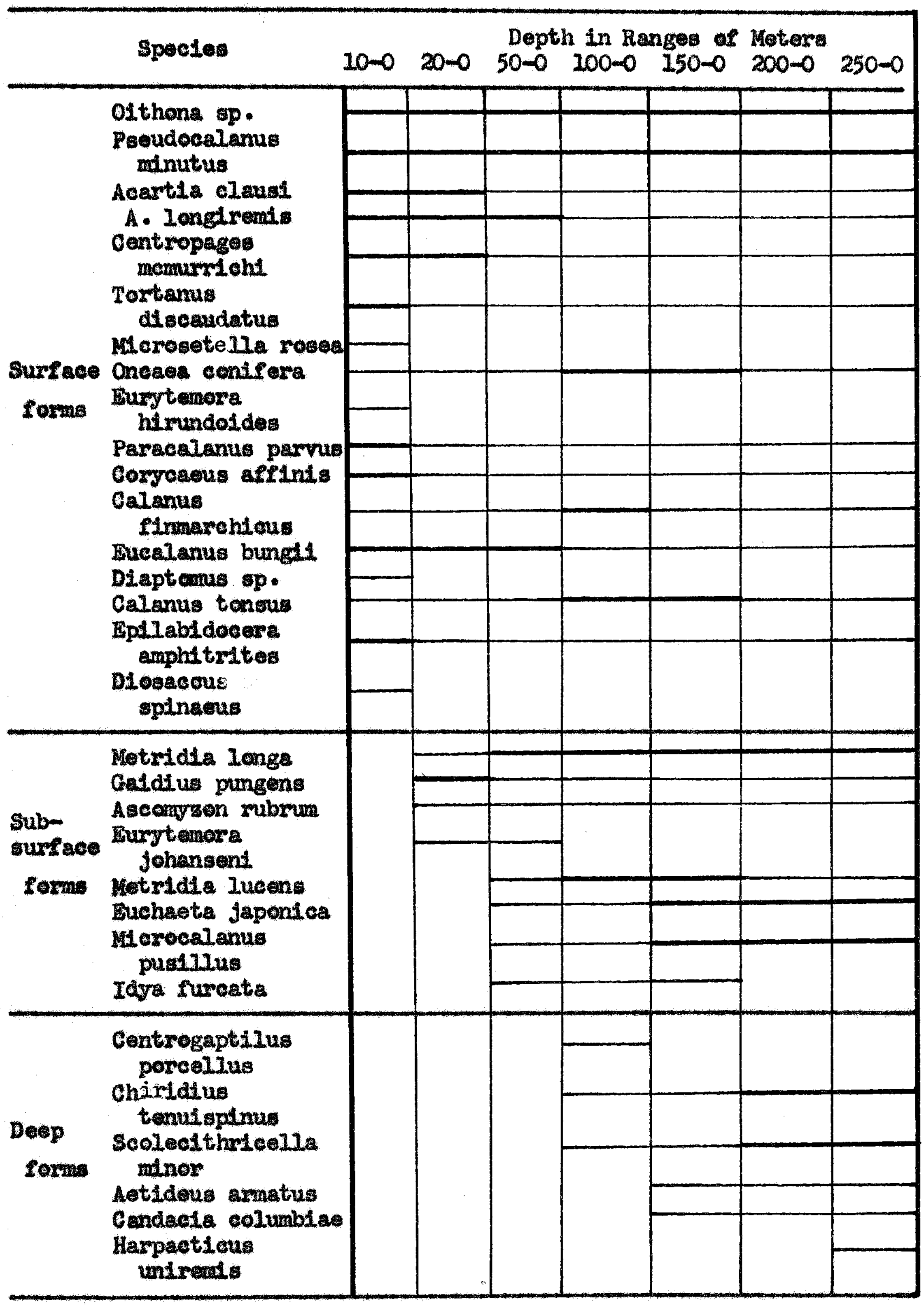


Fig. 13. Histogram showing the occurrence of copepods at different depths, June 8 - 16, 1955. The heavy lines indicate the zones of maximum abundance.

demonstrated by the histograms (Fig. 14). The total zooplankton values are plotted in numbers per cubic meter. The shaded portion of the histograms represents the number of copepods in the catch and the narrow column to the right shows the volume of diatom cells per liter present in the same plankton sample.

At 10-0 meters, all stations but two (Stations 7 and 30) have concentrations higher than 2000 animals per cubic meter; seven display concentrations ranging from 2000 to 4000 animals (Stations 1, 2, 16, 18, 33, 36, and 41); three more exhibit numbers of the order of 4000 to 6000 animals (Stations 23, 25, and 31), and seven have higher concentrations (Stations 4, 10, 11, 12, 13, 15, and 22). An inverse correlation exists at 13 out of 19 stations, between zooplankton quantities and diatom volumes. Where high blooms of diatoms occur, such as at Stations 10, 18, 33, 36, and 41, the number of animals is low. Station 12 has a very large number of animals and a low diatom population. Low diatom concentration are also found at Stations 1, 2, 7, 11, 12, 13, 16, 23, 25, and 30.

The situation is somewhat different at 20-0 meters. Stations 5, 26, 27, and 28 have concentrations below 2000 animals per cubic meter; Station 14 shows a value of 2800 animals per cubic meter; Stations 17, 20, 24, 25, 32, and 38, have values ranging from 4000 to 6000 animals; and Stations 21 and 35 have over 10,000 animals per cubic meter. An inverse correlation between zooplankton and phytoplankton is apparent at Station 38 where diatoms predominate and zooplankton counts are low. The number of animals increases markedly at Station 35, near by, where

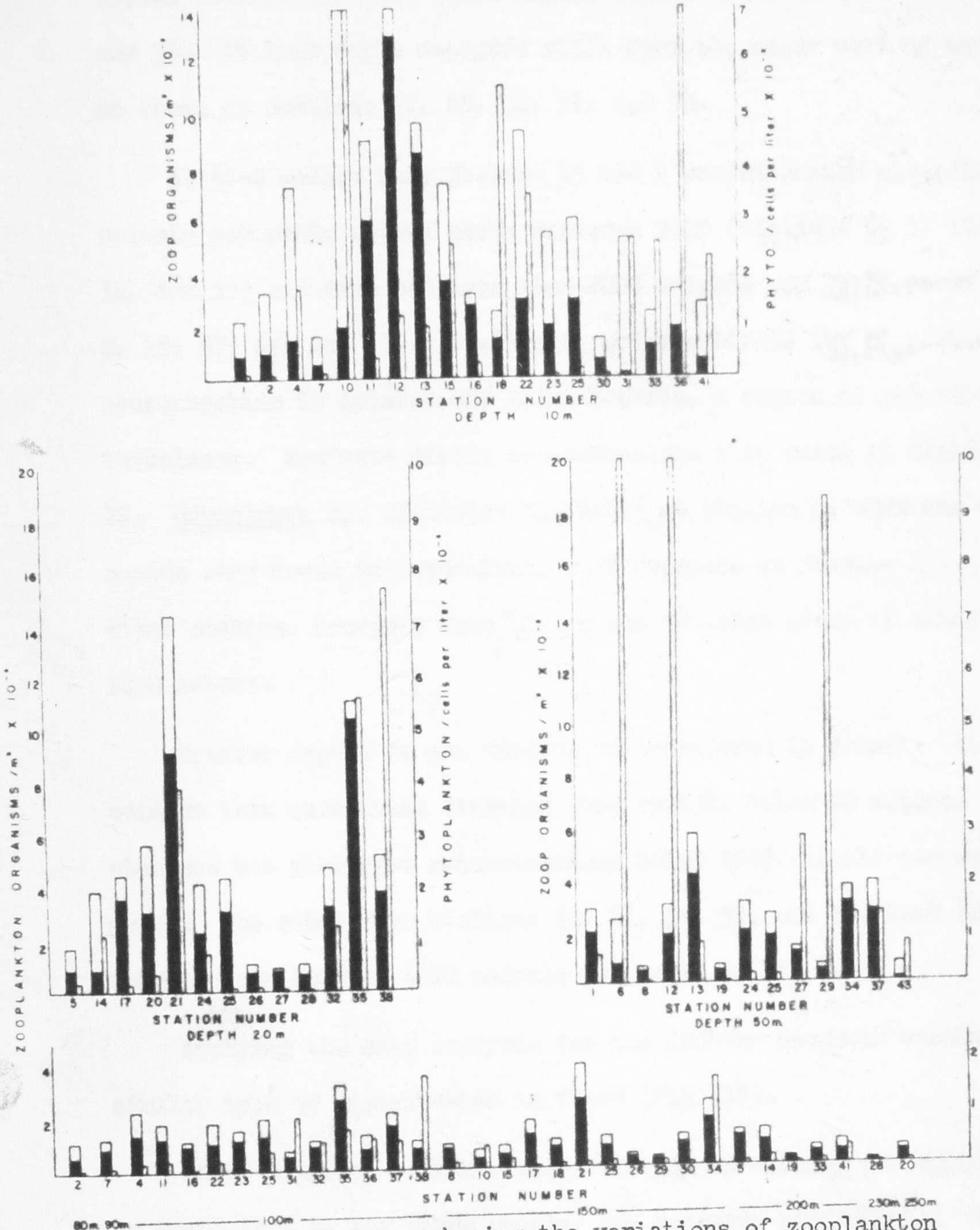


Fig. 14. Histograms showing the variations of zooplankton and phytoplankton at constant depths, June 8 - 16, 1955.

diatoms are less numerous. At Stations 5, 17, 20, 24, 25, 26, 27, and 28, diatom volumes are low. Much higher counts are recorded at Stations 21 and 35. At this depth copepods still form the major part of the catch, as shown at Stations 17, 25, 32, 35, and 38.

At 50-0 meters only Station 13 had a concentration exceeding 4000 animals per cubic meter; seven exceeded 2000 (Stations 1, 6, 12, 24, 25, 34, and 37) and five had less than 2000 animals per cubic meter (Stations 8, 19, 27, 29, and 43). Station 6, which exhibits the highest diatom concentration is located off Point Roberts, a region of relatively great turbulence. Moderate diatom concentrations also occur at Stations 12 and 29. Oikopleura sp. dominated the catch at Station 6, eggs and euphausids were found to predominate over copepods at Station 13. At all other stations copepods were always the dominant group of animals at 50-0 meters.

Greater depths do not need to be considered in detail. It is evident that quantities decrease very rapidly below 50 meters. All stations but five have concentrations below 2000 animals per cubic meter. The other five stations (4, 21, 34, 35, and 37) have values ranging from 2000 to 4000 animals per cubic meter.

Applying the same analysis for the lighter November catches, a similar type of distribution is found (Fig. 15).

At 10-0 meters a higher concentration of animals per cubic meter is found than at any other depths, and copepods predominate. At 20-0 and 50-0 meters copepods are still the predominant form, but the relative concentrations of animals are much smaller. Below 50 meters,

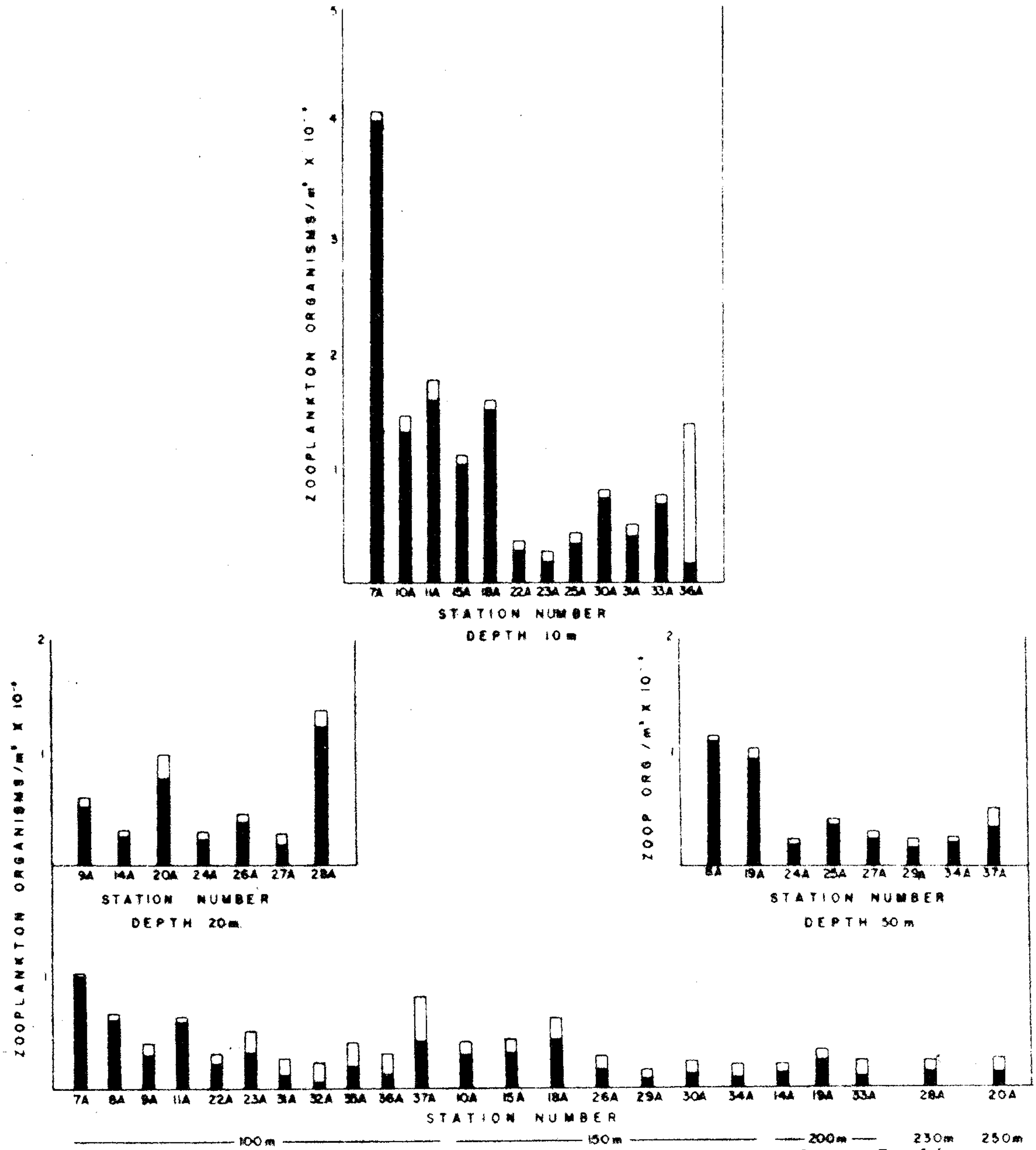


Fig. 15. Histograms showing the variations of zooplankton at constant depths, November 7 - 10, 1955.

where mature individuals aggregate, catches are very small, except for chaetognaths, euphausids, and amphipods. Diatom volumes are so small in November that they do not appear on the histograms.

c. Some Characteristics of the Most Important Groups

1) Copepods.

Copepods, either in the adult or larval stages, generally formed the main bulk of the zooplankton. There were more species and more individuals present in June than in November. Fraser (1918) also noted fewer numbers of copepods in the winter at Departure Bay.

In the month of June, whenever copepods dominated the catch, Pseudocalanus minutus, Acartia longiremis, and Oithona sp. were mainly responsible. These three species together contributed 65% of all copepods taken during the cruise. They were supplemented by Calanus sp. (15%), Metridia longa (5%), Eucalanus bungii (5%), Metridia lucens (3%), and Centropages mcmurrichi (3%). All other species contributed together only 2% of the total catch of copepods, in terms of numbers.

Wherever juveniles were very abundant the same three dominant species were responsible. Calanus sp. also contributed very high percentages of juveniles.

In the month of November, Pseudocalanus minutus, Oithona sp., and Calanus finmarchicus were the most numerous representatives of the zooplankton and formed 77% of the total number of copepods. Next came Metridia lucens (10%), Scolecithricella minor (2%), Microcalanus pusillus (2%), Corycaeus affinis (2%), Acartia longiremis (2%), Paracalanus parvus (1%), and Euchaeta japonica (1%); all other species formed less than 1% of the total catch.

The following summarizes the features of the species regarded as significant. Little attention is given here to the rarer species which must have some importance but contributed little to this study. A systematic treatment of the various species common in the British Columbia waters has been prepared by Campbell (1929) and most of the species studied here have been reported as characteristic of the area.

Pseudocalanus minutus

The commonest species in June and November has a universal distribution in the Strait of Georgia. It is very abundant throughout the area and is found at all depths sampled. This suggests wide limits of survival for the species. It is one of the commonest species at Friday Harbor (Johnson, 1932), where it is most abundant in the spring and autumn. Cameron (1955) mentions that P. minutus was so common everywhere in the Queen Charlotte Islands as to be useless as an indicator of water movements.

The percentages of P. minutus forming the total catch are fairly uniform for June and November: 29% of the total number in June, and 28% in November.

There is a definite degree of variation in the ratio of males, females and juveniles forming the catch for different periods of the year. The males appear to be more abundant at the onset of breeding. For example, in June, from a catch of 7629 individuals, 12% were males and 38% females. Several females were egg-bearing and already 50% of the catch was made up of juveniles. The number of males diminishes more rapidly than the females after the breeding season. Thus in November, 1955, 1396 individuals were caught and the males amounted to only 4% of the catch, and the females to 25%. By this time breeding must have been completed by this species, because no egg-bearing females could be found. Furthermore, the juveniles accounted for 71% of the catch.

Acartia

The genus Acartia is represented by two species in the Strait of Georgia: A. longiremis and A. clausi. Of the two species, Acartia longiremis is by far the most abundant and is characteristic of the whole Strait. It seems to be present at all seasons but shows wide fluctuations in abundance. Thus 18% of the copepods taken in June was made up of A. longiremis, while the same species accounted for less than 2% of the catch in November. Wilson (1938) mentions that in company with A. clausi these species fom the chief constituents of the plankton of Chesapeake Bay. Bigelow and Leslie (1930) found A. longiremis dominant in Monterey Bay at stations near land and in comparatively shallow parts at a few stations farther out. At Friday Harbor, Johnson (1932) notes that A. longiremis is present at all seasons but never in very large numbers. He gives the monthly distribution of A. longiremis in the years 1927-1928, 1928-1929 (Table IV).

TABLE IV

Average monthly distribution of Acartia longiremis in 1927-1928 and 1928-1929 (after Johnson, 1932)

A. longiremis	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	June	July	Aug.
1927 - 1928	+	8	17	4	1	3	4	5	9	9	10	2
1928 - 1929	+	+	2	1	+	+	+	+	3	5	5	2

+ present (counts animals in 1 ml of sample)

The abundance of Acartia in June (Fig. 16) corresponded to the peak of main increase in the Fraser discharge, and since the genus is known to be euryhaline it is suggested that in our region it reaches its peak abundance in summer, when low salinity warm water is widely distributed. It is distributed in the upper 20 meters throughout the Strait and reaches its maximum concentrations at Stations 13 and 21, which are located near the middle of the Strait opposite the Fraser River estuary.

The waters become almost isothermal in November at 8.5°C and the upper zone of low salinity is found only in the vicinity of the Fraser in the upper four meters (Tully and Dodimead, 1954). These physical conditions may account for the low quantities of both species of Acartia found in November and for their distribution in the deeper waters.

During the breeding season, males and females share the catch in fairly uniform numbers, 25% for the males, and 32% for the females. When breeding is not taking place, females far outnumber the males. For example, in November when the temperatures were too cold for the species

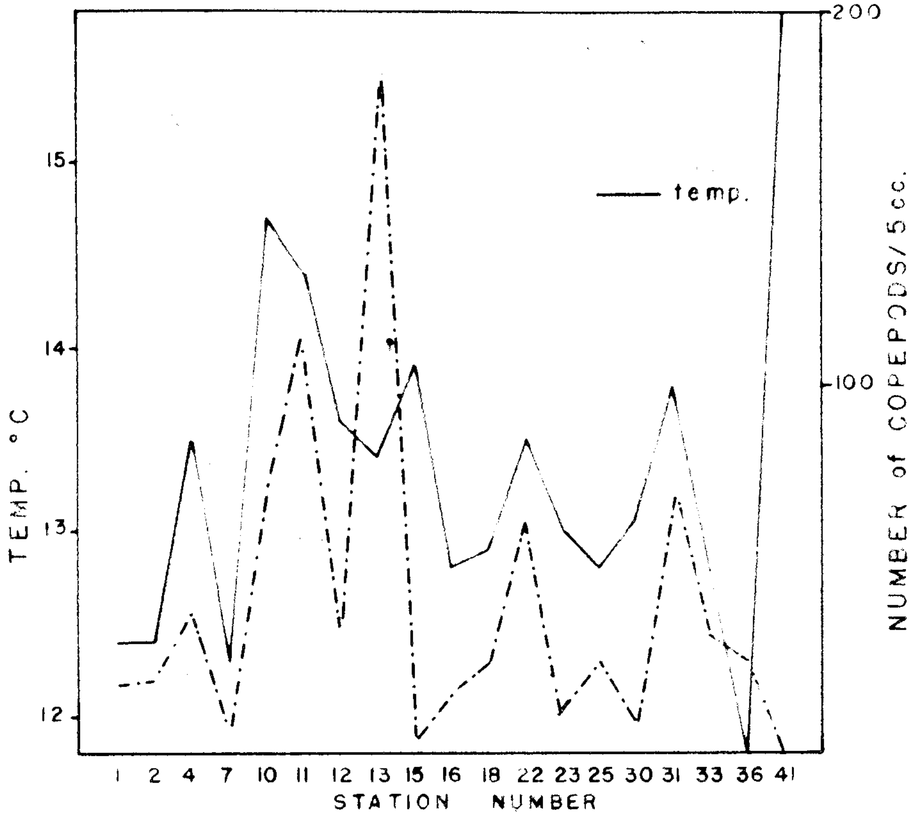


Fig. 16 (a) Numbers of Acartia longiremis found in the upper 10 meters plotted against surface temperatures, June 8 - 16, 1955.

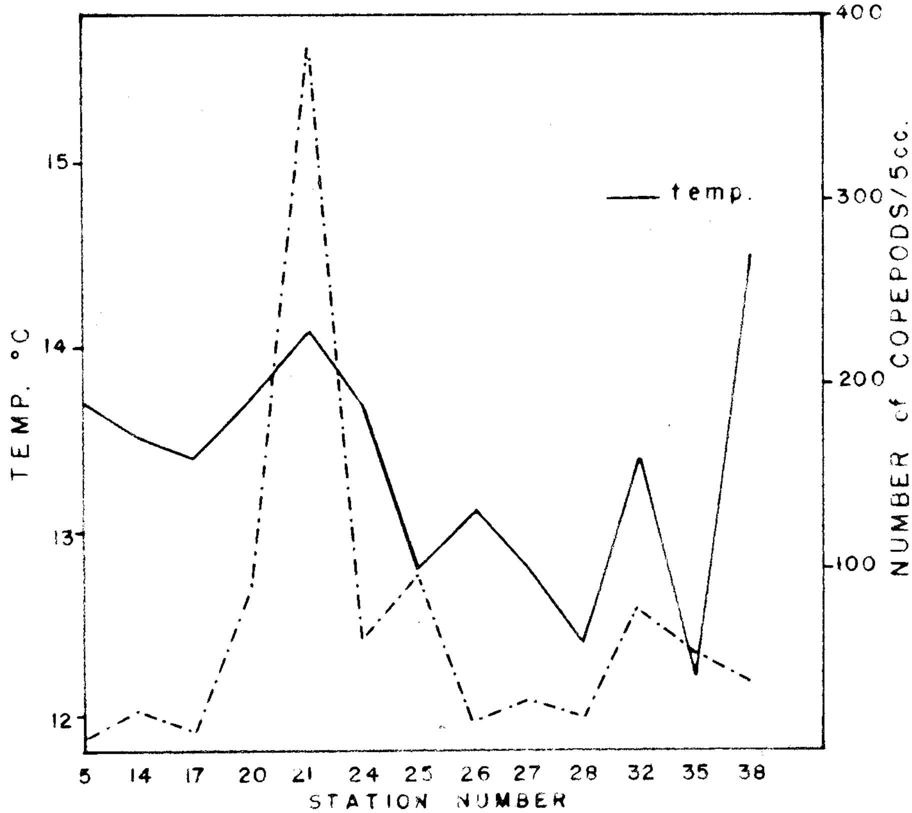


Fig. 16 (b) Numbers of Acartia longiremis found in the upper 20 meters plotted against surface temperatures, June 8 - 16, 1955.

to reproduce (Giesbrecht, 1905 *ex* Cameron, 1955 gives 11°C as the minimum temperature for reproduction) but warm enough for survival, the females accounted for 80% of the catch, and the males for 14%. ~~The few~~ The few copepodids stages taken in the fall were in a late period of development, and showed many adult characteristics.

Acartia clausi is euryhaline (Cameron, 1955) and should have been found in large numbers in June, but only scattered animals were found throughout the "upper zone". No reason, as yet, can account for this unusual distribution since Cameron (1955) reported the species as common in most areas in the Queen Charlotte Islands. The possibility arises that the main concentration has been missed, or existed outside the areas investigated. *A. clausi* is rare in November: two specimens only have been found at Station 7A.

Oithona

This microcopepod has two representatives in the Strait of Georgia: *O. helgolandica* and *O. plumifera*. An analysis of several samples showed that *O. helgolandica* was always more common than *O. plumifera*. The former was very abundant in the Strait in June when it formed 18% of the catch, but was still more important in November, when it formed 25% of the catch. Samples from most stations were analysed only for total counts of the genus. At several stations, however, the individuals were determined to species and subdivided into sexes. The sample taken at Station 11 which is a representative sample from 100-0 meters indicated the following composition: *O. helgolandica*, 3 males, 66 females, and 4 juveniles; *O. plumifera*, 7 females. Every sample thus analysed produced a much greater number of *O. helgolandica*.

Oithona was found at all depths at all stations in abundance but with a greater concentration in 50-20 meters. O. helgolandica which is a littoral species (Wilson, 1932), is able to stand a wide range of physical and chemical fluctuations of the waters. Its abundance suggests limits of survival beyond those found in the Strait. On the other hand, O. plumifera, which is a pelagic species and chiefly tropical in its distribution (Wilson, 1932), is not able to achieve great abundance unless the waters have the optimum conditions for the reproduction and development of the species. Both a high temperature and salinity will be required. Since these conditions are seldom met in the Strait of Georgia in summer, this may account for the scarcity of the species. When the temperature and salinity distributions are more homogeneous in November (see II) Oithona helgolandica attains a higher concentration. O. helgolandica is also reported to be more numerous in the fall on the Pacific Coast at Friday Harbor (Johnson, 1932) and at La Jolla (Esterly, 1928).

Calanus

The pattern of distribution of this genus is difficult to interpret from the available data. Because of taxonomic difficulties, the juveniles of Calanus tonsus and Calanus finmarchicus could not be identified with certainty to species.

Two things made this genus important: first, the presence of a large number of juveniles, and second, the presence of a great swarm of adults at Station 18 (Fig. 5). Juveniles of Calanus accounted for 14% of the catch in June and 23% in November, thus making it one of the most significant constituents of the zooplankton. This swarming behaviour has been noted by several authors (Esterly, 1905; Bigelow and Leslie, 1930; Johnsen, 1932).

It seems unusual that Calanus finmarchicus and Calanus tonsus should breed in such numbers in the Strait since both are more pelagic than littoral in distribution (Sars, 1903) and thus must result from invasions from oceanic water through the Strait of Juan de Fuca. When more is known about the distribution of each species in the Straits of Georgia and Juan de Fuca, some more apparent explanation may be evident.

The adults of C. finmarchicus were present at all but three stations and always in small numbers. A total of 13 males and 90 female s were identified. C. tonsus occurred in much larger numbers than C. finmarchicus. A total of 909 individuals were identified as males. As for C. cristatus, only four immature females were found in the Strait.

In November, only C. finmarchicus could be found, and it was never present in abundance. The juveniles were spread throughout the area, but were most abundant at Stations 7A and 8A, within the influence of the Fraser River.

Metridia

Metridia is one of the most prominent genera among the less numerous copepods found in the Strait of Georgia. It is represented by two species: M. lucens and M. longa.

The species M. lucens is generally found with Calanus finmarchicus in 100-0 meters hauls. The males, which are less numerous than the females (193 males, 512 females) are found in shallower water than the females. In November the males were found at all depths. Samples taken at 20-0 meters and 10-0 meters yielded several adult specimens. The females, on the other hand, were absent from the upper 50 meters.

Metridia has an extensive vertical migration. Esterly (1928) notes that they are absent from the surface during the day, but are very abundant at the surface at night. The males of M. lucens, although less abundant than the females, are more generally distributed. Males were found at 31 stations in June, and females at 26. In November males were taken at 24 stations, and females were found at 18.

M. lucens is more numerous in the fall. Like Calanus finmarchicus, it has two breeding periods, one in the spring, and one in the fall. The spring spawn must take place quite early in the season in the Strait, since in mid-June only 16% of the species were made up of young, while 84% were adults. Except for two males of Metridia longa, all the November catch of Metridia was made up of M. lucens. Breeding of this species was taking place extensively in November. The catch in November was as follows: 26% males, 33% females, and 41% young.

There are wide seasonal fluctuations in the abundance of Metridia longa. It was found in greater numbers than M. lucens in June, but was very rare in November. It is not known whether this is a typical seasonal variation.

Eucalanus bungii

Campbell (1929) mentions the presence of E. elongatus near Station 1 in the Strait of Georgia. As the main distinctive character of this species she claims the presence of a thorax with rounded ends to be diagnostic. I believe the specimens which she records belong to the species Eucalanus bungii. Johnson (1932) and Davis (1949) associate the above character with E. bungii and not with E. elongatus. The latter bears points laterally on the posterior thoracic border.

Eucalanus bungii was found during the June cruise only. The catches were made up mostly of juveniles that live in the upper layers. Cameron (1955) did not find E. bungii shallower than 50 meters in the Queen Charlotte Islands, but it was found in greater numbers in 50-0 meters during this study. The adult males and females were generally found in the deep tows, but a good percentage were also distributed from 100-50 meters. Because of the uniformity of temperature and salinity of the lower zone from 50 meters down, it is not surprising to find them in shallower depths in the Strait than in the Queen Charlotte Islands. The greatest abundance of this species in Pacific waters is recorded at 200 fathoms at Scripps (Esterly, 1928). The greatest numbers of E. bungii were caught at Stations 13 and 21, but the distribution was ubiquitous in the Strait of Georgia.

Centropages mcmurrichi

This calanoid was also common in June only in the Strait of Georgia. Unlike the preceding species, it is a true pelagic form, occurring close to the surface of the sea. Two distinct areas of abundance were found, the first located around Stations 13, 20, 21, and 22, and the other centered around Stations 34, 35, 37, and 38. Centropages mcmurrichi can apparently tolerate wide ranges of fluctuation in salinity, as shown by its presence in waters of salinity as low as 2‰, and as high as 20‰, and also by the fact that heavy breeding was taking place in parts of the

Strait having a salinity less than 10 ‰. Twenty-four percent were males, 19% were females, and 57% were immature. In these two regions, relatively high phytoplankton concentrations occur. Where there was a very low concentration of diatoms such as at Stations 1, 2, 4, 5, 7, 11, 15, 16, 17, 19, 27, 41, and 43 this species of copepod was less abundant. In regions of very high phytoplankton concentrations, such as at Stations 6, 10, 12, and 36 the concentrations of C. mcmurrichi were also low. It seems then that the species needs a supply of diatoms high enough to provide ample food, but not so high that it may cause exclusion. "According to Hardy's view (1936) .... certain of the animals during a part of the day swim upward into the layer of water where diatoms are being produced. The duration of their sojourn in the upper layer is inversely related to the concentration of the phytoplankton. Thus they are excluded vertically for a considerable period of time when diatom production has resulted in a dense swarm of diatoms" (Hardy, 1936 ex Sverdrup et al, 1954).

The young of the species were most abundant in 20-0 meters, and the adult a little deeper (Table V).

TABLE V

Numbers of juvenile and adult Centropages mcmurrichi taken at 10-0, 20-0, 50-0, 100-0, and 150-0 meters, June 8 - 16, 1955.

	Depth in Ranges of Meters				
	10-0	20-0	50-0	100-0	150-0
Juveniles	68	107	111	143	69
Adults	41	70	93	93	80

Other species of restricted distribution.

Among the species encountered occasionally but never in abundance, in the plankton samples were: Oncaea conifera, Scolecithricella minor, Microcalanus pusillus, Corycaeus affinis, Euchaeta japonica, Paracalanus parvus, Tortanus discaudatus, Epilabidocera amphitrites, Gaidius pungens, Chiridius tenuispinus, and a few others. The species not listed were represented by only a few scattered individuals.

Oncaea conifera has been shown to live in the polar regions as well as in the tropics (Wilson, 1932). It can therefore adapt itself to considerable flustuations in the environment. In the Queen Charlotte Islands, Cameron (1955) found that its presence was generally characteristic in areas of high surface temperature (above 13.5°C) and that it inhabited the upper 75 meters. It is distributed even deeper in the Strait of Georgia. It was found at all depths, but never in abundance in hauls taken shallower than 100 meters. It was common at Stations 5, 14, 29, and 31 at 100 meters or deeper. Ten males and 90 females were counted from 33 stations in June. All the males but one were found attached to the females, indicating that the species breeds in these latitudes. In November 25 females were noted at 16 different stations, but no males were found.

Scolecithricella minor was found only occasionally in June, but frequently in November. Typically this copepod is a pelagic form (Sars, 1903) and is not found in low salinity water. Its distribution in the Strait varied with the seasons. In June neither adults nor young were found in the supplementary hauls taken shallower than 50 meters, but both were present in the deeper hauls. The high salinity of the "lower zone" was apparently suitable for the species, judging by the abundance of copepodids present. In November both adults and young occurred throughout the water column, even in the 10-0 meters hauls. They were present throughout the area, but never in large numbers. In November juveniles accounted for 45% of the catch, adult males 15%, and adult females 40%.

Microcalanus pusillus is one of the smallest calanoids. It is widely distributed in deep water but never found in the upper 50 meters. In June it was present at two-thirds of the stations. The centers of abundance were located at Stations 20 and 33. Males formed 47% of the catch, and females 53%. M. pusillus was caught most commonly in the November hauls. It was absent at one station and common at Stations 14A, 20A, and 28A. The catch comprised 43% males, 56% females, and 1% young.

According to Esterly (1928) Corycaeus affinis occurs in greatest abundance in June-September, and least in February-May at La Jolla. During the two years that observations were made, a period of least abundance began in November and extended through June. On the other hand Esterly (1928) found there was a great increase in July. The data recorded here does not agree with his findings. Corycaeus affinis appears to be much more numerous and widespread in November than in June in the Strait of Georgia. In June it was taken in less than one-half of the tows, and never occurred in any quantity. In November it was abundant at several stations and present in more than two-thirds of the samples. All representatives obtained were adult and came from the "upper zone".

Euchaeta japonica was the largest of the copepods found in the

Strait of Georgia. In June, males, females, and young were always found deeper than 50 meters and were never in large numbers. They were present at half the stations. The males made 30% of the catch, the females 10%, and the young 60%. E. japonica was present at all stations in November and at four of them in fair numbers. The young were found in shallow water and the adults in deeper water. Males formed 16% of the total number, females 15%, and juveniles 69%.

Paracalanus parvus. Very small numbers were counted in June. The species was found at almost every station in November although never in abundance. It usually occurred near the surface of the water. The females always outnumbered the males (93% against 7%).

Tortanus discaudatus is defined as a summer species by Wilson (1932). It was never found in any quantity during this study. It appears to be a euryhaline species. In the summer it was confined to the "upper zone" and in the autumn it was restricted to the area adjacent to the Fraser estuary. Only males (65%) and young (35%) were found in November.

Epilabidocera amphitrites was found very infrequently in the summer, and always in small numbers. The catch was made up mostly of young (67%). The distribution could only be estimated, due to low catches. On the basis of the distribution of those animals taken, the species is assumed to congregate in the upper 20 meters. In the month of November only one juvenile was seen in all the samples studied.

Gaidius pungens and Chiridius tenuispinus have been described as

Arctic species by Sars (1903). They were very rare in June and occurred in the "lower zone". They were found in two-thirds of the hauls in November, but again in small numbers.

All other forms listed (see pp. 19, 20, 21) but not discussed were represented by only a few individuals and were too rare to enable drawing any conclusions from their distribution.

2) Appendicularians.

The only appendicularia identified to genus was Oikopleura. The widespread occurrence of these appendicularians (Fig. 17) is indicated in the June plankton, demonstrating the favourable conditions provided in the Strait of Georgia for the growth of these organisms. Thus Oikopleura was sufficiently abundant to be given the second place in the list of abundant zooplankters. In the shallow tows, appendicularians were represented only by larvae which were found at all stations, sometimes in numbers great enough to suggest centers of production. In such cases they far exceeded the number of copepods as illustrated at Stations 2, 4, 6, 10, 14, 15, 22, and 41 (Table I). Johnson (1932) never found them in great abundance at Friday Harbor, but found them constantly present. He also found a slight increase in June and October, when temperatures were apparently optimum at 9.3°C - 10.6°C. The larger numbers indicated above were found slightly below 12°C in the Strait of Georgia. Bigelow (1930) found O. labradorensis for the most part in temperatures below 12°C. According to this author, "since it is most plentiful in temperatures of 12°C - 13°C at La Jolla, 12°C may be set as its upper optimum limit in the northeastern Pacific." It can thus

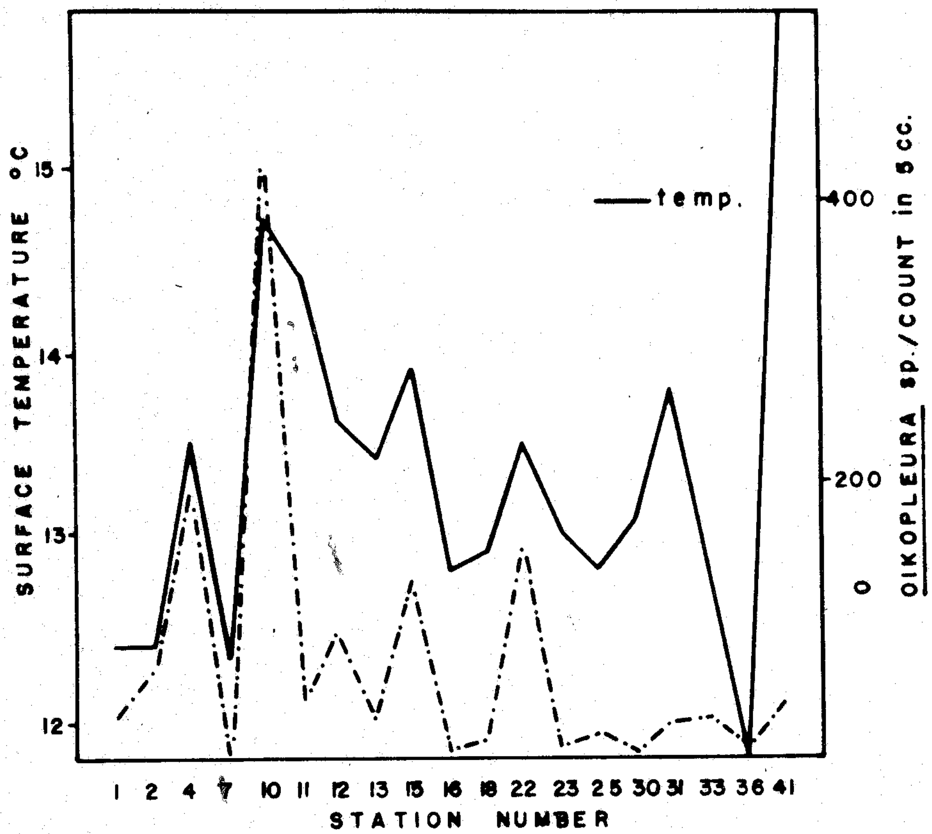


Fig.17. Numbers of Oikopleura spp. found in the upper 10 meters plotted against surface temperatures, June 8-16, 1955.

be concluded that when temperatures of this order exist in the Strait, such as were present in June, 1955, appendicularians will reach a peak of abundance or an increase in numbers. Campbell (1929) found them uniformly distributed at all depths in the Strait of Georgia. She reported also a greater frequency in surface hauls (5-0 yards) at 76% of the stations, but she made no mention of heavy concentrations in her summer catches.

The hauls made in November yielded only small numbers of Oikopleura. Apparently their period of abundance does not occur in the autumn, or at least in November, because only scattered adults were taken during this period.

3) Euphausids.

Euphausids pass through a number of larval stages in their growth from the eggs to the adult individuals. The literature is somewhat confused concerning the number of stages. Every author recognizes the first six stages: nauplii 1 and 2, metanauplii, and calyptopis 1, 2, and 3. They are succeeded by various furcilia and cyrtopia stages. Ruud (1932) has adopted a limited number of stages: nauplii 1 and 2, metanauplii, calyptopis 1, 2, and 3, early furcilia, intermediate furcilia, late furcilia, and all cyrtopia.

The samples studied contained all the larval stages, but for the purpose of this discussion I have limited treatment to the following number of developmental stages:

1. nauplii and metanauplii,
2. all calyptopis stages,
3. all furcilia stages,
4. all cyrtopia stages.

No adults were taken at any of the stations that yielded larvae.

The method of reproduction of this crustacean is very similar to that which occurs in the copepods. The eggs are shed in the water, but the growth is slow and the animals do not reach sexual maturity until they are two years old (Ruud, 1932).

The euphausids were present at every station in at least some stage of development in June. Nauplii and metanauplii formed 9% of the catch, calyptopis 40%, furcilia 43%, and cyrtopia 8%. The supplementary hauls in 20-0 meters and 10-0 meters contained more than half of the nauplii and metanauplii, so it was evident that the two larval stages were concentrated in the surface layers. Calyptopis were also found in the 10-0 meters but were more abundant in 50-0 meters and 100-0 meters, suggesting a deeper distribution. Furcilia were abundant at all depths, but cyrtopia were only found twice in abundance above 50 meters. This indicates that the species has a deeper distribution as the animals develop (Table VI).

No larval stages of euphausids were found in November in the Strait of Georgia. Some size variations occurred, but always within the adult stage. The minimum length found was twenty-nine mm. and some euphausids were as long as 45 mm. Total counts in each sample are given in Table VII.

TABLE VI

Larval stages, by numbers, of euphausids,

June 8 - 16, 1955

Stn. No.	Date	Depth (m)	Nauplii and Metanauplii	Calyptopis	Furcilia	Cyrtopia
1	June 13	10	-	1	-	-
1	"	50	1	1	5	1
2	"	10	1	4	1	-
2	"	80	1	3	5	2
4	"	10	4	1	-	-
4	"	100	5	12	12	1
5	"	20	-	1	2	-
5	"	200	-	3	-	10
6	"	50	-	35	-	3
7	"	10	1	1	-	-
7	"	90	-	1	-	1
8	"	50	-	1	-	17
8	"	110	-	1	13	9
10	"	10	-	1	-	1
10	"	150	-	4	2	1
11	"	10	-	33	18	-
11	"	100	-	44	20	11
12	"	10	74	7	1	3
12	"	50	3	3	4	1
13	"	10	-	2	-	-
13	"	50	-	9	17	12
14	June 14	20	4	1	2	1
14	"	200	11	2	6	3
15	"	10	1	1	1	-
15	"	150	-	2	6	3
16	June 13	10	-	3	6	-
16	"	100	-	13	8	25
17	"	20	4	3	3	1
17	"	150	5	8	18	12
18	June 14	10	-	18	5	1
18	"	150	-	1	17	1
19	"	50	-	7	-	1
19	"	200	8	4	1	-
20	"	20	4	10	5	2
20	"	250	4	8	11	6

TABLE VI (concluded)

Stn. No.	Date	Depth (m)	Nauplii and Metanauplii	Calyptopis	Furcilia	Cyrtopia
21	June 13	20	11	46	75	1
21	"	150	7	133	160	21
22	June 14	10	3	16	6	-
22	"	100	6	6	4	1
23	June 16	10	-	-	-	-
23	"	100	2	-	-	-
24	June 14	20	2	2	2	-
24	"	50	3	9	5	-
25	June 16	10	1	1	2	-
25	"	20	-	5	3	-
25	"	50	1	13	12	-
25	"	100	3	29	12	1
25	"	150	5	42	41	1
26	June 14	20	-	-	1	1
26	"	150	-	3	3	1
27	"	20	-	-	1	-
27	"	50	1	-	1	-
28	"	20	-	2	-	33
28	"	230	1	2	1	3
29	June 15	50	1	2	-	1
29	"	150	-	1	2	1
30	June 14	10	-	8	2	1
30	"	150	-	21	13	1
31	June 15	10	-	3	15	1
31	"	100	-	29	11	1
32	"	20	3	7	-	-
32	"	100	2	6	-	-
33	"	10	1	-	-	-
33	"	200	4	25	84	2
34	"	50	-	15	24	1
34	"	150	-	26	65	1
35	"	20	-	2	4	-
35	"	100	1	37	39	3
36	"	10	-	1	16	-
36	"	100	-	57	91	3
37	"	50	-	47	37	-
37	"	100	-	35	50	-
38	"	20	-	7	-	-
38	"	100	-	3	2	4
41	June 8	10	1	1	2	-
41	"	200	13	18	11	-
43	June 9	50	1	1	1	-

TABLE VII

Concentration of adult euphausids taken at different depths, based on a total count of the animals in each sample, November 8 - 11, 1955

Depth (m)	Numbers of adult euphausids (12 individual samples) 1	2	3	4	5	6	7	8	9	10	11	12
10	0	42	0	0	0	0	0	0	0	0	0	0
20	38	0	0	0	0	0	0	0	0			
50	94	0	8	0	0	0						
60	0											
65	0											
100	83	10	67	24	15	31	6	41	32	122		
110	103											
150	29	53	11	60	24	21	7	151				
200	24	46	22									
230	22											
250	152											

The four instances in which adult euphausids were found above 50 meters may be indicative of tidal mixing bringing up deeper forms to the surface layers. Three of these four hauls, for example, were made off Active Pass, and the fourth haul was made off Gabriola Pass. Strong tidal currents and considerable mixing take place at both these points.

Twenty-four hauls were made at depths exceeding 100 meters, and each one contained euphausids. The general pattern of distribution suggests large concentrations from 65 meters downward.

Horizontally, the euphausids were found throughout the area of the Strait of Georgia.

From these data it can be stated first, that the population has a deeper distribution as the animals mature and second, that spawning takes place in late winter or early spring. In June, 84% of the young had reached the cyrtopia stages. In November, all the young had reached the adult stage. The adults apparently carry the population through the winter months.

4) Chaetognaths.

Chaetognaths were found in fairly high concentrations in the plankton samples. A preliminary study showed that at least three species are found in the waters of the Strait. These are: Sagitta elegans, Eukrohnia hamata, and Sagitta lyra. The identification of the species was made possible by referring to Lea (1955). In June, S. elegans formed the bulk of the Chaetognath population, and was represented by immature as well as mature stages. Immature stages only were found in the supplementary hauls taken in the 10-0 and 20-0 meters, and mature individuals were taken in 50-0 meters and deeper. Most of the population was concentrated in the upper 100 meters, and was widespread throughout the Strait. Several specimens of E. hamata were found mixed with S. elegans, but they never reached any high proportions. The quantitative distribution of S. elegans was not analysed, but they were included in the total counts. At Stations 5 and 17, two specimens of S. lyra were taken in the deep hauls. This pelagic species had been reported from the Queen Charlotte Islands, but nowhere else in B.C. waters (Lea, 1954), and its presence supports the evidence that there is an intrusion of oceanic water into the basin of the Strait through the Strait of Juan de Fuca.

Only two chaetognath species were found in November: Sagitta elegans and Eukrohnia hamata. The former was taken at every station, while the latter was recorded only at Station 37. Total counts of chaetognaths taken in November indicated no immature individuals but several adults. These were present in all samples below fifty meters (Table VIII) but were generally absent in samples from 10-0 and 20-0 meters.

TABLE VIII

Concentration of adult chaetognaths taken at different depths, based on a total count of the animals in each sample, November 8 - 11, 1955

Depth (m)	Numbers of adult chaetognaths (12 individual samples)											
	1	2	3	4	5	6	7	8	9	10	11	12
10	4	6	0	0	0	0	1	0	0	1	0	0
20	10	0	1	7	0	0	0	0	0			
50	16	10	15	5	1	43						
60	11											
65	7											
100	5	31	34	28	29	22	16	13	26	54		
110	16											
150	58	50	30	28	33	22	14					
200	20	36	23									
230	37											
250	50											

5) Amphipods.

On the whole, amphipods did not form a very conspicuous part of the plankton catches, but their large size adds significantly to the volume of zooplankton present.

Although amphipods were found at all depths, the center of abundance of immature forms was situated between 50 meters and the surface whereas the adults were located in deeper water (Table IX).

Total counts were made from the November plankton samples.

TABLE IX

Concentration of adult amphipods taken at different depths, based on a total count of the animals in each sample, November 8 - 11, 1955

Depth (m)	Numbers of adult amphipods (12 individual samples)											
	1	2	3	4	5	6	7	8	9	10	11	12
10	0	1	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	3	0	0	0			
50	2	0	1	0	0	1						
60	1											
65	0											
100	11	16	10	10	21	14	2	0	0	126		
110	6											
150	35	15	27	15	14	35	7					
200	40	34	28									
230	41											
250	65											

The greater abundance of amphipods in the deepest hauls in November contrasted with their predominance in June in shallower water. This fact was due to the absence of immatures in the hauls taken in November. 1.8% of adult amphipods were found at 65-0 meters and shallower, and 98.2% were obtained at 100-0 meters and deeper. In the 100-0 meter haul at Station 37A amphipods were (following copepods) the most abundant representatives of the plankton.

6) Gastropods.

Although several groups of gastropods form part of the plankton, their small size makes them one of the relatively minor constituents. They include the young spiral-shaped gastropod larvae, the early clam larvae, and the pteropod larvae. Except for the latter group, these gastropod larvae are members of the plankton for a short time. They are next to the appendicularians and euphausids in relative abundance in the samples, and are found throughout the Strait of Georgia in the summer and in the autumn. Their main distribution is between 100-20 meters (Table X). The group has been found at all depths outside these limits, but not in high numbers. Their distribution was ubiquitous in June and November. Campbell (1929) found them at 75% of the stations in the 100-50 yard, and 30-20 yard hauls.

TABLE X

Vertical distribution of gastropod larvae and concentrations at each depth, June 8 - 16, 1955

Depth (m)	No. of larvae taken	No. of hauls made at each depth	Approx. No. of larvae per haul	% of the catch of larvae
10-0	19	19	1	2
20-0	71	13	6	6
50-0	123	13	9	11
100-0	407	14	29	37
150-0	316	11	28	29
200(+)-0	157	7	22	14

Early clam larvae appeared in small numbers at two-thirds of the stations, and their vertical distribution was identical with that of gastropod larvae.

Only six adult pteropods, were seen in June, and none were seen in November. This form is truly pelagic and is apparently brought into the Strait by the intrusion of oceanic water through the Strait of Juan de Fuca.

7) Ostracods and Cladocerans.

Ostracods and cladocerans were among the crustaceans occurring regularly but never in abundance in the plankton samples examined. The former group was found at two-thirds of the stations in June. Only five mature individuals were caught above 50 meters. The remaining 118 individuals came from deeper tows. At Stations 20 and 21, ostracods were common but, in contrast to other areas, one-third of the total number of individuals was taken from a deep haul (200-0 meters) at Station 41.

Both immature and mature ostracods were picked up in November. In the supplementary hauls from 50-0, 20-0, and 10-0 meters, most of the catch consisted of immature individuals, while the deeper hauls contained more adults. The data obtained could not be used to establish the center of abundance for this group because of the small number of very deep hauls. Ostracods were ubiquitous in November. The immatures accounted for 40% of the total catch and the adults formed the remaining 60%.

It was common during June to pick up a few adult cladocerans from the southern region of the Strait, but none could be found north of the Fraser River. The population was centered around Station 6 in 50-0 meters and the most removed individual was found at Station 22. The cladocerans were living beneath the diatom population and in the region of maximum diatom concentrations. Dakin and Colefax (1940) have also found cladocerans in greater abundance right at or slightly after a maximum phytoplankton bloom, and living beneath the diatom population.

During November, three immature cladocerans and eight adults were found at Station 19A in a 200-0 meter haul.

8) Larvae.

Larvae of all kinds were very frequently encountered in the plankton catches. Over ninety percent were restricted to three groups: copepod larvae, barnacle larvae, and crab larvae. Most forms were abundant in June, but rare in November.

As a rule, copepod nauplii and metanauplii appeared in greater numbers in 10-0 meters, barnacle nauplii somewhat deeper (50-0 meters), and cypris larvae of barnacles at 10-0 meters. Crab larvae were encountered much deeper. The zoeal stage was found rarely above 50 meters, and the metazoeal stage was centered in 100(+)-0 meters (Table XI).

TABLE XI

Average numbers of copepod, barnacle, and crab larvae caught in each haul, June 8 - 16, 1955

Depth (m)	Copepod		Barnacle		Crab		
	nauplii	metanauplii	nauplii	cypris	zoea	metazoea	megalops
10-0	9	4	2	1	<1	<1	<1
20-0	5	5	3	1	<1	<1	<1
50-0	12	8	6	1	<1	1	<1
100-0	7	8	3	1	<1	1	<1
100(+)-0	9	11	2	1	1	2	<1

The copepod and barnacle larvae were observed at every station in varying concentrations. The crab larvae were also noticed at most of the stations, but always in smaller numbers than copepod and barnacle larvae.

In addition to the larvae discussed above, a number of other less frequent types were found. These larvae included fish, shrimp, polychaete, coelenterate, holothurian, and many others. Few larvae were encountered in November.

9) Diatoms.

Since the concentration of diatoms was fairly heavy at the time of the first cruise, and the dinoflagellate concentration was very light, phytoplankton was considered primarily in terms of diatoms.

Of the 111 samples collected on the June survey, all showed several species of diatoms (see pp. 26 and 27) whereas during November there was a dearth of diatoms (see p. 31).

In spite of the comparatively large number of species found in June, few species were individually predominant in the samples. Among the forty-six species identified, the following nine were most conspicuous, both in terms of abundance and regularity of occurrence: Skeletonema costatum, Thalassiosira nordenskioldii, Nitzschia seriata, Rhizosolenia semispina, Biddulphia longicruris, Thalassionema nitzschioides, Chaetoceros decipiens, Chaetoceros affinis, and Chaetoceros curvisetus. Most of the other species taken in June were only found at a few stations, or were represented by scattered individuals. Coscinodiscus wailesii was the only genus commonly found in November. It is found at all seasons at Departure Bay (Gran and Angst, 1931). An accurate count was not possible with the counting chamber used because of the large size of this species. However, it could be observed with the binocular. No count was made, but observation of the samples permits describing it as "common". Johnson (1932) calls it an important species which is taken frequently at Friday Harbor during the late summer and fall months, and totally absent from March to July. It was never seen in any of the June samples in the Strait of Georgia. Its distribution seemed to be ubiquitous.

Skeletonema

The genus *Skeletonema* is represented in the samples examined by only one species, *Skeletonema costatum*. No other genera of diatoms exceeded it in abundance in June (Fig. 18). It occurred at all the stations from which samples were examined, and most of the time in very high concentrations. *S. costatum* was responsible for the very high concentrations encountered at Stations 6 and 12 and was predominant in the Hardy Recorder samples. Johnson (1932) mentions that it is very abundant at Friday Harbor, and is dominant at times in June and July. Gran and Thompson (*ex* Johnson, 1932) found it dominant in the San Juan Channel on June 30, 1930 and between Spieden and Jones Islands on July 11, 13, and 22, and in East Sound on August 8. The heavy concentrations observed in the Strait of Georgia were not maintained through to November, since not a single cell was encountered in the fall samples.

Thalassiosira

The genus *Thalassiosira* is represented by three species in the samples examined: *T. nordenskioldii*, *T. rotula*, and *T. condensata*. Of these the first was, by far, the most predominant in both June and November. *Thalassiosira nordenskioldii* was second in abundance only to *Skeletonema costatum* in June in the Hardy Recorder hauls, and the former reached its greatest abundance in a cross-section from Vancouver to Nanaimo (Fig. 19). In this latter cross-section over a distance of about fifteen miles *T. nordenskioldii* made up over 50% of the catch, and for another ten miles it formed more than 75% of the total yield. Generally speaking, the genus *Thalassiosira* came third in abundance, surpassed only by the genera *Chaetoceros* and *Skeletonema*. No individual species of *Chaetoceros* ever exceeded

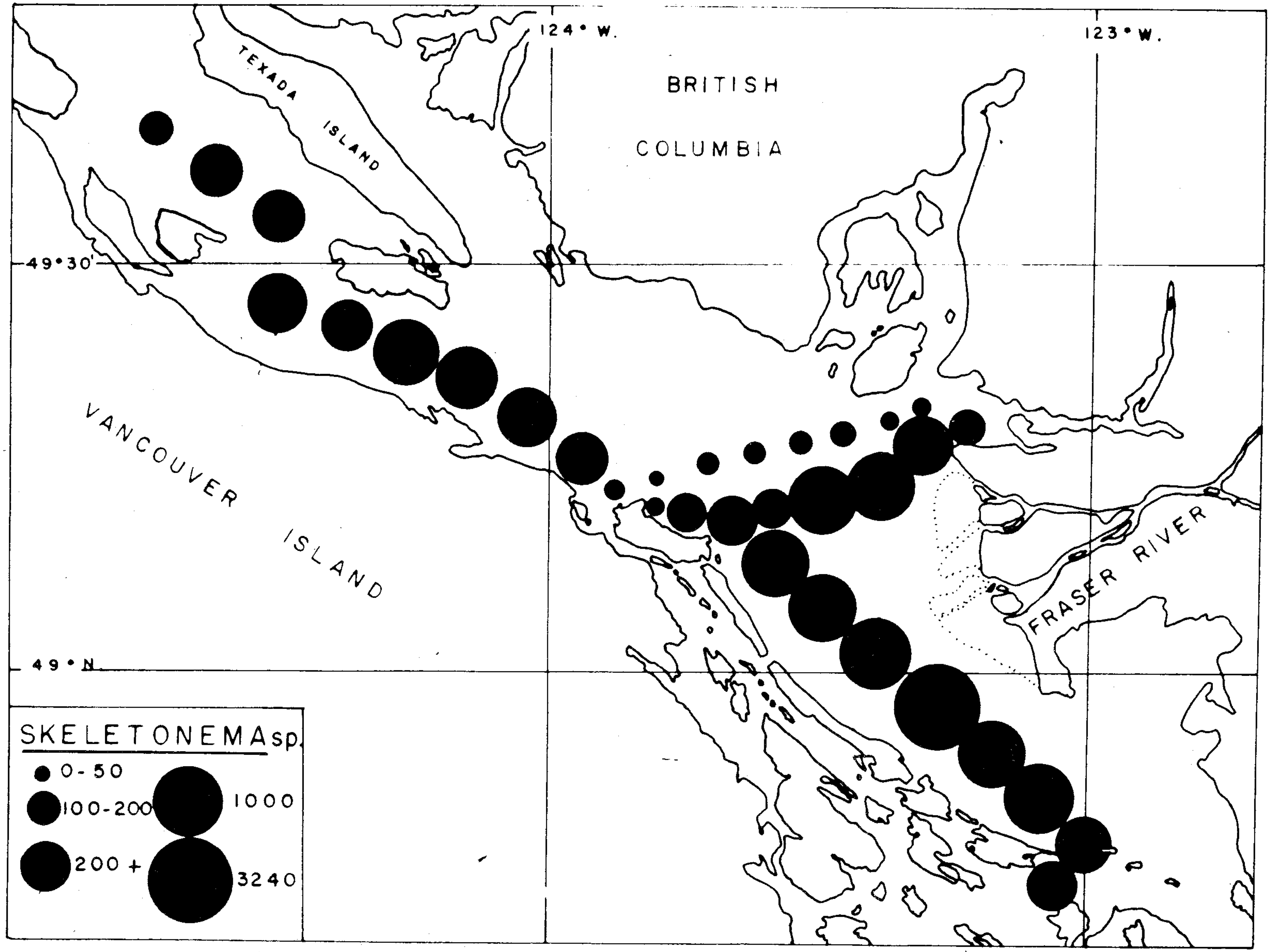


Fig. 18. Abundance of Skeletonema costatum at 10 feet, June 8 - 16, 1955.

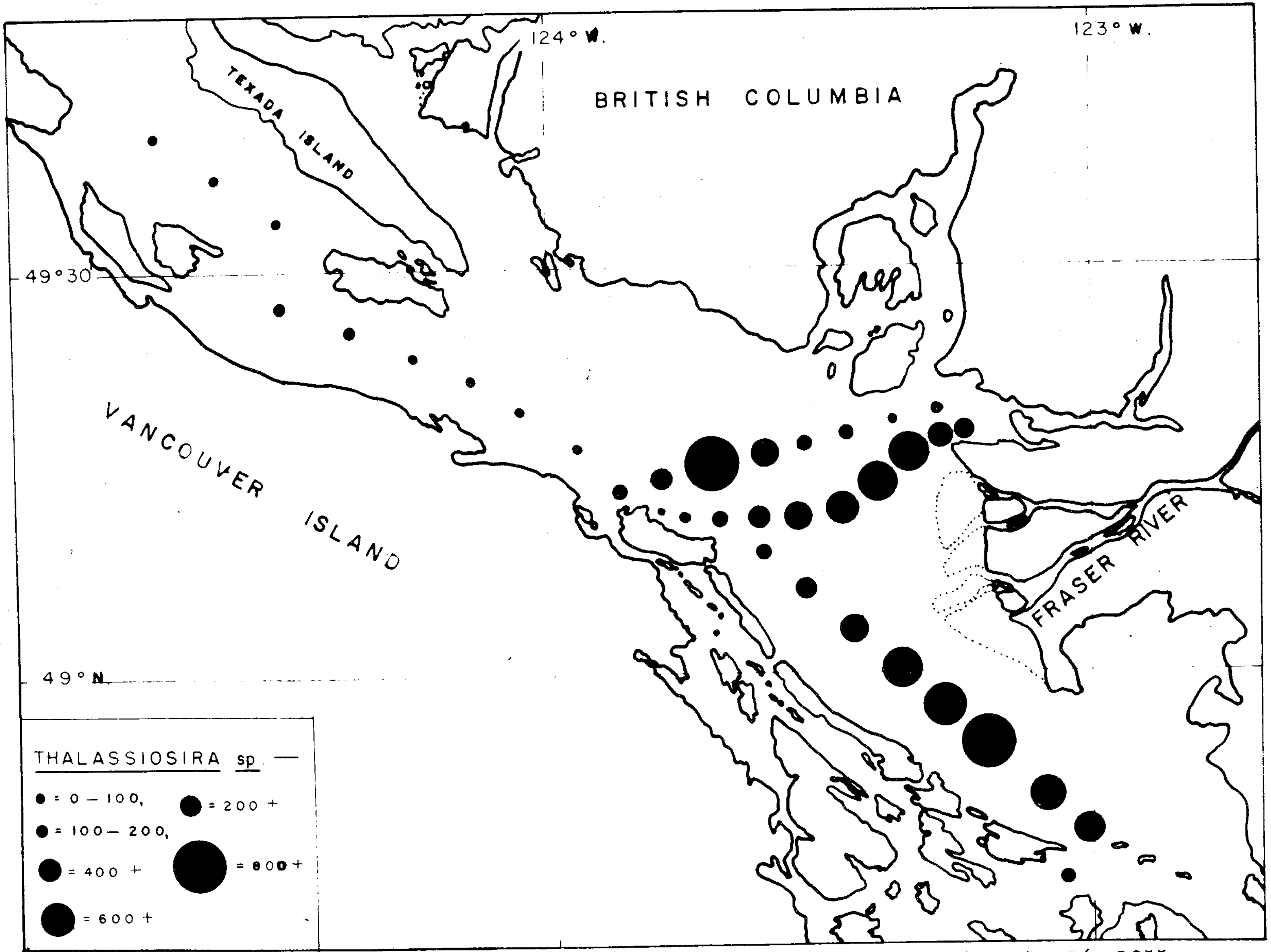


Fig. 19. Abundance of Thalassiosira spp. at 10 feet, June 8 - 16, 1955.

T. nordenskioldii. All species of Thalassiosira were nearly always present in the vertical haul samples, and very often T. nordenskioldii was present in great abundance.

Chaetoceros

The genus Chaetoceros, as a whole, is the most troublesome taxonomically. It was always present, represented by several species, and the chains of cells were usually so much twisted in the counting chamber that identification was difficult and time-consuming. Some species could not be identified because of their very small size using ordinary methods. On the whole, however, the more abundant species had characters sufficiently clear-cut to permit identification. The three most abundant species were: C. curvisetus, C. decipiens, and C. affinis. C. curvisetus was the species most consistent in appearance for it occurred at 80% of the stations. High concentrations of this latter species occurred in the central and northern regions of the Strait in June (Fig. 20). C. affinis was fairly regular throughout the central and northern Strait, but was missing at most of the stations in the southern Strait. C. decipiens had a rather patchy distribution in the southern and central Straits, but was fairly well represented in the northern Strait.

Nitzschia

The genus Nitzschia was predominant in June. It was found in large numbers in the vertical haul catches, especially in the deeper hauls. At three meters it rarely occurred in high concentrations, suggesting a deeper distribution. The only species attaining numerical significance were: Nitzschia seriata, and Nitzschia pungens. Sometimes one and some-

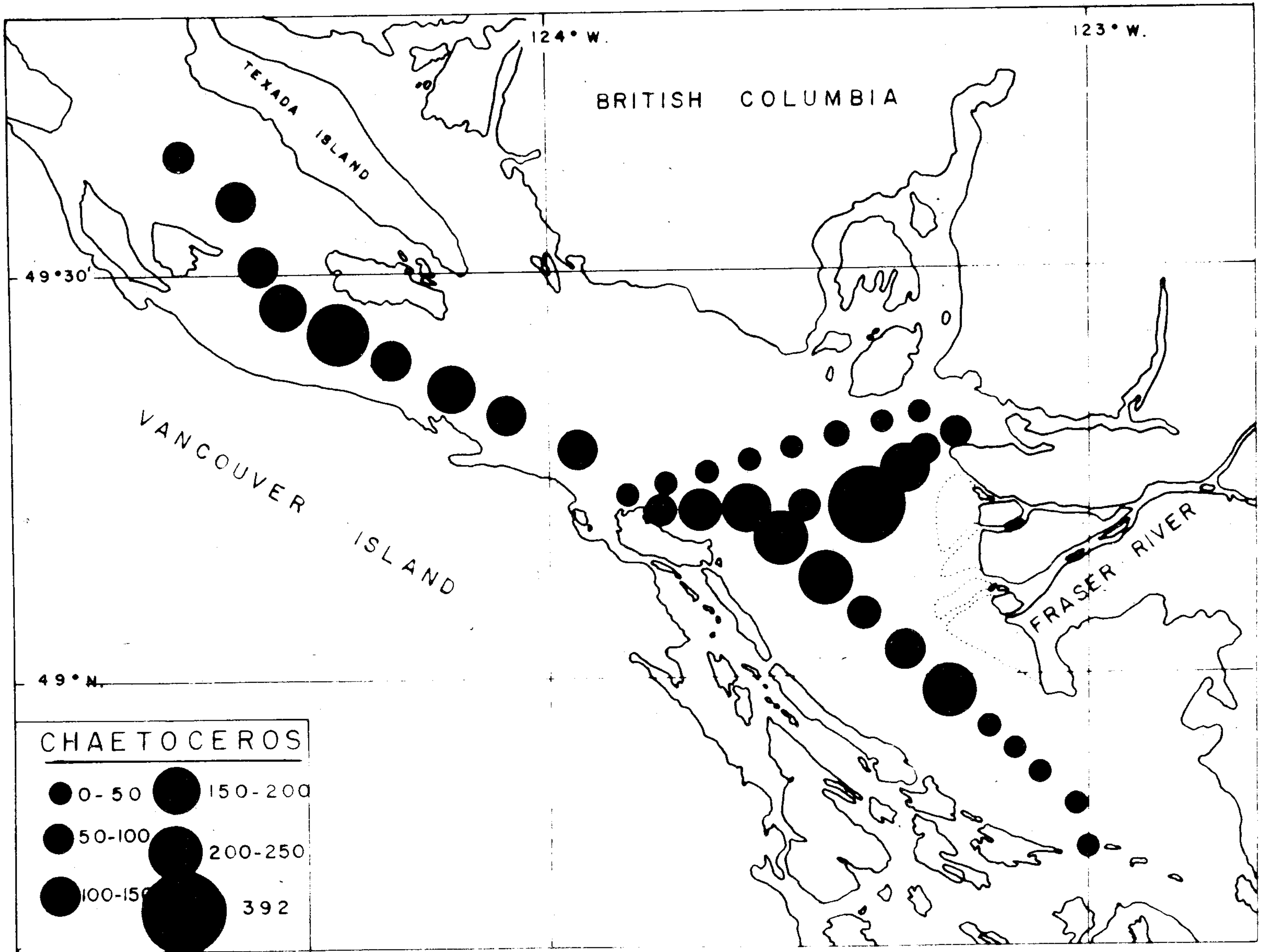


Fig. 20. Abundance of Chaetoceros spp. at 10 feet, June 8 - 16, 1955.

times the other appeared abundant, although size variations make it difficult in some instances to identify to species with certainty. For this reason, the species were not tabulated separately. Many species of Nitzschia occur in deep water at La Jolla in summer, although this genus is typically a winter or spring form (Allen, ex Johnson, 1932). Johnson (1932) adds that the winter temperatures at La Jolla are comparable with the summer temperatures at Friday Harbor, where many species were present at several stations in July. He assumes that temperatures may constitute the limiting factor and that the species found in our latitudes belong to a different biological race than those found further south. The data reported here seem to support this argument. It would appear that summer populations in the Strait of Georgia belong to the northern race, although more information is needed, especially over the winter months to substantiate this claim. It is possible that the genus may be present (although unlikely) following the November period.

Rhizosolenia

Representatives of this genus were found in abundance all over the Strait in June. One species, R. semispina, was very common, and another, R. stolterfothii, was found occasionally. All other species identified (R. hebetata, R. delicatula, and R. styliformis) were not abundant. R. semispina is typical of the warmer waters of the Strait in summer. According to Cupp (1943) R. semispina has been found in abundance only in the Gulf of California. Although it was not abundant in November, its occurrence together with its abundance in the warmer waters of the Strait in June suggest a similar situation to that recorded by Cupp

(1943). Johnson (1932) does not report R. semispina in abundance from Friday Harbor when the waters in summer reach higher temperatures. As a rule Johnson (1932) never found the species of Rhizosolenia abundant at any time of the year at Friday Harbor.

Biddulphia

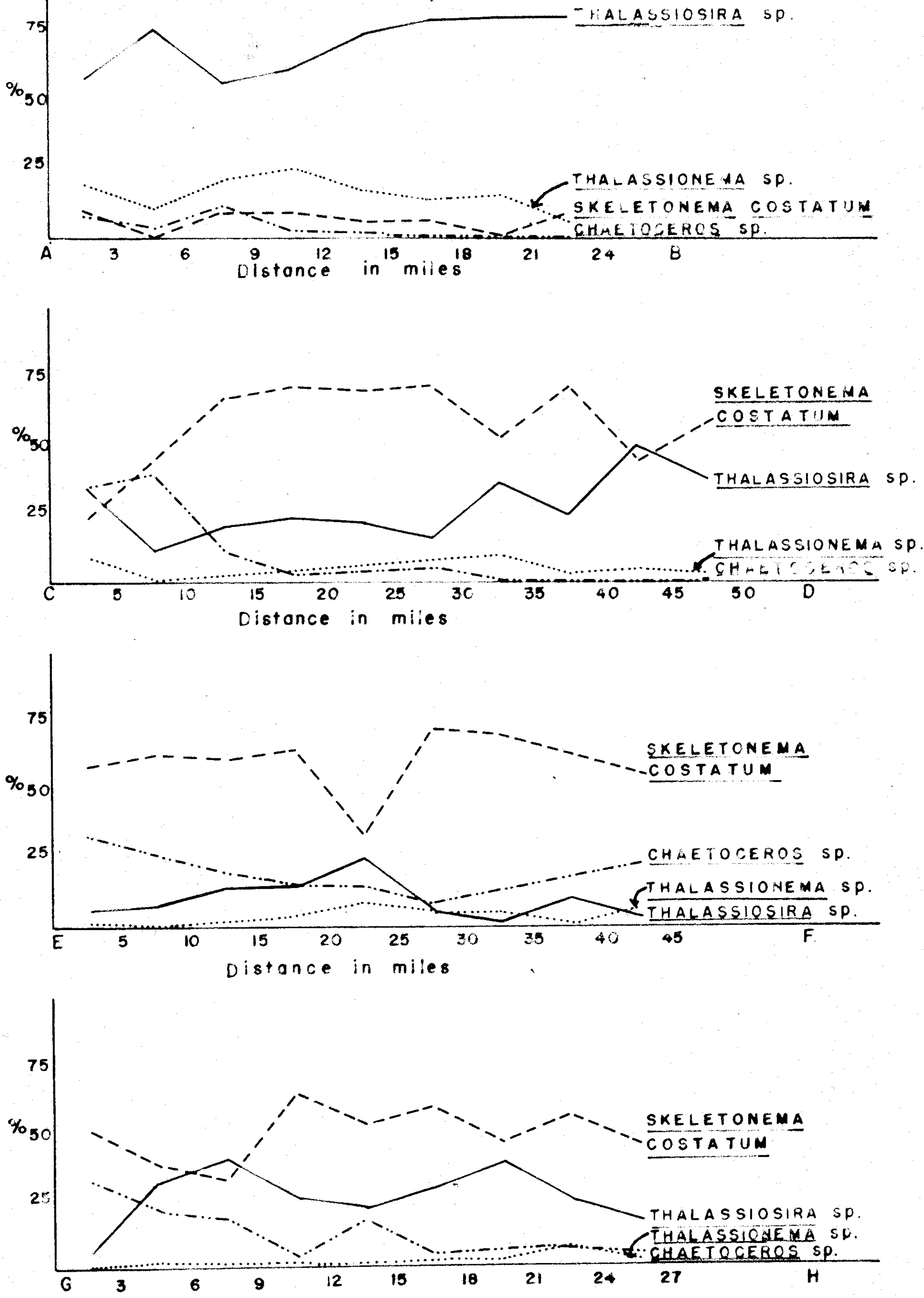
The genus Biddulphia was represented by three species, Biddulphia longicruris, B. laevis, and B. aurita. Of these, only B. longicruris occurred regularly. In fact, it was universal in distribution, and in June it reached very high concentrations. The neritic conditions found in the Strait of Georgia seem to account for its abundance. Allen (1922) and Johnson (1932) report that it was never met with in any considerable numbers at La Jolla and Friday Harbor respectively. Johnson (1932) notes that B. longicruris has been noted in abundance in East Sound, Orcas Island, in June. This island is located at the southern end of the Strait.

Thalassionema

Thalassionema nitzschioides was abundant and regular in distribution in June. It was present in more than two-thirds of the samples and had its maximum concentration off Point Roberts. This genus may have been confused at times with Thalassiothrix under the magnification used in counting. Cupp (1943) recognizes Thalassionema as a neritic species very common from California to Alaska, while he describes Thalassiothrix as oceanic and widespread. Johnson (1932) found Thalassiothrix nearly always present at Friday Harbor although seldom abundant. He does not mention Thalassionema at Friday Harbor. Gran and Angst (1931) do not include Thalassionema in their record of the diatoms occurring at Puget Sound.

Figure 21 shows the percentage distribution at a depth of ten feet of the four most predominant genera along the Hardy Recorder cross-sections (Fig. 1). Along the line A-B, *Thalassiosira* far exceeds all other genera, but on all other lines (C-D, E-F, G-H) *Skeletonema* is more abundant, except in a few localities where *Chaetoceros* and *Thalassiosira* are found in greater numbers. Along the line C-D most of the catch is made up of *Skeletonema* and *Thalassiosira*. *Chaetoceros* values are high only in the first few miles of the tow. The line E-F indicates much higher numbers of *Chaetoceros*. Where the percentage of *Chaetoceros* diminishes for a few miles in the middle of the tow, *Thalassiosira* replaces it and shows relatively high concentrations. The last cross-section, G-H, is a transition line where both *Skeletonema* and *Thalassiosira* have high concentrations. The order of magnitude of the phytoplankton volumes along the four cross-sections are presented in Figure 22. The highest values are found opposite Point Roberts on section C-D. This area is a region of strong tidal mixing.

On the line A-B values go on increasing from Point Grey to Gabriola Island, but decrease slightly in the immediate vicinity of Vancouver Island. Hutchinson and Lucas (1931) also observed this phenomenon. Along the line E-F, values are in very close agreement with those of Hutchinson and Lucas. A slight increase is found south of Texada Island, but values go on decreasing northward. The volumes encountered around Stations 37 and 38 correspond to those found at the mouth of Vancouver Harbour. The line C-D again agrees with the findings



THALASSIOSIRA sp.
THALASSIONEMA sp.
SKELETONEMA COSTATUM
CHAETOCEROS sp.
%
75
50
25
A
3
6
9
12
15
18
21
24
B
Distance in miles
SKELETONEMA COSTATUM
THALASSIOSIRA sp.
THALASSIONEMA sp.
CHAETOCEROS sp.
C
5
10
15
20
25
30
35
40
45
50
D
Distance in miles
SKELETONEMA COSTATUM
CHAETOCEROS sp.
THALASSIONEMA sp.
THALASSIOSIRA sp.
E
5
10
15
20
25
30
35
40
45
F
Distance in miles
SKELETONEMA COSTATUM
THALASSIOSIRA sp.
THALASSIONEMA sp.
CHAETOCEROS sp.
G
3
6
9
12
15
18
21
24
27
H
Distance in miles

Fig.21.

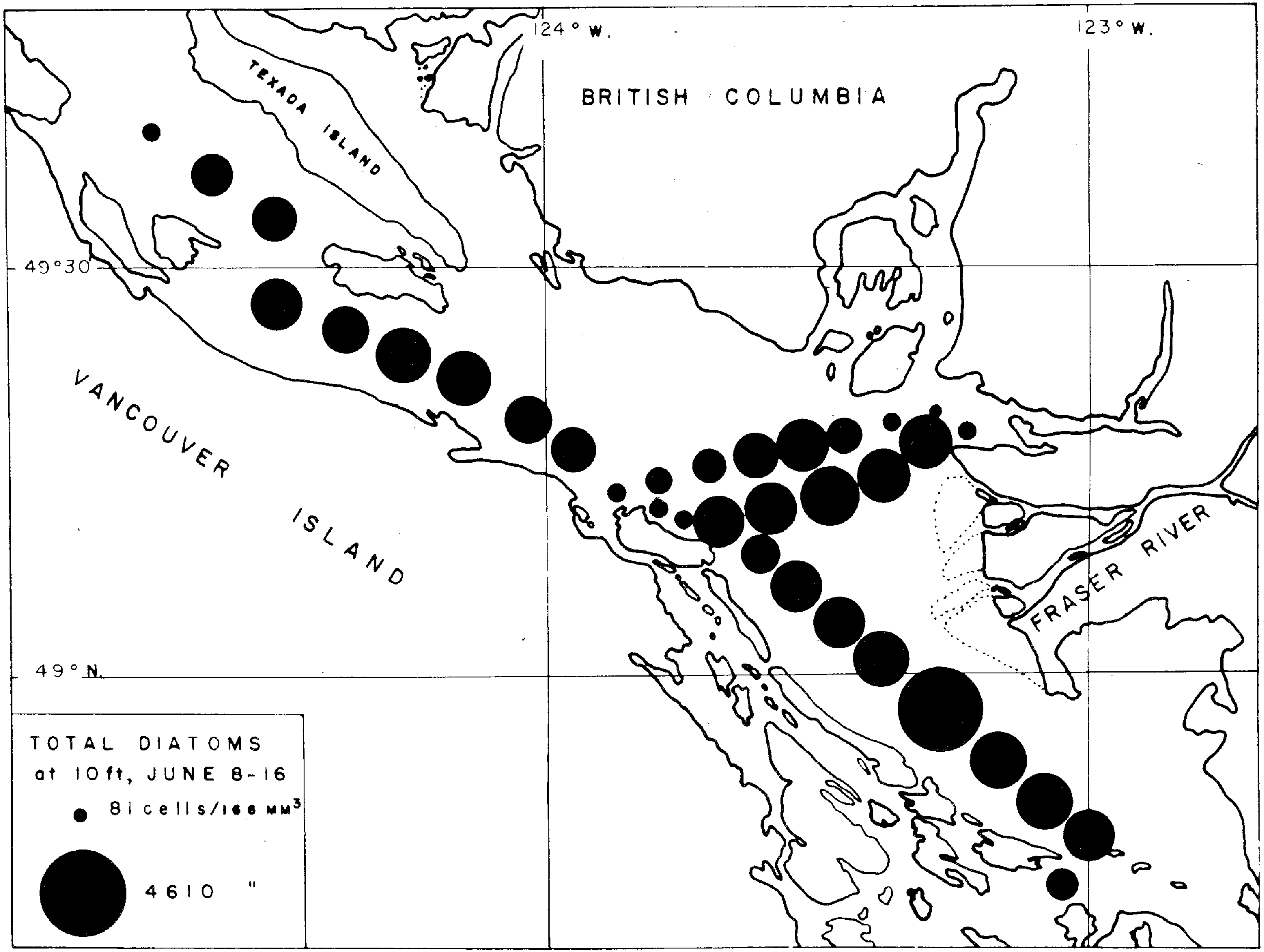


Fig. 22. Total phytoplankton abundance at 10 feet, June 8 - 16, 1955.

of Hutchinson and Lucas. Volumes of diatoms increase steadily southward until they reach their maximum opposite Point Roberts. They then decrease steadily in the last few miles of the section. The only cross-section which does not fit in with their results is the V-shaped line opposite the Fraser River. The values obtained in this cross-section (G-H) are much higher than those found on the line A-B. However, knowing the seasonal variation that can occur both in phytoplankton abundance and all the physical and chemical factors operative from year to year, it is not surprising to find some inconsistencies between data reported for 1932, and that obtained in 1955.

VI. CONCLUSIONS

1. During the summer when oceanographic conditions in the Strait of Georgia vary widely a great variety of organisms is found. During the autumn, when the waters reach an almost homogeneous state, the number and variety of forms diminished considerably. In June, over 34 species of copepods, 45 species of diatoms, and 27 other groups of plankton organisms occurred in contrast with 21 species of copepods, 5 species of diatoms, and 19 other groups present in November.

2. Three centers of different concentration of zooplankton can be recognized and associated with the physical and chemical characteristics of the waters in the Strait of Georgia.

A) an area of high concentration with warm surface temperatures and strong mixing of water masses;

B) an area of intermediate concentration with colder surface temperatures and little mixing of water masses;

C) an area of low concentration with still colder surface temperatures and little mixing of water masses.

3. The number of diatoms found in June was low compared with the very high values known from some other areas of the world. The data suggest that the sampling may have preceded or followed a period of greater abundance. The waters north of the Fraser River contained large quantities of *Chaetoceros* and *Skeletonema* and those south of the Fraser River showed high quantities of *Thalassiosira* and *Skeletonema*. Few diatoms are taken close to the Fraser River estuary. The region is characterized by very low salinities and high turbidity.

4. Vertical distribution of zooplankton was apparent and the relative importance of the different groups of plankton organisms varied at 10-0 meters, at 20-0 meters, at 50-0 meters, and deeper. Copepods are grouped into surface forms, sub-surface forms, and deep-water forms. Many more species were found in the "upper zone" (50-0 meters) than at greater depth. Generally the larval stages inhabited the first few meters and the adults lived at a greater depth.

5. Although the number of species of zooplankton and phytoplankton was large only a small number of forms were dominant. The copepods Pseudocalanus minutus, Acartia longiremis, and Oithona sp. contributed 65% of all copepods in June and Pseudocalanus minutus, Oithona sp., and Calanus finmarchicus formed 77% of the total number in November. Also the diatoms Skeletonema costatum, Thalassiosira nordenskioldii, and Chaetoceros decipiens always exceeded, by far, all other species in June, and Coscinodiscus wailesii was predominant in November.

6. The ratio of adult males to females was, in some copepod species, unequal in June and November, the males being more abundant at the onset of breeding but later diminishing in numbers more rapidly than the females after the breeding season.

7. Copepods generally formed the bulk of the zooplankton. They were very numerous in June, but the numbers decreased in November. When juveniles were very abundant the three dominant species (Pseudocalanus minutus, Acartia longiremis, and Oithona helgolandica) were responsible.

8. Appendicularians reached a peak in June in regions of optimum temperature for this group (12°C). In such areas they far exceeded

the copepod population and dominated the catch.

9. The population of euphausids is found to be distributed vertically according to age. There is a deeper distribution of the species as the larvae mature. Spawning takes place in late winter and early spring in the water of the Strait of Georgia.

10. Both juvenile and adult chaetognaths were present in the June catches. Immature forms were found in the supplementary hauls taken in 10-0 and 20-0 meters. Mature forms occurred in 50-0 meters and deeper. No larval forms were found in November.

11. The center of abundance for amphipods lies between 50-0 meters in June and below 50 meters in November. The shallower June distribution is laid to the presence of several immature individuals.

12. Over 90% of the larvae caught in June belonged to three groups only: copepod larvae, barnacle larvae, and crab larvae. Copepod larvae were in the upper layer (10-0 meters), barnacle larvae were found somewhat deeper (50-0 meters), and crab larvae were encountered much deeper (100-0 meters).

13. Diatoms were most abundant around a depth of 10 meters. The western portion of the Strait supported a higher concentration than the colder, less saline eastern portion. The heaviest concentrations occurred a little south of the Fraser River estuary in an area of "steep" temperature and salinity gradients.

14. The euryhaline plankton organisms were found in great abundance during June and November 1955. Their distribution in the Strait of Georgia is only slightly affected by the oceanographic conditions because

the fluctuations in the physical and the chemical characteristics of the water lie within the limits of tolerance of the organisms. The stenohaline plankton organisms are limited to the more stable "lower zone". Within this "lower zone" the abundance and distribution of the stenohaline forms do not vary very much since temperatures and salinities are fairly constant in space and time. The euryhaline heliophyllic forms (diatoms) are the most abundant. They are found in regions where fresh water originating from the Fraser River and saline water in the Strait mix. This mixing process favours phytoplankton abundance in at least two ways. The mixed waters may contain certain physical and chemical factors lacking in any one of the fresh and sea water masses alone. Also the entrainment of deeper saline water into the upper zone may bring up nutrients where they are available to phytoplankton.

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