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The phytal animals on the thalli of *Sargassum serratifolium* in the *Sargassum* region, with reference to their seasonal fluctuations*

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Abstract

In the *Sargassum* region on the coast of Mukaishima, in the Inland Sea of Japan, the phytal animals living on *Sargassum serratifolium*, and the alga itself as a habitat for phytal animals, were studied from August, 1966 to August, 1968. The standing crop of *Sargassum*/m² bottom was 4.93 kg/m² (March, 1967) and 3.53 kg/m² (February, 1968) in the most luxuriant season, and 0.4 to 0.5 kg/m² (July, 1967 and 1968) in the off-season. The individual number of phytal animals per mean plant, without sessile fauna, reached a maximum in late winter and early spring (about 130,000 in 1967, 266,000 in 1968) when *Sargassum* was luxuriant, and a minimum in summer (about 15,000 in both years) when *Sargassum* was declining. Among the phytal animals, benthonic copepods (Harpacticoida) were very abundant in most seasons. Their dominance decreased in spring, whilst nematode dominance increased. It appears that such seasonal changes are closely related to the standing crop of *S. serratifolium.* Fluctuations in numbers of most groups of the meiofauna of phytal animals, such as foraminiferans, ostracods, isopods, amphipods, copepods, tanaids and nematodes, are connected with changes in the standing *Sargassum* crop. Seasonal fluctuations of some groups, such as echinoderms, actinians, mysids and decapod crustaceans (macrofauna), were, however, independent of *Sargassum* crop variations. The individual number of phytal animals/m² bottom in the *Sargassum* region were compared with findings of previous studies in other habitats, such as naked sandy and mud bottoms.

Introduction

In the open sea, most biological life is supported by great quantities of phytoplankton. This is because seaweeds are restricted to littoral areas where light can penetrate. In small bays, inlets or inland seas, however, as suggested by PETERSEN (1918), seaweed production is as important as phytoplankton production. PETERSEN investigated the biological production in the Limfjord of Denmark, and pointed out that the production of benthonic animals depends upon the presence of *Zostera marina. Z. marina* is not itself directly consumed but, when decaying, it is consumed as a marine deposit or detritus.

It has been recognized that seaweed regions are important for growth of young and juvenile fish. The OKAYAMA PREFECTURE FISHERIES EXPERIMENT STATION (1922—1925) concluded, after investigating the *Zostera* region in Okayama Prefecture, that juvenile fish grow in the *Zostera* region and then migrate toward the sea. The *Zostera* region is, therefore, important as a nursery ground for juvenile fish. The ecological advantages of seaweed regions are summarized by FUSE (1962a) as (1) they provide a breeding habitat for many fish; (2) abundance of food: phytal epifauna and epiphyte; (3) oxygen content of the water is high; (4) protection for juvenile fish is afforded against tidal currents and waves; (5) they provide opportunity for small and juvenile fish to escape from large predators. KITAMORI and KOBAYASHI (1958), KITAMORI et al. (1959), KIKUCHI (1961), FUSE (1962a, b), HATANAKA and IIZUKA (1962a, b, c) and others have made surveys on fish in seaweed regions from the same viewpoint. Most of these authors noted the abundance of food organisms on the seaweeds. KITAMORI et al. (1959) pointed out that it is necessary to survey the lives of the food organisms themselves. FUSE (1962a, b) and KIKUCHI (1962, 1967) surveyed animal communities in the *Zostera* region or the *Sargassum* region by the basket, macro-plankton net, and dredging methods, etc. They found that the animal communities in seaweed regions include characteristically "phytal" epifauna besides true benthonic animals. KITA and HARADA (1962) studied the phytal organisms on the blades of *Zostera*, and revealed an abundance of phytal animals, related to the abundance of epiphytes (unicellular and micro-algae).

The abundance of epifauna and epiphyte on seaweeds has been noted since earlier in this century. In Europe, many authors have described the fauna on some species of marine algae. OHM (1964) and HAGERMAN (1966) studied fauna in the *Fucus* vegetation. JANSSON (1966, 1967), ZAVODNIK (1967b), NAGLE (1968) and others investigated animals on intertidal algae.

In the Inland Sea of Japan, the seaweed region is composed of the *Sargassum* community Garamoba and the *Zostera* community Amamoba. The significance of the *Sargassum* region was clarified during the investigation of fish in the *Zostera* region by the Marine

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Research Group of Kyoto University (1959). HARADA (1962), a member of this group, surveyed the life of a black rockfish *Sebastes inermis* CUVIER et VALENCIENNES, at Kasaoka Bay in the Inland Sea of Japan, and at Naka-Umi along the coast of the Japan Sea. He observed that juvenile *S. inermis* congregate on the bottom layer after their pelagic larval period, and then migrate to the *Zostera* and *Sargassum* regions; in the adult stage they inhabit rock reefs. In other words, juveniles on the bottom layer feed on macrozooplankton, and later move to *Zostera* and *Sargassum* regions and feed on phytal animals. As they grow, most of them aggregate in the *Sargassum* region and feed on organisms on the hard sea-bottom. On rock reefs, the seaweed regions are important for the developmental stages of many fish besides *S. inermis*, this importance is related to the feeding habits of the respective growing stages.

Although the significance of seaweed regions has been established, fewer reports have been published on *Sargassum* regions than on *Zostera* or *Fucus* regions. The author, therefore, describes here the result of investigations on phytal animals in the *Sargassum* region.

Topography and collecting methods

Among seaweeds, *Zostera marina* and *Z. nana* constitute the *Zostera* region at low tidal and subtidal levels of the soft sea-bottom. The *Sargassum* region thus consists of *Sargassum* spp. and is restricted to the subtidal area of the hard sea-bottom. Other algae form narrower belts in the intertidal zone.

The investigation was carried out in the *Sargassum* region on the coast of Mukaishima Island in the northwest area of Bingo-nada, central part of the Inland Sea of Japan. The investigated area is 4 to 7 m deep at high tide and 1 to 4 m at low tide. On the bottom, many piles of stones occur, and large rocks are scattered here and there.

Sampling was carried out at low tide, once or twice a month, from August, 1966 to August, 1968. For quantitative study purposes collection was made by means of a bag measuring 22 cm square at the base, 100 cm long, and made of XX13 gauze (0.1 mm mesh opening). The diver carefully enveloped a plant of *Sargassum* with this bag, and cut the discoid holdfast off. After closing the mouth of the bag, the diver carried it up to the boat. Most animals (excluding protozoans and small nematodes) on the thalli could be collected by this method, samples were then kept in 5 % formalin solution. Large animals, such as molluscs, echinoderms and decapod crustaceans, were sorted by hand. Estimation of the meiofauna was made by counting the number of individuals appearing in each $^1/_{100}$ subsample. The number of animals per plant was calculated on the basis of 5 subsamples.

To estimate algal growth, 10 *Sargassum* plants were collected, total length of stipes, volume and wet weight were measured for all plants collected, and the surface area of the laminae measured by the following method. Laminae taken from the plant were placed on printing paper. After exposure to light, the darkened parts of the paper were cut out and weighed. This weight was then compared with the weight of 1 cm^2 of the same paper untreated, to obtain the total surface area. The surface area estimated, however, did not correspond exactly to all habitats of phytal animals, since linear stipes, air-sacs and receptacles were ignored.

The density of *Sargassum serratifolium* was estimated by 10 samples of 1 m^2 quadrate. Water temperature and chlorinity were measured during collection to record environmental factors.

Although the pelagic organisms could not be ignored in the *Sargassum* region, the present observations were exclusively limited to non-pelagic animals.

Results

Seasonal variations in environmental factors

The water temperature in the area surveyed (Fig. 1), reaches its maximum (about 28 °C) in late

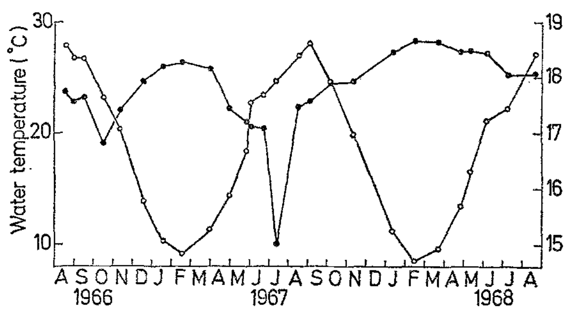

Fig. 1. Seasonal changes in water temperature (open circles) and chlorinity (solid circles) in the *Sargassum* region

summer, and its minimum (about 9 °C) in February. The seasonal change of the water temperature generally agreed with that of the daily record in the surface layer off the Mukaishima Marine Biological Station (HIROTA and SAIKI, 1968; KATAYAMA and SAIKI, 1968). Chlorinity ranges from about 17.00 to 18.50‰, and is generally high in winter. The maximum value was 18.28‰ in February, 1967, and 18.66‰ in February, 1968. It was lower in the wet season, from April to August. Chlorinity variations also agreed with the data from daily observations off the Mukaishima Marine Biological Station. In October, 1966, low chlorinity, in conjunction with occurrence of a red tide, was recorded.

Profile of the Sargassum region

The *Sargassum* region is composed mostly of *S. serratifolium* or, alternatively, such species as *S. piluliferum*, *S. tortile*, *S. thunbergii* and *S. horneri* mixed with the former species. Among these, *S. serratifolium* grows from the lowest tidal level to 7 to 8 m depth. *S. thunbergii* grows near the low tide level. The area of occurrence of *S. piluliferum*, *S. tortile* and *S. horneri* was found to be between those of the preceding 2 species.

Generally, *Sargassum horneri*, which possesses filament-like laminae and *S. tortile* with subfilament-like laminae, are taller than *S. serratifolium* which has leaf-like laminae. In the luxuriant season, therefore, the filament-like *Sargassum* apparently dominate the seascape in spite of their actual low density.

Many algae, beside these, grow in this region. Most of them appear to be important as food or habitat of the phytal animals. After the reproductive season, from spring to early summer, *Sargassum* spp. (perennial algae) declines and sprouts new thalli from the old discoid holdfast.

Standing crop and growth of Sargassum serratifolium

Sargassum serratifolium is attached to rocks with a discoid holdfast which has a few short stipes (Hirose, 1965). The growth is due to the expansion of the stipes until a height of about 1.5 m is attained; thereafter ramification occurs.

As shown in Fig. 2, the wet weight per plant reveals that minimum growth is in July, increasing in the following months until a maximum is reached in February or March. Afterwards, growth decreases rapidly until July. Weight measurements were about 50 g in July, 1967 and 1968, 808 g in March, 1967, and 579 g in February, 1968.

Total length of the stipes per plant showed changes similar to those in wet weight. Average total length was 1.0 to 1.5 m in July, 1967 and 1968, 15.3 m in March, 1967, and 11.9 m in February, 1968.

The mean number of *Sargassum serratifolium*/m^2 throughout the year was about 6.1 (Fig. 3). Therefore, it appears that seasonal variation is hardly observable with 0.95 fiducial intervals by the t test.

As mentioned above, the mean standing crop/m^2 of *Sargassum serratifolium* and its seasonal fluctuation were estimated. The change of the standing crop/m^2 agreed with the change of wet weight of the individual alga, since no change in density of number of plants was obtained. In the luxuriant season, the standing crop was 4.93 kg/m^2 in March, 1967, and 3.53 kg/m^2 in February, 1968. It was about 0.4 to 0.5 kg/m^2 in July (the withered season) of both years.

Seasonal change in growth of *Sargassum serratifolium* may be summarized as follows: Summer: the old frond of the preceding year is carried away and the plants rebuild from a discoid holdfast and some new stipes. The standing crop is the lowest in the year, about 0.5 kg/m^2. Autumn: the stipes grow rapidly and begin to branch into many ramifications. The growth rate attains its maximum for the year. Winter: *Sargassum* are very luxuriant. The standing crop reaches its maximum in late winter, although it varys annually; the *Sargassum* region is like a submerged forest. Later, the growth rate of *Sargassum* falls rapidly, and defoliation by grazing animals and

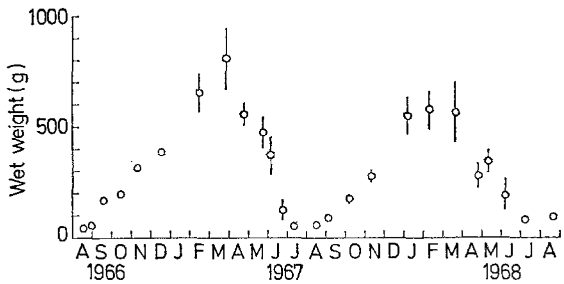

Fig. 2. *Sargassum serratifolium*. Seasonal variations of mean wet weight. Open circles: mean value, lines indicate standard errors

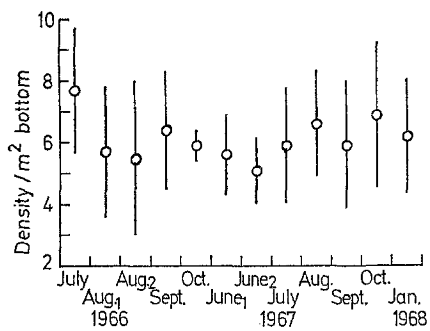

Fig. 3. Seasonal variation of density of *Sargassum serratifolium* /m^2 bottom. Open circles: mean value; attached lines: 0.95 fiducial intervals

withering begun in early spring, gains force. Spring: this is the reproductive season of *S. serratifolium*. Many receptacles are produced around the tips of each ramification. After reproduction, the middle and basal parts of the frond are completely withered and defoliated. From April onward, many fronds are washed away by tides. Therefore, the standing crop decreases quite rapidly. The appearance of the *Sargassum* region varys greatly, due to the weight of the epiphytic bryozoans, which bend the thalli onto the bottom of the sea. New stipes from a holdfast occur and grow in late spring.

Seasonal changes in the standing crop of component algae in the *Sargassum* region have been investigated at 3 stations in Kasaoka Bay by Fuse (1962b) and

HARADA (1962). The maximum standing crop at these 3 stations was 28.8 kg/m² (April, 1956), 22.4 kg/m² (June, 1956) and 9.6 kg/m² (April, 1956), respectively. These values are higher than the present ones, i.e. 4.93 kg/m² (March, 1967) and 3.53 kg/m² (February, 1968). Precise comparison between the results of these surveys is, however, impossible, since the samples taken off Mukaishima were restricted to *Sargassum serratifolium* species, while the samples collected in Kasaoka Bay included various algae belonging mainly to the genus *Sargassum*. The difference in standing crop quantities between the stations was due to different density of the plants resulting from different topography and nature of the 2 bottoms.

Sargassum as a habitat of small animals

The thalli of *Sargassum* provide a habitat for small animal groups and, therefore, changes in the standing crop of algae greatly influence their lives and reproduction. The surface area seems to be the most important factor of the habitat, but it was impossible to measure the surface area accurately because of the presence of the receptacles, air-sacs and stem-like parts of the frond with many projections and pleats.

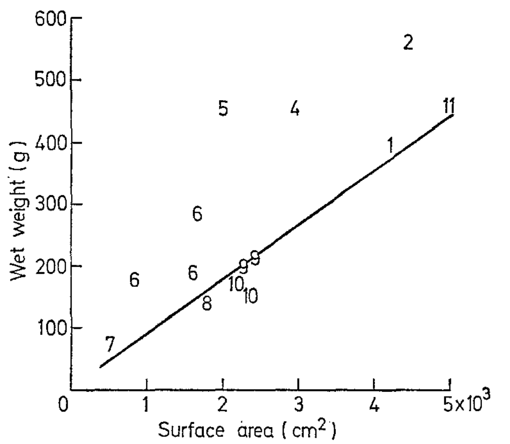

Fig. 4. *Sargassum serratifolium*. Relationship between wet weight and surface area of leaf-like parts. Numerals indicate collection months

The mean surface area per plant exceeded 0.5 m² in February and March, but decreased to about 0.05 m² in July. Therefore, the surface area of *Sargassum* ranged from about 3 m²/m² bottom to 0.3 m²/m² bottom. The *Sargassum* plants contribute to the increase of the habitat area compared with the naked sea bottom. The relation between surface area and wet weight of the frond reveals the seasonal difference (Fig. 4). A linear relationship between them was found from July to the following January, but the relationship from February to June was different. During the latter period, receptacles were not included in estimating the surface area increase, thus the relation is not precise. Considering this fact, it seems that the relation between surface area and the frond wet weight is positive throughout the year. Therefore, change in wet weight could be considered as an index of quantitative changes in the habitat.

Individual number and composition of phytal animals

Phytal animals can be divided into 2 groups: (1) sessile animals adhering to the thalli as barnacles, bryozoans and ascidians; (2) mobile or vagile animals crawling on and swimming among the thalli. In this paper, only the second group will be considered.

The variations in total number of individuals of non-sessile, phytal animals per mean plant and per gram algae throughout the year are shown in Fig. 5.

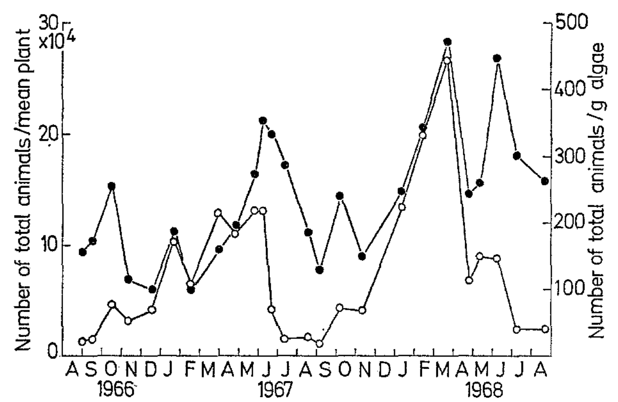

Fig. 5. Seasonal fluctuation of individual numbers/mean plant of *Sargassum serratifolium* (open circles) and density/g algae of phytal animals (solid circles)

The change in the number per plant paralleled the total number in the *Sargassum* region, as the density of the algae was stable throughout the year. The total number of individuals was minimum from July to September (about 15,000/plant); maximum numbers occurred in early spring (130,000 in 1967 and 265,000 in 1968). These fluctuations were closely related to the standing crop of *Sargassum serratifolium*. The total number of individuals thus increases gradually towards winter, coincident with *Sargassum* growth, and reaches the maximum in spring when the standing crop of *Sargassum* is most abundant. During and after April, the numbers decrease considerably. While the density of animals/g algae varys seasonally, with a range from 100 to 470, the maximum in 1967 was about 350/g algae (June) and, in 1968, about 470/g algae (March). Minimum population density occurred in autumn or winter; 100/g algae in the first part of the surveyed years (December and February), and 130/g algae in the latter part (September). High densities were observed in the seasons when the total animals per plant and the standing crop of *Sargassum* reached maximum values. However, low population density did not always coincide with small standing crops of *Sargassum*.

Seasonal variation in the composition of phytal animals is shown in Fig. 6. Throughout the year, the benthonic Copepoda was the dominant group, exceeding 50% of the total population in most months. The maximum abundance of the benthonic copepods was 82.8% in October, 1967, when the total number of animals began to increase. It descended to 35 to 40% in spring (March to May) when the total number of animals was most abundant.

Nematoda was next in abundance to the benthonic copepods. The number of nematodes per plant exceeded that of copepods in late winter and early spring (about 40%), but was lower in summer and autumn (about 5 to 10%).

As a whole, the ratio of occurrence of benthonic copepods decreased from winter to early summer, while that of nematodes increased. Other groups also tended to increase slightly, and such trend was most noticeable in late spring and early summer, when the total number of animals attained its maximum. However, the order of abundance was not reversed. Amphipods increased considerably (about 20%) from May to July; ostracods formed 7.5 to 8.0% in the first part of the year, but their numbers decreased to below 2% in the latter part. Isopod and polychaete numbers increased slightly from May to July, while molluscs showed 2 periods of increase, i.e. February to May and August to September.

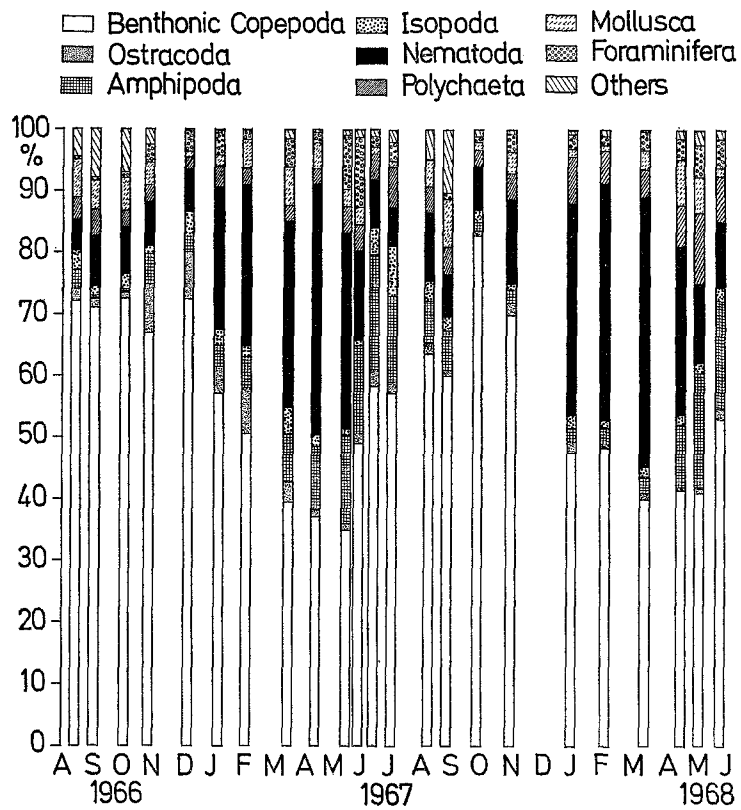

Fig. 6. Seasonal variation of percentage composition of the phytal animals present on *Sargassum serratifolium*

The correlation between composition of animal groups and the standing crop of *Sargassum* is very close. From July to October, when new *Sargassum* fronds are growing, the amount of the benthonic copepods is very high, that of nematodes low. Amphipods fall below 7% after August. From November to February, when the *Sargassum* fronds grow and ramificate rapidly, copepods decrease, nematodes increase. Interestingly, during the reproductive season of *Sargassum* (February and March) the animal composition hardly changes.

In the withering season, the animal composition changes conspicuously. The percentage occurrence of benthonic copepods is minimal throughout the year (35 to 40%), while nematodes are the most abundant.

Amphipods increase and reach their maximum population, about 17 to 19%. Whereas most other groups increase in number of individuals, their percentage occurrence shows no marked change. Changes in composition of animal species seems to depend upon the increase of the reproduction of the phytal animals which, in turn, depends upon a rise in water temperature and increase of detritus resulting from the decline and decomposition of *Sargassum*. More specifically, the increase of detritus may contribute to the increase of nematodes.

Mobile fauna

Foraminifera

Minimum number of individuals, below 100/plant and about 1/g algae, was found in August and September (Fig. 7). From March to June, both numbers

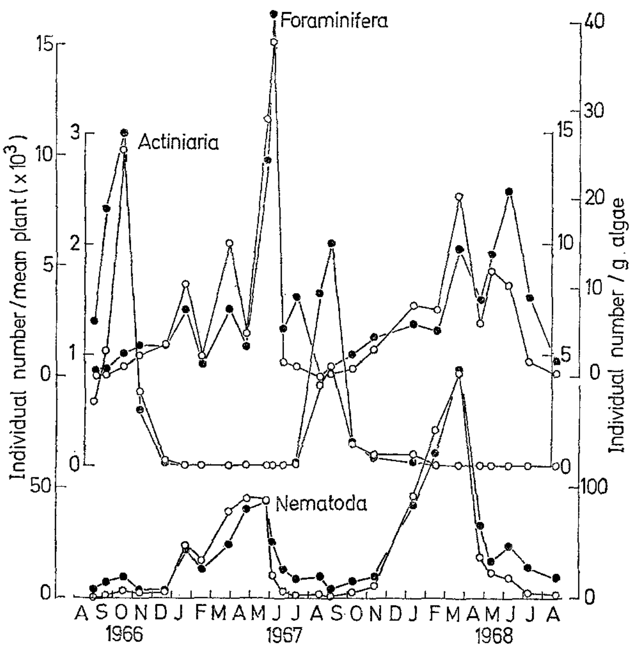

Fig. 7. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant (open circles) and density/g algae (solid circles)

and density increased substantially and reached 15,128/plant and 40.9/g algae.

Anthozoa (Actiniaria)

Actinians are generally sessile animals, although *Boloceroides mcmurrichi* (KWIETNIEWSKI) is mobile and an inhabitant of the thalli of *Sargassum* spp. Actinians occurred on the thalli from summer to winter and did not occur in the season when *Sargassum* was luxuriant (Fig. 7). The maximum number of individuals in the first part of the years surveyed was 2,844/plant (October, 1966), and 890/plant in the second part (September, 1967). The density in these maximum periods was 16.0 and 10.0/g algae, respectively.

Plathelminthes

Turbellarians occurred throughout the year, although the individual numbers were scarce (0.5 to 5.0/plant). Only *Stylochoplana clara* KATO were collected by the bag method; the large turbellarian *Thysanozoon brocchii* (RISSO) was observed during the diving.

Nemertina

Two to 4 individuals were found per mean plant in June, 1967 (Table 1).

Table 1. *Seasonal occurrence of individual numbers of Plathelminthes, Nemertina, Pycnogonida and Acarina per mean Sargassum plant*

Date	Plathelminthes	Nemertina	Pycnogonida	Acarina
1966				
Aug. 17	3.2	—	—	—
Aug. 30	5.1	—	—	—
Sept. 16	3.7	—	0.5	10.6
Oct. 14	1.8	—	—	—
Nov. 10	2.5	—	—	—
Dec. 18	2.1	—	—	—
1967				
Jan. 19	—	—	—	28.1
Feb. 16	2.3	—	—	23.3
March 27	2.3	—	—	—
April 24	2.4	—	—	—
May 23	1.0	—	—	—
June 4—5	—	4.0	—	59.2
June 20	1.3	1.3	—	8.6
July 10	2.6	—	—	13.1
Aug. 16	1.2	—	—	—
Sept. 3—4	1.6	—	4.6	4.3
Oct. 3—6	0.5	—	—	—
Nov. 9	2.4	—	12.1	—
1968				
Jan. 8	—	—	32.8	—
Feb. 12	—	2.2	—	44.7
March 21	—	—	—	—
April 24	0.7	0.7	0.7	13.4
May 9	—	—	—	39.5
June 7	2.3	—	—	11.5
July 5	1.2	1.8	—	—
Aug. 21	4.5	—	—	—

Nematoda

The small and immature specimens passed through the XX13 gauze. The collection of nematodes should be improved to obtain quantitative samples. The individual number per plant started to increase in early winter. It reached its maximum in late winter and early spring when *Sargassum* was luxuriant, 44,914/plant in April, 1967 and 116,357/plant in March, 1968 (Fig. 7). In summer and autumn, when the standing crop of *Sargassum* was scarce, the individual number was also small, below 5,000/plant. The fluctuation of the density of nematodes/g algae coincided with that of the individual number, 88/g algae in May, 1967 and the maximum of 206/g algae in March, 1968. A minimum of 8 individuals/g algae occurred in September of both years. The decrease in numbers in early summer was also very sudden, as in other groups. This resulted from the disappearance of the withered thalli of *Sargassum* in late June.

HAGERMAN (1966) reported that the density of nematodes on the *Fucus* vegetation in Øresund (Sweden) was 6.05/g algae in June, when the population density was the highest. WIESER (1959) pointed out that increase of detritus on algae accompanied the increase of nematodes. DAHL (1948) divided the sedimentation of detritus into 4 grades (0, 1, 2 and 3), since the amount of detritus affects the individual number of phytal animals. Although an exact analysis of the detritus factor was not made in the present study, the grade of detritus in summer seemed to correspond roughly to 3.

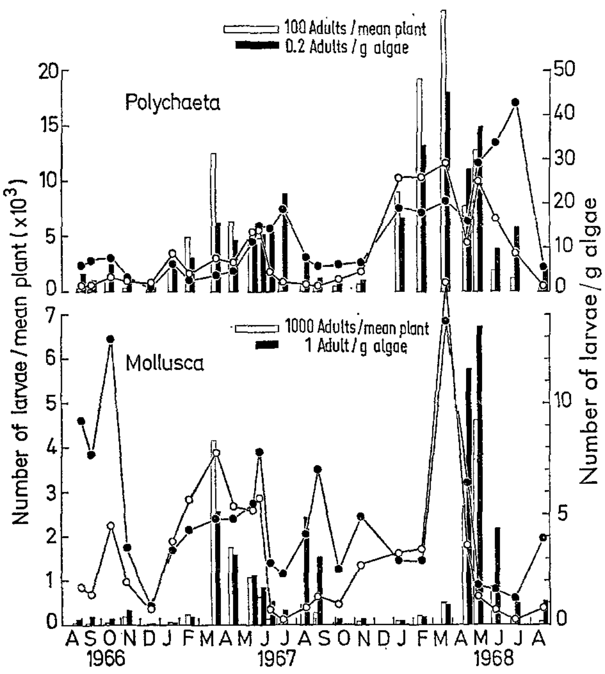

Fig. 8. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant and density/g algae. Open circles and histograms: individuals numbers of larvae plus young ones, and adults, respectively; solid circles and histograms: density of larvae plus young, and adults, respectively

Annelida (Polychaeta)

Small non-sessile polychaetes and a number of their larvae were found on *Sargassum*. Many of the larvae were essentially inhabitants (as adults) of other habitats such as intertidal and subtidal bottoms. They might only have settled by chance on the thalli of *Sargassum*.

The number of adults was most abundant in March: 250 and 508 individuals/plant in 1967 and 1968, respectively (Fig. 8). The number of individuals was generally few in autumn and numerous in late winter and spring. Although the seasonal fluctuation of the population density of polychaetes was roughly proportional to that of the individual number, the increase in population density occurred in summer of both years. The density of larvae increased in early summer, when the thalli were withered.

Mollusca

Adult molluscs were most abundant in spring, and then decreased towards summer (Fig. 8); in late summer, they increased again. Molluscan larvae began to increase in winter and reached a maximum in March. The increase in the population density of the adults was found to occur in spring and late summer, 5/g algae both spring and summer in 1967, and 13.5 and 1/g algae, respectively, in 1968. The individual number of larvae increased in spring and autumn. The adults in March, 1967 and May, 1968 (over 4,000/mean plant) were almost entirely composed of small pelecypods. Moreover, the increase of the individual number in late summer was caused by an increment of small gastropods. The proportion of gastropod larvae increased gradually towards summer and exceeded the pelecypod numbers in midsummer. Most mollusc larvae were also as temporal or casual as polychaete larvae.

(1) Polyplacophora. A few *Placiphorella japonica* (DALL), a subtidal species dwelling on the hard sea bottom, were found in the summer of 1967.

(2) Gastropoda. (a) Prosobranchia. More than 10 species of prosobranchs were taken. Of these, *Zafra mitriformis* (ADAMS) was the most abundant over a period of many months. The increase of adults and larvae in late summer, however, seemed to be related chiefly to increased numbers of *Australaba picta* (ADAMS). *A. picta* increased abruptly and constituted more than 70% of the prosobranchs. *Z. mitriformis* occurred in every season, but varied in number from

month to month. *Z. mitriformis*, *Z. pumila* (DUNKER) and *A. picta* are genuine phytal animals. Although *Diala varia* ADAMS, *Diala* sp., *Alcyna ocellata* ADAMS and Triphoridae spp. were the representative phytal animals, their individual numbers did not constitute an important part of the community as a whole. (b) Opisthobranchia. Small eolids are known to exist as phytal animals on *Sargassum*. Three species of opisthobranchs, *Catriona pupillae* BABA, *C. purpureoanulata* BABA and *Petalifera punctulata* TAPPARONE-CANEFRI, were collected from *S. serratifolium*. Their numbers were, however, low. *C. pupillae* was the smallest in size, but most abundant. Although it is not essentially a phytal animal, the large doris *Dendrodoris nigra* (STIMPSON) was also found.

(3) Pelecypoda. Among the 6 species of pelecypods collected, no phytal animals occurred. All were sessile animals on rocky reefs. *Hiatella flaccida* (GOULD) was abundant on the thalli of *Sargassum serratifolium*. The increase in number of pelecypods in spring was mostly attributed to increased numbers of *H. flaccida*. Young *Spondylus cruentus* LISCHKE, *Pinctada fucata* (GOULD) and *Monia umbonata* (GOULD) were also collected. The occurrence of these shell-fish was presumably accidental. They could not mature on the thalli, since the latter would disappear before maturation of the shell-fish. *M. umbonata* was dominant in spring. *Anomia chinensis* PHILIPPI, which is a very common species on rocks and stones was, remarkably, not found on the thalli of *S. serratifolium*. HAGERMAN (1966) found *Mytilus* spat to comprise more than 50% of the total number of animals on *Fucus serratus* in Øresund in August. In the present investigation, however, *Mytilus* was not usually found. *Musculus cupreus* (GOULD), a parasite in the testa of ascidians, was found on *Sargassum* only before commencement of its parasitic life.

Pycnogonida

Pycnogonida is a rare group among phytal animals. The occurrence of this group is shown in Table 1.

Acarina (Hydracarina)

According to HAGERMAN (1966), Acarina was very abundant on *Fucus serratus* in Øresund and made up more than 35% of the total animals in April and May. OHM (1964) also reported that halacarids were rather dominant in Kiel Bay (Germany). In the present area under study, however, no abundant occurrence was observed. This group was found chiefly in summer, but a clear seasonal sequence could not be ascertained because of its poor occurrence.

Crustacea

(1) Ostracoda. The individual numbers were 4,855/plant maximum (February, 1967), and 120/plant minimum (September, 1967) (Fig. 9). Density/g algae increased in winter and summer. Ostracods were not so abundant in this survey, although HAGERMAN (1966) found a rich ostracod population composing more than 25% of the total population on the *Fucus* vegetation in Øresund.

(2) Benthonic Copepoda. Copepoda are genuine phytal animals including no calanoid, and few cyclopoid, species. Benthonic copepods, mainly Harpacticoida, were very abundant on thalli of *Sargassum*. They were the most important constituent of the non-sessile phytal animals; they comprised more than 50% of the total population almost all the year round.

Individual number increased in winter and early summer (Fig. 9). Maximum population was about 65,000 and 106,000/plant in 1967 and 1968, respectively. The minimum individual number was more than 6,000/plant. Not only individual numbers, but also number of different species was very large. Density of benthonic copepods revealed a peak in June, as in other groups, and another peak in autumn. In Øresund, the benthonic copepods (Harpacticoida) on the *Fucus* vegetation were not found to be the most important group (HAGERMAN, 1966).

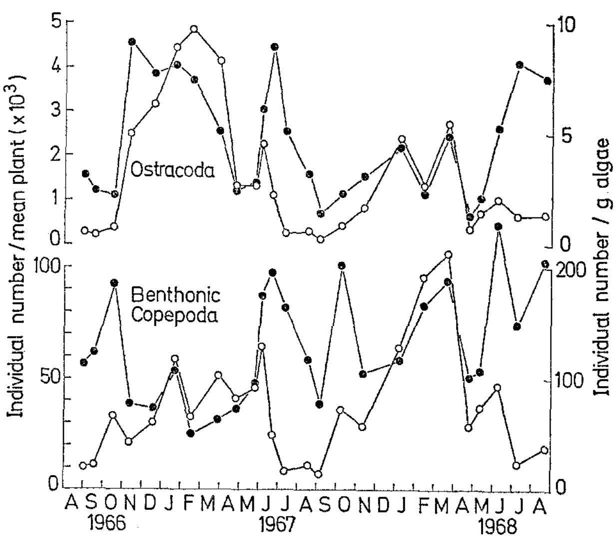

Fig. 9. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant (open circles) and density/g algae (solid circles)

(3) Mysidacea. The mysids (opposum shrimps) occurred all the year round, but number of individuals per plant was few (Fig. 10). According to KIKUCHI (1967), the mysids were the most abundant small crustaceans in the *Zostera* region of Tomioka Bay, Amakusa. Numbers increased slightly in late summer and autumn, and reached a maximum in September, 1966 and November, 1967 (55 and 24 individuals,

respectively). Density/g algae showed a similar fluctuation.

(4) Tanaidacea. Tanaids also occurred in all seasons, but were not important as regards individual numbers (Fig. 10). Individual numbers increased in early summer and reached a maximum, 360 and 665/plant, respectively, in May, 1967 and June, 1968. Maximum density was 1.8 and 3.4/g algae.

(5) Isopoda. The mean number of individuals of the large isopods *Paranthura* sp., *Cymodoce japonica* RICHARDSON and *Holotelson tuberculatus* RICHARDSON per plant was few. Two species of small isopods were

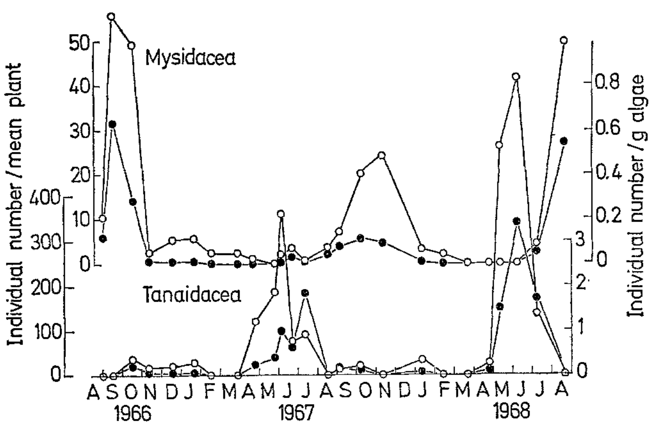

Fig. 10. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant (open circles) and density/g algae (solid circles)

found. Of these, *Munna* sp. was the most abundant amongst all isopods. The number of individuals reached a minimum in summer and a maximum in early spring (Fig. 11). Maximum number was 5,480/plant in March, 1967 and 4,500 in March, 1968. Population density increased in June and July, 3 months after the increase of individual numbers. Although *Idotea* spp. usually occurred abundantly on *Fucus* (DE LA CRUZ, 1963; HAGERMAN, 1966), they were not found on *Sargassum* in the present study.

(6) Amphipoda. Amphipoda were next to benthonic copepods and nematodes in dominance. The individual number per plant increased from January to May and decreased suddenly in July (Fig. 11). Maximum population numbers were found to be 18,855 in May, 1967 and 16,855 in May, 1968. Population density peak slightly delayed from that of the individual number and the maximum was 63 individuals/g algae in June, 1967 and 82 individuals/g algae in June, 1968. In autumn, both number of individuals and density dropped to a minimum, about 500/plant and 2/g algae.

Amphipods are divided into caprellids and gammarids. Among the gammarid amphipods, small species such as *Ericthonius pugnax* DANA and *Eurystheus japonicus* NAGATA were abundant. The former builds a tubular dwelling of mud on the surface of *Sargassum* thalli. Other small gammarids (*Aoroides secunda* GURJANOVA, *Photis reinhardi* KRØYER, *Corophium* spp., Amphilochidae, Calliopiidae and Leucothoidae) were also numerically important. Excluding *Ampithoe lacertosa* BATE, *Paradexamine barnardi* SHEARD and *Podocerus inconspicuus* (STEBBING) the large gammarids, *Pleustes panopla* (KRØYER), *Pontogeneia rostrata* GURJANOVA, and *Ampithoe valida* SMITH, occurred infrequently. The caprellid amphipods were mostly

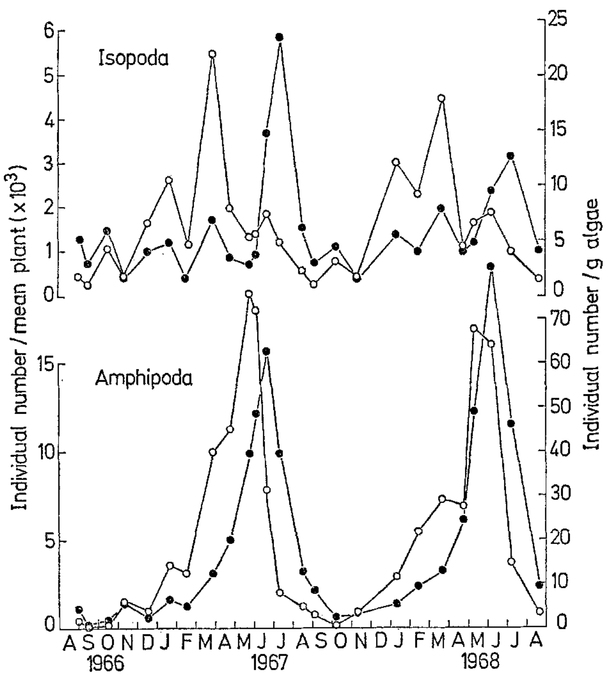

Fig. 11. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant (open circles) and density/g algae (solid circles)

comprised of *Caprella scaura* TEMPLETON. *C. aequilibra* SAY, *C. subinermis* MAYER and *C. bidentata* UTINOMI were not numerous. Seasonal fluctuations of caprellid amphipods agreed with those of gammarids.

(7) Decapoda. Individual numbers increased in September and October but, from winter to early summer, occurrence was rare, despite the luxuriance of *Sargassum* growth (Fig. 12). The maximum number of individuals per plant was 220 in September, 1967. Among Decapoda, macrurans were the most abundant, brachyurans few, and anomurans scarce. My preliminary accounts of macrurans have already been published (MUKAI, 1969). Small hippolytid shrimps [*Latreutes acicularis* ORTMANN, *L. mucronatus* (STIMPSON), *Eualus leptognathus* (STIMPSON), *Hippolyte ven-*

tricosa H. MILNE-EDWARDS, *Heptacarpus geniculatus* (STIMPSON) and *Palaemon ortmanni* (RATHBUN), *Periclimenes akiensis* KUBO and *Processa* sp.] were found. Among these, *L. acicularis* was the most abundant in autumn, but did not occur in spring when this species was numerous in the *Zostera* region.

A few species of the anomurans (*Pagurus* spp.) were identified. Among brachyurans, *Pugettia quadridens* (DE HAAN) was dominant. Other small brachyurans were not important numerically.

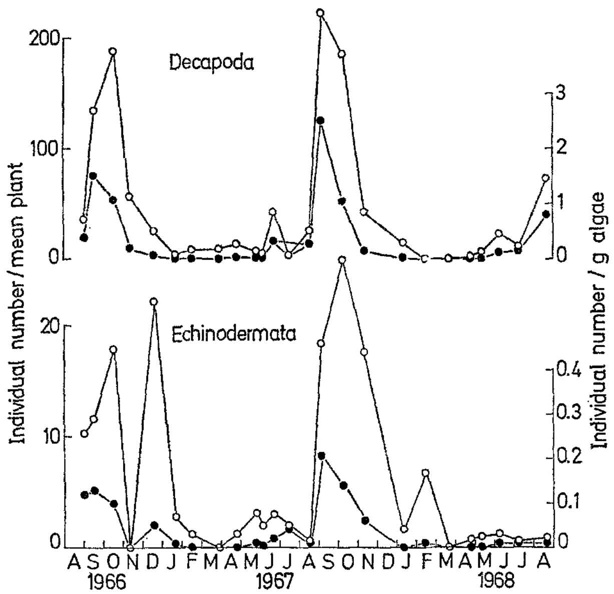

Fig. 12. Seasonal fluctuation of individual numbers/mean *Sargassum serratifolium* plant (open circles) and density/g algae (solid circles)

Echinodermata

Ophiuroids (*Ophiothrix* spp.) were most abundant, but young of echinoids and asteroids occurred in considerable numbers (Fig. 12). Number of individuals increased in autumn, as in decapods. In the maximum growth season, the total number of individuals was over 20/plant.

Sessile fauna

Poriferans, hydrozoans, polychaetes, bryozoans, cirripeds and ascidians were collected. Among these, hydrozoans and bryozoans were so abundant that the surface of *Sargassum* thalli was almost covered with them in spring and early summer. Sessile animals were not counted.

Discussion

During the present investigation, a maximum of 130,000 (May and June, 1967) and 266,000 (March, 1968), and a minimum of 15,000 (July to September, both years) mobile phytal individuals were counted on a single plant of *Sargassum serratifolium*. Expressed in terms of number/m^2 bottom, these figures are equivalent to 793,000, 1,600,000 and 89,000, respectively.

In an investigation of the phytal animals on *Fucus serratus* in Øresund, Sweden (HAGERMAN, 1966), numbers of individuals per plant (170 g, mean weight), excluding bryozoans, were 25,000 in the summer. This value is equivalent to 4,600,000/m^2 algal surface (including bryozoans). If one excludes bryozoans as sessile animals, this figure becomes reduced to less than 100,000. However, this estimation is not directly comparable with the present results. Considering the structure of algae, the number of phytal animals present on *Sargassum*/m^2 bottom seems to be higher than the value reported for *Fucus*.

CHAPMAN (1955) found 376,800 individuals of phytal animals on *Corallium granifera*/m^2 intertidal rocky bottom in the Azores. COLMAN (1940) gave the number of animals on some algae/m^2 intertidal rocky surface as follows: 274,340 *Lichina pygmaea*; 202,735 *Ascophyllum nodosum*; 5,170 *Pelvetia canaliculata*; 15,162 *Fucus spiralis*; 75,000 *Fucus vesiculosus*; 400,114 *Ascophyllum nodosum* and *Polysiphonia lanosa*; 97,416 *Fucus serratus*; 200,337 *Gigartina stellata*; and 141,550 holdfasts of *Laminaria digitata*. These values include sessile animals such as bryozoans. If one eliminates sessile animals, the value may drop to less than half. The difference in numbers between previous investigations and the present study may be attributed chiefly to differences in species of algae and their vertical distribution. WIESER (1952) studied the vertical distribution of phytal animals in the intertidal zone and found that the specific vertical levels for various animals and, therefore, the distribution of the animals, varied with algal species. This result would suggest a close relationship between abundance of animals and construction of the algae. Differences in the surface areas of the algae also affect the number of animals inhabiting them. Furthermore, differences in the amount of standing crop of algae/m^2 bottom were observed. The maximum wet weight of an average plant is about 800 g in *Sargassum serratifolium* and 360 g in *Fucus serratus* (HAGERMAN, 1966). Consequently, we determined that the standing crop/m^2 bottom is also dependent upon the algal species.

The individual number of animals/g algae is easily comparable. In *Fucus* in Øresund, the density of animals was highest in August (147.1 individuals/g algae) and the lowest value was in May (16 individuals). In the present investigation, 350 and 470 animals/g algae were observed on *Sargassum serratifolium* in July, 1967 and March, 1968, respectively; minimum numbers occurred in winter (99/g algae). COLMAN (1940) reported that the densities of animals on *Pelvetia canaliculata*, *Fucus spiralis*, *Lichina pygmaea*, *Fucus vesiculosus*, *Ascophyllum nodosum* and *Polysiphonia lanosa*, *Fucus serratus*, *Gigartina stellata* and *Laminaria digitata* (holdfast only) were 0.94, 2.66, 160.5, 7.5, 27.98, 11.88, 74.31 and 56.62/g algae, respectively. On the northeast coast of the island of Velika Figarola in the North Adriatic, ZAVODNIK (1967a, b) observed 22.2 animals/g *Fucus virsoides*. It is concluded that the animals on *S. serratifolium* are more abundant than those on other algae. The variation in density of animals/g algae is presumably determined by differences in the shapes of algae and the surface area/g. WIESER (1951, 1952) stressed that a close relation existed between number of phytal animals and "specific surface" of algae, which latter is represented by shape, height, consistency and degree of branching. On the other hand, as suggested by a quantity analysis by DAHL (1948), it seems that the amount of detritus on the thalli profoundly influences the density of the inhabiting animals. The volume of detritus on the thalli is affected by various factors such as water conditions, current, secretion of mucous matter from the thalli, and planktonic organisms.

Animals on sandy and muddy bottoms are, in general, very abundant. The maximum numbers observed by previous authors are as follows:

2,000,000/m² bottom SMIDT (1951, Danish Wadden Sea)

12,500,000/m² muddy bottom REES (1940, Bristol Channel, UK)

993,000/m² bottom WIGLEY and MCINTYRE (1964, East Coast, USA)

50,000—650,000/m² sandy shore FENCHEL (1967, Øresund, Sweden)

20,000—616,000/m² sandy shore RENAUD-DEBYSER and SALVAT (1963, Straits of Dover and Bassin d'Arcachon, France).

Regarding individual numbers, the epifauna (sessile and vagile) on algae was not abundant compared with that on sandy and muddy bottoms. The standing crop of the latter was also much more numerous than the former. Nevertheless, it appears that phytal animals constitute very important food for animals of higher trophic levels, because of the ease with which predators can find them, their high nutrient value, and high turnover rate. Therefore, phytal animals contribute more than benthonic animals towards production of fish in seaweed regions.

Among phytal animals, benthonic copepods were the most abundant and nematodes next in number. HAGERMAN (1966) reported that, throughout the year, the dominant group present on *Fucus* vegetation was ostracods, and that these comprised more than 37% of the total animal population. Moreover, benthonic copepods were not abundant and comprised only 28.3% of the total in June at their maximum, and 2% in August. OHM (1964) observed phytal animals on the *Fucus* vegetation in Kiel Bay, Germany, and mentioned that harpacticoid copepods (almost benthonic) were rare in summer, but composed more than 60% of the total animals in winter. DAHL (1948) also reported harpacticoid copepods as very common in the *Fucus* zone. Ostracods formed only 8% of the population in the *Sargassum* region of the present area. According to DAHL (1948), the volume of detritus influences the number of nematodes. In the present investigation, the individual number of nematodes began to ascend in early spring, when, with the increase of withered algae, detritus was steadily augmented.

No relationship between fluctuations in the standing crop of *Sargassum serratifolium* and phytal animals was observed by FUSE (1962b). According to this author, although the standing crop of *Sargassum* reached its maximum in April and its minimum in August, the individual number of phytal animals reached their maximum in January and their minimum in June. In the present study, seasonal fluctuations of the individual number of animals generally corresponded with those of the standing *Sargassum* crop. The difference between these results may depend upon the different units used. For example benthonic copepods, which numerically comprised more than $^1/_2$ the total animals, could be practically ignored in estimating standing crop. On the other hand, decapods, although few in number, were significant as regards their wet weight. Seasonal fluctuations in the wet weight of the decapods did not agree with fluctuations in *Sargassum* weight.

The agreement between the number of animals and the standing crop of algae obtained in the present study suggests that the increase and the decrease of the algae directly influences that of the animals. The fluctuations of each group of animals may be divided into 2 patterns: Actiniaria, Mysidacea, Decapoda and Echinodermata, although rather large in size and small in number throughout the year, were few from winter to early summer when the *Sargassum* crop was luxuriant. The second pattern of fluctuation was observed in most groups of phytal animals, especially the smaller species. The numbers of these groups agreed with fluctuations of the standing crop of algae, i.e. they reached a maximum from winter to late spring. Ostracoda, Isopoda, Polychaeta, Mollusca, Nematoda, Amphipoda and Foraminifera propagated during this season and became abundant successively. The tanaids and the benthonic copepods were the latest group in maximum occurrence.

Summary

1. In the *Sargassum* region on the coast of Mukaishima, in the Inland Sea of Japan, the seasonal fluctuation and faunal composition of phytal animals were investigated quantitatively.

2. Seasonal changes of *Sargassum serratifolium* as a habitat of phytal animals are described. The standing crop of the plant reaches a maximum in late winter and a minimum in summer. The density of the plants/m^2 bottom is about 6.1; no significant fluctuation of this average has been obtained.

3. The number of animals per plant attains a minimum in summer and a maximum in early spring. The benthonic copepods dominate in most seasons. Nematodes are next in abundance to the benthonic copepods. The occurrence of nematodes is closely related to the quantity of detritus on *Sargassum*.

4. These results are compared with previous findings on some algae in other localities, and the comparative abundance of phytal animals in the *Sargassum* region is considered.

5. Although fluctuations in the numbers of most animal groups depend upon variations in the standing *S. serratifolium* crop, fluctuations of some large-sized groups are independent of this.

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