

NOAA Technical Report ERL 403-PMEL 30



# Microzooplankton in the Surface Waters of the Strait of Juan de Fuca

Alexander J. Chester

Pacific Marine Environmental Laboratory  
Seattle, Washington

December 1978

**U.S. DEPARTMENT OF COMMERCE**  
**Juanita Kreps, Secretary**

National Oceanic and Atmospheric Administration  
Richard A. Frank, Administrator

Environmental Research Laboratories  
Boulder, Colorado  
Wilmot N. Hess, Director

## NOTICE

The NOAA Environmental Research Laboratories do not approve, recommend, or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to the NOAA Environmental Research Laboratories, or to this publication furnished by the NOAA Environmental Research Laboratories, in any advertising or sales promotion which would indicate or imply that the NOAA Environmental Research Laboratories approves, recommends, or endorses any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this NOAA Environmental Research Laboratories publication.

## CONTENTS

	Page
Abstract .....	1
1. INTRODUCTION .....	1
1.1 Physical Oceanography .....	2
1.2 Ecological Significance of Microzooplankton .....	2
2. FIELD AND LABORATORY METHODS .....	4
3. DISTRIBUTION OF PHYTOPLANKTON .....	4
4. DISTRIBUTION OF MICROZOOPLANKTON .....	6
4.1 Ciliates .....	6
4.1.1. Tintinnids .....	7
4.1.2. Oligotrichs .....	11
4.1.3. Other Ciliates .....	15
4.2 Other Protozoa .....	16
4.3 Metazoa .....	16
5. SUMMARY .....	16
6. ACKNOWLEDGMENTS .....	18
7. REFERENCES .....	18
Appendix. Tabulated Microzooplankton Data .....	20



# MICROZOOPLANKTON IN THE SURFACE WATERS OF THE STRAIT OF JUAN DE FUCA

Alexander J. Chester

**ABSTRACT.** Microzooplankton organisms were enumerated from surface seawater samples obtained at three stations in the Strait of Juan de Fuca during 13 cruises from 1976 to 1977 (tabulated data appear in Appendix). Ciliates were the most abundant group; maximum concentrations exceeded 10,000 liter<sup>-1</sup>. The ciliate community was composed almost exclusively of oligotrichs, tintinnids, and the gymnostome species, *Mesodinium rubrum*. These groups made up an average of 60%, 10%, and 30%, respectively, of the total ciliate numbers at each station. Twenty-six tintinnid species and 15 oligotrich species were identified during the 2-year study. The population peaks of most of these organisms coincided with periods of high biological activity during spring and summer. Certain species, however, such as the tintinnid *Stenosemella ventricosa*, were most common during winter months. The ecological role of oligotrichs and tintinnids as particle grazers is distinguished from that of *M. rubrum*, a ciliate deriving its nutrition from photosynthetic endosymbionts.

## 1. INTRODUCTION

Biological oceanographers have traditionally relied on fine-mesh plankton nets to sample the zooplankton quantitatively. Although larger organisms may be effectively collected this way, a significant portion of the total zooplankton community is overlooked because it is too small to be retained by the net (Lohman, 1908; Hansen and Andersen, 1962). As a consequence, the smaller zooplankton is one of the least studied components of marine food webs. The so-called microzooplankton (roughly defined as all animal plankters smaller than 200  $\mu\text{m}$ ) include such common groups as ciliates, other protozoans, and minute metazoans, particularly juvenile crustaceans.

The Strait of Juan de Fuca is a deep estuary

connecting the inland marine waters of Washington State and British Columbia with the Pacific Ocean (Fig. 1). Although aspects of plankton research have been actively pursued in Puget Sound and off the Pacific coast, virtually no quantitative studies have been conducted in the Strait of Juan de Fuca. This is especially true for the microzooplankton, where only a few publications are known for the entire northeast Pacific region. The exploitation of Alaskan oil deposits and anticipation of increased oil transport through the Strait of Juan de Fuca to Washington State refineries have generated many environmental concerns. The research reported herein, detailing the seasonal distribution of microzooplankton in the Strait of Juan de Fuca, was completed in conjunction with an overall plankton baseline program sponsored by NOAA's Marine Ecosystems Analysis (MESA) Puget Sound Project.

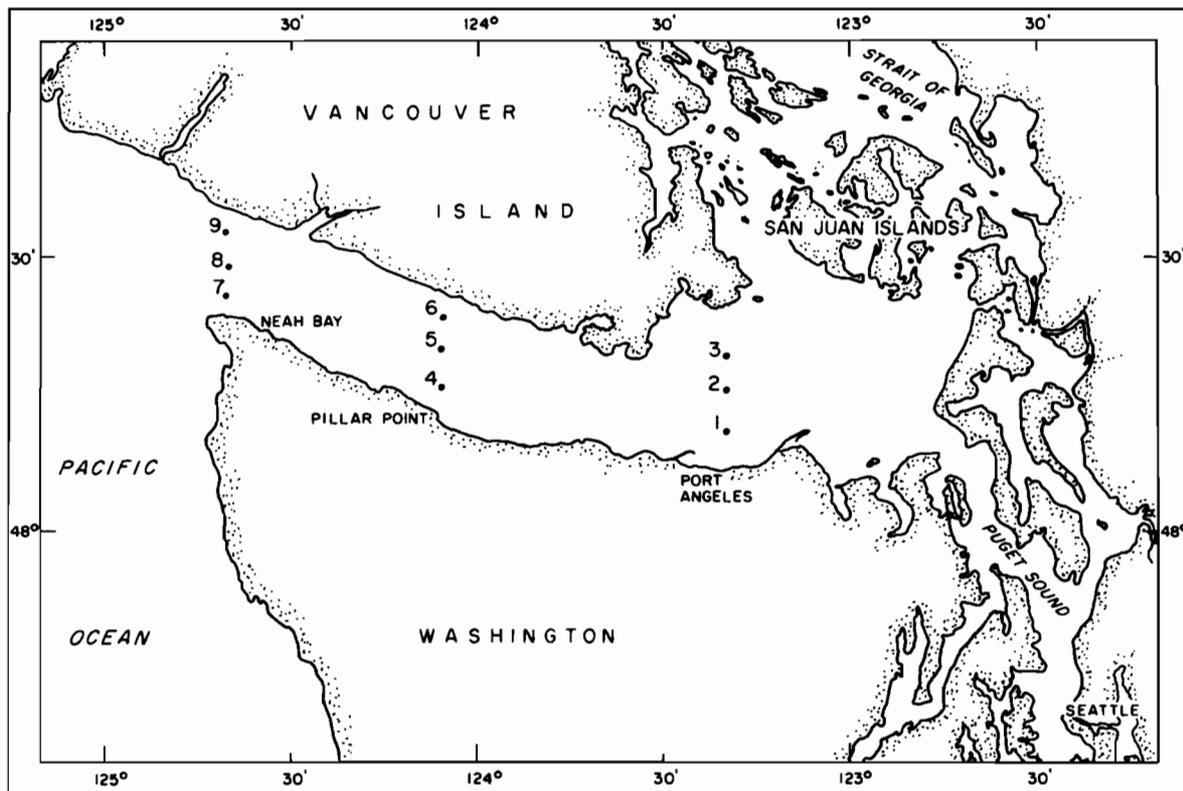


Figure 1. Area chart and station locations.

## 1.1 Physical Oceanography

The Strait of Juan de Fuca is characterized hydrographically as a two-layered system with an annual net westward flow of relatively fresh water in the upper 30 m and more saline oceanic water below. The strait receives a large influx of fresh water from drainages into Puget Sound and from the Fraser River which empties into the Strait of Georgia to the north. There are two periods of high runoff. The major one occurs in late spring with maximum snow melt in the Cascade and Olympic mountain ranges. A second runoff period occurs in late autumn and winter when precipitation is high.

Herlinveaux and Tully (1961) reviewed the physical oceanography of the Strait of Juan de Fuca. They found that salinity dominated the density structure throughout the year. During the summer a thermocline coincided with the halocline to reinforce the stability of the upper layer. In the winter, waters were either isothermal or the upper layers tended to be slightly colder than deeper waters. The authors considered the tides and tidal currents as important oceanographic components of the Strait of Juan de Fuca system. During flood tide dense ocean water enters the

strait and flows beneath the upper zone. The area east of Port Angeles is a region of exchange where brackish water contributed by the Strait of Georgia is enriched with ocean water and mixed to homogeneity. Part of this water returns to the deep zone of the Strait of Georgia; part escapes seaward in the upper zone of the Strait of Juan de Fuca during ebb tide.

## 1.2 Ecological Significance of Microzooplankton

Quantitative studies of microzooplankton have been infrequent due to difficulties in sampling, preservation, identification, and laboratory culture. Notable early investigations that described the composition and abundance of small zooplankton were conducted by Lohmann (1908) and Bigelow et al. (1940). More recently Beers and Stewart (1967, 1970, 1971) studied the microzooplankton off La Jolla, California, and in the eastern tropical Pacific Ocean and concluded that small zooplankton comprised approximately 95% of the numbers and 20% of the biomass of the total zooplankton community. The authors speculated that the microzooplankton could be an im-

portant trophic intermediary, especially in the open ocean where phytoplankton cells tend to be small and are thus more efficiently ingested by smaller grazers (see also Parsons and LeBrasseur, 1970). Although absolute microzooplankton biomass was greater in coastal waters than in the open ocean, the ratio of microzooplankton to phytoplankton biomass (chlorophyll *a*) was greater in the open ocean. LeBrasseur and Kennedy (1972) found no decrease in microzooplankton biomass from nearshore to open ocean. Rather, the annual average standing stock was at least three times greater at Ocean Station P in the Gulf of Alaska than in the Strait of Georgia, B.C. However, since only animals retained by a 44- $\mu$ m mesh were considered, it is likely that many protozoans escaped detection. Chester (1975, 1978) reported greater numbers and biomass of microzooplankton closer to shore off the Washington coast. He demonstrated a significant aggregation of ciliates in an offshore subsurface chlorophyll maximum layer.

Marine planktonic ciliates, represented chiefly by the Orders Tintinnida and Oligotricha, are numerically the most important fraction of the microzooplankton. For example, Beers and Stewart (1969) found ciliates comprised 95% of the numbers and 13%–28% of the microzooplankton biomass off southern California. It has long been speculated that ciliates play an important role in the marine food web. Lohmann (1908) noted the presence of small red and yellow particles within tintinnid ciliates and commented that these particles were ingested algal cells. Kofoid and Campbell (1939) emphasized the selective grazing activity of certain tintinnid species on coccolithophorids, the coccoliths of which are often found decorating the loricae. Campbell (1954) reported that tintinnids directly ingest bacteria, microflagellates, coccolithophorids, diatoms, dinoflagellates, and smaller ciliates.

Much recent evidence suggests that marine planktonic ciliates graze on small photosynthetic organisms and are ecologically significant in transferring energy to higher trophic levels. Gold (1970) found that tintinnids cultured on a mixture of photosynthetic flagellates have maximum division rates of about one per day. Doubling rates as fast as 12 hours were observed by Heinbokel (1977). Johansen (1976) studied ciliate populations in eastern Canadian waters and found a positive correlation between tintinnid and nanoplankton abundances. She found extreme variability of ciliate population size over short time periods and stressed the volatile cyclical nature of these species. Johansen (1976) and Blackburn (1974) both concluded that tintinnids could easily control natural blooms of small phytoplankters.

During a 5-month study off California, Beers and Stewart (1970) estimated that ciliates grazed an average of 54% of the calculated daily production of < 10  $\mu$ m phytoplankton. The calculations assumed that ciliates ingested the equivalent of three times their cell carbon per day. This assumption was largely supported by Heinbokel's (1977) experimental work with tintinnids. He found that ingestion rates increase with increasing algal concentration until a maximum rate is attained, after which grazing remains constant as food levels continue to rise. Daily ingestion rates of 2.4 to 4.8 times body weight were suggested at saturating algal concentrations. Heinbokel estimated that ciliates consumed at least 10%, and at times up to 50%, of the total daily primary production off the southern California coast.

Certainly other modes of nutrition beside direct ingestion of plant cells are available to some pelagic ciliates. For instance, the genus *Mesodinium* is widely known for its photosynthetic symbionts and ability to swarm, causing large red water patches (Taylor et al., 1971; Hibberd, 1977). Burkholder et al. (1967) described a bloom of ciliates, thought to be oligotrichs, in Puerto Rican coastal waters. These ciliates contained brown-pigmented bodies, took up radioactive carbon, and contained chlorophyll *a*. Chester (1978) found high concentrations of the tintinnid *Stenossemella ventricosa* close to the bottom at nearshore stations and speculated that they might be feeding on the rich organic matter of the continental shelf sediments. It is also possible that some ciliates graze on bacteria or bacterially rich detritus in the pelagic zone.

There is very little quantitative information regarding grazing pressures experienced by microzooplankton. Qualitative reports in the form of gut content records illustrate the wide range of organisms which derive at least a portion of their nutritional needs from tintinnid ciliates: salps, polychaete larvae, rotifers, larger ciliates, copepods, chaetognaths, euphausiids, pelagic shrimp, and larval fish (Heinbokel, 1977, and references cited therein). Small metazoans such as copepod nauplii are likely to fall prey to larger carnivorous zooplankters and fish larvae.

Rapid generation times and high rates for other physiological processes (e.g., nutrient regeneration, Johansen, 1976) of microzooplankton are expected because of their small size, and contribute to the view that they have an ecological impact far greater than indicated by their biomass. This study was conducted to characterize the seasonal distribution and abundance of these organisms in the Strait of Juan de Fuca and to describe more fully their ecological role within the plankton community.

## 2. FIELD AND LABORATORY METHODS

Thirteen cruises were taken in the Strait of Juan de Fuca during 1976 and 1977 (Table 1). In general, during each cruise a transect was completed across the strait at Port Angeles, Pillar Point, and Neah Bay. Each transect consisted of three stations (Fig. 1). Only the Port Angeles line was sampled during the May 1976 cruise because of mechanical failure of the vessel.

Temperature, salinity, net zooplankton, ichthyoplankton, pleuston, microzooplankton, and phytoplankton species and pigment data were gathered during sampling periods. Only microzooplankton and chlorophyll *a* data are treated in this report. Additional information has been reported previously by Chester et al. (1977). Microzooplankton and pigment samples were obtained at midchannel stations only (stations 2, 5, 8). Niskin bottles were used to collect water from 0, 10, 20, 30, 40 and 50 m. Chlorophyll concentration was measured from each depth with a shipboard fluorometer (Turner, model 111) following the discrete sample method of Lorenzen (1966). One-liter subsamples were removed from the surface water bottle, preserved in an acetate-buffered 0.6% formaldehyde solution, and returned to the laboratory for microzooplankton analysis.

Microzooplankton samples were analyzed by sedimentation using a Zeiss inverted microscope (Utermöhl, 1931). Preserved samples were allowed to settle in the original collection jars for several days. The volume was then reduced to about 80 ml by siphoning off the excess. The concentrated sample was transferred to a Zeiss settling chamber and resettled for at least another 24 hours before analysis. Routine counting was accomplished at 160 × magnification, but initial identifications were often made at 250 × or 400 ×. Ciliates, other protozoans, and metazoans were enumerated. The major taxonomic references used to identify ciliates were Kofoid and Campbell (1929), Wailes (1925, 1943), Leegaard (1915), Kahl (1930-35), and Hada (1932, 1937).

Members of the Tintinnida were usually identified to species based on morphological characteristics of the lorica. These forms readily abandon their loricae during the collection and preservation process. Therefore, it is difficult to establish with certainty whether a particular specimen was living at the time of collection. For this analysis all loricae were counted and included in biomass estimates. Non-tintinnid ciliates were more difficult to identify because of distortions due to preservation; also, many ciliate species have not yet been

Table 1. Cruise Designations, Dates, and Vessels for Strait of Juan de Fuca Plankton Study.

Cruise	Dates	Vessel
SF7601	23-24 Feb. 1976	<i>Commando</i>
SF7602	5-6 Apr. 1976	<i>Commando</i>
SF7603	17-18 May 1976	<i>Hydah</i>
SF7604	28-30 Jun. 1976	<i>Snow Goose</i>
SF7605	3-5 Aug. 1976	<i>Snow Goose</i>
SF7606	14-16 Sept. 1976	<i>Snow Goose</i>
SF7607	12-14 Nov. 1976	<i>Snow Goose</i>
SF7701	11-13 Jan. 1977	<i>Snow Goose</i>
SF7702	22-25 Feb. 1977	<i>Snow Goose</i>
SF7703	5-7 Apr. 1977	<i>Snow Goose</i>
SF7704	1-3 Jun. 1977	<i>Snow Goose</i>
SF7705	25-29 Jul. 1977	<i>Snow Goose</i>
SF7706	3-5 Oct. 1977	<i>Snow Goose</i>

described. These often had to be combined within a major category on the basis of approximate size.

The biomass of ciliates was estimated using methods similar to those of Beers and Stewart (1970). Cell volume was calculated by assigning simple geometric shapes to each species or group and measuring the appropriate dimensions of several individuals. It was assumed that tintinnid protoplasm volume was equal to one-half lorica volume. This was probably true for larger species but may have underestimated the protoplasmic volume of smaller species. An approximated biomass in terms of carbon was determined by assuming a specific gravity of one, a water content of 80%, and an organic carbon content of 40% of the dry weight.

## 3. DISTRIBUTION OF PHYTOPLANKTON

There is little published information dealing directly with the seasonal distribution of phytoplankton in the Strait of Juan de Fuca. The available data are largely limited to the San Juan Archipelago (e.g., Gran and Thompson, 1930; Phifer, 1933, 1934a; Thompson and Phifer, 1936) and Puget Sound proper (e.g., Hirota, 1967; Booth, 1969; Munson, 1969; Winter et al., 1975; Campbell et al., 1977). Phifer (1933) found two major diatom maxima in the waters of the San Juan Islands. These occurred from late May to early June and from mid-July to mid-August. He later (Phifer, 1934b) studied the vertical distribution of diatoms in the Strait of Juan de Fuca for a single cruise during July and reported that most diatoms were found in the upper 25 m. Shim (1976) observed diatom populations in the Strait of

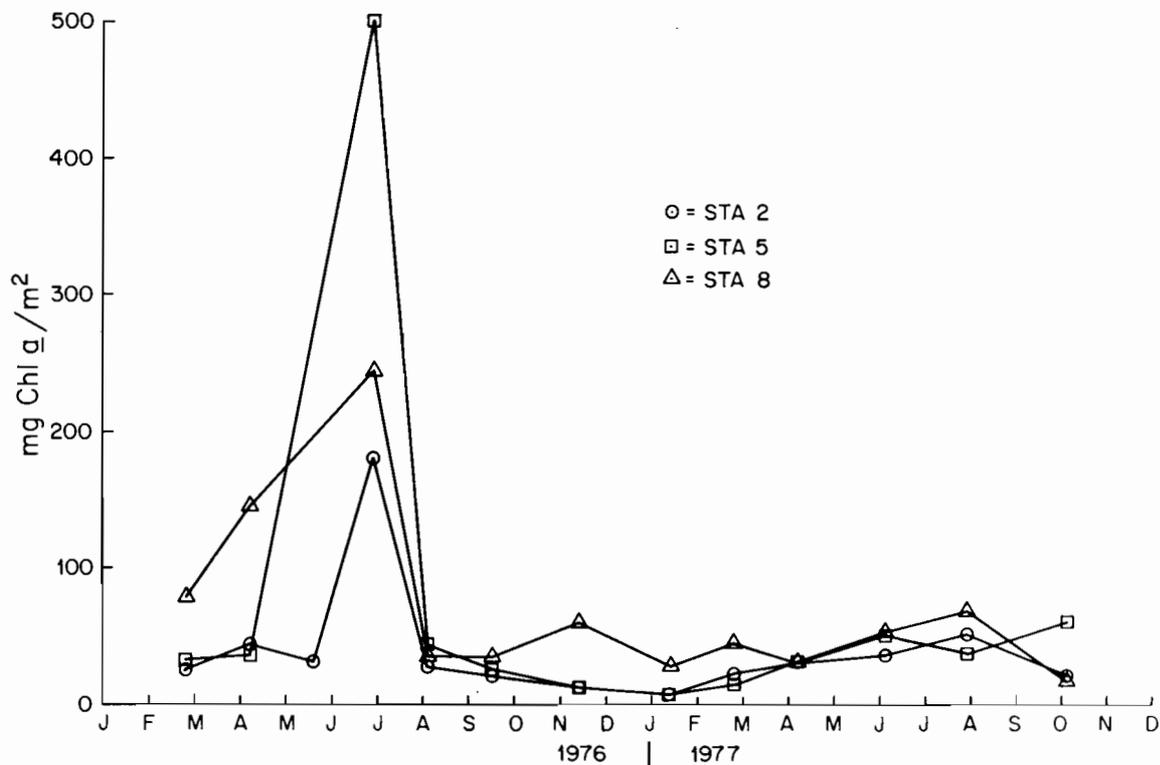


Figure 2. Chlorophyll concentration ( $\text{mg}/\text{m}^2$ ) in the upper 50 meters at three stations in the Strait of Juan de Fuca, 1976-1977.

Georgia, B.C., and the eastern part of the Strait of Juan de Fuca and also reported two major diatom maxima. He generally found a rapid increase in standing crop in April, followed by a sharp decline in May. A second peak occurred during the early summer months. Winter et al. (1975) noted that the annual pattern of phytoplankton growth in Puget Sound was dominated by several intense blooms between early May and September and commented that the onset of blooms in the main basin of Puget Sound is late for the latitude of  $48^\circ\text{N}$ . They stated that algal concentrations changed drastically within time periods shorter than the biweekly sampling interval used during 1963-65. They shifted to daily sampling for later studies.

Munson (1969) found incident light, freshwater runoff, and tidal range were the three factors most useful in predicting the onset and disappearance of blooms in Puget Sound. Campbell et al. (1977) identified wind stress as a fourth important variable. These factors may also control phytoplankton growth in the Strait of Juan de Fuca where tidal currents, thermohaline properties, and wind stress affect water column stability. The formation of a stable upper layer is usually prerequisite to the occurrence of a phytoplankton bloom because the average light intensity in a

vigorously mixed water column is insufficient for sustained growth.

Measuring the chlorophyll *a* content is the only rapid chemical method known for estimating the biomass of living phytoplankton cells in seawater. Values integrated over the upper 50 m show that a large spring bloom was in progress at all stations during late June 1976 (Fig. 2). Point values as high as  $25 \text{ mg Chl } a/\text{m}^3$  were observed at that time. By August, pigment concentrations had declined to pre-bloom levels. Progressively lower levels were encountered at the two innermost stations (2 and 5) through January 1977. At these stations moderately increasing chlorophyll values were noted during the following spring and summer. The outermost station (8) was the site of a distinct autumn phytoplankton bloom during November 1976. Winter chlorophyll concentrations were significantly greater at station 8 than at stations 2 and 5 during both 1976 and 1977. No large phytoplankton bloom was observed in the strait during 1977. Surface concentrations in the range of only  $1\text{-}2 \text{ mg}/\text{m}^3$  were commonly measured. It is possible that a bloom did occur between sampling periods and was therefore not detected. The data, collected over such widely spaced time intervals, does not permit resolution of the question.

**Table 2. Relative Dominance of the Three Most Common Ciliate Categories in the Strait of Juan de Fuca, Expressed as a Percentage of Total Ciliate Numbers.**

Cruise	Station	Tintinnids	Oligotrichs	<i>Mesodinium rubrum</i>
SF7601	2	67	24	10
	5	55	33	11
SF7602	5	2	50	48
	8	3	98	0
SF7603	2	6	48	46
SF7604	2	13	36	51
	5	24	19	57
	8	43	53	4
SF7605	2	1	39	59
	5	1	44	54
	8	1	80	19
SF7606	2	1	15	83
	5	2	78	19
	8	1	92	7
SF7607	2	7	44	48
	5	0	64	36
	8	5	50	35
SF7701	2	0	59	41
	5	3	20	77
	8	11	20	69
SF7702	2	19	60	20
	5	6	63	31
	8	6	52	43
SF7703	2	2	79	18
	5	2	61	34
	8	3	92	5
SF7704	2	2	63	35
	5	2	86	12
	8	26	73	1
SF7705	2	9	29	59
	5	1	95	3
	8	1	99	1
SF7706	2	1	75	22
	5	1	85	14
	8	1	85	14

**Table 3. Percentage Similarity Values for Station-to-Station Comparisons of Ciliate Populations During Strait of Juan de Fuca Cruises, 1976-77.**

Cruise	Stations		
	2,5	5,8	2,8
SF7601	<u>62</u>	--	--
SF7602	--	16	--
SF7603	--	--	--
SF7604	<u>82</u>	43	43
SF7605	<u>89</u>	52	52
SF7606	<u>35</u>	82	22
SF7607	<u>73</u>	<u>68</u>	47
SF7701	<u>53</u>	<u>79</u>	47
SF7702	<u>65</u>	<u>65</u>	<u>60</u>
SF7703	<u>65</u>	53	<u>83</u>
SF7704	<u>74</u>	36	26
SF7705	29	86	25
SF7706	58	<u>73</u>	<u>70</u>

Note: Underlined values indicate high similarity between stations.

## 4. DISTRIBUTION OF MICROZOOPLANKTON

Station records of abundance and occurrence of all microzooplankton are included in the Appendix.

### 4.1 Ciliates

The ciliate community of the Strait of Juan de Fuca was composed almost exclusively of oligotrich and tintinnid species and the gymnostome species, *Mesodinium rubrum*. Averaged over 13 cruises, tintinnids made up about 10%, oligotrichs 60%, and *M. rubrum* 30% of the total ciliate numbers (Table 2).

During winter months, surface ciliate concentrations were low (<750/liters). Much higher concentrations (2,000-10,000/liters) were found during the spring and summer months when phytoplankton populations were greatest (Fig. 3). During 1976 ciliate population maxima occurred in late June and mid-September, separated by a minimum in August. In 1977 large populations of ciliates were found only in June or July. Although the general pattern is clear, it is apparent that a better picture of the seasonality of these organisms requires a more closely spaced sampling interval than used here. The ciliate community is not only very patchy over short time periods (Johansen, 1976), but its composition also varies from station to station within the Strait of Juan de Fuca.

This aspect of spatial heterogeneity is in part analyzed as comparisons of the species composition of the samples. The Percentage Similarity (PS) index (Whittaker, 1960) has proved to be the most useful approach to determine sample similarity with respect to species composition. The PS of two samples, X and Y, is calculated as follows:

$$PS = 100 - 50 \left( \sum_{i=1}^n |x_i - y_i| \right) = \min(x_i, y_i)$$

where  $x_i$  and  $y_i$  are the percents of total individuals that belong to the  $i^{\text{th}}$  category in samples X and Y, and  $n$  is the total number of categories. Miller (1970) used Monte Carlo computer techniques to show that PS is a downward-biased estimator. This bias decreases with increasing sample size and also decreases with decreasing diversity of the community. That is, samples from a population strongly dominated by one or a few categories will tend toward a higher PS. PS is primarily sensitive to shifts in the more abundant groups. Miller found that with sample sizes of 2000 and 1000 individuals, a PS as low as 80%

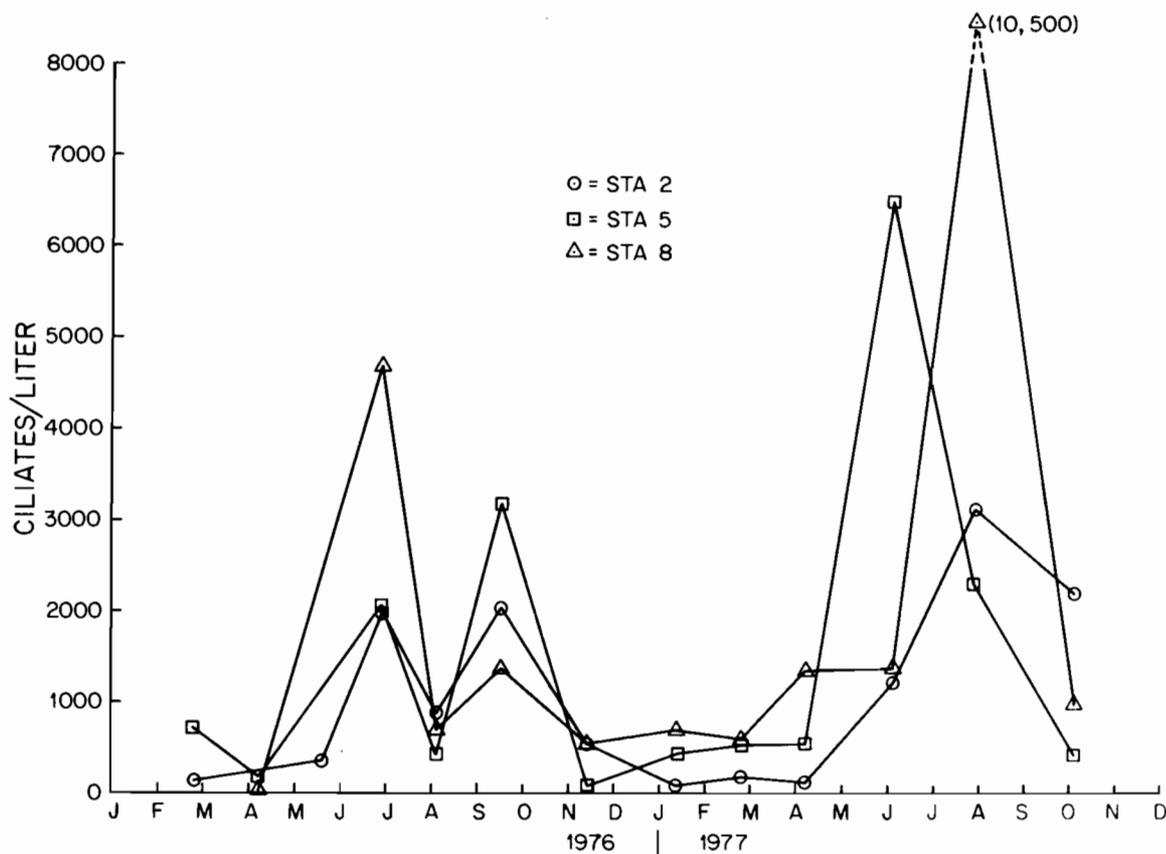


Figure 3. Ciliate concentrations in surface waters of the Strait of Juan de Fuca, 1976-1977.

and 75%, respectively, could be obtained when comparing two samples taken from the same population. Because many of our samples contained fewer than 1000 individuals and because not all ciliate categories were of equal taxonomic weight, the acceptance level required to consider two samples identical should be lowered somewhat. The following criteria were adopted:

- (1) if  $PS \geq 70$ , the samples showed excellent agreement and were considered to have the same population distribution;
- (2) if  $60 \geq PS < 70$ , agreement was fair and it was likely that populations were the same;
- (3) if  $PS < 60$ , agreement was poor and samples probably came from a different ciliate community.

The PS matrix (Table 3) shows the degree of similarity in species composition from station to station on any one cruise. On only one cruise (SF7702) was the character of the ciliate community similar throughout the strait. All other cruises

where comparisons were possible indicated distinct differences in species composition. Station 5, located approximately midway along the axis of the strait, was pivotal in that its ciliate community sometimes resembled that at station 2 and at other times resembled that at station 8. Therefore, for the most part, ciliate composition was not constant from one end of the strait to the other. Rather, distinct spatial differences existed with respect to the dominant species.

#### 4.1.1 Tintinnids

Tintinnids are free-swimming, pelagic, ciliated protozoa. Each organism is attached to a delicate organic test, the "lorica," by a posterior contractile stalk. The anterior portion of the cell is characterized by a strongly developed oral cilium that acts both to propel the animal through the water and to capture food particles. Tintinnids vary in length from 20 to 1000  $\mu\text{m}$ , but most are in the 50 to 150  $\mu\text{m}$  range. They reproduce primarily

**Table 4. Tintinnid and Oligotrich Species Identified from Samples from the Strait of Juan de Fuca, 1976-77**

Tintinnids	Oligotrichs
<i>Acanthostomella norvegica</i> (Daday) Jörgensen	<i>Lohmanniella oviformis</i> Leegaard
<i>Codonellopsis contracta</i> Kofoid and Campbell	<i>Lohmanniella spiralis</i> Leegaard
<i>Dictyocysta reticulata</i> Kofoid and Campbell	<i>Strombidium acuminatum</i> (Leegaard)
<i>Eutintinnus lusus-undae</i> Entz	<i>Strombidium compressum</i> (Leegaard)
<i>Eutintinnus pectinis</i> Kofoid and Campbell	<i>Strombidium conicum</i> (Lohmann)
<i>Eutintinnus rectus</i> Wailes	<i>Strombidium cornucopiae</i> (Wailes)
<i>Eutintinnus tubulosus</i> Ostenfeld	<i>Strombidium crassulum</i> (Leegaard)
<i>Eutintinnus turris</i> Kofoid and Campbell	<i>Strombidium delicatissimum</i> (Leegaard)
<i>Favella franciscana</i> Kofoid and Campbell	<i>Strombidium lagenula</i> Fauré-Fremiet
<i>Helicostomella subulata</i> (Ehrenberg) Jörgensen	<i>Strombidium pulchrum</i> (Leegaard)
<i>Parafavella gigantea</i> (Brandt) Kofoid and Campbell	<i>Strombidium strobilus</i> (Lohmann)
<i>Parundella translucens</i> (Wailes) Kofoid and Campbell	<i>Strombidium sulcatum</i> Claparède and Lachmann
<i>Proplectella columbiana</i> (Wailes) Kofoid and Campbell	<i>Strombidium typicum</i> Bütschli
<i>Ptychocylis drygalskii</i> Brandt	<i>Strombidium vestitum</i> (Leegaard)
<i>Salpingella acuminata</i> (Claparède and Lachmann) Jörgensen	<i>Strombidium viride</i> Stein
<i>Salpingella curta</i> Kofoid and Campbell	
<i>Stenosemella nivalis</i> (Meunier) Kofoid and Campbell	
<i>Stenosemella ventricosa</i> (Claparède and Lachmann) Jörgensen	
<i>Tintinnopsis beroidea</i> Stein	
<i>Tintinnopsis coronata</i> Kofoid and Campbell	
<i>Tintinnopsis kofoidi</i> Hada	
<i>Tintinnopsis levigata</i> Kofoid and Campbell	
<i>Tintinnopsis lohmanni</i> Lachmann	
<i>Tintinnopsis minuta</i> Wailes	
<i>Tintinnopsis parvula</i> Jörgensen	
<i>Tintinnopsis strigosa</i> Meunier	

by binary fission (see Heinbokel, 1977, for a review and some new observations), but conjugation and resting cyst formation have also been reported. Although little is known about the abundance of ciliates in the marine plankton, many qualitative observations, dating back to the work of Müller (1776, cited in Kofoid and Campbell, 1929) and carried out over geographically diverse regions, show that tintinnids are present in virtually all surface waters that have been examined. Several freshwater species are known from larger lakes, but the vast majority of the nearly 1000 described species are restricted to marine environments. Estuaries and nearshore areas generally have few tintinnid species, but these often occur in high numbers. The predominantly neritic tintinnid genera, *Tintinnopsis* and *Stenosemella*, have loricae heavily agglutinated with arenaceous and biologically derived particles (Gold and Morales, 1976). The open ocean is characterized by a more diverse tintinnid fauna predominated by species with hyaline loricae.

Twenty-six tintinnid species in 13 genera were identified in samples from the Strait of Juan de Fuca during 1976 and 1977 (Table 4). The number of species present in the strait at each sampling period is shown in Figure 4. No more than about half the total number of species found were

present during any one cruise. Gold and Morales (1975) also found that less than half of the total number of tintinnid species in the New York Bight were present at any one time. In the Strait of Juan de Fuca, a minimum number of species occurred during early spring; a maximum number occurred during early or mid-summer; autumn values were intermediate.

The population density and biomass of tintinnid ciliates found during this study are given in Figures 5 and 6. Tintinnids appeared to be more abundant in 1976 than 1977, but this may be the result of random daily variations rather than of significant yearly differences. Maximum tintinnid concentrations occurred during early or mid-summer when phytoplankton numbers were also high. Maximum concentrations and biomass coincided with the spring bloom of 1976. Population densities were sparse during winter and autumn months. The distribution of most tintinnid species mirrored this general pattern. *Helicostomella subulata*, an abundant hyaline species, is typical (Fig. 7). This organism was virtually absent in all months except June, July, and August. Lohmann (1908) reported that *H. subulata* (cited as *Tintinnus subulatus*) in Kiel Bay is common in summer and rare in winter. Johansen (1976) found a similar situation for eastern Canadian waters.

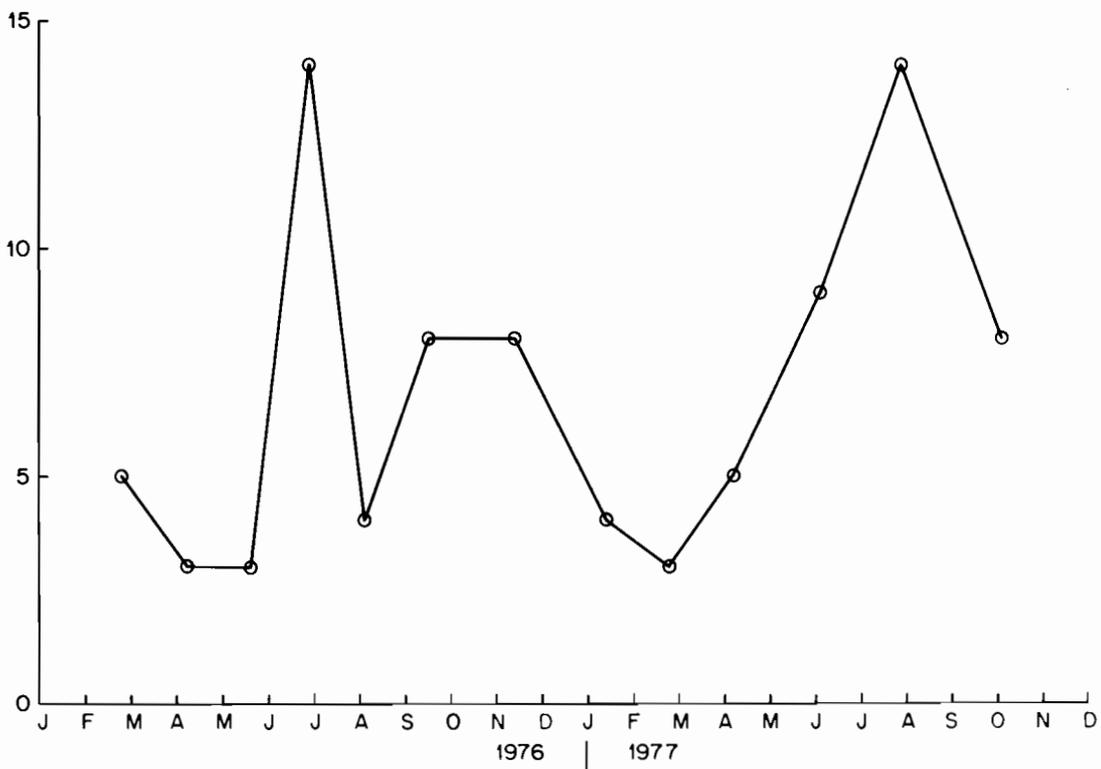


Figure 4. Number of tintinnid species found during Strait of Juan de Fuca study, 1976-1977.

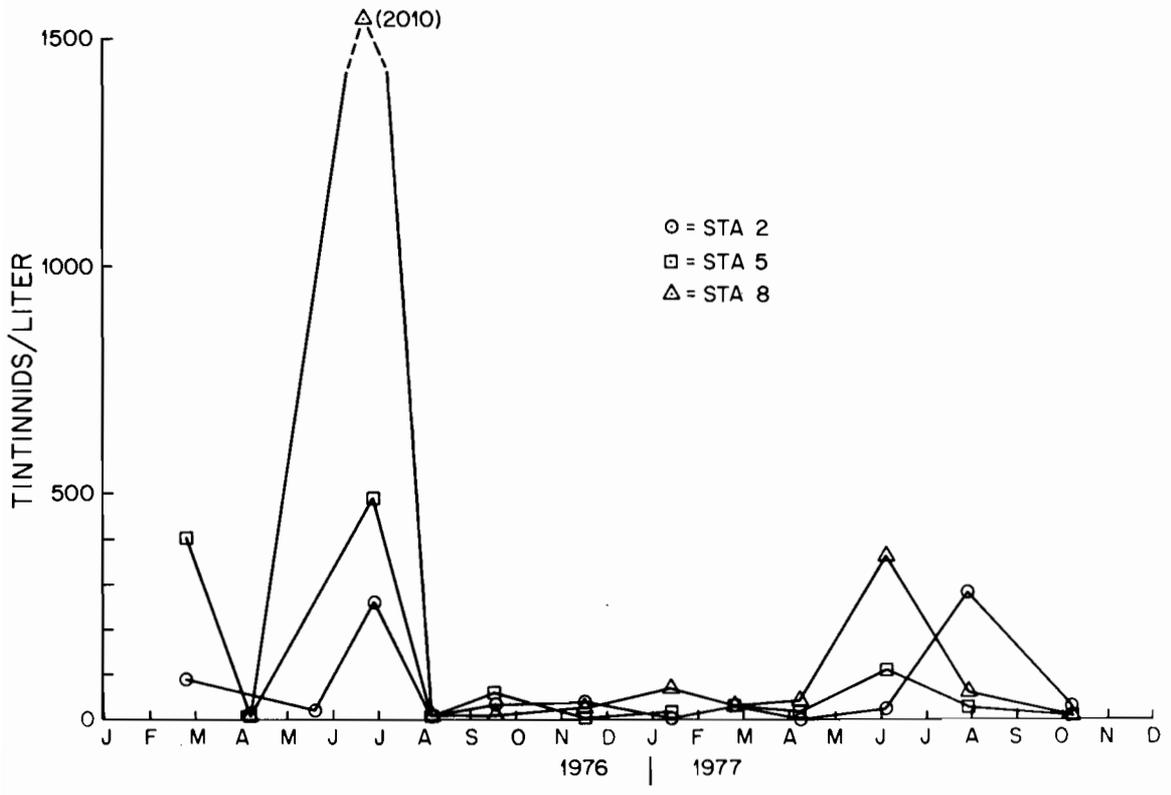


Figure 5. Tintinnid concentrations in surface waters of the Strait of Juan de Fuca, 1976-1977.

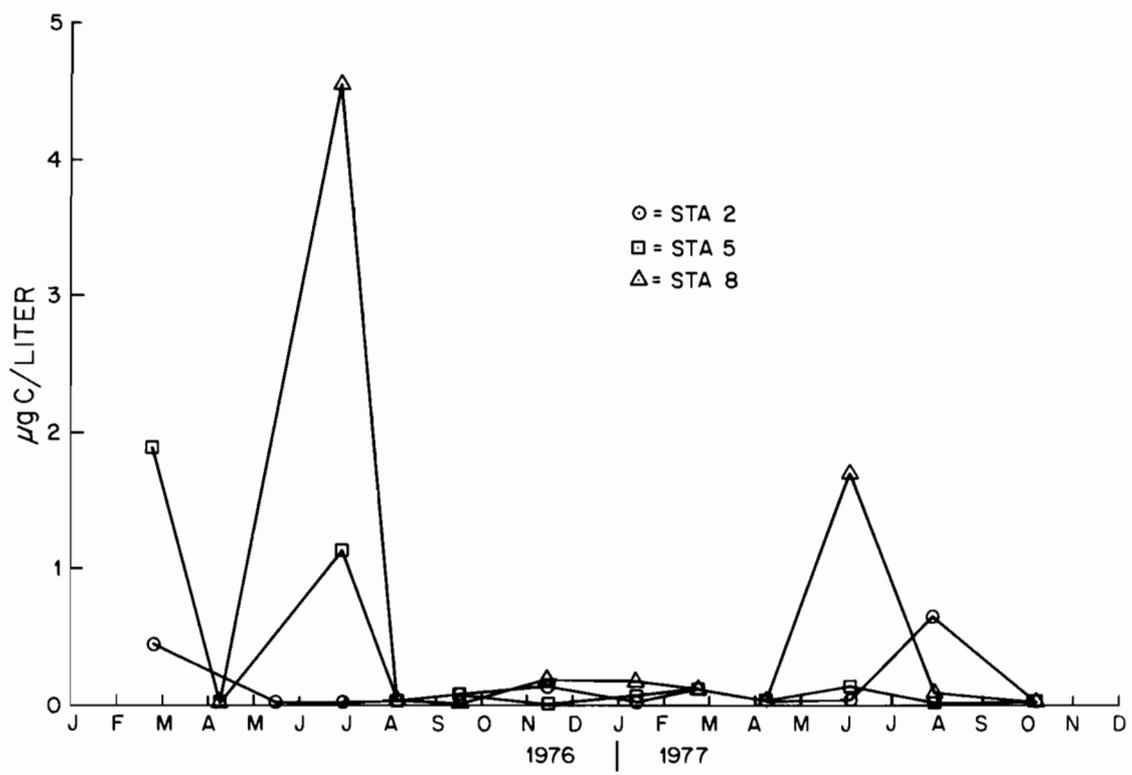


Figure 6. Tintinnid biomass ( $\mu\text{g C/l}$ ) in surface waters of the Strait of Juan de Fuca, 1976-1977.

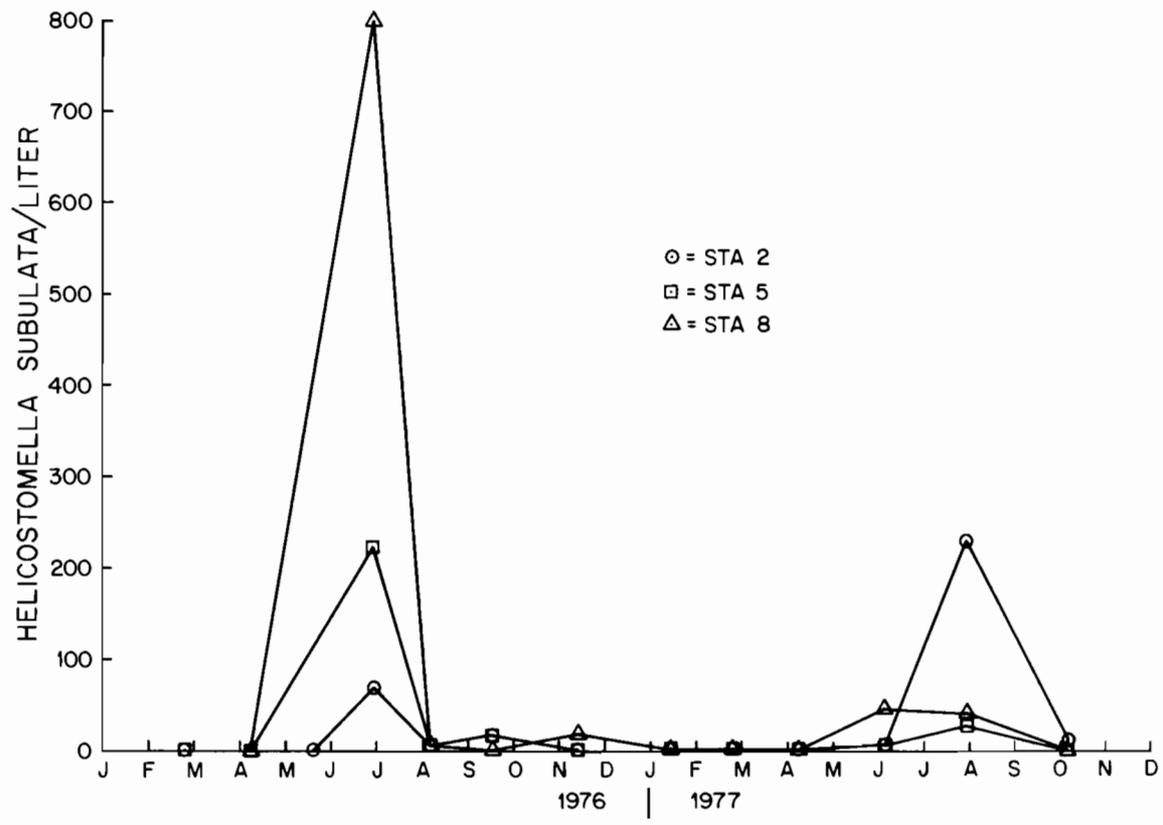


Figure 7. Concentration of *Helicostomella subulata* in the surface waters of the Strait of Juan de Fuca, 1976-1977.

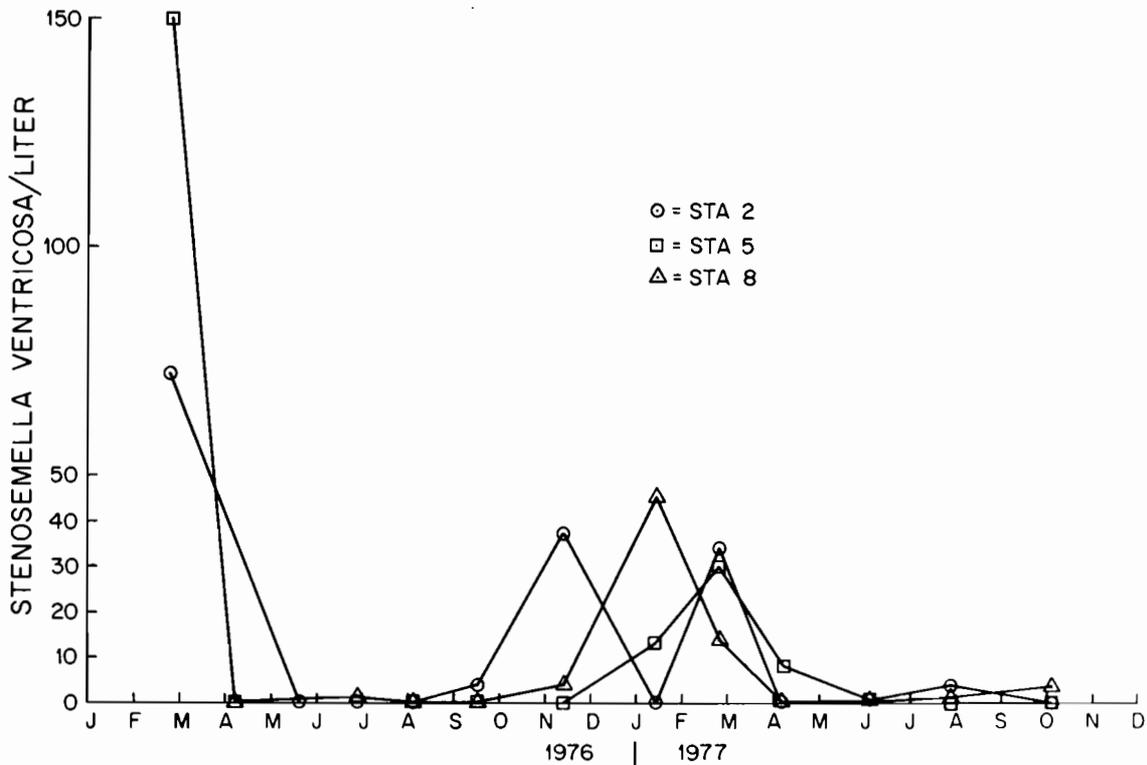


Figure 8. Concentration of *Stenosemella ventricosa* in surface waters of the Strait of Juan de Fuca, 1976-1977.

*Eutintinnus* spp., *Tintinnopsis strigosa*, and *Tintinnopsis kofoidi* are also primarily summer species in the Strait of Juan de Fuca.

Two species, *Stenosemella ventricosa* and *Tintinnopsis parvula*, showed an opposite distributional pattern. These organisms were most abundant during the colder months (Figure 8 shows the distribution of *S. ventricosa*). A previous study (Chester, 1975, 1978) demonstrated high concentrations of living *S. ventricosa* close to the bottom at neritic stations off the Washington coast during July. It was speculated that the organism grazes on organic sediments of the continental shelf and, in so doing, cycles energy directly back to the pelagic food web. A different conclusion was reached by Echols and Fowler (1973). They reported large numbers of empty *S. ventricosa* loricae in modern continental shelf sediments off southern Washington and northern Oregon and suggested that living populations of this tintinnid congregate off river mouths, with their loricae subsequently transported to the central shelf by physical processes. Gold and Morales (1976) found that *S. ventricosa* produces loricae which are distinctly arenaceous and composed primarily of non-biologically derived mineral particles. They speculated that these tintinnids first produce their loricae in the sediments and then, coated with particles, take up their planktonic

existence. This hypothesis is indirectly supported by the evidence of near-bottom populations in July off the Washington coast and the present observations of winter surface populations in the Strait of Juan de Fuca. An alternative explanation might be based on specific water temperature tolerances. Perhaps *S. ventricosa* requires the relatively cooler waters near the bottom during the summer.

#### 4.1.2 Oligotrichs

Oligotrichs often are the most abundant protozoan group in the nearshore plankton (e.g., Beers and Stewart, 1970). They have been divided into "sheathed" and "unsheathed" forms based on the presence or absence of a hyaline sheath tightly bound to the cell body. Whereas tintinnids can readily abandon their loricae if disturbed, the oligotrich sheath is intrinsically bound to the cell. The sheath is never agglutinated with particles and lacks the robustness of a true lorica. The oligotrichs usually possess a powerfully contractile oral band of cilia which extends freely from the sheath. Many of the smaller unsheathed varieties are poorly preserved in formaldehyde, rendering

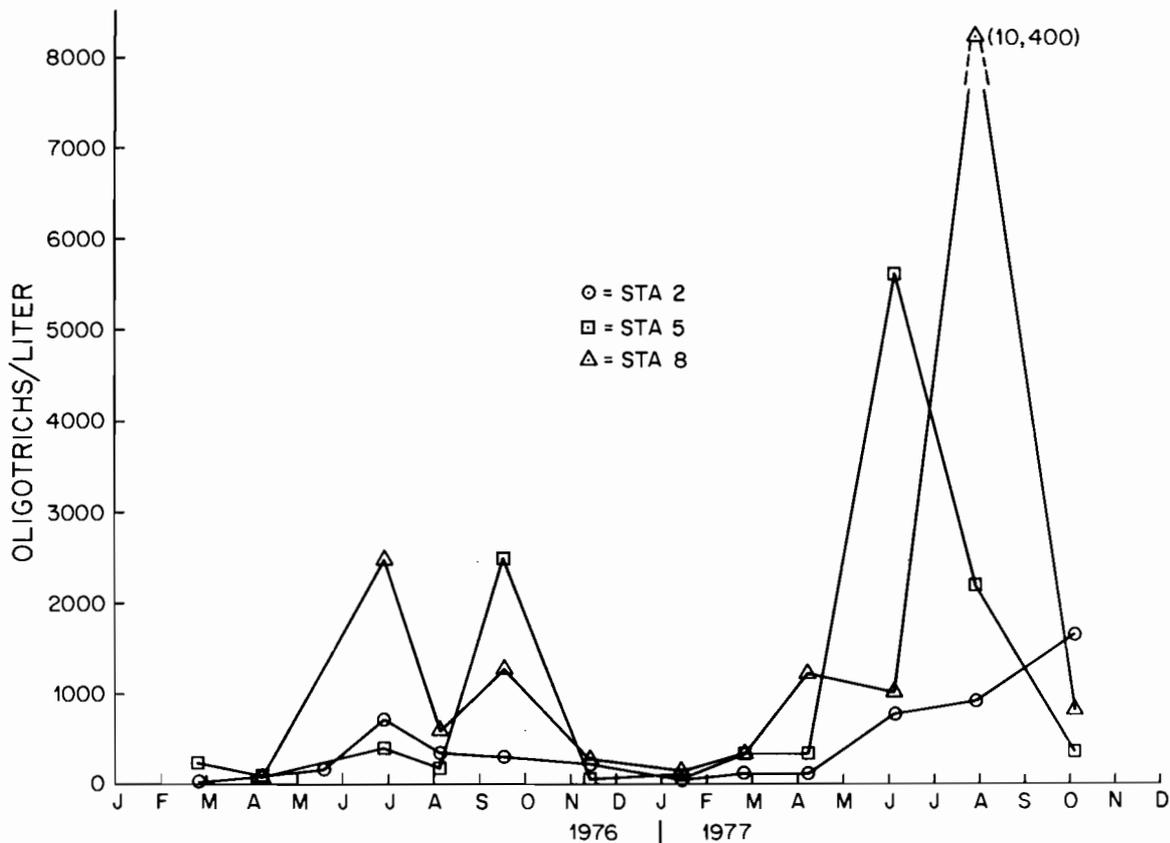


Figure 9. Concentration of oligotrichs in surface waters of the Strait of Juan de Fuca, 1976-1977.

identification impossible. Also, this group has not been extensively treated in the taxonomic literature. For the most part, taxonomic works using formaldehyde-preserved material (e.g., Leegaard, 1915) were consulted for this study.

Oligotrichs were the most common protozoans in the Strait of Juan de Fuca. They accounted for an average of 60% of the total ciliate numbers at a given station. The genera *Strombidium* and *Lohmanniella* were most abundant. Thirteen *Strombidium* species and two *Lohmanniella* species were identified in the samples (Table 4). In contrast to the tintinnids, oligotrichs appeared to be most numerous in 1977 (Fig. 9). As with the tintinnids, however, this trend might be more related to specific daily variations than to any generalized yearly pattern. There was no striking difference in biomass from one year to the next (Fig. 10). The average organism size was therefore smaller in 1977 than in 1976.

The seasonal distribution of oligotrichs resembled that found for tintinnids. Population blooms occurred during the spring-summer periods of greater phytoplankton concentration.

The population minimum occurred during late autumn and winter. The sheathed species *Strombidium conicum*, *Strombidium strobilus*, and *Strombidium cornucopiae* (Figs. 11-13) show this distribution but also clearly demonstrate "boom or bust" population trends. During 1976, for example, *S. cornucopiae* bloomed in early summer, no bloom was observed in August, and *S. conicum* dominated in September. In 1977 *S. cornucopiae* did not bloom, while *S. strobilus* blooms alternated with *S. conicum* blooms at station 8. *S. strobilus* dominated in late February and early June; *S. conicum* bloomed in early April and late July. At station 5, however, blooms of *S. strobilus* and *S. conicum* occurred simultaneously in early June. Oligotrich blooms were usually absent or greatly reduced at station 2 during both 1976 and 1977. These complex relationships are difficult to clarify because of the long time intervals between sampling periods. It is likely that these volatile cycles for individual ciliate species are complicated events occurring over time scales much shorter than our sampling interval (see also Johansen, 1976).

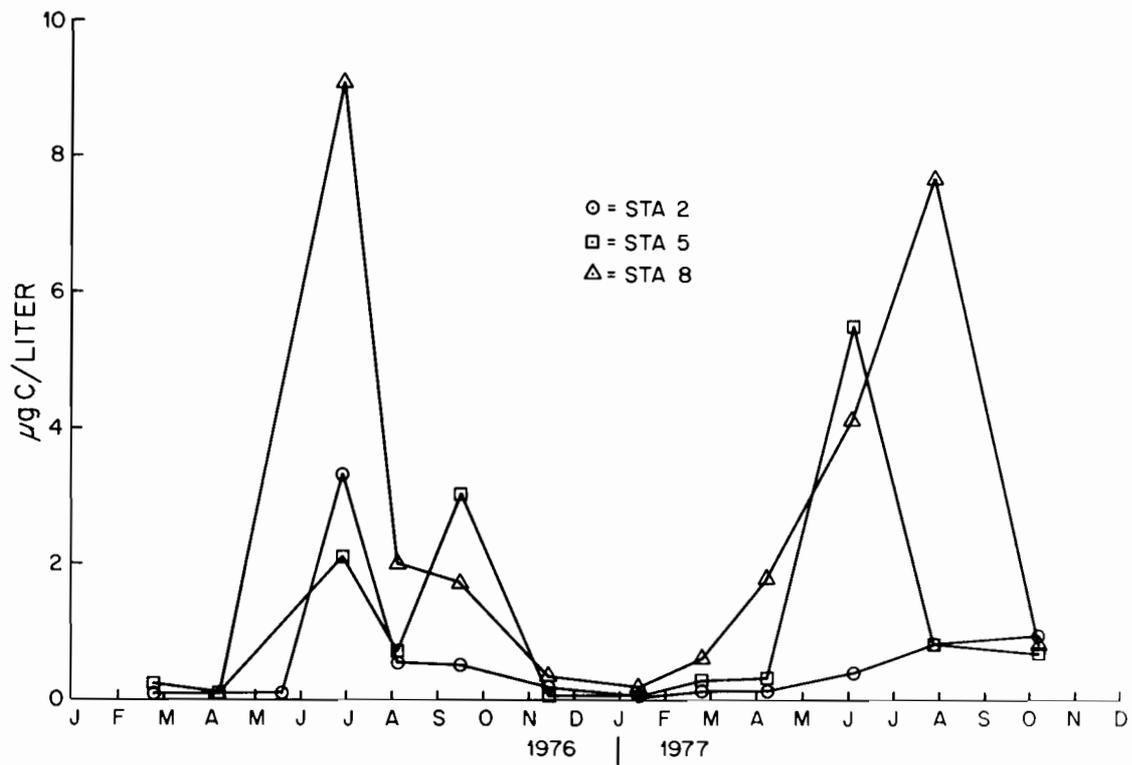


Figure 10. Oligotrich biomass in surface waters of the Strait of Juan de Fuca, 1976-1977.

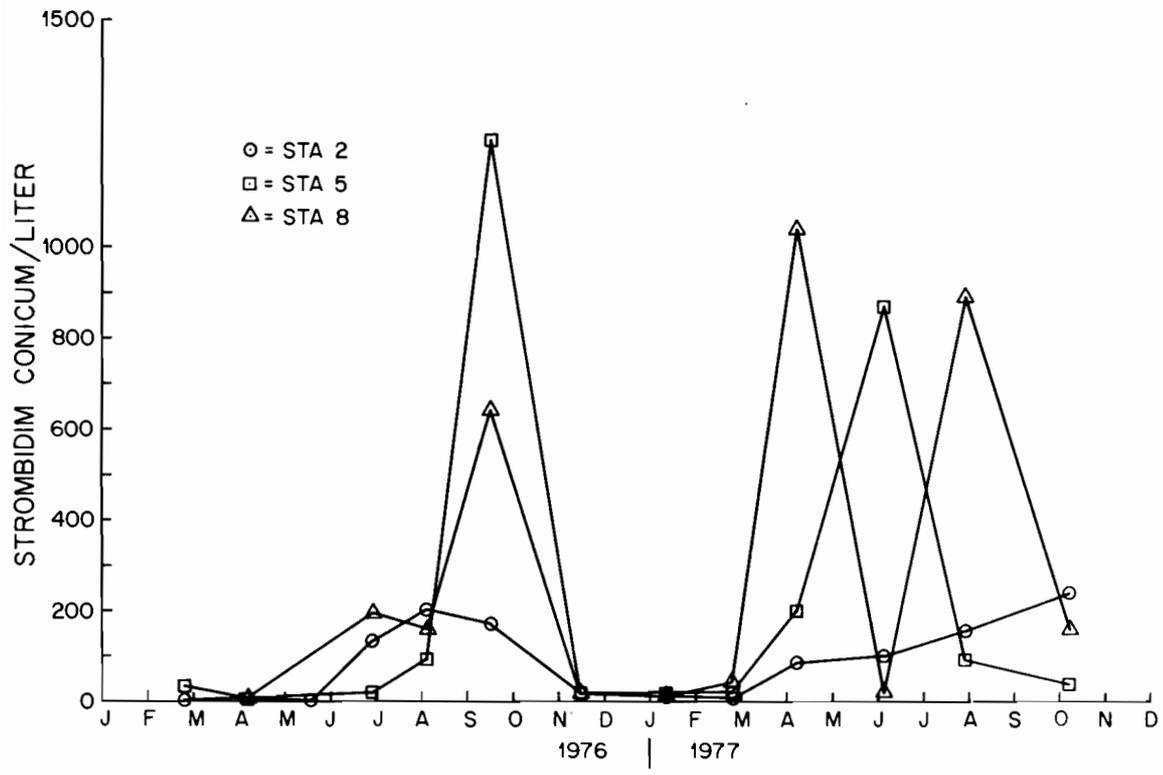


Figure 11. Concentration of *Strombidium conicum* in surface waters of the Strait of Juan de Fuca, 1976-1977.

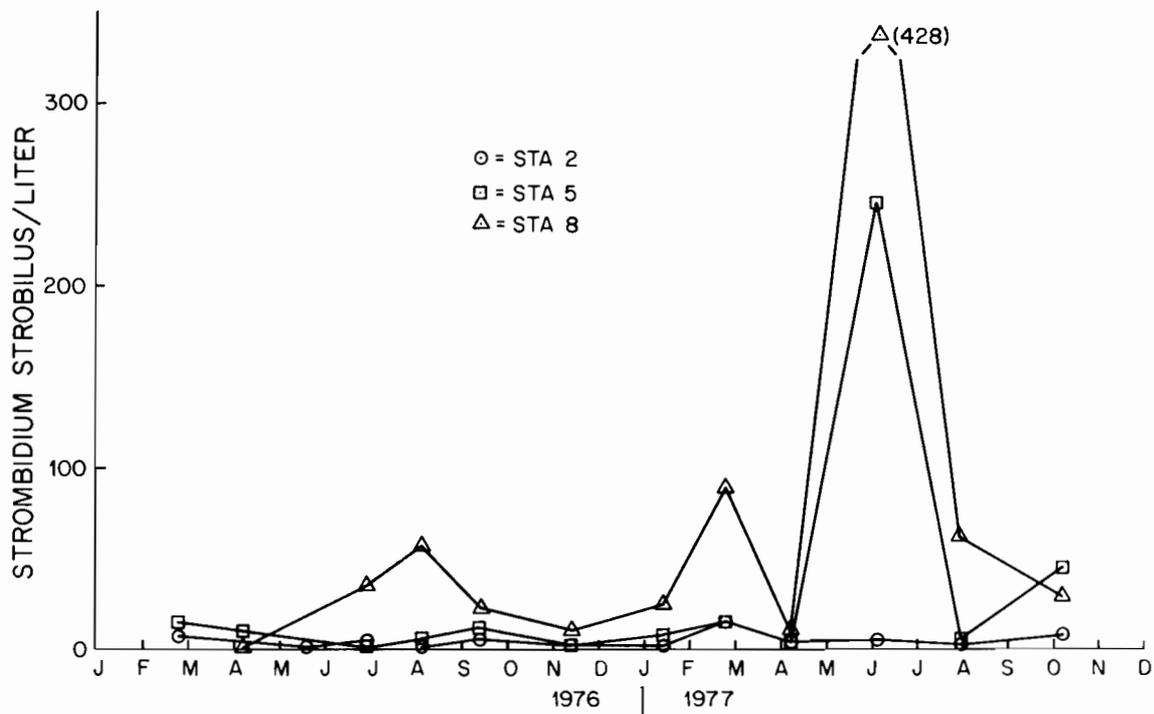


Figure 12. Concentration of *Strombidium strobilus* in surface waters of the Strait of Juan de Fuca, 1976-1977.

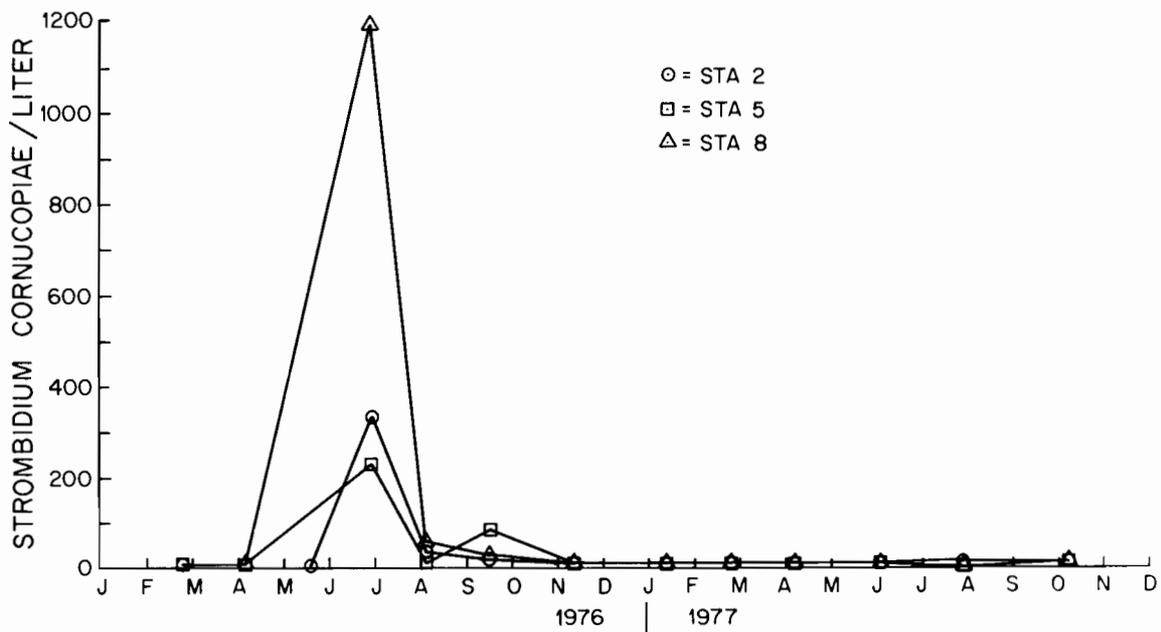


Figure 13. Concentration of *Strombidium cornucopiae* in surface waters of the Strait of Juan de Fuca, 1976-1977.

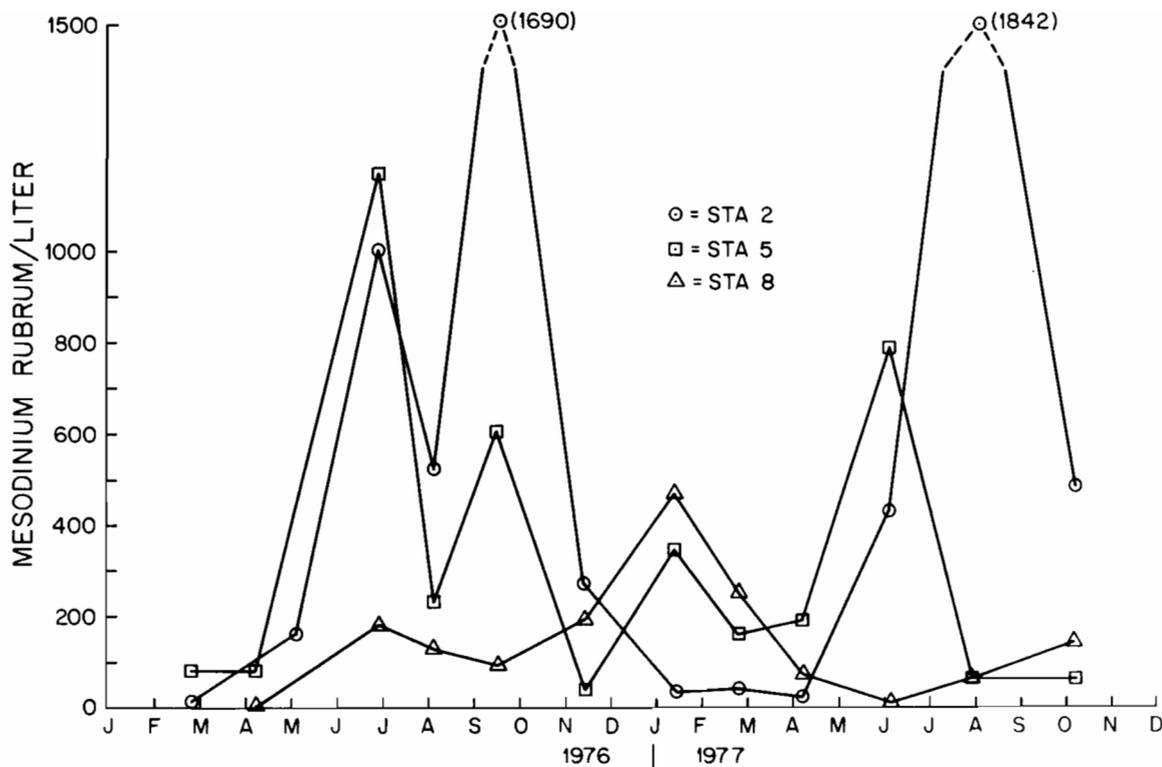


Figure 14. Concentration of *Mesodinium rubrum* in surface waters of the Strait of Juan de Fuca, 1976-1977.

#### 4.1.3 Other Ciliates

Tintinnids and oligotrichs are the major protozoan grazers of small phytoplankton cells in the Strait of Juan de Fuca. However, several other ciliate taxa, which often exhibit different ecological roles, may occur in significant concentrations.

Chief among these is *Mesodinium rubrum*. (This report follows the taxonomic opinion of Taylor et al. [1971] and assumes synonymy between *M. rubrum* Hamburger and Buddenbrock and *Cyclotrichium meunieri* Powers.) *M. rubrum* is a marine holotrich ciliate that is widely distributed geographically and well known for its ability to bloom to red water proportions (Taylor et al., 1971). It is mainly found in extremely neritic locations such as bays and fjords but has been reported to bloom over areas as large as 250 km<sup>2</sup> in upwelling regions off the coast of Peru and Ecuador (Ryther, 1967). The organism contains reddish-brown chloroplasts that Lohmann (1908) assumed were symbiotic algae. *M. rubrum* contains photosynthetically active chlorophyll (Ryther, 1967), is positively phototropic (Bary and Stuckey, 1950), and has a greatly reduced cytostome. Ultrastructural studies revealed that

the small pigmented bodies were true chloroplasts, but no algal nucleus could be identified (Taylor et al., 1971). More recently Hibberd (1977) found a nucleus associated with the chloroplasts and concluded that each *M. rubrum* contained a symbiotic alga separated from the ciliate cytoplasm by a single membrane.

Lohmann's (1908) original description of this species from Kiel Bay (first cited as *Halteria rubra*) includes this distributional account: "These were never absent from the plankton and attained their maximum of 390,000 individuals per 100 liters in October; however, a slight bloom was also noticed in spring." *M. rubrum* was also present in the Strait of Juan de Fuca during all sampling periods (Fig. 14). The highest concentrations encountered ( $\approx 1800$ /liter) occurred at station 2 during both summers. At this location the organisms declined drastically during winter months. A similar distribution was reported by Buchanan (1966). He found peak numbers of *M. rubrum* during summer in a small inlet near Vancouver, B.C. In contrast, at station 8, *M. rubrum* concentrations were uniformly low, except for moderate increases in the winter months. At station 5 the pattern was intermediate and irregular throughout the year.

*Mesodinium rubrum* is a distinctly neritic species which attains its maximum concentration at the innermost part of the strait. It is quite likely that this organism blooms to red water proportions at certain times of the year. As such it is one of the more interesting species encountered and occupies a unique ecological niche quite apart from that of tintinnids and other particle-grazing ciliates.

Two other holotrich species, *Tiarina fusus* and *Didinium nasutum*, were also significant at times. *T. fusus* was present only between July and November. It reached concentrations as great as 105/liter. *D. nasutum* was generally not as abundant and was primarily a spring-summer-fall inhabitant of the plankton.

## 4.2 Other Protozoa

Protozoa other than ciliates were rare in the Strait of Juan de Fuca. An exception may be the unarmored phagotrophic dinoflagellate *Noctiluca miliaris*. This species possesses a large vacuole which makes the cell either neutrally or positively buoyant. Each cell has one flagellum and a large mobile tentacle that aids in the capture of food. Field observations indicate that the species acts primarily as an herbivore, but Sweeny (1971) has reported a green *Noctiluca* with intravacuole algal symbionts. *N. miliaris* has a world-wide distribution and may be seasonally common in neritic waters. Wailes (1943) reported the species sometimes so numerous in British Columbian waters as to color large areas a reddish or pinkish hue and form windrows on beaches.

*N. miliaris* was never seen in such numbers in the Strait of Juan de Fuca study. Generally it was present from spring through summer, but highest concentrations observed (greater than 50/liter) coincided with the autumn phytoplankton bloom at station 8.

Other protozoa occasionally seen in the strait were foraminiferans and radiolarians. Radiolarians, particularly *Lithomelissa setosa*, were most abundant during late summer and early autumn. Foraminiferans were very rare, and only a few were noted during the study.

## 4.3 Metazoa

All juvenile stages of crustaceans and other invertebrates, as well as minute many-celled adults such as rotifers, are included in this category. These organisms were seldom abundant enough to obtain statistically reliable results. In

addition, the degree of avoidance to water bottle samplers is unknown. This sampling technique does, however, yield better quantitative data than do net hauls for small metazoans (Hansen and Andersen, 1962).

Copepods, especially nauplii and to a lesser extent copepodid stages, were the most numerous metazoans. During 1976, maximum numbers of nauplii (to 160/liter) were collected in the summer (Fig. 15). Concentrations decreased rapidly through autumn and winter at stations 2 and 5, but a large peak was observed at station 8 during the local November phytoplankton bloom. In 1977 maximum nauplii densities at station 8 occurred during spring. At stations 2 and 5 the maximum was observed in summer. In general, nauplii concentrations were lower in 1977 than in 1976 and showed some correlation with phytoplankton biomass. Post-naupliar copepods were less numerous than nauplii. They were relatively rare in the samples and may have been better able to avoid the sampler. Still, the general trend is similar to that of nauplii. Higher concentrations were seen through the summer and during the fall phytoplankton bloom.

Other invertebrate juveniles were also common. These included trochophore larvae, mitraria larvae, larvaceans, and barnacle cyprids. Trochophores, primarily those of polychaete worms, were most common in the early summer period and during the autumn phytoplankton bloom at station 8. Maximum concentrations of over 300/liter were encountered. Mitraria larvae, specialized trochophores of the polychaete *Owenia fusiformis*, were found in small numbers during the month of June in both 1976 and 1977. Juvenile larvaceans were more common and occurred mostly during summer and early fall.

Rotifers were the only adult metazoa encountered during this investigation. *Trichocera marina* was the most common species, but *Synchaeta* sp. was also occasionally seen. Rotifers were common in June and July of both years. A maximum density of over 100/liter was observed during the 1976 spring phytoplankton bloom. A few rotifers persisted through the autumn months, but they were completely absent during winter.

## 5. SUMMARY

The microzooplankton includes a large variety of protozoans and metazoans that are too small to be adequately sampled by conventional plankton nets. Although they are small, their specific metabolic rates (reproduction, ingestion,

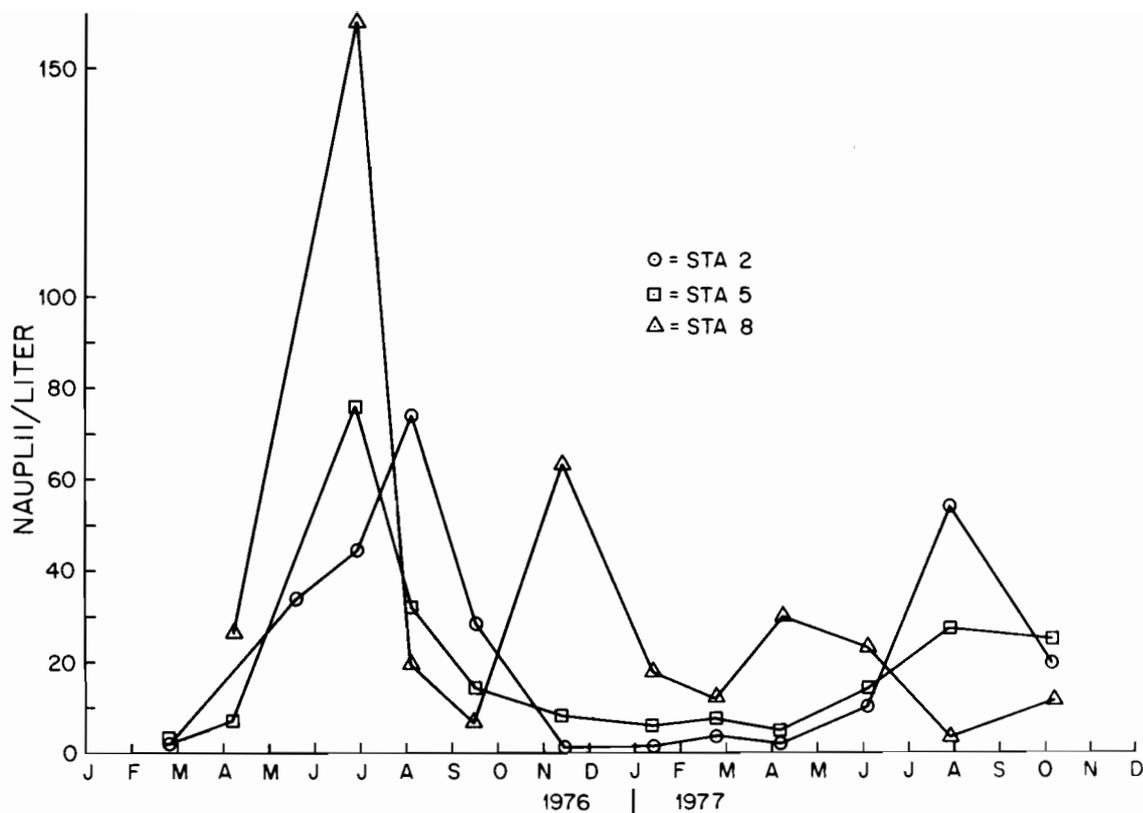


Figure 15. Concentration of nauplii in surface waters of the Strait of Juan de Fuca, 1976-1977.

nutrient recycling, etc.) far exceed those of the larger zooplankton. Their ecological role may therefore be significantly greater than indicated by biomass alone.

In the Strait of Juan de Fuca, a large estuary joining the inland waters of Washington State with the Pacific Ocean, ciliates numerically dominate the microzooplankton community. Oligotrichs and tintinnids, active phytoplankton grazers, are usually the most abundant ciliate taxa. A total of 26 tintinnid species and 15 oligotrich species were identified from the surface waters during a 2-year study. The population peaks of most of these species (e.g., tintinnids—*Helicostomella subulata*, *Eutintinnus* spp.; oligotrichs—*Strombidium conicum*, *S. strobilus*) usually coincided with periods of highest phytoplankton concentration during the spring and summer. However, certain species, such as the tintinnid *Stenosemella ventricosa*, were most abundant during winter months. The distribution of *S. ventricosa* may be related to some combination of temperature preference and lorica building requirements. Besides the particle grazing ciliates, large concentrations of *Mesodinium rubrum* were present, especially at innermost sites. *M. rubrum* derives its nutrition from photosynthetic endo-

symbionts and as such occupies a distinctly different position in the pelagic food web of neritic waters than do other ciliates. Protozoans other than ciliates include the heterotrophic dinoflagellate *Noctiluca miliaris* and various foraminiferans and radiolarians. These were seen infrequently during the study.

Metazoans, including juvenile crustaceans, trochophore larvae, mitraria larvae, and larvaceans were recorded. Adult rotifers were also frequently encountered. In general, metazoans followed a pattern similar to that of protozoans, i.e., they were usually most abundant during the periods of high phytoplankton population density.

The data gathered verify the volatile "boom or bust" nature of many of these species and reinforce the view that microzooplankton may react quickly to increased phytoplankton concentrations in such a way as to influence the numbers of at least the smaller photosynthetic organisms. Although the general trends are clear, the rapid changes in community composition and size limit the interpretations. A better picture of the distribution of specific organisms and an understanding of interspecies relationships require a more comprehensive sampling schedule in terms of both time and space.

## 6. ACKNOWLEDGMENTS

I wish to thank Jerry D. Larrance and David M. Damkaer for their encouragement, support, and critical review of this work. Special thanks also go to David A. Tennant for his help with field observations and data analysis.

This research was supported by a contract with NOAA's Marine Ecosystem Analysis (MESA) Puget Sound Project.

## 7. REFERENCES

- Bary, B. M., and R. G. Stuckey, 1950. An occurrence in Wellington Harbour of *Cyclotrichium meunieri* Powers, a ciliate causing red water, with some additions to its morphology. *Trans. Roy. Soc. N.Z.*, 78:86-92.
- Beers, J. R., and G. L. Stewart, 1967. Micro-zooplankton in the euphotic zone at five locations across the California Current. *J. Fish Res. Bd. Can.*, 24: 2053-2068.
- Beers, J. R., and G. L. Stewart, 1969. The vertical distribution of microzooplankton and some ecological observations. *J. Cons. Perm. Int. Explor. Mer*, 33: 30-44.
- Beers, J. R., and G. L. Stewart, 1970. Numerical abundance and estimated biomass of microzooplankton. *Bull. Scripps Inst. Oceanogr.*, 17:67-87.
- Beers, J. R., and G. L. Stewart, 1971. Micro-zooplankters in the plankton communities of the upper waters of the eastern tropical Pacific. *Deep-Sea Res.*, 18:861-883.
- Bigelow, H. B., L. C. Lillick, and M. Sears, 1940. Phytoplankton and planktonic protozoa of the offshore waters of the Gulf of Maine. *Trans. Amer. Phil. Soc.*, 31:149-191.
- Blackbourn, D. J., 1974. The feeding biology of tintinnid protozoa and other inshore microzooplankton. Ph.D. thesis, Univ. of British Columbia, 224 pp.
- Booth, B. C., 1969. Species differences between two consecutive phytoplankton blooms in Puget Sound during May, 1967. M.S. thesis, Univ. of Washington, Seattle, 28 pp.
- Buchanan, R. J., 1966. A study of the species composition and ecology of the protoplankton of a British Columbia inlet. Ph.D. thesis, Univ. of British Columbia, 268 pp.
- Burkholder, P. R., L. M. Burkholder, and L. R. Almodovar, 1967. Carbon assimilation of marine flagellate blooms in neritic waters off southern Puerto Rico. *Bull. Mar. Sci. Gulf Caribbean*, 17:1-15.
- Campbell, A. S., 1954. Tintinnia, pp. 166-180. In: R. C. Moore (ed.), *Treatise on invertebrate paleontology* (part D). Univ. of Kansas, Lawrence.
- Campbell, S. A., W. K. Peterson, and J. R. Postel, 1977. Phytoplankton production and standing stock in the main basin of Puget Sound. Final report to municipality of metropolitan Seattle, 132 pp.
- Chester, A. J., 1975. Ciliate microzooplankton distribution relative to a subsurface chlorophyll maximum off the Washington coast. M.S. thesis, Univ. of Washington, Seattle, 84 pp.
- Chester, A. J., 1978. Microzooplankton relative to a subsurface chlorophyll maximum layer. *Mar. Sci. Commun.*, 4:275-292.
- Chester, A. J., D. M. Damkaer, D. B. Dey, and J. D. Larrance, 1977. Seasonal distributions of plankton in the Strait of Juan de Fuca. ERL/MESA Technical Memorandum 24, 74 pp.
- Echols, R. J., and G. A. Fowler, 1973. Agglutinated tintinnid loricae from some recent and late pleistocene shelf sediments. *Micropaleontology*, 19:431-443.
- Gold, K., 1970. Cultivation of marine ciliates (Tintinnida) and heterotrophic flagellates. *Helv. Wiss. Meeresunters*, 20:264-271.
- Gold, K., and E. A. Morales, 1975. Seasonal changes in lorica sizes, and the species of Tintinnida in the New York Bight. *J. Protozool.*, 22:520-528.
- Gold, K., and E. A. Morales, 1976. Studies on the sizes, shapes, and the development of the lorica of agglutinated Tintinnida. *Biol. Bull.*, 150:377-392.
- Gran, H. H., and T. G. Thompson, 1930. The diatoms and the physical and chemical conditions of the seawater of the San Juan Archipelago. *Publ. Puget Sound Biol. Sta.*, 7:169-204.
- Hada, Y., 1932. Report of the biological survey of Mutsu Bay, Part 24. The pelagic Ciliata, suborder Tintinninea. Contributions from the marine biological station, Asamushi, Aomori-Ken 93, Japan. Pp. 553-573.
- Hada, Y., 1937. The fauna of Akkeshi Bay, Part 4. The pelagic Ciliata. *J. Fac. Sci. Hokkaido Imp. Univ.*, 5:143-216.
- Hansen, V. K., and K. P. Andersen, 1962. Sampling the smaller zooplankton. *Rapp. P.-V. Reun. Cons. Int. Explor. Mer*, 153:39-47.
- Heinbokel, J. F., 1977. Functional and numerical responses of coastal tintinnids: implications for the neritic food chain. Ph.D. thesis, Univ. of California, San Diego, 174 pp.
- Herlinveaux, R. H., and J. P. Tully, 1961. Some oceanographic features of the Juan de Fuca Strait. *J. Fish Res. Bd. Can.*, 18:1027-1071.
- Hibberd, D. J., 1977. Observations on the ultrastructure of the cryptomonad endosymbiont of the red-water ciliate *Mesodinium rubrum*. *J. Mar. Biol. Ass. U.K.*, 57:45-61.
- Hirota, J., 1967. Use of free-floating polyethylene cylinders in studies of Puget Sound phytoplankton ecology. M.S. thesis, Univ. of Washington, Seattle, 83 pp.
- Johansen, P. L., 1976. A study of tintinnids and other protozoa in eastern Canadian waters with special reference to tintinnid feeding, nitrogen excretion and reproduction rates. Ph.D. thesis, Dalhousie Univ., Nova Scotia, 155 pp.

- Kahl, A., 1930-1935. Urtiere oder Protozoa. 1: Wimpertiere oder Ciliata (Infusoria), Eine Bearbeitung der freilebenden und ectocommensalen Infusorien der Erde, unter Ausschluss der marinen Tintinnidae. Parts 18, Allgemeiner Teil und Prostomata; 21, Holotricha; 25, Spirotricha; 30, Peritricha und Chonotricha. In: *Die Tierwelt Deutschlands* (Friedrich Dahl, ed.), Gustav Fischer, Jena.
- Kofoid, C. A., and A. S. Campbell, 1929. A conspectus of the marine and freshwater Ciliata belonging to the suborder Tintinnoinea, with descriptions of new species principally from the Agassiz expedition to the eastern tropical Pacific, 1904-1905. *Univ. Calif. Publ. Zool.*, 34:1-403.
- Kofoid, C. A., and A. S. Campbell, 1939. The Ciliata: the Tintinnoinea. *Bull. Mus. Comp. Zool.*, 84:1-473.
- LeBrasseur, R. J., and O. D. Kennedy, 1972. Microzooplankton in coastal and oceanic areas of the Pacific subarctic water mass: a preliminary report, pp. 355-365. In: A. Y. Takenouti et al. (eds.), *Biological Oceanography of the Northern North Pacific Ocean*. Idemitsu Shoten, Tokyo.
- Leegaard, C., 1915. Untersuchungen über einige Planktonciliaten des Meeres. *Nyt Mag. Naturvidensk.*, 13:1-37.
- Lohmann, H., 1908. Untersuchungen zur Feststellung des vollständigen Gehaltes des Meeres an Plankton. *Wiss. Meeresunters.*, Abt. Kiel, N.S. 10:129-370.
- Lorenzen, C. J., 1966. A method for the continuous measurement of *in vivo* chlorophyll concentration. *Deep-Sea Res.*, 13:223-227.
- Miller, C. B., 1970. Some environmental consequences of vertical migration in marine zooplankton. *Limnol. Oceanogr.*, 15:727-741.
- Munson, R. E., 1969. The horizontal distribution of phytoplankton in a bloom in Puget Sound during May, 1969. Non-thesis master's report, Univ. of Washington, Seattle. 13 pp.
- Parsons, T. R., and R. J. LeBrasseur, 1970. The availability of food to different trophic levels in the marine food chain, p. 325-343. In: J. H. Steele (ed.), *Marine Food Chains*. Oliver and Boyd, London.
- Phifer, L. D., 1933. Seasonal distribution and occurrence of plankton diatoms at Friday Harbor, Wash. *Univ. Wash. Publ. Oceanogr.*, 1:39-81.
- Phifer, L. D., 1934a. Phytoplankton of East Sound, Wash., Feb. to Nov. 1932. *Univ. Wash. Publ. Oceanogr.*, 1:97-110.
- Phifer, L. D., 1934b. Vertical distribution of diatoms in the Strait of Juan de Fuca. *Univ. Wash. Publ. Oceanogr.*, 1:83-96.
- Ryther, J. H., 1967. Occurrence of red water off Peru. *Nature*, 214:1318-1319.
- Shim, J. H., 1976. Distribution and taxonomy of planktonic marine diatoms in the Strait of Georgia, B.C. Ph.D. thesis, Univ. of British Columbia, 252 pp.
- Sweeny, B. M., 1971. Laboratory studies of a green *Noctiluca* from New Guinea. *J. Phycol.*, 7:53-58.
- Taylor, F. J. R., D. J. Blackburn, and J. Blackburn, 1971. The red-water ciliate *Mesodinium rubrum* and its "incomplete symbionts": a review including new ultrastructural observations. *J. Fish. Res. Bd. Can.*, 28:391-407.
- Thompson, T. G., and L. D. Phifer, 1936. The plankton and properties of the surface waters of the Puget Sound region. *Univ. Wash. Publ. Oceanogr.*, 1:115-134.
- Utermöhl, H., 1931. Neue Wege in der quantitativen Erfassung des Planktons. *Int. Ver. Theor. Angew. Limnol. Verh.*, 5:567-597.
- Wailes, G. H., 1925. Tintinnidae from the Strait of Georgia, B.C. *Contrib. Can. Biol.*, N.S., 2:533-541.
- Wailes, G. H., 1943. Canadian Pacific fauna. 1. Protozoa. *Fish. Res. Bd. Can. and Univ. of Toronto*. 46 pp.
- Whittaker, R. H., 1960. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecol. Monogr.*, 30:279-338.
- Winter, D. F., K. Banse, and G. C. Anderson, 1975. The dynamics of phytoplankton blooms in Puget Sound, a fjord in the northwestern United States. *Mar. Biol.*, 29:139-176.

## APPENDIX: Tabulated Microzooplankton Data by Species for Cruises in the Strait of Juan de Fuca, 1976-77

The tables list species collected on cruises in the Strait of Juan de Fuca, 1976-77. All values are numbers per liter.

### Cruise SF 7601

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>	3	35	
<i>Stenosemella ventricosa</i>	72	150	
<i>Tintinnopsis beroidea</i>	2	35	
<i>T. minuta</i>	2	7	
<i>T. parvula</i>	11	170	
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>		33	
<i>S. compressum</i>		28	
<i>S. strobilus</i>	8		
<i>S. B</i>		5	
<i>Lohmanniella</i> sp.	2		
Sheathed oligotrichs	14	98	
Unsheathed oligotrichs	8	58	
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	13	82	
<u>Metazoa</u>			
Nauplii	2	3	
Post-naupliar copepods	2		

### Cruise SF7602

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>		1	
<i>Tintinnopsis beroidea</i>			1
<i>T. parvula</i>		1	
<u>Oligotrichs</u>			
<i>Strombidium strobilus</i>		10	1
<i>S. delicatissimum/vestitum</i>		32	1
<i>S. spp.</i>		24	1
<i>Lohmanniella oviformis</i>		3	1
<i>L. spp.</i>			3
Sheathed oligotrichs		6	26
Unsheathed oligotrichs		9	7
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>		80	
Miscellaneous ciliates		1	
<u>Other Protozoa</u>			
Foraminiferans			1
<u>Metazoa</u>			
Nauplii		7	26
Trochophore larvae			1

## Cruise SF7603

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>	1		
<i>Tintinnopsis beroidea</i>	18		
<i>T.</i> sp.	1		
<u>Oligotrichs</u>			
<i>Strombidium delicatissimum/vestitum</i>	133		
<i>S. pulchrum</i>	9		
<i>S.</i> spp.	25		
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	158		
<i>Didinium nasutum</i>	1		
Miscellaneous ciliates	1		
<u>Other Protozoa</u>			
<i>Noctiluca miliaris</i>	21		
Miscellaneous protozoa	2		
<u>Metazoa</u>			
Nauplii	34		
Post-naupliar copepods	4		

## Cruise SF7604

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>			20
<i>Eutintinnus pectinis</i>	14	36	150
<i>E. rectus</i>			7
<i>E. tubulosus</i>	17	13	160
<i>E. turris</i>	8	22	110
<i>Favella franciscana</i>			7
<i>Helicostomella subulata</i>	65	225	800
<i>Stenosemella nivalis</i>	3	4	4
<i>S. ventricosa</i>			1
<i>Tintinnopsis beroidea</i>			167
<i>T. coronata</i>	2	3	
<i>T. kofoidi</i>		3	28
<i>T. levigata</i>		3	20
<i>T. strigosa</i>	152	184	536
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	130	21	189
<i>S. cornucopiae</i>	332	234	1190
<i>S. delicatissimum/vestitum</i>	52	15	90
<i>S. lagenula</i>			10
<i>S. strobilus</i>	2		35
<i>S. viride</i>			35
<i>S.</i> spp.	39	19	860
<i>Lohmanniella oviformis</i>	8	10	
<i>L. spiralis</i>	60	27	23
Sheathed oligotrichs		16	
Unsheathed oligotrichs	94	55	26
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	1003	1170	180
<i>Tiarina fusus</i>			26
<u>Other Protozoa</u>			
<i>Noctiluca miliaris</i>	33	13	13
<u>Metazoa</u>			
Nauplii	44	76	160
Post-naupliar copepods	2	1	14
Cyprid larvae	2		
Trochophore larvae	2		35
Mitraria larvae	3	1	9
Rotifera ( <i>Trichocera</i> sp.)	6	19	106
Rotifera ( <i>Synchaeta</i> sp.)			3
Larvaceans	13	4	41

## Cruise SF7605

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Eutintinnus tubulosus</i>	1		
<i>Helicostomella subulata</i>	5	3	8
<i>Salpingella curta</i>			1
<i>Tintinnopsis beroidea</i>		2	
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	204	93	158
<i>S. cornucopiae</i>	50	9	42
<i>S. delicatissimum/vestitum</i>			63
<i>S. strobilus</i>		5	57
<i>S. viride</i>		5	29
<i>S. spp.</i>	51	43	
<i>Lohmanniella spiralis</i>	4	11	7
Sheathed oligotrichs	3		135
Unsheathed oligotrichs	31	20	70
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	518	227	133
<i>Tiarina fusus</i>	3		
Miscellaneous ciliates	9		
<u>Other Protozoa</u>			
<i>Noctiluca sp.</i>	4	1	
<u>Metazoa</u>			
Nauplii	74	32	19
Post-naupliar copepods	3	1	
Rotifera ( <i>Trichocera sp.</i> )	4		
Larvaceans	3		

## Cruise SF7606

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Eutintinnus pectinis</i>		3	
<i>E. turris</i>			2
<i>Helicostomella subulata</i>	14	20	1
<i>Stenosemella ventricosa</i>	4		
<i>Tintinnopsis beroidea</i>	4	34	13
<i>T. coronata</i>	1		
<i>T. lohmannii</i>			2
<i>T. parvula</i>	4		
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	168	1231	641
<i>S. cornucopiae</i>	20	79	20
<i>S. delicatissimum/vestitum</i>	10	351	186
<i>S. pulchrum</i>	1		1
<i>S. strobilus</i>	6	22	12
<i>S. typicum</i>			31
<i>S. viride</i>	9	21	54
<i>S. spp.</i>	20	181	125
<i>Lohmanniella oviformis</i>		10	17
<i>L. spiralis</i>	8	38	20
Sheathed oligotrichs	8	228	93
Unsheathed oligotrichs	48	293	106
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	1690	606	93
<i>Tiarina fusus</i>	23	12	
Miscellaneous ciliates		13	3
<u>Metazoa</u>			
Nauplii	28	14	7
Post-naupliar copepods	6	4	7
Rotifera ( <i>Trichocera sp.</i> )	1	1	
Larvaceans	8	1	1

## Cruise SF7607

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>			1
<i>Dictyocysta reticulata</i>			2
<i>Eutintinnus lusus-undae</i>			1
<i>Favella franciscana</i>			1
<i>Helicostomella subulata</i>			15
<i>Parafavella gigantea</i>			4
<i>Stenosemella ventricosa</i>	37		4
<i>Tintinnopsis beroidea</i>	1		
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	9	4	17
<i>S. strobilus</i>		1	10
<i>S. typicum</i>	3		
<i>S. viride</i>	1	1	1
<i>S. spp.</i>	186	25	40
<i>Lohmanniella oviformis</i>		5	29
<i>L. spiralis</i>	10	3	
Sheathed oligotrichs	4	1	24
Unsheathed oligotrichs	24	17	149
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	262	32	188
<i>Tiarina fusus</i>	4		40
Miscellaneous ciliates	3		9
<u>Other Protozoa</u>			
<i>Noctiluca miliaris</i>			53
Radiolarians ( <i>Lithomelissa setosa</i> )	1	5	47
<u>Metazoa</u>			
Nauplii	1	8	63
Post-naupliar copepods			11
Trochophore larvae			335
Rotifera ( <i>Trichocera</i> sp.)			11
Larvaceans			14

## Cruise SF7701

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Acanthostomella norvegica</i>			13
<i>Codonellopsis contracta</i>			13
<i>Stenosemella ventricosa</i>		13	45
<i>Tintinnopsis beroidea</i>			1
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	6	13	
<i>S. delicatissimum/vestitum</i>	4	43	
<i>S. strobilus</i>		7	24
<i>S. typicum</i>			8
<i>S. B</i>		9	52
<i>spp.</i>	25	11	15
<i>Lohmanniella spiralis</i>			6
<i>L. spp.</i>		1	1
Unsheathed oligotrichs	10	7	28
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	31	345	470
<i>Didinium nasutum</i>			4
Miscellaneous ciliates			1
<u>Other Protozoa</u>			
Radiolarians ( <i>Lithomelissa setosa</i> )		1	1
<u>Metazoa</u>			
Nauplii	1	6	17
Post-naupliar copepods	1	3	3
Larvaceans	1		

## Cruise SF7702

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Stenosemella ventricosa</i>	34	30	14
<i>Tintinnopsis beroidea</i>			4
<i>T. parvula</i>	3		14
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	3	10	42
<i>S. delicatissimum/vestitum</i>	46	251	131
<i>S. strobilus</i>	14	14	90
<i>S. typicum</i>			9
<i>S. viride</i>		3	3
<i>S. B</i>	18	21	8
<i>S. spp.</i>	14	14	4
<i>Lohmanniella spp.</i>	1	1	9
Unsheathed oligotrichs	19	18	13
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	39	163	254
<u>Other Protozoa</u>			
Radiolarians ( <i>Lithomelissa setosa</i> )			3
Foraminiferans			3
<u>Metazoa</u>			
Nauplii	3	7	12
Post-naupliar copepods			5

## Cruise SF7703

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Proplectella columbiana</i>		1	10
<i>Salpingella acuminata</i>		1	
<i>Stenosemella ventricosa</i>		8	
<i>Tintinnopsis beroidea</i>	2		33
<i>T. parvula</i>		1	
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	84	197	1033
<i>S. delicatissimum/vestitum</i>		58	26
<i>S. strobilus</i>	2	1	9
<i>S. viride</i>	2	8	29
<i>S. B.</i>		5	
<i>S. spp.</i>	11	32	74
<i>Lohmanniella oviformis</i>		14	
<i>L. spiralis</i>			23
Unsheathed oligotrichs	3	19	28
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	23	189	70
<i>Didinium nasutum</i>	2	7	
Miscellaneous ciliates		7	
<u>Metazoa</u>			
Nauplii	2	5	30
Trochophore larvae			6

## Cruise SF7704

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Eutintinnus pectinis</i>			4
<i>E. rectus</i>			48
<i>E. tubulosus</i>			28
<i>E. turris</i>			52
<i>Helicostomella subulata</i>	3	3	45
<i>Proplectella columbiana</i>	3	30	
<i>Tintinnopsis beroidea</i>	3	71	
<i>T. levigata</i>			176
<i>T. parvula</i>	10	2	7
<u>Oligotrichs</u>			
<i>Strombidium conicum</i>	101	873	19
<i>S. crassulum</i>			62
<i>S. delicatissimum/vestitum</i>	595	3365	278
<i>S. pulchrum</i>	5	2	
<i>S. strobilus</i>	5	245	428
<i>S. typicum</i>			1
<i>S. viride</i>	23	115	
<i>S. spp.</i>	3	483	74
<i>Lohmanniella spiralis</i>			89
<i>L. spp.</i>	8	9	
Unsheathed oligotrichs	33	520	66
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	433	793	13
<i>Didinium nasutum</i>			4
<u>Metazoa</u>			
Nauplii	10	14	23
Post-naupliar copepods			7
Trochophore larvae			85
Mitraria larvae		2	
Rotifera ( <i>Trichocera</i> sp.)			1
Larvaceans			9

## Cruise SF7705

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Eutintinnus pectinis</i>		1	
<i>E. tubulosus</i>	7		1
<i>E. turris</i>	1		3
<i>Favella franciscana</i>	6		
<i>Helicostomella subulata</i>	232	29	41
<i>Proplectella columbiana</i>		1	3
<i>Ptychocyclus drygalskii</i>	1		
<i>Salpingella curta</i>	3		
<i>Stenosemella nivalis</i>	2		
<i>S. ventricosa</i>	4		1
<i>Tintinnopsis beroidea</i>			12
<i>T. kofoidi</i>	7		
<i>T. levigata</i>	20	1	
<i>T. parvula</i>			5
<u>Oligotrichs</u>			
<i>Strombidium acuminatum</i>	68	23	37
<i>S. conicum</i>	154	90	893
<i>S. cornucopiae</i>	11		4
<i>S. delicatissimum/vestitum</i>	497	1945	8060
<i>S. pulchrum</i>	3	4	
<i>S. strobilus</i>	3	4	63
<i>S. typicum</i>		10	
<i>S. viride</i>	24	45	1205
<i>S. spp.</i>	97	51	142
<i>Lohmanniella oviformis</i>	3		
<i>L. spiralis</i>	20	5	
<i>L. spp.</i>		1	
Unsheathed oligotrichs	32	12	52
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	1842	63	64
<i>Tiarina fusus</i>	105	18	20
<i>Didinium nasutum</i>	1		1
Miscellaneous ciliates		5	1
<u>Other Protozoa</u>			
<i>Noctiluca miliaris</i>	8		
Foraminiferans	1		
Radiolarians	1		
<u>Metazoa</u>			
Nauplii	54	27	3
Post-naupliar copepods	3	1	
Trochophore larvae	27		
Rotifera ( <i>Trichocera</i> sp.)	38	8	1
Larvaceans	11		1

Cruise SF7706

Species	Station		
	2	5	8
<u>Tintinnids</u>			
<i>Codonellopsis contracta</i>	8		
<i>Helicostomella subulata</i>	9		
<i>Parundella translucens</i>		3	1
<i>Salpingella curta</i>			1
<i>Stenosemella nivalis</i>	8		
<i>S. ventricosa</i>			3
<i>Tintinnopsis levigata</i>	1		3
<i>T. minuta</i>	1		
<u>Oligotrichs</u>			
<i>Strombidium compressum</i>			4
<i>S. conicum</i>	238	38	162
<i>S. delicatissimum/vestitum</i>	1157	102	330
<i>S. strobilus</i>	8	45	30
<i>S. sulcatum</i>	8		11
<i>S. typicum</i>	9	29	17
<i>S. viride</i>	5	4	
<i>S. spp.</i>	60	38	33
<i>Lohmanniella oviformis</i>	3		3
<i>L. spiralis</i>	21	35	4
Unsheathed oligotrichs	152	79	232
<u>Other Ciliates</u>			
<i>Mesodinium rubrum</i>	487	63	139
<i>Tiarina fusus</i>	21		
<i>Didinium nasutum</i>	24		4
Miscellaneous ciliates	7		
<u>Other Protozoa</u>			
<i>Noctiluca miliaris</i>	1		
Foraminiferans	1		
Radiolarians ( <i>Lithomelissa setosa</i> )	3		
( <i>Dictyophimus histricosus</i> )		13	
<u>Metazoa</u>			
Nauplii	19	25	11
Post-naupliar copepods	3	8	
Trochophore larvae	3		
Rotifera ( <i>Trichocera</i> sp.)	1		
Larvaceans	7		