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ECOLOGICAL STUDIES ON THE TERRESTRIAL ALGAE FOUND IN THE COASTAL SAND DUNE IN SAN-IN REGION, JAPAN**

By

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Although algae are generally considered to be aquatic organisms, their occurrence in arid soils has been known for a long time, and their presence in extremely dried regions such as desert and semi-desert or desert-steppe has also been reported by many authors (KILLIAN and FEHER, 1935 ; CHANTANACHAT and BOLD, 1962 ; CAMERON, 1964 ; OCAMPO-PAUS and FRIEDMAN, 1966 ; FRIEDMAN, LIPKIN, and OCAMPO-PAUS, 1967 : HOLLERBACH and SHTINA, 1969 ; NOVICHKOVA-IVANOVA, 1964, 1967 ; FRIEDMAN, 1971). [1~9] The results described in these reports show that many subaerial and terrestrial algae may be able to passably torelate to extremely desicated habitat.

It is commonly regarded that in a coastal sand dune district, a distinctive seed plants vegetation develops under the influence of such peculiar ecological factors as dried sandy substrates, plenty of wind-borne salts, and an unstability of substrate by wind.

Publications however, on the algal vegetation of a coastal sand dune have hardly been noticed.

The present report deals as a preliminary note with ecological and taxonomical studies of terrestrial algae found in the coastal sand dune district in western Japan.

Materials and Methods

The samples of soils and sands used in this studies were obtained from the sand dunes situated on the coastal district of San-in region, Japan (Tottori, Kaike, Taishya, Sashimi, Nima and Masuda).

Mixed cultures and unialgal cultures (non bacteria-free) are generally used, especially for a counting of biomass the former culture was mainly adopted. Media used in the culture are mostly BOLD's modified BRISTOL solution with 2% of agar (BOLD, 1949) [10] and BOLD's Basal Medium (BBM) *viz.* the former basal solution containing certain trace-elements (BISCHOFF and BOLD, 1963). [11] The cultures were incubated under a 12-hr day and a 12-hr night cycle at 20°C and at 1000-1500 luxes. The counting of colonies were examined under the stereoscopic binocular microscope at one month after the cultivation started.

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** Dedicated to Prof. Yositeru Nakamura on the occasion of his retirement.

Results and Discussion

1. Algal biomass in coastal sand dunes

On the estimating of algal biomass in the soils, there are some problems awaiting solution yet. We have following two main methods *viz.* the culture method ; after incubation for 4–6 weeks, the presence of algae is determined microscopically or by visual examination for the coloring and are also enumerated directly from soils by fluorescence microscopy.

According to some data by BURGES, 1958 [12] and ALEXANDER, 1961 [13] the algal biomass in the soil gives values ranging usually from about 1,300–800,000 cells per 1 gram soil. Some examples of the results of algal biomass obtained from the sand dune compared with that of cultivated and forest soils in San-in region are given in table 1.

Table 1. Algal biomass in varied habitats

sample No.	cells/1 g soil	habitat	sample No.	cells/1 g soil	habitat
S-70 - 1	34,860	cultivated soils	T-P-V	2,050	sand dune stable zone
	58,060			643	
S-70 - 2	7,070		T-69-5	1,675	
	9,010		K-P-VIII	1,218	
S-70 - 4	6,630		Ta-100-V	6,140	
	14,500			3,090	
K-70-20	2,210	forest soils	Ta-P-III	6,470	
	2,560		N-P-III	1,820	
K-70-21	20		N-P-VIII	3,180	
	50		Ta-5-VII	890	unstabled zone
K-70-22	40		Ta-10-VII	900	
	90		Ta-20-VII	5	
			T-20-V	9	
			K-10-VIII	68	
			K-15-VIII	4	

According to the results, the biomass of cultivated and forest soils give values ranging from 20–58,000 cells per 1 gram soil, however, in the case of sand dune, the algal biomass give values ranging from 4–6,500 cells per 1 gram soil. In detail, the biomass of unstable zone (mostly lacking of vegetation, or scarcely developed small colonies of such plants as *Salsola komarovii* and *Carex kobomugi*) is less scanty than that of stable zone (mostly covered with a large vegetation of perennial plants such as *Vitex rotundifolia* and *Ischaemum anthephroides* var. *eriostachyum*). It seems possible that the differences of algal biomass causing different habitats is ascribed to the differences of each ecological conditions relating to the water-hold capacity, stability of substrates against wind, and the influence of wind-borne salts.

On the vertical distribution of algae, some interesting results were obtained (Figure 1). According to these data, it may be indicated that the vertical distribution of algae found in stable habitats shows a typical pattern of vertical distribution which was

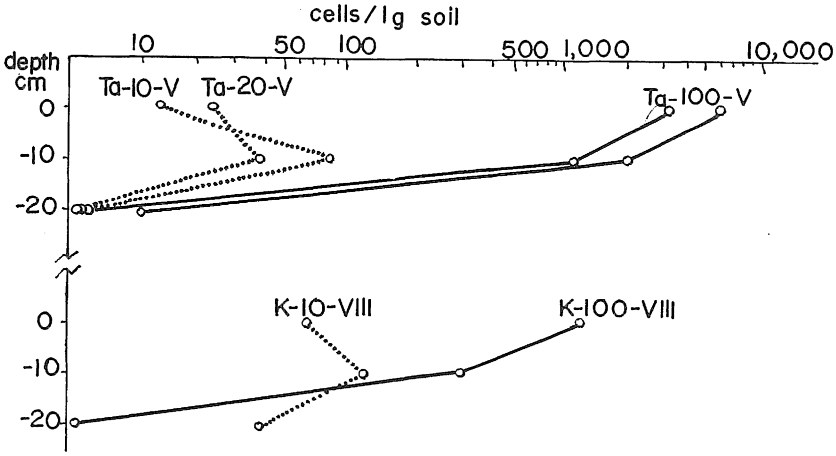

Fig. 1. Vertical distribution of algae in Taishya(Ta)and Kaike(K)sand dune. Dotted lines indicate the algal biomass in unstable zones, and solid lines indicate the same in stable zones.

already pointed out on many soils by BRISTOL-ROACH, 1927 [14] ; TCHAN and WHITEHAUSE, 1953, [15] and HOLLERBACH and SHTINA, 1969. [16] On the contrary, in unstable habitats, the vertical distribution is characterized by its sub-surface peaked pattern of distribution. The reason of such an unusual distribution of algae seems to be a results of an influence of sand moving in unstable habitats by strong wind.

2. Algal distribution and environmental condition

As mentioned above, the coastal sand dune has many peculiar ecological factors compared with those of other soil surfaces especially on such factors as an unstability against wind, a small water-hold capacity and an existence of wind-borne salts.

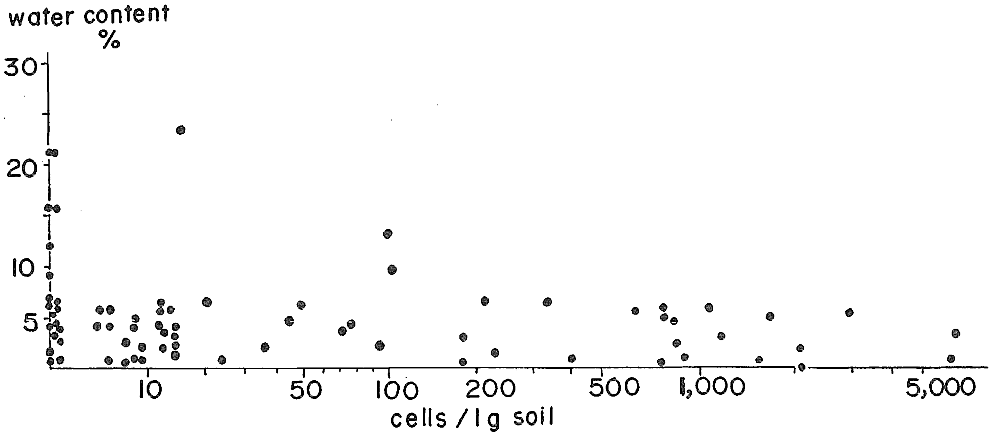

Fig. 2. Scattered diagram of correlation with algal biomass and water contents of habitat.

Further, it is possible that these factors participate complicately in setting a limit to the distribution of algae.

Figure 2 represents a correlation between algal biomass and water contents of habitats. From the figure, it is apparent that there is not a clear correlation between the algal biomass and the water contents of habitats. However, it may be able to point out that the most of algal vegetation develop in relatively dried habitats, since the algae found in these habitats presumably have a physiological adaptability against dessication.

A relation of algal biomass with the complex conditions of pH and chlorinity of habitats is represented in figure 3. It will be seen from the figure that the most algal vegetation considerably develop in habitats with relatively low concentration of chlorinity, at the same time, these habitats is also assumed in the range of weak acid to neutral condition.

Concernning to this phenomenon, an experiment was carried out to check up the relation between an algal distribution and an environmental factor. The results of the experiment on the effect of pH factor of habitat upon the photosynthetic activity of sand dune algae and *Zygogonium ericetorum*, a terrestrial alga commonly occur in acid habitat (AKIYAMA and SAGAWA, 1970) [16] is represented in figure 4. According to the result of this experiment, it is clear that the optimum pH value of photosynthetic activity of each alga and the optimum pH value of habitat is closely related with each other.

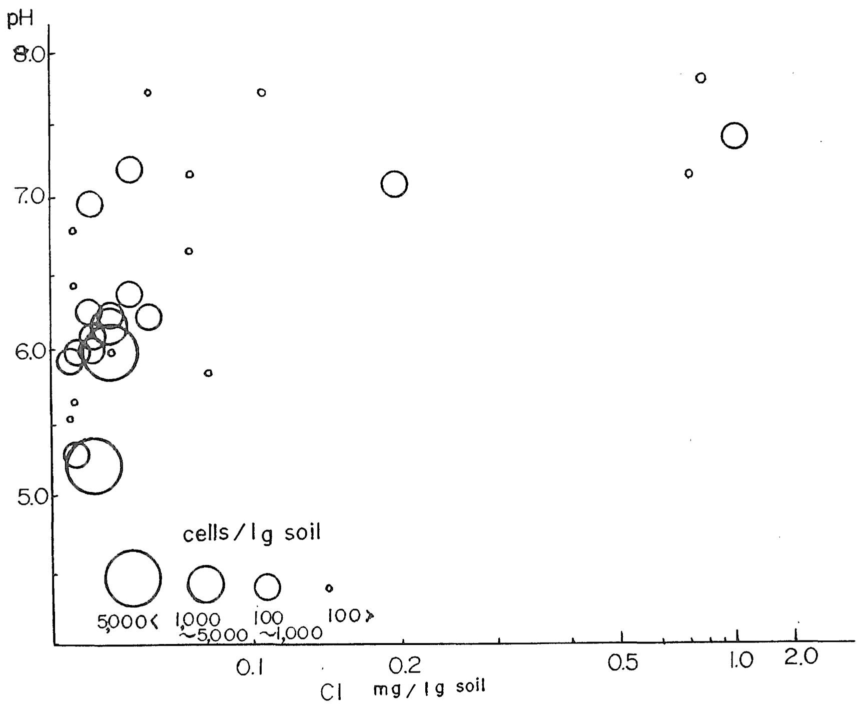

Fig. 3. Scattered diagram of correlation with algal biomass and complex conditions of pH and chlorinity of habitat.

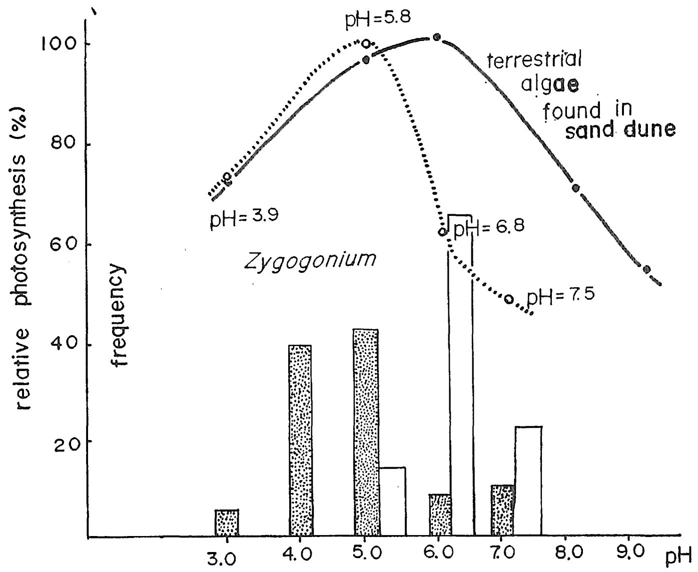

Fig. 4. Effect of pH on the photosynthetic activity of terrestrial algae, and the frequency of occurrence of the same algae under varied pH of each algal habitat.

3. Seasonal distribution of algae

It is well known fact that the most of freshwater and marine algal vegetation develop rhythmically relating to a seasonal environmental change of habitats. Some examples of the seasonal change of algal biomass found in sand dune algal habitats are given in table 2. Though, it is only an inadequate data, it may be able to regard that there is a fairly change of algal biomass in accordance with the seasonal change, especially in the unstable zone. A similar tendency concernnig with the number of algal species is also recognized as shown in table 3.

A sample of a definite composition of algal species found in the season when the algal vegetation was markedly developed is given in table 4.

It should be noticed that the algal composition found in an unstable zone is markedly limited compared with that of a stable zone. Such species as *Pleurococcus naegelii*, *Stichococcus bacillaris* and *Chlorella* spp. are relatively abundant in summer and autumn, however, the most of these species excepting one species *Chlorella vulgaris* are not observed in spring. On the contrary, in a stable zone, a remarkable development of algal composition can be seen. In this zone, such algae as *Klebsormidium*[18] *flaccidum*, *Klebsormidium subtile*, *Pleurochloris anomala*, *Chlorococcum* sp. besides the former species are abundant. Additionally, it is interest that the following species which are commonly found in acid soils in Japan (AKIYAMA, 1965)[(7)] also occur in this zone (pH=5.55−5.9), *viz. Monodus subterraneus*, *Heterothrix exilis*, *Heterococcus viridis*, *Planktosphaeria gelatinosa*, *Selenastrum gracile*, and *Cylindrocystis brebissonii*.

Table 2. Seasonal change of algal biomass (cells/1 g soil) found in Taishya sand dune.

month	depth \ distance from beach (m)	0−19	20−49	50−69	70−99	100−
III	0 cm	1	0	0	250	6,470
	−20	0	0	0	5	80
V	0	14	24	7	780	6,140
	−10	200	36	7	0	2,040
	−20	0	0	0	0	12

Table 3. Seasonal change of number of algal species found in Taishya sand dune.

month	distance from beach (m)	0−9	10−19	20−49	50−69	70−99	100−
III		0	1	0	0	1	13
V		2	1	1	2	0	6
XI		2	4	3	8	9	23

4. A list of terrestrial algae found in the coastal sand dune

The following list includes fourty-nine taxa in total. Those are consisted of twenty-six taxa of Chlorophyceae, seven taxa of Xanthophyceae, eleven taxa of Cyanophyceae and five taxa of Bacillariophyceae.

The following symbols indicates localities (T=Tottori, K=Kaike, Ta=Taishya, N=Nima, S=Sashimi, M=Masuda) and the Month (Roman no.) of appearace.

CHLOROPHYCEAE

1. **Chlamydomonas** sp. T-V, Ta-III, XI
2. **Stichococcus bacillaris** NAEGELI T-VIII ; Ta-III, XI.
3. **Klebsormidium flaccidum** (KUETZ) SILVA, MATTOX et BLACKWELL
   T-VIII ; Ta-III, V, VIII, XI ; K-VIII.
4. **Klebsormidium subtile** (KUETZ.) SILVA, MATTOX et BLACKWELL
   Ta-III, V, VII, XI ; T-VIII ; K, VIII.
5. **Characium orissicum** PHILIPOSE var. ? T-V.
6. **Chlorella vulgaris** BEIJERINCK T-V, VIII ; Ta-III, V, VII, XI ; S-IX,
   K-VIII ; M-III.
7. **Chlorella zofingiensis** DOENZ. Ta-III.
8. **Chlorella saccharophilia** (KRUEG.) MIGULA T-VIII ; Ta-XI.
9. **Chlorella minutissima** FOTT et NOVAKOVA Ta-VIII, XI.
10. **Chlorococcum** sp. T-VIII ; Ta-III, V, XI ; S-IX.

Table 4. Species composition of terrestrial algal vegetation found in the sand dune of Taishya in November.

distance from beach (m)	0	10	20	50	70	100−1	100−2
status of habitats	unstable zone (no seed-plant vegetation)			relatively stable		stable zone (*Pinus* forest)	(*Pinus* and *Robinia*)
pH	7.5	7.6	7.4	6.27	6.52	5.90	5.55
chlorinity (mg/1 g soil)	1.34	0.09	0.06	0.04	0.03	0.04	0.02
water content (%)	15.1	0.31	–	1.16	0.63	1.30	1.37
algae	*Chlorella saccharophilia*	*Chlorella vulgaris*	*Pleurococcus naegelii*	*Pleurococcus naegelii*	*Chlamydomonas* sp.	*Chlamydomonas* sp.	*Chlamydomonas* sp.
	Scenedesmus bijuga	*Stichococcus bacillaris*	*Stichococcus bacillaris*	*Stichococcus bacillaris*	*Stichococcus bacillaris*	*Stichococcus bacillaris*	*Stichococcus bacillaris*
		Klebsormidium subtile	*Chlorella sacchalophilia*	*Chlorella vulgaris*	*Klebsormidium subtile*	*Klebsormidium subtile*	*Klebsormidium subtile*
		Bracteacoccus sp.		*C. saccharophilia*	*Chlorella vulgaris*	*K. flaccidum*	*H. flaccidum*
				C. minutissima	*C. saccharophilia*	*Pleurococcus naegelii*	*Pleurococcus naegelii*
				Chlorococcum sp.	*Bracteacoccus* sp.	*Chlorella vulgaris*	*Chlorella vulgaris*
				Hantzschia amphioxys	*Planktosphaeria gelatinosa*	*C. saccharophilia*	*C. sacchalophilia*
				Navicula sp.	*Monodus subterraneus*	*C. minutissima*	*Chlorococcum* sp.
					Hantzschia amphioxys	*Chlorococcum* sp.	*Planktosphaeria gelatinosa*
						Planktosphaeria gelatinosa	*Tetracystis* sp.
						Tetracystis sp.	*Selenastrum gracile*
						Pleurochloris anomala	*Nephrodiella semilunaris*
						Botrydiopsis arhiza	*Cylindrocystis brebissoni*
						Monodus subterraneus	*Pleurochloris anomala*
						Hantzschia amphioxys	*Monodus subterraneus*
							M. dactylococcoides
							Heterothrix exilis
							Heterococcus viridis
							Navicula mutica
							Pinnularia borealis
							Hantzschia amphioxys
number of species	2	4	3	8	9	15	(23) 21

11. **Bracteacoccus** sp. Ta-III, XI ; S-IX.
12. **Planktosphaeria gelatinosa** G. M. SMITH Ta-III, XI : M-III ; N-III.
13. **Dictyochloris** sp. Ta-XI.
14. **Spongiochloris** sp. M-III.
15. **Scotiella nivalis** (SCHUTT.) FRITSCH T-VII, Ta-III, V, VII, XI ; N-III ; S-IX.
16. **Pleurococcus naegellii** CHODAT Ta-III, XI ; K-VIII.
17. **Tetracystis** sp. Ta-XI.
18. **Chlorosarcina stigmatica** DEASON S-IX.
19. **Protosiphon botryoides** (KUETZ.) KLEBS M-III.
20. **Selenastrum gracile** REINSCH Ta-XI ; S-IX.
21. **Monoraphidium minutum** (NAEG.) KOMARKOVA-LEGNEROVA S-IX.
22. **Scenedesmus bijuga** (TURP.) LAGERH. Ta-VII, XI ; S-IX ; K-VIII.
23. **Scenedesmus quadricauda** (TURP.) DEBREB. Ta-XI.
24. **Scenedesmus obliquus** (TURP.) KUETZ. K-VIII.
25. **Cylindrospermum brebissonii** MENEGH. T-VIII ; Ta-XI ; M-III.
26. **Cosmarium urceum** W. et G. S. WEST Ta-XI.

XANTHOPHYCEAE

1. **Monodus subterraneus** PETERSEN T-VIII ; Ta-III, V, VII, XI ; K-VIII ; S-IX ; M-III.
2. **Monodus dactylococcoides** PASCHER Ta-XI.
3. **Pleurochloris anomala** JAMES Ta-III, VII, XI ; K-VIII.
4. **Botrydiopsis arhiza** BORZI Ta-IXI ; T-VIII.
5. **Heterothrix exilis** PASCHER Ta-XI ; T-VIII.
6. **Heterococcus caespitosum** VISCHER Ta-XI
7. **Heterococcus mainxii** VISCHER Ta-XI
8. **Heterococcus viridis** CHODAT Ta-XI.

BACILLARIOPHYCEAE

1. **Pinnularia borealis** EHREMB. Ta-XI ; K-VIII.
2. **Navicula mutica** KUETZ. ? Ta-XI ; K-VIII.
3. **Navicula** sp. Ta-VIII, XI.
4. **Nitzschia obtusa** W. SMITH var. **scalpelliformis** GRUNOW. K-VIII.
5. **Hantzschia amphioxys** (EHREMB.) GRUNOW T-VIII ; Ta-XI ; K-VIII.

CYANOPHYCEAE

1. **Synechococcus cedrorum** SAUVAGEAU Ta-VII.
2. **Phormidium tenue** (MENEGH.) GOMONT. T-VIII ; Ta-V, VII, XI ; K-VIII ; N-III ; S-IX.
3. **Oscillatoria chalybea** (MERT.) GOMONT. Ta-XI
4. **Oscillatoria** sp. Ta-XI
5. **Nostoc punctiformae** (KUTZ.) HARIOT Ta-VII ; S-IX ; N-III.
6. **Nostoc ellipsosporum** (DESM.) RABENH. ex BORNET et FLAH. T-VIII.

7. **Nostoc** sp. Ta-V, VII ; K-VIII ; S-IX.
8. **Anabaena** sp. Ta-VII ; K-VIII.
9. **Tolypothrix tenuis** (KUETZ.) JOHS. SCHM. em. ? Ta-XI
10. **Scytonema** sp. Ta-VII ; S-IX.

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