

Species Composition and Primary Production of the Benthic Algal Assemblage along a Channel in Salt Marsh, Kyōnggi Bay, Korea

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潮間帶 鹽濕地 水路지역의 底生藻類의 種組成 및 一次生産

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ABSTRACT

Studies on species composition, primary production of benthic algal assemblage were carried out along a channel of the salt marsh near Inch'ōn, Kyōnggi Bay, Korea. Possible biological, physical and chemical factors controlling the algal assemblage were also examined. The overall diatoms were encountered one hundred and thirty-seven taxa, of which the dominant species were *Paralia sulcata* and *Cymatosira belgica*. These two species accounted for 32.6% relative abundance throughout the study period. Diatom taxa had no clear seasonal pattern in abundance analysis. But at the algal blooming period in spring, euglenoids occurred with a high abundance. The chlorophyll a content of benthic algae showed definite seasonal pattern. The algal biomass of the channel was regulated primarily by water content of sediment. Grazing by zoobenthos appeared to influence the spatial fluctuation in the algal biomass of the sediment surface. The algal photosynthesis was measured in the laboratory with oxygen method. Photosynthetic rate was independent of the temperature under the lower irradiance. The gross production from March to November was estimated to be 190 g C/m² at the channel slope. Photosynthetic efficiency was 0.37% on the basis of the photosynthetically active radiation for the study period.

INTRODUCTION

Sediment in intertidal salt marsh is periodically inundated by the flood tide and exposes to intense insolation and desiccation. Benthic organisms associated with the sediment response rapidly to drastic environmental change and maintain high biological production. Especially, primary production by microalgae along the channel and creek in intertidal salt marsh is very high and plays a major role in supporting numerous zoobenthos and maintains biological diversities. The taxonomy and ecology of benthic diatoms are a subject

that has all but been ignored by phycologists in Korea. Shim and Cho(1984) presented a distributional pattern of benthic diatoms inhabiting an intertidal salt marsh near Inch'ön in Korea and reported that benthic diatoms could be classified into two communities such as the upper and lower zone community. Kim and Cho(1985) have reported that diatom habit associated with sediment supported two life such as nonmotile-attached and free-living form.

Some authors suggested that the annual gross production by microalgae on tidal flats frequently fall between $80\sim 200\text{ g C/m}^2$ (Pomeroy, 1959; Steele and Baird, 1968; Leach, 1970; Gallagher and Daiber, 1974). Further informations are available on the photosynthetic activities of benthic diatoms (Gallagher and Daiber, 1973; Whitney and Darley, 1983; Booth and Dromgoole, 1984). There is ample evidence that benthic diatoms can photosynthesize at extremely low light intensity reaching maximum rate and that high light intensities don't produce significant inhibition in mixed field assemblages.

This study was designed to estimate the gross primary production of benthic algal assemblage along the channel in salt marsh and determine which environmental factors were important in controlling the algal biomass. In addition, we examined the relative abundance for seasonal change of diatom taxa.

STUDY AREA

The study area, approximately 80 ha, was a semi-enclosed area, which had banks landwards around the area, and had connection with the open sea through the main channel(Fig. 1). The incomplete bank had been constructed seawards and at the high tide,

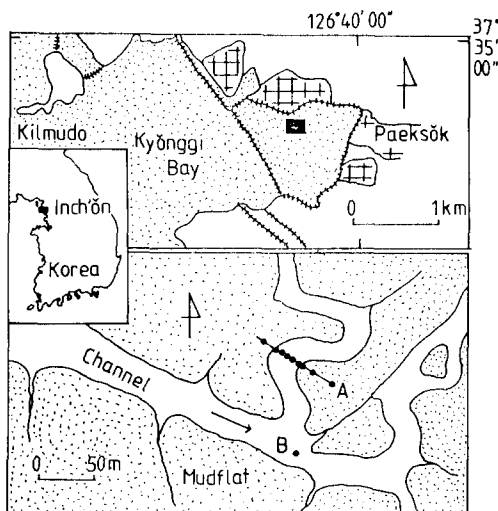


Fig. 1. A map showing the study area(black rectangular region) of the intertidal salt marsh, Kyönggi Bay, An arrow indicates the flood tidal current.

flooding sea water overflowed above the bank. This intertidal marsh showed homogeneously a silt loam texture composed of 15% sand, 64% silt and 21% clay. This muddy marsh drained with well-branched and developed channels and creeks. Saline plant, *Suaeda japonica*, spread scatteredly and sparsely on the mudflat and *Zoysia sinica* had the sporadical patches. A large tributary channel with 20 m width and 5 m depth was chosen for sampling and a transect line was drawn across the channel(Fig. 1). A1, A2 and A9 station were mudflat, A4 and A7 station were the channel middle slope, and A5, A6 and B station were the channel lower slope(Fig. 4). Station B was horizontally the same level with A5 and A6 station in Fig. 4. Daily mean hours of

tidal exposure to desiccation were 23.4 hr at mudflat and 15.5 hr at channel slope. The mudflat was not flooded by the high tidal current around the neap tidal period and sometimes very dry condition persisted for many days. Materials were collected at the five positions along the horizontal line at each sampling station. Seasonal samples were taken at A1-2, A4 and B station throughout the study period. We had nineteen sampling surveys from March to November, 1982.

MATERIAL AND METHOD

Soil analysis In field, sediment temperature was measured from 10:00 to 16:00 on each sampling day and water temperature also measured during the flood tide at the another day. pH, electric conductivity, sodium, potassium, phosphorus and organic nitrogen of sediment were determined by the methods from our previous paper (Kim and Cho, 1985). Organic matter was analyzed with Schollenberger method. Exactly 10 ml of 0.4 N chromic acid solution mixed with 0.5 g oven-dried soil and digested in the phosphoric acid bath. This sample was diluted to 100~200 ml volume with distilled water and titrated with ferrous ammonium sulfate using orthophenanthroline indicator (Black *et al.*, 1965).

Chlorophyll and diatom Sediment samples for taxonomic study of benthic diatoms and chlorophyll extraction were collected by using a 10 cm-long and 3.0 cm-diameter plastic tube. Top 2 mm of sediment surface was scraped with a scalpel blade and fixed in 4% formaldehyde solution diluted with filtered seawater. In laboratory, after shaking vigorously a small quantity was taken three times to make finally 10 ml volume. This material was mixed with concentrated nitric acid and boiled gently for 20~30 minutes. This procedure destroyed most of all organic matter in the sample and left empty frustules with the associated sediment. After neutralizing the materials by repeated washings with distilled water, permanent mounts were prepared with pleurax media. Diatom taxa were identified and enumerated with Olympus BH-2 microscope at 1,000× magnification. The relative abundance of the diatom taxa was based on counts of 500 cells in each sample (McIntire and Overton, 1971). In identifying the taxa, following literatures were mainly referred (Hustedt 1927~66, 1930; Hendey 1964; Patrick and Reimer 1966, 1975; Germain 1981; Krammer and Lange-Bertalot 1986).

To determine the microalgal chlorophyll, top 1 cm of sediment was cut with cores and stored in -40°C deep-freezer for later works. After extraction with acetone in refrigerator for 24 hours, absorbances were checked at 665 nm and 750 nm. The extracts were then acidified with 2 drops of 10% hydrochloric acid and the absorbances were remeasured at two wavelengths (Lorenzen, 1967). Chlorophyll a content and pheopigment percentage were calculated with Lorenzen's (1967) equations.

Agal photosynthesis and respiration Top 1 cm mud surface were taken with petri dish (8.0 cm diameter) at A1 and A4 station from March to July. The dish was inserted in the incubation chamber which was 11 cm in diameter, 8.0 cm in height and 750 ml in

volume. The filtered sea water was slowly siphoned into each chamber, without disturbing the sediment surface. The incubation time necessary to give a detectable change in dissolved oxygen depended on temperature, irradiance and algal abundance. It ranged from 30 to 90 minutes. A few manipulation of the fan circulator during incubation created currents and prevented the oxygen stratification. The chamber temperature was regulated in the water bath. Light was supplied with a 400 watt high pressure sodium lamp. Irradiance was controlled by changing the distance between the lamp and the chamber. Respiration was determined under the dark condition. As benthic algae has the endogeneous metabolic rhythm, incubation in the light was carried out from 9:00 to 16:00 hours(Gallagher and Daiber, 1973). The end of each incubation, duplicate water samples were removed from each chamber and duplicate titrations were performed on each bottle. Oxygen evolution data were converted to a carbon basis using a photosynthetic quotient of 1.0(Pomeroy, 1959). After all procedure completed, three cores on each chamber were taken to extract the algal chlorophyll.

RESULTS

Environmental factors Mud temperature was dependent on the solar irradiation. At heavy cloudy day, the ninth day of May, sediment temperature was similar with the maximum air temperature(Fig. 2). Peak temperature of sediment surface was observed 40°C in July on the mudflat. Throughout the survey period, water temperatures were similar with the mean air temperatures. Fraction of sediment water content based on fresh soil weight varied from 18% to 31% at the mudflat and from 37% to 80% at channel slope(Fig. 3). This difference between two stations was due to tidal flood hours, and the percolation phenomenon from the mudflat to the slope was observed after tidal emergence. Actually, during the ebb tide, the thin layer of water film continuously flowed on the sediment surface at channel slope. Various sediment properties were investigated through the season, along topographical transect across the channel and with depth(Table 1, Fig.

Table 1. Summary of chemical characteristics for upper top sediment at each sampling station. Standard deviations are included in the parenthesis

Factors	Sampling stations			Seasonal sampling numbers
	Mudflat (A1-A2)	Channel middle slope (A4)	Channel lower slope (B)	
pH	7.60(±0.20)	7.58(±0.12)	7.44(±0.13)	14
Coductivity (mmho)	7.01(±2.08)	5.68(±1.45)	4.88(±1.19)	13
Sodium(mg Na/g)	14.39(±3.81)	13.86(±1.64)	11.33(±3.28)	9
Potassium(mg K/g)	0.90(±0.17)	1.09(±0.12)	0.92(±0.16)	9
Phosphorus(µg P/g)	0.59(±0.26)	0.98(±0.20)	0.86(±0.26)	9
Organic nitrogen(mg N/g)	0.57(±0.24)	1.31(±0.22)	1.20(±0.25)	9
Organic matter(mg/g)	8.72(±0.95)	24.09(±2.35)	27.29(±2.84)	14

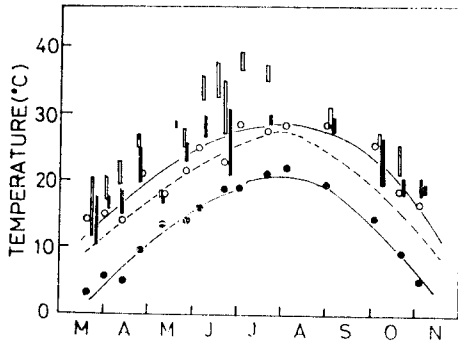


Fig. 2. Seasonal changes of the superficial sediment temperature (solid bar; channel slope, open bar; mudflat), water temperature during flood tide (broken line), and maximum and minimum air temperature (solid line).

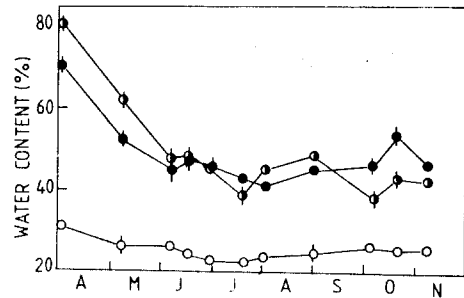


Fig. 3. Seasonal changes of water content of sediment. Semi-closed circle; lower slope, closed circle; middle slope, open circle; mudflat.

4, Fig. 5). pH values of sediment were between 7 and 8 to show a alkaline property. Electric conductivities of the mudflat were higher than those of channel slope, however, soil water contents were reverse. Conductivities varied from 2.0 mmho to 13.0 mmho at the mudflat and from 2.8 mmho to 9.0 mmho at the slope. Pattern of sodium concentration accorded with that of conductivity (Table 1). Sodium was the most greater component in this saline environment. Saline salts were concentrated by the water evaporation on the sediment surface, especially on the mudflat surface (Fig. 5). However, extractable potassium content had no significant differences among the stations and through the season.

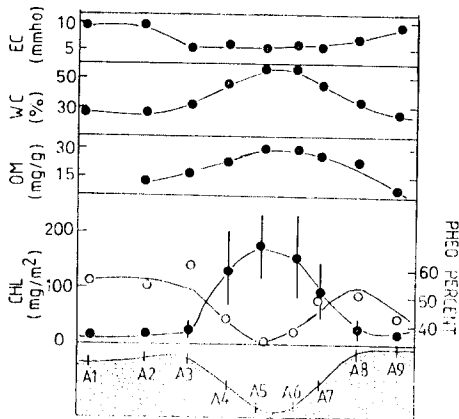


Fig. 4. Topographical changes, electric conductivity (EC), water content (WC), organic matter (OM), chlorophyll a (CHL; solid circle) and pheopigment percentage (open circle) along the channel transect. These data are mean values (n=15) measured in May, July and October, 1982.

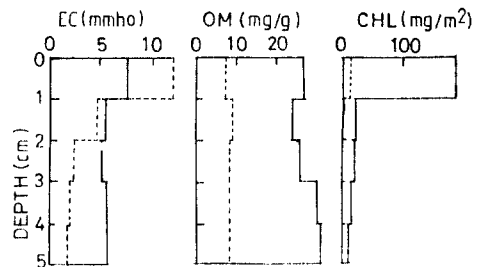


Fig. 5. Profiles of mean electric conductivity, organic matter and chlorophyll a content in upper 5cm of sediment. Solid line indicates data of middle slope and broken line does data of mudflat.

Organic matters of the sediment ranged from 7.9mg/g to 11.0mg/g at the mudflat and from 21.9mg/g to 34.0mg/g at the slope. Organic matters of the mudflat were almost constant with the depth, however, increased with depth at the channel slope(Fig. 5). Sediment below 0.5cm depth revealed the very black color after May and very awfully odor was spread arround at the channel slope in June-August. Under these reduced condition, the decomposition of organic matter would be inhibited. The distributional pattern of organic nitrogen was similar with that of organic matter(Table 1). Organic nitrogen amounted to be 4.4% to 6.5% of organic matter.

Species composition Diatom floristic composition was investigated on A4 station of the channel slope. One hundred and thirty-seven taxa were enumerated during the study period. Eighteen species have not been identified, which was composed of 13% or more the total cell numbers. Those over 2.5% relative abundance were arbitrarily considered of high importance. Seasonal changes of these nine taxa in relative abundance are displayed in Fig. 6. The important taxa accounted for 8.3% of total species numbers, but 58.0% of all cell numbers counted in diatom assemblage. Diatom taxa below 2.5% abundance, with exception of unidentified taxa, were listed in Table 2. Rare taxa below 0.1%, 0.5% and 1.0% relative abundance comprised 47%, 78% and 84% of total species numbers, respectively. However, the three groups accounted for only 2.5%, 12.5% and 18.0% of total cell counts. Their floristic characteristics would be important in comparison with their numerical contributions in the algal assemblage.

Paralia sulcata and *Cymatosira belgica* invariably maintained their abundance until the end of study, however, their relative abundance had not a clear seasonality. Association of *Paralia sulcata* and *Cymatosira belgica* would be unusual because *Paralia sulcata* was considered as typical epipellic diatom and *Cymatosira* species as sand-attached diatom(Hendey,

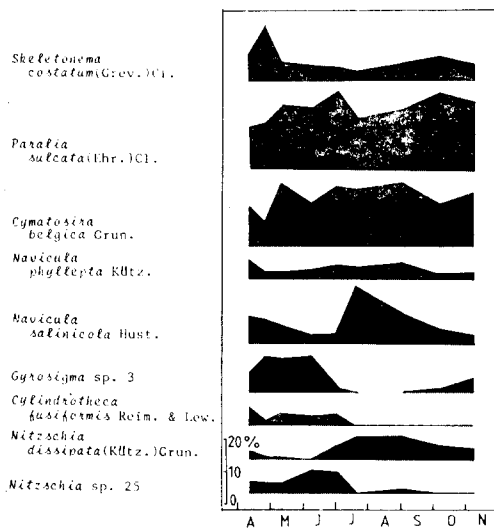


Fig. 6. Relative abundance for the important benthic diatom taxa on the channel slope.

1964). This association was found on the mudflat of Küm river estuary(Kim and Cho, 1985). Especially, *Paralia sulcata* was found as the most abundant species on the sediment(Shim and Cho, 1984; Kim and Cho, 1985) and also in the planktonic diatom community in the west coast of Korea(Shim and Cho, 1984). *Navicula salinicola* and *Nitzschia dissipata* occurred with high abundance in June and August. The common diatom species had low and more or less uniform frequency throughout the study period. This algal group was composed of *Cyclotella meneghiniana*, *Rhaphoneis amphiceros*, *Rhaphoneis surirella*, *Navicula phyllepta* and *Nitzschia pellucida*. The another taxa, which were a little or

Table 2. Taxa, less than 2.5% relative abundance, which belong to each stratified abundance range through the study period on the channel slope of the intertidal salt marsh

Taxa ranged 1.0~2.5%	
<i>Cyclotella meneghiniana</i> Kütz.	<i>Gyrosigma spencerii</i> (W.S.) Cl.
<i>Rhaphoneis amphiceros</i> (Ehr.) Ehr.	<i>Amphiprora alata</i> Ehr.
<i>Rha. surirella</i> (Ehr.) Grun.	<i>Cylindrotheca gracilis</i> (Bréb.) Grun.
<i>Plagiogramma vanheurckii</i> Grun.	<i>Nitzschia pellucida</i> Grun.
<i>Pinnularia ambigua</i> Cl.	
Taxa ranged 0.5~1.0%	
<i>Cyclotella stylorum</i> Bright.	<i>Navicula salinarum</i> Grun.
<i>Thalassiosira eccentrica</i> (Ehr.) Cl.	<i>Stauroneis salina</i> W.S.
Taxa ranged 0.1~0.5%	
<i>Cyclotella comta</i> (Ehr.) Kütz.	<i>Gyrosigma fasciola</i> (Ehr.) Cl.
<i>Cyc. stelligera</i> Cl. & Grun.	<i>Amphiprora hyalina</i> Eulen.
<i>Thalassiosira nordenskiöldii</i> Cl.	<i>Gomphonema parvulum</i> (Kütz.) Kütz.
<i>Actinoptychus splendens</i> (Shadb.) Ralfs.	<i>Cymbella affinis</i> Kütz.
<i>Act. undulatus</i> (Bail.) Ralfs	<i>Cym. delicatula</i> Kütz.
<i>Biddulphia aurita</i> (Lyngb.) Bréb. & God.	<i>Cym. ventricosa</i> Kütz.
<i>Diatoma elongatum</i> (Lyngb.) Ag.	<i>Amphora angusta</i> (Greg.) Cl.
<i>Campylosira cymbelliformis</i> (A.S.) Grun.	<i>Amp. coffeaeformis</i> Ag.
<i>Synedra ulna</i> (Nitz.) Ehr.	<i>Cylindrotheca closterium</i> Reim. & Lew.
<i>Achnanthes deflexa</i> Reim.	<i>Nitzschia apiculata</i> (Greg.) Grun.
<i>Ach. haukiana</i> Grun.	<i>Nit. epithemioides</i> Grun.
<i>Ach. minutissima</i> Kütz.	<i>Nit. littoralis</i> Grun.
<i>Navicula cryptocephala</i> Kütz.	<i>Nit. obtusa</i> var. <i>scapelliformis</i> Grun.
<i>Nav. gracilis</i> Grun.	<i>Nit. palea</i> (Kütz.) W.S.
<i>Nav. scopulorum</i> Bréb.	<i>Nit. vermicularis</i> (Kütz.) Grun.
<i>Diploneis weissflogi</i> (A.S.) Cl.	<i>Surirella gemma</i> (Ehr.) Kütz.
<i>Amphiptera rutilans</i> (Trent.) Cl.	<i>Sur. ovata</i> Kütz.
<i>Gyrosigma balticum</i> Rabh.	
Taxa less than 0.1%	
<i>Melosira distans</i> (Ehr.) Kütz.	<i>Navicula flantica</i> Grun.
<i>Mel. granulata</i> (Ehr.) Ralfs	<i>Nav. forcipata</i> var. <i>densestriata</i> A.S.
<i>Mel. varians</i> Ag.	<i>Nav. giffeniana</i> Fog
<i>Coscinodiscus kützingii</i> A.S.	<i>Nav. mutica</i> Kütz.
<i>Cos. lacustris</i> Grun.	<i>Nav. radiosa</i> Kütz.
<i>Cos. lineatus</i> Ehr.	<i>Nav. rhyncocephala</i> Kütz.
<i>Cos. nitidus</i> Greg.	<i>Nav. viridula</i> (Kütz.) Ehr.
<i>Cos. nodulifer</i> A.S.	<i>Nav. viridula</i> var. <i>rostrata</i> (Kütz.) Cl.
<i>Cos. obscurus</i> A.S.	<i>Diploneis oblongella</i> (Näg.) Cl.
<i>Actinocyclus ehrenbergii</i> Ralfs	<i>Pinnularia borealis</i> Ehr.
<i>Act. ehrenbergii</i> var. <i>ralfsii</i> (W.S.) Hust.	<i>Trachyneis aspera</i> (Ehr.) Cl.
	<i>Frickia lewisiana</i> (Grev.) Heid.

Podosira stelligera (Bail.) Mann
Asteromphalus heptactus (Bréb.) Ralfs
Biddulphia dubia (Bright) Cl.
Bid. *obtusa* (Kütz.) Hust.
Cerataulus turgidus Ehr.
Eucampia zodiacus Ehr.
Anaulus balticus Simon.
Fragilaria pinnata var. *lancettula* Hust.
Ceratoneis arcus Kütz.
Diatoma vulgare Bory
Meridion circulare var. *constricta* V.H.
Synedra delicatissima W.S.
Syn. *ulna* var. *contracta* Östrup.
Syn. *vaucheriae* Kütz.
Achnanthes hungarica Grun.
Ach. *lanceolata* (Bréb.) Grun.
Cocconeis placentula var. *lineata* Cl.
Navicula alpha Cl.
Nav. *capitata* var. *hungarica* Ross
Nav. *cari* Ehr.

Pleurosigma angulatum (Quek.) W.S.
Ple. *diverse-striatum* Meist.
Gomphonema clevei Fricke
Gom. *olivaceoides* Hust.
Gom. *sinuata* Greg.
Cymbella naviculiformis Auers.
Rhopalodia gibberula (Ehr.) O. Müll.
Nitzschia acicularis W.S.
Nit. *dubia* W.S.
Nit. *navicularis* (Bréb.) Grun.
Nit. *obtusa* W.S.
Nit. *panduriformis* Greg.
Nit. *parvula* Lew.
Nit. *punctata* (W.S.) Grun.
Nit. *punctata* var. *minor* Hust.
Nit. *sigma* (Kütz.) W.S.
Nit. *sinuata* var. *tabellaria* Grun.
Nit. *tryblionella* var. *levidensis* Grun.
Hantzschia amphioxys (Ehr.) Grun.
Surirella fastuosa (Ehr.) Kütz.
Sur. *ovata* var. *pinnata* Kütz.

scarcely observed in summer, were *Skeletonema costatum*, *Pinnularia ambigua*, *Gyrosigma spencerii*, *Gyrosigma* sp. 3 and *Cylindrotheca fusiformis*. In spring, euglenoids were accounted for approximately 17% of the total diatom cell counts. Compared with diatoms, euglenoids have a very large cell volume. Their contribution to benthic algal assemblage would be very highly important.

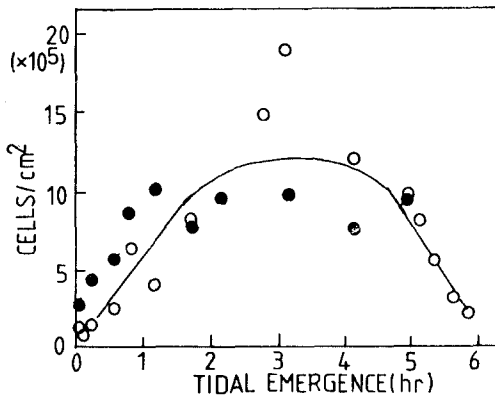


Fig. 7. Vertical migration of benthic algal assemblage during the tidal emergence at two positions of channel slope, water well-drained(closed circle) and poor-drained(open circle) position.

Algal migration After tidal emergence, it could be observed with naked eye that green or brown color appeared on the muddy surface, dense algal mat was formed and then surface was frothy with bubbles of gas. Quantitative analysis about algal migration was conducted on the two positions; One was well-drained mud and another was poor-drained mud at June, 6 and 19. Poor-drained station was waterlogged for a long time after tidal emergence. Benthic algae were harvested with lens tissues(Eaton and Moss, 1966). The harvested algal taxa were raphid pennate diatoms such as *Navicula*, *Gyrosigma*, *Nitzschia* and euglenoids. Cell counts captured with lens tissues in

series of time schedules were summarized in Fig. 7. On the well-drained position, algae finished the movement toward surface within one hour after the emergence, however, on poor-drained position the pattern was different. The algae completed their downward migration before the return of the tide. Therefore migratory movement was controlled by tidal rhythm and water content of sediment (Palmer and Round, 1967). We did not investigate further detailed mechanism for migratory rhythm of benthic algae. It was suggested that this reaction would be a positive phototactic response and primarily a diurnal rhythm, not a tidal rhythm (Palmer and Round, 1967). We conclude that it is a subtle mechanism to maintain a large quantity of algal biomass under variable tidal influence.

Chlorophyll Chlorophyll a content declined from 244mg/m² in spring to 65mg/m² in autumn at the middle slope and markedly decreased after May at the lower slope (Fig. 8B). At the mudflat chlorophyll content ranged from 7mg/m² to 25mg/m² and did not show the clear seasonal pattern. Chlorophyll a content peaked at March on channel lower slope, at April on channel middle slope and at May on mudflat. The peak time had a one-month difference among three stations. Visual observation throughout the study period gave some indication of the spatial and seasonal variation in algal biomass. During the spring, a rich algal mat was developed on the surface. This specific green color was due to the presence of the euglenoids on the surface. Chlorophyll content of euglenoids would significantly contribute to the total photosynthetic pigment in comparison with their numbers. During the later spring and early summer, brown-green color developed on surface sediment, however, completely disappeared in summer and early fall and surface color became to be a dull grey. Especially, these phenomenon was conspicuously observed with naked eye on the channel lower slope.

Functional chlorophyll a decreased markedly with sediment depth (Fig. 5). Chlorophyll more than 75% of total pigment was extracted above 1cm depth and considerable chlorophyll was detected below the surface. It would be due to the disturbance by the animal activities and by the people who disturbed and dug the sediment to search for the crabs or other zoobenthos. As light did not penetrate below 0.5cm depth sediment (Perkins, 1963), naturally living diatoms would not persist within the sediment for many days. Many siliceous diatom frustules were detected within the sediment, however, no distinction was made between living and dead cells because frustules were treated with acid.

The pheopigment percentage varied from 51% in spring to about 65% in summer at mudflat and from 33% to 45% at middle slope, and from 31% to 60% at lower slope (Fig. 8A). The percentage pheopigment increased after May on the all stations. The pheopigment percentage negatively correlated with functional chlorophyll along transect across the channel (Fig. 4).

From the chemical data of along topographical transect of channel, correlation between chlorophyll and water content, organic nitrogen, organic matter, phosphorus and potassium were +0.982, +0.887, +0.818, +0.596 and +0.643, respectively. With pH, sodium and conductivity, coefficient values were -0.776, -0.668 and -0.225, respectively. Calculated

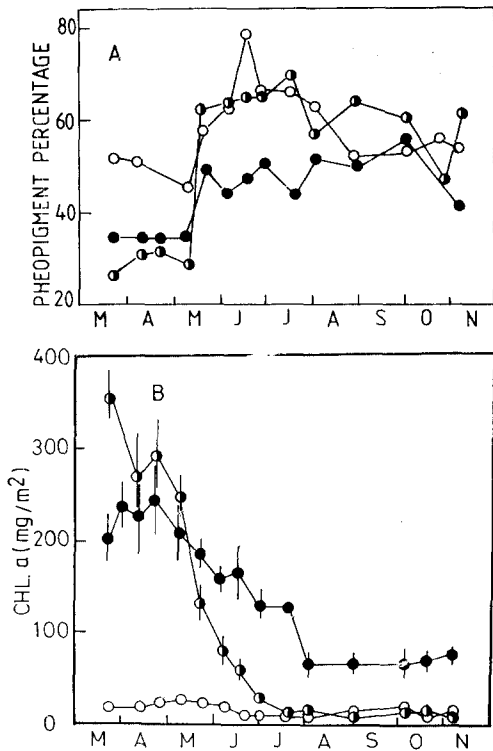


Fig. 8. Seasonal changes of pheopigment percentage of total pigment(A) and chlorophyll a content of benthic algal assemblage(B). The symbols are identical with those of Fig. 3.

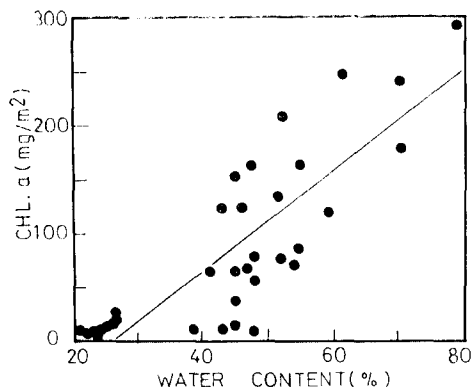


Fig. 9. Relationship between water content and chlorophyll a standing crop of sediment through the study period. $y = -94.612 + 3.877x$, $r = 0.734$.

with seasonal data, correlation between chlorophyll and water content of sediment had $+0.734$ (Fig. 9). It was suggested that sediment water content would considerably regulate the algal growth and biomass. Two assumptions would be considered about the sharp decrease of chlorophyll at the lower slope. One is environmental factor and another is grazing effect. In field, many burrows of crabs(*Macrophthalmus japonica*, etc.) spread along the channel slope. The algal yellow-green mat on sediment surface disappeared around the burrows. To illustrate the grazing effect, the number of burrow per $0.1m^2$ were counted and chlorophyll was determined at August along the same horizontal level on channel slope. Chlorophyll standing crop decreased to 80% in comparison with intactly ungrazed area. Conversely, nonfunctional pheopigment increased from 52% to 60% of total pigment.

Photosynthesis and production: Sediment materials taken A1 and A4 station were subjected to a series of irradiance at two temperatures(Fig. 11B). Less than 40w

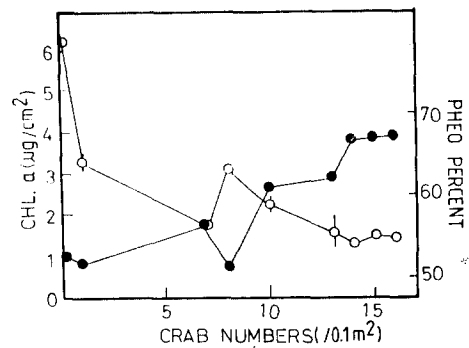


Fig. 10. Relationship between the number of crab, chlorophyll a content(open circle) and pheopigment percentage(closed circle) to illustrate the grazing effect on benthic algal by zoobentos.

/m² irradiance, photosynthetic rates were independent of temperature. Above 40 w/m², algal photosynthesis increased sharply with irradiance and temperature change. Maximum hourly rate of photosynthesis was estimated to be 149 mg O₂/m² and 306 mg O₂/m² at two temperatures. The temperature effect on photosynthesis, as reflected in Q₁₀ value, was about 1.8. A series of temperature at the 150 w/m² irradiance, there was a more or less pronounced decrease in photosynthetic rate over 30°C (Fig. 11A). In this condition below 25°C, the Q₁₀ value was 1.9. Correlation between photosynthesis and chlorophyll a content showed highly linear significance with a determination coefficient of 0.979 (Fig. 12). Mean respiration of sediment were 6.1±2.1 mg C/m²/hr at mudflat and 11.4±1.6 mg C/m²/hr at channel slope. Respiration was measured six times throughout season and no significant difference was found. To estimate the net algal production it was necessary to separate the algal respiration from heterotrophic respiration. After scraping the sediment surface, the O₂ consumption was measured in darkness to estimate the heterotrophic respiration. Respiration rate declined to 85~90% of that of undisturbed sediment. It is probable that the respiration of the benthic community would be predominated by heterotrophic organisms such as bacteria and meiofauna (Pomeroy, 1959; Gallagher and Daiber, 1973).

Daily production was estimated in terms of daily mean sediment temperature, chlorophyll

a content and sunshine duration as predictor variables. Total production during the study period accounted for the sum of daily production. This estimation was based on the assumptions that production would be related to chlorophyll a standing crop, temperature and sunshine duration, and maximum photosyn-

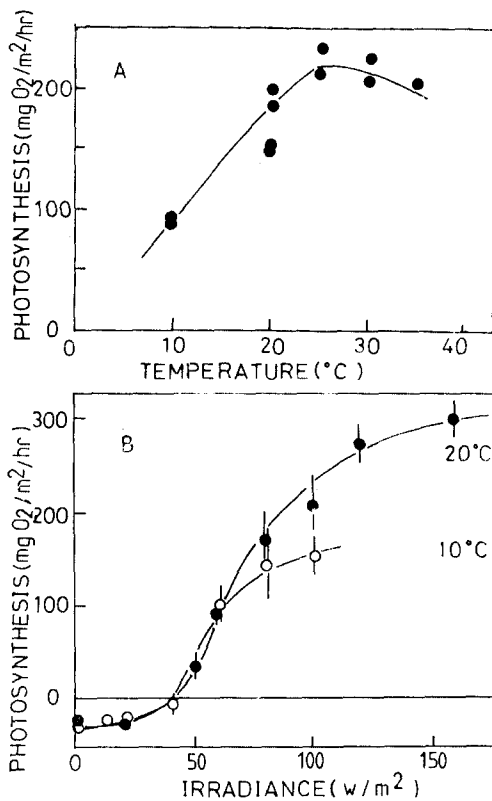


Fig. 11. Photosynthesis-temperature curve(A) and photosynthesis-irradiance curve(B) of benthic algal assemblage.

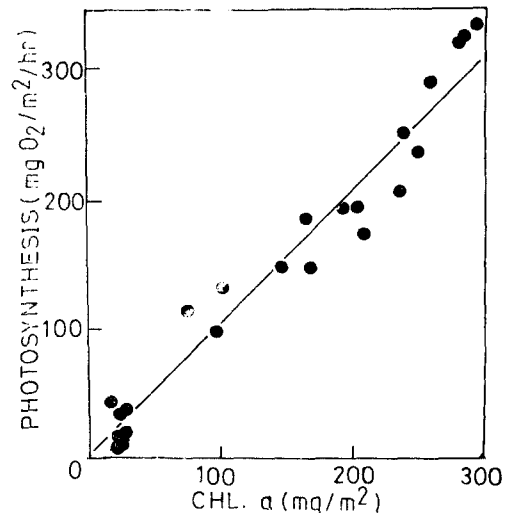


Fig. 12. Relationship between photosynthesis and chlorophyll a content of benthic algal assemblage at 20°C, 150w/m² condition. $y=2.522+1.017x$, $r=0.979$.

Table 3. Net production(Pn), respiration(R) and daily gross production(Pg) of the benthic algal assemblage on mudflat and channel slope at the intertidal salt marsh

Month	Sunshine duration (hr/day)	Pn(mg C/m ² /hr)		R(mg C/m ² /hr)		Pg(mg C/m ² /day)	
		flat	channel	flat	channel	flat	channel
Mar.	7.14	5.6	73.2	8.0	11.4	232	795
Apr.	7.86	5.6	116.8	9.1	12.2	263	1,210
May.	6.12	7.8	97.3	5.3	11.6	176	873
Jun.	8.02	-1.6	60.0	6.2	11.2	135	751
Jul.	7.14	-3.7	53.1	6.1	10.5	120	631
Aug.	6.79	-1.9	27.8	6.1	11.4	134	461
Sep.	7.37	7.3	38.2	6.8	11.4	217	555
Oct.	6.87	9.3	34.6	6.8	11.4	227	511
Nov.	5.48	6.6	32.7	6.8	11.4	199	453

thesis be maintained during the sunshine. Moreover, production was estimated without correcting for the insolation and inundation hours. When the sediment were flooded with tidal current, we assumed that metabolic activities were similar with those of emergence state. Hourly net production, respiration and daily production per month were summarized in Table 3. Net production per hour at channel slope amounted to be 117 mg C/m² in April, decreased to be 28 mg C/m² in August and slightly increased in October.

DISCUSSION

Benthic algal flora and biomass associated with sediment changed topographically and seasonally along the channel and coincided with the environmental factors as follows. First, water content of sediment, especially the top superficial surface, would be very important for migration and movement of the epipellic benthic algae. Sediment interstitial water could be regarded as movement media for benthic algae necessary to migrate downward or upward the surface. Water content below the level would inhibit migratory movement and reduce the growth and biomass of algae. In the study area which had a sharp discontinuity in sediment water content, water in sediment can primarily regulate the distribution of algae. For example, chlorophyll a standing crop was proportional to sediment water content(Fig. 9). Second, organic matters such as organic carbon and nitrogen also play an important role in the distribution and biomass of benthic algae. Moreover the organic matter acts as the source for inorganic nutrients such as phosphate, nitrate and ammonia. In Küm river estuary, inorganic nutrient concentrations of sediment amounted to be more 25 to 300 fold than that of ground sea water(Kim and Cho, 1985). Inorganic nutrients would be supplied by the microbial decomposition of organic matters and by the direct cell disintegration of microorganisms. The euglenoid distribution would have a close relationship with enrichment of organic matters. The characteristic green algal mat was developed very well on the sediment contaminated with waste sludge. Such a sediment enriched with organic matters

was observed near the flood-controlling water gate around the study area. Third, electric conductivity of sediment would act negatively to algal biomass. Water evaporation by insolation resulted in the concentration of salts in upper sediment surface. Saline salts did not show a significant discontinuity during season and between the sampling stations (Table 1). Saline salts would not likely to affect directly on spatial or seasonal algal distribution in this study area. It was reported that benthic diatom had a broad salinity range for cell division and colonizing the substrates (Williams, 1964; Amspoker and McIntire, 1978). Fourth, sometimes zoobenthos grazed heavily on the benthic algae to decrease algal biomass. The sharp decline in chlorophyll a standing crop at lower slope was due to the environmental as well as biological regulation.

Under low irradiance photosynthesis was independent of temperature. This result was in accord with Pomeroy's (1959) experimental data measured at the Georgia salt marsh. The benthic algal production under the canopy of dense halophytes was not sensitive to sediment temperature, but function of light intensities (Van Raalte *et al.*, 1976). But Gallagher and Daiber's (1973) results showed that temperature had the same amplitude on the photosynthesis at both low and high illuminance. No evidence was found for inhibition at high irradiance at either temperature, in fact, photosynthetic activities would increase appreciably over 150 w/m^2 (Fig. 11B). The benthic algal ability to tolerate and utilize the high irradiance may be an adaptation to intertidal environment. Moreover, benthic algae have a good acclimation ability to different desiccation and irradiance condition (McIntire and Wulff, 1969; Whitney and Darley, 1983). The maximum photosynthesis occurred at significantly high irradiance in summer than winter (Whitney and Darley, 1983).

From our algal incubation, photosynthetic activity per unit chlorophyll a content was estimated to be $0.39 \text{ mg C/mg chl/hr}$ (Fig. 12). This value was far lower than data of epiphytic diatoms measured by IRGA method (Booth and Dromgoole, 1984). The results using oxygen method were similar with our data in photosynthetic activity (McIntire and Wulff, 1969). With the dissolved oxygen method, algal photosynthesis would be estimated to be lower than that of exposed condition. The reasons lie in two points; One would be due in part to self-shading effect of microalgal cells (Gallagher and Daiber, 1973), another would be the algal downward migration in sediment.

Gross production during the study period was 52 g C/m^2 and 190 g C/m^2 at channel slope, and respiration was 59 g C/m^2 and 98 g C/m^2 , respectively. The annual production of benthic algae on the Georgia salt marsh was estimated to be 200 g C/m^2 (Pomeroy, 1959). Annual production in the Delaware salt marsh was about 80 g C/m^2 by using oxygen method in laboratory (Gallagher and Daiber, 1974). The algal productivity in an estuarine mudflat was measured to be $31 \text{ g C/m}^2/\text{yr}$ by using ^{14}C method (Leach, 1970). Primary production of diatom attached to sand grain ranged from 4 to $9 \text{ g C/m}^2/\text{yr}$ in a sandy beach (Steele and Baird, 1968). Our results showed a high production of the benthic algal assemblage in comparison with other author's results. Solar radiation at Inch'on was $1,029,000 \text{ kcal/m}^2$ from March to November, of which PhAR would amount to be 50% of the total radiation. On the basis of photosynthetically active radiation, photosyn-

thetic efficiency were 0.10% at mudflat and 0.37% at channel slope. Benthic algae may be more important to intertidal salt marsh energetics as autotrophic organisms than its quantity indicates since it is immediately available for the algal-detritus feeders in sediment ecosystem.

적 요

경기만 조간대 염습지의 수로에서 저생규조류의 종조성, 현존량 및 일차생산성을 생물학적, 물리화학적 저토 환경과 관련시켜서 조사하였다. 저생규조류는 총 137 taxa가 관찰되었고, 이 중 *Paralia sulcata*와 *Cymatosira belgica*가 우점종으로써 조사 기간 중 출현 총 개체수의 32.6%를 차지하였다. 규조류의 종별 상대적 수도는 계절에 따라 뚜렷한 변화가 없었다. 저생조류의 현존량은 주로 저토함수량에 의하여 영향을 받았고, 계절적 변화가 뚜렷하였으며, 개와 같은 저서동물의 섭식에 의하여 부분적으로 현존량 차가 크게 나타났다. 특히 춘계에 다량의 euglenoid의 출현은 현존량 및 일차생산성의 계절적 변화를 보다 크게 하였다. 실내 배양을 통한 용존산소법으로 측정된 광합성은 저광하에서는 온도의 영향을 거의 받지 않았고, 40 w/m² 이상의 광도에서는 온도의 영향을 크게 받았다. 조사기간 중 수로연변 저토에서 저생조류의 총생산량은 190 mg C/m²이며 총생산에 대한 광합성 효율은 조사기간의 총 PhAR에 대해 0.37%이었다.

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