STUDIES ON THE EPIPHYTIC COMMUNITIES

1. ABUNDANCE AND DISTRIBUTION OF MICROALGAE AND SMALL ANIMALS ON THE *ZOSTERA* BLADES[1]

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With 5 Text-figures and 6 Tables

Introduction

Small organisms, sedentary or crawling on, are occasionally surprisingly abundant in the submerged vegetations. These organisms, forming the epiphytic communities[3], vary considerably in their composition and quantity according to locality, depth, seasons, species of weeds to which they are attached, and even age of individual blade of weeds.

The *Zostera* and *Sargassum* belts are the submerged marine vegetations dominating in the Seto Inland Sea. *Zostera* occurs in shallow, well-sheltered waters of muddy substratum, whereas *Sargassum* grows on rocks more or less exposed to the open sea. These areas are undoubtedly by far smaller than the open part of the sea where no submerged vegetations occupy the bottom. The major part of the primary production in the sea is, as has been investigated intensively and stressed repeatedly, due to the phytoplankton in water-mass and the contribution from the submerged vegetation is little as a whole. NIELSEN (1955), for example, states that if we wish to consider the amount of matter produced by plants of the sea, we must confine our attention to planktonic algae. Nevertheless, there are good many evidence to suppose that the latter may play an important role in the local production cycle, as has been shown for the first time by PETERSEN (1918) for the *Zostera* fjord. BLINKS (1955) points out the immensely great

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3) The original meaning of the word "epiphyte" is to note a plant growing non-parasitically upon the outside of another plant. In the present paper the term "epiphytic community" is used to include both plants and animals which are living on a plant, *Zostera* in the present case, in the sense of the biotic community. Hence the epiphytic small animals or the epiphytic microalgae, denoting small animals or algae constituting an epiphytic community respectively.

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standing crop of littoral algae and its high productivity. ODUM (1961) has emphasized the fertility of estuaries having three different production units of the phytoplankton, marsh grasses and mud algae. If water samples are taken from among blades of *Sargassum*, they might show distinct differences in the quantities of inorganic nutrient materials from those outside (HARADA, unpublished data). However, these submerged large weeds, such as *Zostera* or *Sargassum*, are usually not taken as food directly by animals and have the fate to be decomposed by bacterias before being utilized by animals (PETERSEN, 1911, 1918; BLINKS, 1955). ODUM and SMALLEY (1959) has named this process as the second type of primary consumption. Apart from this, these weeds carry microalgae like diatoms which reproduce rapidly and are taken as food directly by small animals crawling on or swimming among weeds, that is the first type of primary consumption.

The importance of the microalgae, particulary the benthic or "mud algae", as producers have been realized and suggested by BLINKS (1955), MOUL and MASON (1957), POMEROY (1959, 1960) and ODUM (1961). ROUND (1957, 1960, 1961) has made a series of studies on the fresh-water bottom-living algae. The attached algae in a stream have been studied ecologically by DOUGLAS (1958) recently, who has also developed the methods for estimating populations and has described the apparatus for collecting them. But still little is referred to the epiphytic microalgae.

Thus, the importance of the submerged plant vegetations, the *Zostera* belt in the present case, in the primary production of a community is twofold: firstly the production of its body itself which mostly undergoes delayed utilization of dead tissues and secondly the production of attached microalgae which undergoes direct and immediate utilization of living plant tissues. Furthermore, the role of the submerged vegetation is also in that it affords complex habitats for animals of various kinds. The animals harboured by the seaweeds have been studied by many workers (COLMAN, 1939; etc.), and the predominating amount and variety of amphipods and some snails are reported by KITAMORI, NAGATA and KOBAYASHI (1959) and FUSE (1962) for the *Zostera* belts in the Seto Inland Sea.

In this preliminary study, we are primarily concerned with the composition and quantity of epiphytic microalgae on *Zostera* blades, with reference to some animals attached to *Zostera*. The study was carried out in the Kasaoka Bay during the period of three months from November 1957 to January 1958.

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Physical Environments and Topography

In the Kasaoka Bay, not deeper than 10 metres in most part and sheltered from the major part of the Seto Inland Sea by an island of Kô-no-shima, develop the *Zostera* belts in the shallow part of the bay along the coasts. The tidal range

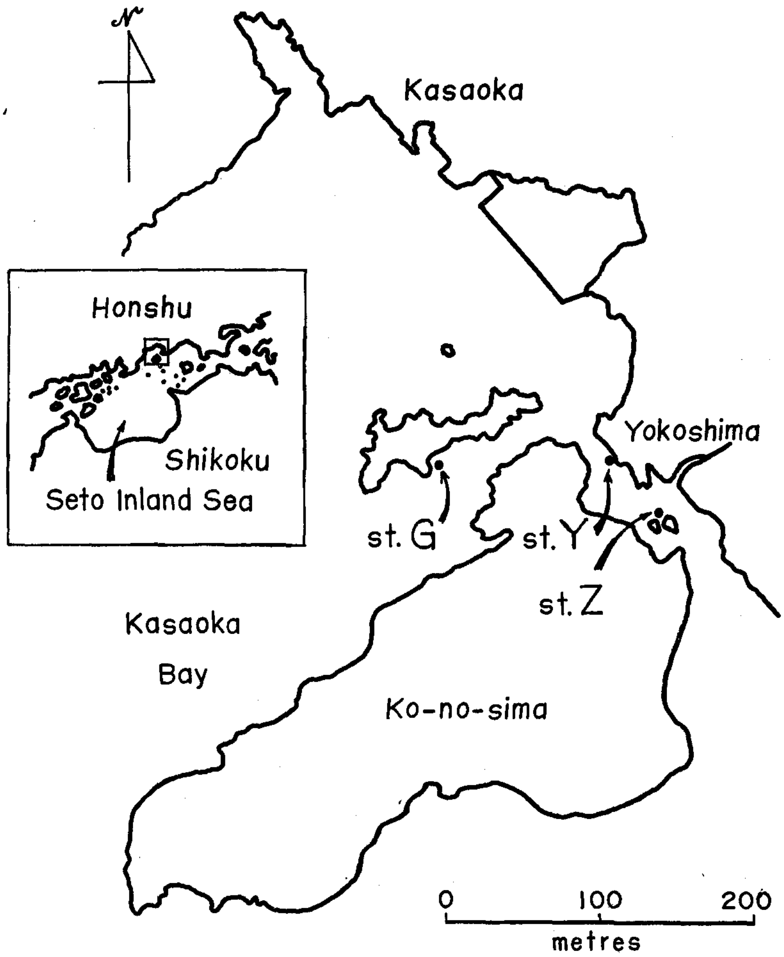

Fig. 1. The map of the area used for the study.

is about 2.5 metres at the inner part of the bay and a part of the *Zostera* belts are exposed at low tide. The mean rate of exchange of water-mass of the bay for a tidal cycle is calculated to be 60 to 70% by MURAKAMI (1954).

The general oceanographic conditions of the Kasaoka Bay has been described in detail by MURAKAMI (1954). Temperature of the surface layers of water ranges from about 7°C in January to about 26°C in late July. O_2-content is almost between 6 and 7 cc/L with a sudden decrease to approximately 4 cc/L in September. The chlorinity comes to its maximum of around 17.8‰, in January and falls down in July to 15.6‰. The content of phosphate-P is minimum in January and is about 9γ/L, whereas in September it reaches to about 20γ/L for its maximum.

Several sampling stations were selected in three *Zostera* belts near the inshore and offshore margins of each belt (St. G, St. Y and St. Z), which are shown in a map in Fig. 1. Inshore parts of two *Zostera* belts of St. G. and St. Y are exposed at low tide. Temperature and chlorinity of surface water and air temperature at St. G and St. Y on the days of collection are shown in Table 1. These *Zostera* belts are associated with the substratum of deep, soft mud.

Table 1. Air temperature, surface water temperature and surface water chlorinity at St. G and St. Y during the period of study.

Locality	St. Y			St. G		
Month	Nov.	Dec.	Jan.	Nov.	Dec.	Jan.
Air Temperature (°C)	10.6	3.5	2.0	13.5	6.0	2.0
Surface Water Temperature (°C)	14.9	8.8	5.7	16.0	8.7	5.7
Surface Water Chlorinity (‰)	16.00	17.06	17.25	17.00	17.21	17.40

Results

Growth

The fully-grown blades of *Zostera* in the main part of the belts measure from 75 to 115 cm at St. G and from 75 to 100 cm at St. Y, although they are rather shorter in the inshore parts.

A series of quantitative collections of *Zostera* in different parts of a belt were made at St. Y by using a 25^2 cm quadrate. The standing crop of *Zostera* (the epiphytic algae not removed off) in wet weight ranges from 704 to 2,352 gr/m^2 with the mean of 1,364 gr/m^2, and the total surface area of the blades per 1 m^2 of bottom surface is from 2.4 to 8.8 m^2 with the mean of 5.1 m^2. The standing crop of *Zostera* in the present case is somewhat smaller than that reported by OHSHIMA (1954).

Composition of Epiphytes and Phytoplankton

Lists of species of microalgae on *Zostera* blades and phytoplankton are shown in Tables 2-4. These microalgae are scraped off from the inner (or upper) side of the *Zostera* blades at a level of approximately 70 cm from the base.

There is little difference in the species composition of phytoplankton between St. G and St. Y. The exception is *Stephanodiscus Palmeriana* (EHR.) GRUNOW which is found only at St. G. However, this seems hardly to be significant as the species is very scanty in number. On the other hand, *Noctiluca scintillans* MACARTNEY is exceedingly abundant at St. G.

The major part of epiphytic microalgae shows the more or less identical composition at all sampling stations and in both months of November and December. *Cocconeis scutellum* EHRENBERG and *Nitzschia longissima* (BRÉB.) RALFS are the dominant algae in all samples. *Mastogloia Braunii* GRUNOW, which is also

Table 2. List of species of the epiphytes at St. Y in November 1957.
(ccc : abundant ; cc : very common ; c : common)

Amphiprora sp.	
Amphora sp. (? *A. angusta* var. *Eulensteinii*)	
Anomoeoneis sp. (? A. *scrians*)	
Chaetoceros sp.	
Cocconeis scutellum EHRENBERG	ccc
Cocconeis sp.	cc
Coscinodiscus sp. (mostly broken pieces)	
Cymbella turgidula var *nipponica* SKVORTZOW	c
Gomphonema parvulum (KÜTZ.) GRUNOW	
Melosira sp. (? *M. italica* (EHR.) KÜTZING)	cc
Nitzzchia longissima (BRÉB.) RALFS	ccc
Nitzschia obtusa W. SMITH	
Nitzschia sp. (? *N. intermedia*)	
Surirella gemma EHRENBERG	
Synedra ulna var. *oxyrhynchus* fo. *contracta* HUSTEDT	c
Tabellaria fenestrata (LYNGB.) KÜTZING	

Table 3. List of dominant species of the epiphytes at Sts. G and Y in December 1957.
(ccc : dominant ; cc : subdominant ; c : common)

St. G—Inshore	
Cocconeis scutellum EHRENBERG	ccc
St. G—Offshore	
Actinocyclus Barkleyi (EHR.) GRUNOW	c
Cocconeis scutellum EHRENBERG	cc
Coscinodiscus spp.	c
Mastogloia Braunii GRUNOW	ccc
Nitzschia longissima (BRÉB.) RALFS	ccc
Nitzschia tryblionella var. *victoriae* GRUNOW	cc
St. Y—Inshore	
Cocconeis scutellum EHRENBERG	ccc
St. Y—Offshore	
Amphora sp.	cc
Cocconeis scutellum EHRENBERG	ccc
Licmophora sp.	cc
Nitzschia longissima (BRÉB.) RALFS	ccc

Table 4. List of species of the phytoplankton at St. G in December 1957.

Bacillariaceae (Diatoms)
Asterionella japonica CLEVE
Biddulphia sinensis GREVILLE
Cerataulina Bergonii H. PERAGALLO
Chaetoceros didymus EHRENBERG
Chaetoceros Lorenzianus GRUNOW
Chaetoceros pervianum BRIGHTWELL
Chaetoceros subsecundus (GRUN.) HUSTEDT
Coscinodiscus lineatus EHRENBERG
Coscinodiscus sp.
Ditylium Brightwellii (WEST) GRUNOW
Eucampia zoodiacus EHRENBERG
Pleurosigma sp.
Rhizosolenia alata BRIGHTWELL
Rhizosolenia calcaravis M. SCHULTZE
Rhizosolenia setigera BRIGHTWELL
Rhizosolenia stiliformis BRIGHTWELL
Nitzschia longissima (BRÉB.) RALFS
Nitzschia seriata CLEVE
Skeletonema costatum (GREV.) GRUNOW
Stephanodiscus Palmeriana (EHRB.) GRUNOW
Surirella gemma Ehrenberg
Thalassiothrix longissima CLEVE et GRUNOW
Thalassiothrix nitzschioides GRUNOW
Triceratium favus EHRENBERG
Dinoflagellata
Ceratium extensum (GOUR.) CLEVE
Ceratium furca (EHRB.) DUJARDIN
Ceratium fusus (EHRB.) DUJARDIN
Ceratium tripos (O. F. MÜLLER) NITZSCH
Ceratium sp.

dominant at St. G, is very few at St. Y. At St. Y, there is a notable presence of fresh-water diatoms, such as *Melosira* sp. (?*Melosira italica* (EHR.) KÜTZING), and brackish ones. This may probably be correlated to the presence of a fresh-water creek running out of a sewer through the *Zostera* belt. In January the relative abundance of *Cocconeis* diminishes at all stations with the increase of other diatoms.

The phytoplankton and epiphytic community have only a few species of microalgae in common with each other. Furthermore, most of those appearing in common are suspected not to be the genuin common components to both. *Surirella gemma* EHRENBERG in the plankton seems to be that coming off occasionally from the surface of *Zostera* blades, and *Coscinodiscus*, *Ceratium* and their fragments among the epiphytes seem to be deposited from the plankton.

Numbers and Distribution of Epiphytic Microalgae

The epiphytes, scraped off from different parts (different levels) of *Zostera* blades over 2 cm length, were placed on a section slide, and numbers of microalgae were counted. At the same time, the quantities of detritus were conveniently measured by means of counting the numbers of 1^2 mm squares which detritus covered. A part of the results are shown in Fig. 2 and Table 5.

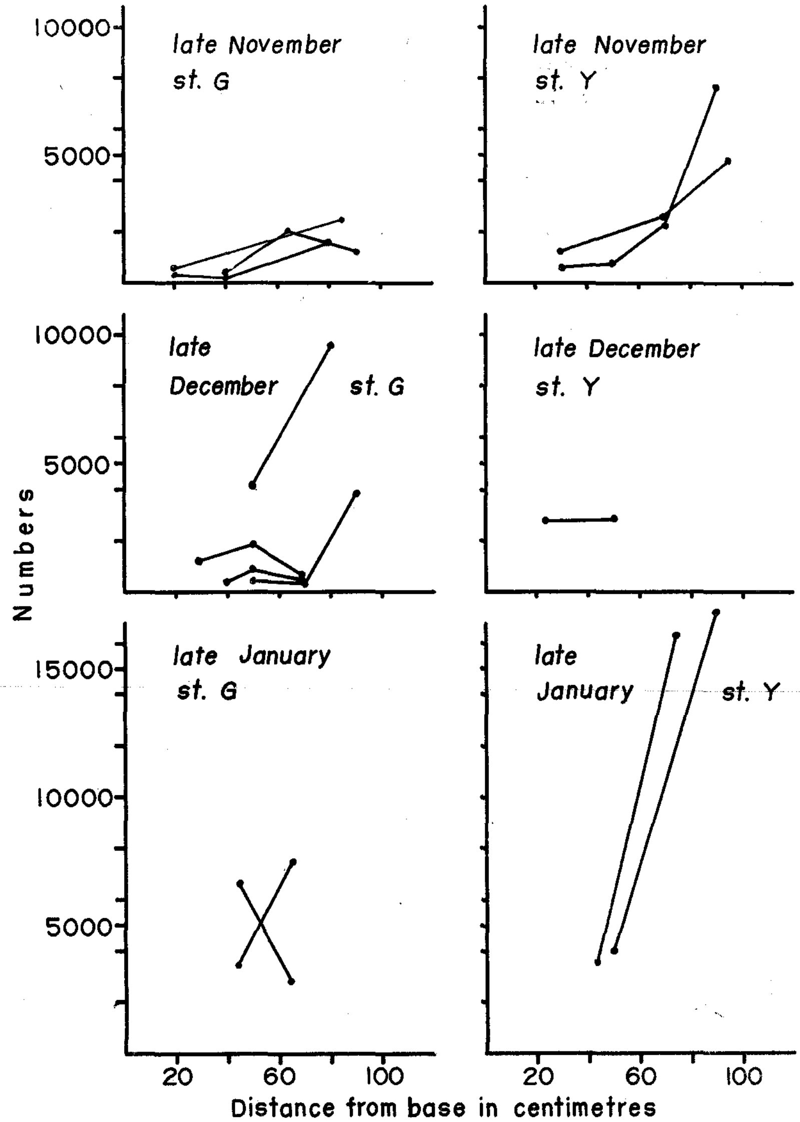

Fig. 2. The distribution of diatoms on the *Zostera* blades. Numbers per 1 cm^2 of the surface area.

Table 5. Number of cells of diatoms and amount of detritus on the *Zostera* blades per 1 cm^2 of surface area at a level of about 70 cm from the base. The amount of detritus is conveniently expressed by the numbers of 1^2 mm squares which it covered when the materials were evenly spread over a slide-glass.

	St. G			St. Y			St. Z
	Nov.	Dec.	Jan.	Nov.	Dec.	Jan.	Nov.
Cocconeis	1500	200	1200	1000	540	2000	1100
Other diatoms	520	33	6200	680	1500	14600	480
Detritus	22.2	7.8	39.2	30.0	39.2	71.8	10.9

In most cases the epiphytic diatoms render a significan increase in number with 2 to 7 orders of magnitude as it goes higher towards the ends of *Zostera* blades. However, it seems likely that numbers and distribution of these micro-algae are variable with any differences in the conditions of *Zostera* blades.

The diatoms increase considerably in number in January and this is due to the remarkable increase of species other than *Cocconeis* which surpasses others in November. Relatively small numbers of diatoms in December may be the result of influences of hard weather preceding the day of sampling.

The detritus is rich at St. Y where turbid water is washing the shore and the *Zostera* belt. The amount of detritus also increases in January, but there is no suggestive evidences to correlate it to the apparently parallel increase of diatoms.

Numbers and Distribution of Epiphytic Small Animals

A number of groups of animals are colonizing on the surface of *Zostera* blades. The most important of them are Hydroids, Polychaetes, Coelenterates, Gastropods, Amphipods, Bryozoas, and Opistobranchs.

Spirorbis foraminosus MOORE et BUSH are abundant on rather older blades, particularly numerous at St. Z. It extends from the tip of blades down to a level of 15 cm from the base and disappears below this level. The population of the species is 2 to 5 individuals per 1 cm length of a blade, with the maximum of 26 individuals at 35 cm from the base.

At St. G, *Diala vitrea* SOWERBY and *Boloceroides mcmurrichi* (KWIETNEIEWSKI) occur in large numbers. The latter has wider range of distribution on a *Zostera* blade, and both are the most numerous near the end of blades, about 80 cm level (Figs. 3 and 4). On the other hand, at St. Y *Caprella kröyeri* DE HAAN is found crawling on blades mostly at 15 to 30 cm from the base (Fig. 5). However, these distributions of movable animals can not be generalized, as the observations were made only at low tide. By examining the stomach contents of *Caprella kröyeri* parts of them are identified as fragments of *Cocconeis*.

Standing Crop of Epiphytes

Samples of the epiphytic matter of *Zostera* blades around a level of 70 cm

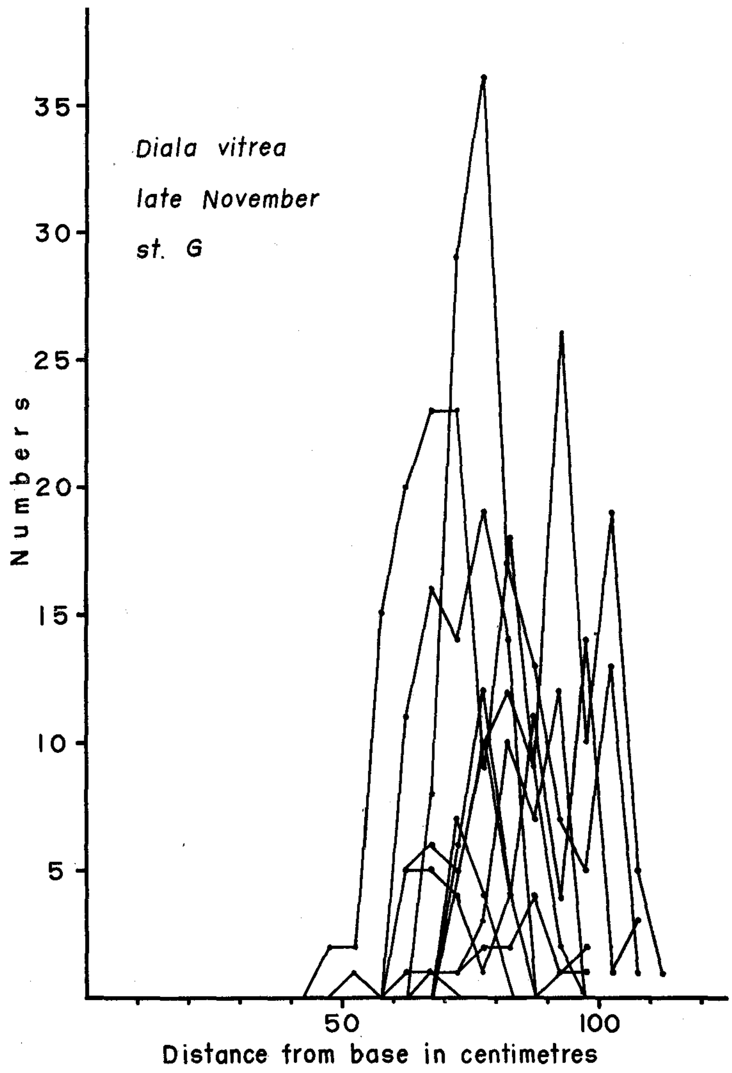

Fig. 3. The distribution of *Diala vitrea* on the *Zostera* blades. Numbers are counted for each 5 cm length of a blade. Ten series of results of sampling are put on the figure together.

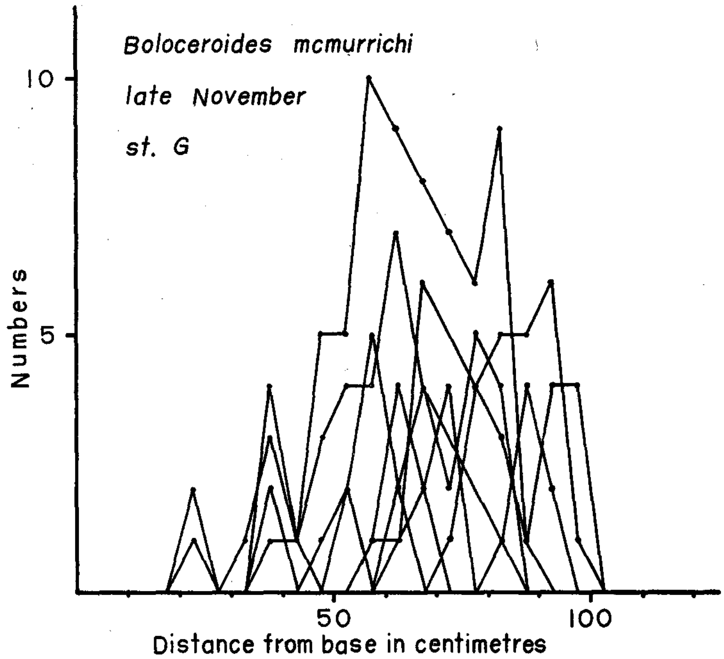

Fig. 4. The distribution of *Boloceroides mcmurrichi* on the *Zostera* blades. Number are counted for each 5 cm length of a blade. Ten series of results of samplings are put on the figure together.

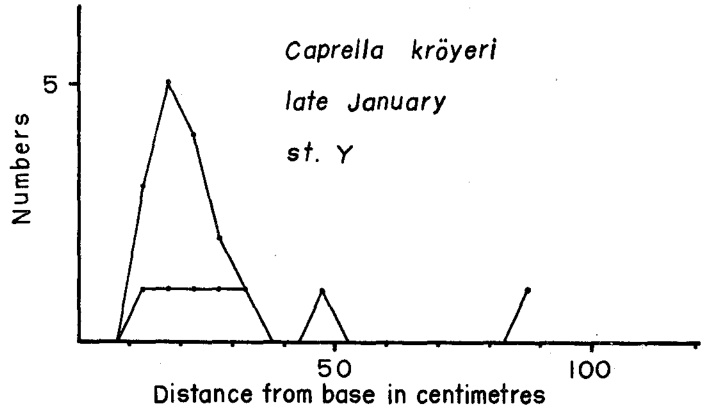

Fig. 5. The distribution of *Caprella kröyeri* on the *Zostera* blades. Numbers are counted for each 5 cm length of a blade. Two series of results of samplings are put on the figure together.

from the base were further treated and measured for the sedimentation volume using a centrifuge (20,000 RPM), dry weight and ignition loss. As has been indicated earlier, these samples contain fairly large amount of detritus which is probably partly organic matter, it is hard to estimate the amount of living microalgae accurately. Considering the results of counts of the diatoms and detritus, 60 to 80% in valume of total amount of materials attached to the *Zostera* blades might safely be attributed to the detritus. Incidentally the mean of dry weights of diatoms is estimated, by rough calculation, to be 0.1 mg/cm^2.

Table 6. Standing crops of the epiphytal matter.

	St. G-off.		St. G-in.	St. Y	
	Nov.	Dec.	Dec.	Nov.	Dec.
Surface area of *Zostera* blades used	461	7741	7185	2769	497
Total volume precipitated in 2 hrs. (mm^3/cm^2)	7.39	7.83	3.15	0.73	5.57
Total volume precipitated by a centrifuge (mm^3/cm^2)	2.88	2.97	0.98	0.31	1.73
Total dry weight (mgr/cm^2)	0.82	7.12	2.13	—	4.97
Ignition loss (mgr/cm^2)	0.214	0.155	0.067	—	0.145

Discussion

TAKANO (1961, 1962) reports more than 38 species of diatoms that grow upon agar seaweeds (Gelidiaceae) and more than ninety all together upon *Sargassum, Ulva, Ulothrix, Enteromorpha, Cystophyllum, Carollina* and others in the waters around Japan. When the present list of species of epiphytes on *Zostera* is compared with that of TAKANO, it is found that only a few species are occurring in common. Among them, the most interesting and probably most important species is *Cocconeis scutellum* which is dominant on *Zostera* as well as on Gelidiaceae, *Sargassum* and *Cystophyllum.* Obviously the species composition of epiphytes varies from a locality to another and from a plant to another. However, if an area is taken small enough, the majority of epiphytic microalgae on the same species of algae is almost identical within it.

A wide range of variation in the population density of diatoms on a *Zostera* blade is noticed clearly. POMEROY (1959), in his discussion on the vertical migration of benthic algae in intertidal sediments, concludes that the algae seek full illumination, and not optimum light, even though it may inhibit photosynthesis. This notion may be applicable to the epiphytic microalgae, when it is considered that more than half of *Zostera* blades are lying on the surface at low tide, and that the algae are more abundant on the upper side of a blade than on the lower. The complex interaction between epiphytes and *Zostera* appears to be acting also for this.

The number of microalgae on *Zostera* blades is far smaller if compared with that on mud flats. MOUL and MASON (1957) gives the figures of 500 to 9,000 per cubic millimetre of mud for diatoms and calculated the total number in a column of mud beneath a square metre of surface as 9.8×10^9. If the similar calculation is made for microalgae on *Zostera* blades, it comes somewhat around 1.1×10^8 in November and 3.7×10^8 in December at St. Y. BLINKS (1955) comments on the immensity of standing crop of littoral algae and regards low grazing as one of the predomiant factors. In the *Zostera* and *Sargassum* belts of the Kasaoka Bay, the epiphytic small animals such as snails, Caprellids and Gammarids, small shrimps and fishes are often astonishingly abundant (FUSE, 1962) and their grazing on the epiphytes should be fairly intense. In a pool of a river, TSUDA and WATANABE (1958) have found the presence of attached materials of 10.93 gr in dry weight upon the surface of stones within an area of $50 \times 50\,cm^2$, which renders the ingition loss of 4.35 gr. The amount of $0.1\,cm^3$ in sedimentation volume by a centrifuge per $5 \times 5\,cm^2$ is given as an average by MIZUNO and others (1958) for the attached algae on stones of river rapids. DOUGLAS (1958) has recorded the maximum of *Achnanthes* population on rocks of a stream as 5.1×10^6 per $1\,cm^2$ and less on stones. As far as is seen from these figures, the standing crop of epiphytes of *Zostera* is not comparable to benthic algae.

The large amount of detritus is noticed on the *Zostera* blades. However, little attention has been paid to the detritus so far in the literatures, and it is at present impossible to say from what sources it is derived—from dead surface tissue of *Zostera* blades, epiphytes, phytoplankton, or suspended matter in water-mass—and how far it is utilized by small epiphytic animals.

Summary

The epiphytic small algae and animals on the *Zostera* blades in winter were investigated in the Kasaoka Bay with special interests to their species composition, distribution and abundance.

Among microalgae the diatoms hold overwhelming majority and generally *Cocconeis scutellum* and *Nitzschia longissima* dominate. The standing crop of diatoms increases as it goes towards the tips of *Zostera* blades, and is 0.1 mgr dry weight per cm^2 as an average.

Diala vitrea, *Boloceroides mcmurrichi*, *Spirorbis foraminosus* and *Caprella kröyeri* are numerous on the *Zostera* blades. The first two animals are abundant near the tips of blades, whereas the latter two are abundant rather near the base.

Discussions on the amount of epiphytic microalgae on *Zostera* are given in relation to the benthic algae reported from different habitats.

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