The Journal of the Oceanological Society of Korea
Vol. 2, No. 1-2, p. 13-23, December 1967

STUDIES ON THE PRIMARY PRODUCTION IN SUYONG BAY*

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ABSTRACT

Seasonal changes in the primary production of surface water in Suyong Bay, Pusan, were measured using a light-dark bottle method. Gross photosynthesis followed a distinct seasonal change with highest levels in spring and fall. Respiration of plankton community showed its maximum only in the late summer and early fall. Net photosynthesis of plankton community is considerably variable throughout year, but followed a seasonal change similar to gross photosynthesis. Seasonal changes in temperature and salinity are related to the seasonal change in plankton metabolism.

INTRODUCTION

The primary production of the oceans depends almost exclusively upon phytoplankton. In any sea region the relationships among all trophic levels of organisms, not to mention their numbers and kinds, are all limited and controlled by the amount of phytoplankton production (Bogorov, 1958). Thus, the quantitative study of phytoplankton production is of fundamental importance to oceanography, and currently it has also begun to be well appreciated in the light of its vital interest to fisheries.

Much data on nearly all the parts of the oceans have been gradually accumlated, in particular, spasmodically over the past decade since the carbon-14 technique was pioneered by Steemann-Nielsen in 1952. At present most marine laboratories all over the world are making intensive studies of phytoplankton production in their regions of interest, but it is only recently in Korea that attention has been paid.

Measuring the production of marine phytoplankton in Korean waters was first made by Choe and Chung (1966) using the *in situ* carbon-14 method. Their investigation covered all the coastal waters of Korea, and revealed that the most productive values were generally found along the east coast of Korea facing the Japan Sea and the lowest along the Yellow Sea. Unfortunately, however, omission was put to the data on the summer and winter seasons, and no picture was presented of seasonal changes in the primary production of any given regions all the year round.

In this paper data on the seasonal production of phytoplankton are reported, together with salinity and temperature for the waters of Suyong Bay, Pusan, which was one of 25 localities studied by the workers mentioned above. The study was initiated in the late summer of 1966 at a single, fixed station in the bay (Fig. 1).

Suyong Bay lies about eight kilometers northeast

Submitted to the Graduate School of Pusan Fisheries College in particl fulfillment of the requirements for the degree of Master of Science.

of downtown Pusan, representing one of inlets arched along the coastline in transition from the Korea Strait to the Japan Sea. It is a small, open bay with a total area of approximately ten square kilometers. The water depths over most of the bay are less than nine meters. Daily tidal change is about one meter. Several brooks empty into it, but their influence is nearly restricted to the surf zone. This may be responsible for the sharp fluctuation of salinity at times along the surf zone, and the zone was considered to be inadequate for performing the present investigation. The outer part of the bay, more or less far from the direct effect of land drainage, was satisfactory.

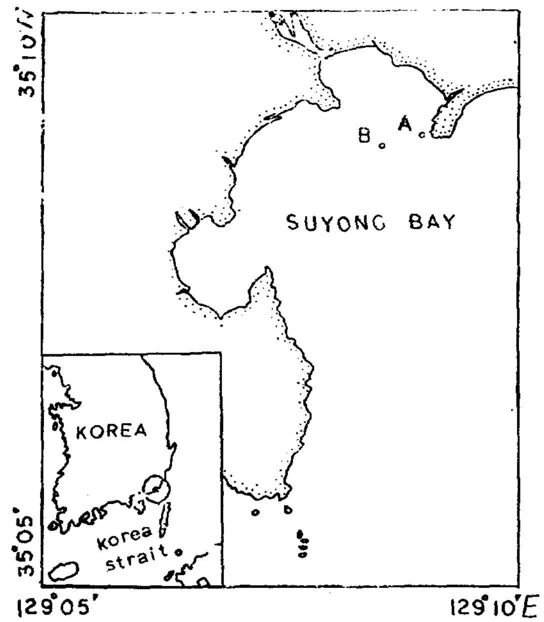

Fig. 1 Map showing the location of the investigation area. The letter A and B denote the stations where experiments were carried out.

Acknowledgements

The author wishes to acknowledge Dr. Byung Don Lee, Director of the Haewundae Marine Laboratory, for the valuable suggestions during the course of the study and for helpful criticism of the manuscript. He also kindly supplied the facilities required for performing the study. Grateful appreciation must be extended to Miss Jung Shin Choe and Mr. Sung Yun Hong who helped to perform the experiments in the field throughout the study.

METHODS

Estimates of primary production were made by measuring changes in dissolved oxygen in light and dark bottles (Gaarder aud Gran, 1927). Commonly termed "light and dark bottle method" this technipue has been widely employed because of its simplicity, but many revealing experiments have shown some convincing evidences that a number of obstacles are inevitably involved in practice; the higher respiration of light-treated populations (Riley, 1938; Gessner and Pannier, 1958; Pratt and Berkson, 1959), the effect of proliferated bacteria (Vaccaro and Ryther, 1954; Steemann-Nielsen, 1954; Ryther, 1956; Steeman-Nielsen; 1958a; Sieburth, 1959; Ragotzkie, 1959), the formation of air bubbles during incubation (Steemann-Nielsen, 1958a; Strickland, 1960), variable photosynthetic quotient (Ryther, 1956; Strickland, 1960; Antia *et al.*, 1963), the reduction of water turbulence (Ohle, 1958; Talling, 1960; Patten *et al.*, 1964), bottle position in relation to energy source (Ohle, 1958; Patten *et al.*, 1964), carbon dioxide limitation at high pH (Talling, 1960), bottle leakage (Patten *et al.*, 1964), and the precision of the Winkler titration (Steemann-Nielsen, 1958a; Strickland, 1960; Patten *et al.*, 1964). From these studies a conclusion may be drawn that the light and dark bottle technique is as useful as the carbon-14 technipue in the routine determination of primary production so far as some recommendations are followed (Patten *et al.*, 1964).

A slight modification of the technique was required. It was necessary to stimulate the agitation of bottled phytoplankters. For this purpose a bottle holder was used which accommodated three light bottles and three dark bottels. This is essentially the bottle holder contrived by McFarland (1963).

The capacity of the sampling bottles was 100 ml. Another three bottles (start bottles) were required to present data on both net photosynthesis and respiration. The start bottles, light and dark ones were filled by syphoning from an one-gallon glass container submerged in water while the bottling was proceeded. The sample water was vigorously stirred and allowed to stand for 30 minutes with a slight warming in subdued light before the bottling when the sampled water was suspected supersaturated, or to be potentially supersaturated. Treble black vinyl papers were used for wrapping dark bottles.

Throughout the entire course of this investigation, experiments were started between 1000 and 1100(local time) and finished at the same time on the following day. Dissolved oxygen was measured by a modification of the Winkler method (Strickland and Parsons, 1960). The oxygen values were converted to epuivalent carbon production using a photosynthetic quotient of 1.2 (Strickland, 1960; Strickland and Parsons, 1960).

RESULTS

Salinity

Salinities in this study were determined with

Table 1. Seasonal salinity, tide, water temperature, duration of day light and cloudiness at Suyong Bay, Pusan

Date			Salinity (‰)	Tide	Temp. (°C)	Duration of Day Light (hr)	Cloudiness*
Aug.	22,	1966	30.20	high	24.6	13.2	1.5(817)
Aug.	29,	1966	32.57	high	24.5	—	—
Sept.	1,	1966	16.44	low	24.4	12.9	3.8(4.0)
Sept.	5,	1966	31.94	high	25.1	12.7	6.3(3.0)
Sept.	24,	1966	33.03	low	21.8	12.0	10(7.0)
Sept.	27,	1966	30.10	low	20.6	11.9	0.9(1.9)
Oct.	5,	1966	34.02	high	21.0	11.6	5.4(4.7)
Oct.	13,	1966	34.31	low	22.0	11.3	3.0(0.9)
Oct.	20,	1966	34.38	high	18.0	11.1	0.7(1.0)
Nov.	2,	1966	33.21	high	18.0	10.7	1.5(0.9)
Nov.	11,	1966	33.60	low	15.6	10.4	0.9(4.5)
Dec.	28,	1966	33.35	low	10.1	9.8	2.9(0.9)
Jan.	6,	1967	34.38	low	12.1	9.9	10(3.3)
Jan.	15,	1967	34.47	high	12.0	10.0	1.5(1.2)
Feb.	2,	1967	34.31	high	11.8	10.4	3.5(3.5)
Feb.	17,	1967	34.56	high	10.1	10.9	1.6(1.7)
Mar.	9,	1967	34.51	high	12.1	11.6	1.9(8.1)
Mar.	23,	1967	34.54	low	12.2	12.2	3.4(1.2)
Apr.	9,	1967	33.98	high	14.1	12.9	10(10)
Apr.	22,	1967	33.71	low	16.2	13.3	1.0(3.6)
May	9,	1967	32.80	low	16.8	13.8	10(2.9)
May	25,	1967	32.94	high	18.1	14.2	2.0(10)
June	7,	1967	33.89	high	17.8	14.5	3.5(8.9)
June	15,	1967	33.96	high	17.9	14.5	1.2(5.5)
July	25,	1967	32.64	high	24.4	14.1	—
Aug.	28,	1967	32.00	low	24.2	13.1	1.2(1.4)
Sept.	26,	1967	32.03	high	25.0	12.0	0(3.4)

* Cloudiness is expressed in tenths of the whole sky. Bracked numbers represent cloudiness of the following day of experiment.

the Mohr titration during the period from August 1966 to February 1967, and with a salinometer (Tsurumi) since then. In any employment, triplicate determinations were made on each sample and the mean salinities were listed in Table 1.

There was a wide range in values. Highest salinities around 34.5‰ occurred in October 1966 and January, February and March 1967, and the lowest salinity 16.44‰ in September 1966 (Fig.3). Daily variation in salinity was surprisingly radical in the surf zone where station A was located. This was related to land drainage and its combination with daily tidal changes.

Over the period of August and September 1966, the present study was carried out at station A. Due to the daily redical change in salinity station B was used for the succeeding experiment.

Station B was much less susceptible to land drainage. The variation of salinity followed a seasonal pattern in relation to seasonal distribution of the amounts of rainfall and evaporation. The over-all seasonal change shows that a slight increase in salinity starts in January 1967. This increase reflects the poor rainfall during the winter season. The maintenance of highest salinities for January 1967 through March 1967 was followed by a decline of April 1967. The decline was maintained over the spring season. Obviously it was correlated with the return of rainy season. The second increase in salinities beginning in June 1967 resulted from a drought at that time.

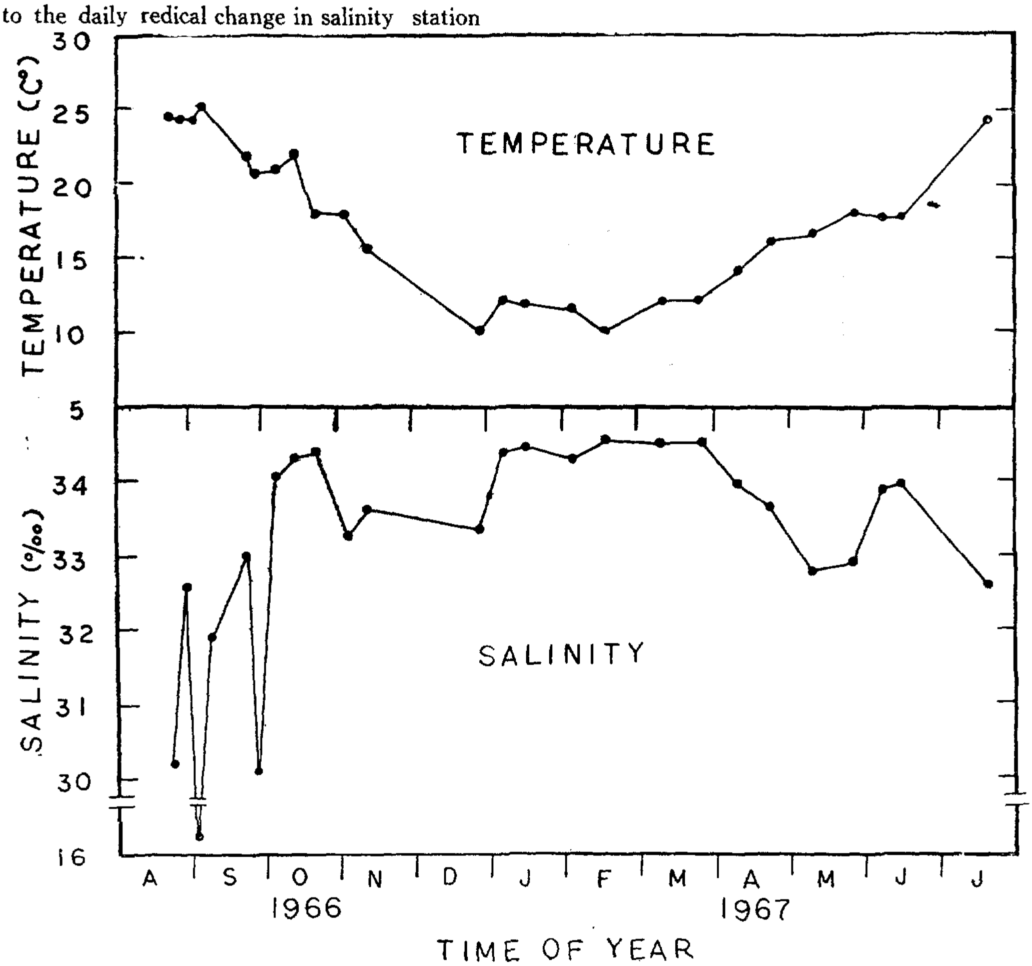

Fig. 2. Seasonal changes in temperature and salinity of the surface water of Suyong Bay, Pusan.

Temperature

The water showed a distinct seasonal changes in temperature throughout the year with an annual range of 15°C, at the surface (Fig.2). The highest water temperatures, more than 24°C, were encountered in August and early September 1966. With the advance of fall, water temperatures gradually decreased and reached the lowest values during winter. Needless to mention, the decrease of surface temperature was accompained by that of air temperatures, but it was notable that temperature for winter did not decrease less than 10 °C in spite of the fact that air temperatures then were far less than -10°C. Water temperature started to increase in late March 1967, and attained the maximum values during summer and early fall.

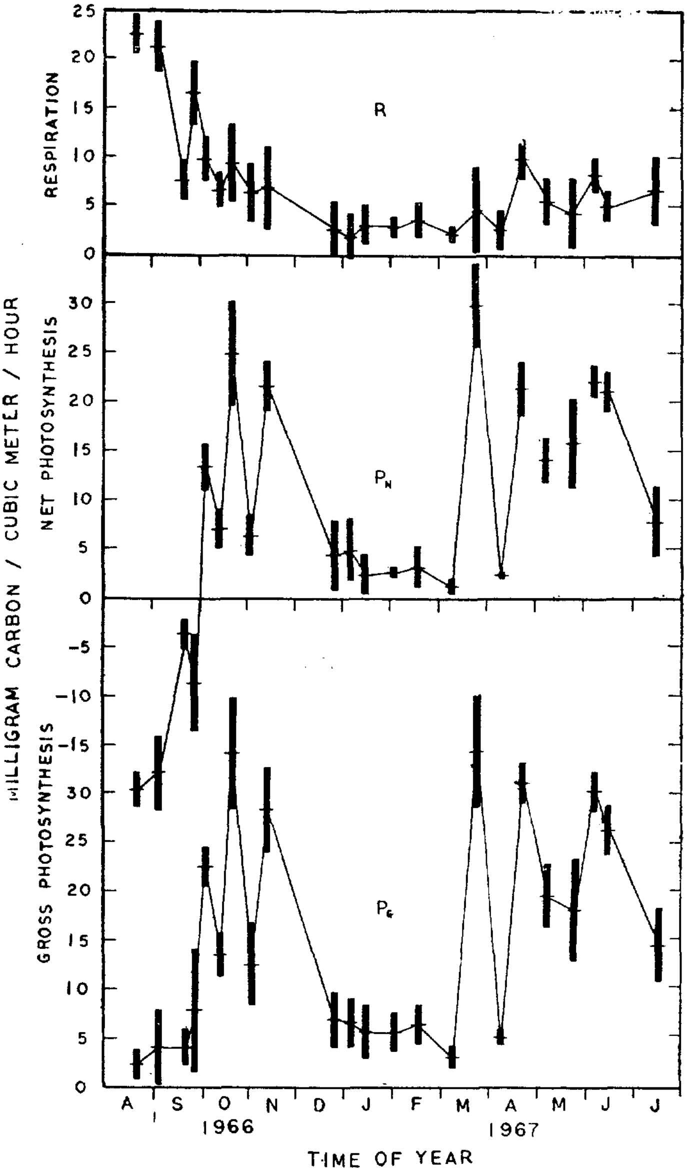

Fig. 3. Seasonal plankton metabolism in the surface water of Suyong Bay, Pusan.

Gross Photosynthesis

Experimental data are summarized in Table 2 and 3. The seasonal pattern of plankton metabolism is shown in Fig. 3.

The rate of gross photosynthesis Pg varied throughout the year with a wide range. Low rates were maintained during the late summer and early fall with an average of 4.38 mg C/m³/hr (SE±0.406). Bursts of high Pg occurred in the early October, and continued throughout the remaining part of the fall season. The mean rate of Pg of this period was 21.94 mg C/m³/hr (SE±1.250). After the fall maximum came a winter depression lasting from December through early March with a mean rate of 5.35 mg C/m³/hr (SE±0.228). In late March started a spring peak, and the spring Pg was kept at high rates even until mid-June except for a case of early April. The mean amounted to 26.90 mg C/m³/hr (SE±0.625) during this period.

Thus it is evident that seasonal change in the rate of Pg follows a distinct pattern with two peaks, i.e., spring and fall. The highest rate of the spring Pg exceeded the lowest August-September rate by a factor of 6.0 (Student's t=3.404, where t(.995)=2.878).

Table 2. Seasonal oxygen values for start bottles and 24 hr dark and light bottles from samplings of the surface water at Suyong Bay, Pusan. Data represent mean oxygen values and the 95% confidence limits expressed in mg oxygen per liter.

Date of Sampling			Start Bottle Mean±95%CI		Light Bottle Mean±95%CI		Dark Bottle Mean±95%CI	
Aug.	22,	1966	7.20	0.101	6.35	0.053*	6.26	0.089*
Sept.	5,	1966	7.80	0.114	7.10	0.203*	6.93	0.120*
Sept.	24,	1966	8.41	0.085	8.27	0.038*	8.12	0.100*
Sept.	27,	1966	7.74	0.094	7.40	0.149*	7.11	0.152*
Oct.	5,	1966	7.71	0.096	8.20	0.087*	7.37	0.078*
Oct.	13,	1966	7.45	0.033	7.70	0.100*	7.21	0.076*
Oct.	20,	1966	7.60	0.112	8.48	0.263*	7.27	0.186*
Nov.	2,	1966	7.87	0.088	8.09	0.006*	7.66	0.131
Nov.	11,	1966	7.99	0.089	8.70	0.103*	7.76	0.061*
Dec.2	6,	1966	10.10	0.127	10.23	0.131	10.02	0.152
Jan.	6,	1967	8.72	0.107	8.87	0.114	8.66	0.052
Jan.	15,	1967	8.85	0.025	8.93	0.103	8.76	0.103
Feb.	2,	1967	8.56	0.052	8.65	0.029*	8.47	0.052
Feb.	17,	1967	9.15	0.032	9.26	0.100	9.03	0.036
Mar.	9,	1967	8.85	0.003	8.90	0.052	8.78	0.038*
Mar.	23,	1967	9.24	0.087	10.40	0.249*	9.06	0.255
Apr.	9,	1967	8.49	0.038	8.59	0.065*	8.39	0.074
Apr.	22,	1967	9.44	0.127	10.33	0.131*	9.01	0.025*
May.	9,	1967	8.43	0.066	9.05	0.193*	8.19	0.131*
May.	25,	1967	7.73	0.117	8.45	0.288*	7.53	0.228
June	7,	1967	7.53	0.063	8.54	0.100	7.14	0.108*
June	15,	1967	6.80	0.033	7.78	0.137*	6.57	0.087*
July	25,	1967	7.02	0.065	7.37	0.073*	6.72	0.073*
Aug.	28,	1967	8.82	0.102	9.05	0.038	8.41	0.231
Sept.	26,	1967						

* Difference from start bottle is significant at the confidence limits of 95% level.

Tabe 3. Seasonal plankton production of the surface water at Suyong Bay, Pusan. Data represent mean production values and the 95% confidence limits expressed in mgC/m³/hr.

Date of Sampling			Pg Mean±95%CI		R Mean±95%CI		Pn Mean±95%CI	
Aug.	21,	1966	2.24	1.61	22.67	2.07	-19.74	1.73
Sept.	5,	1966	4.11	3.76	21.33	2.66	-17.30	3.69
Sept.	24,	1966	3.91	1.82	7.63	2.16	-3.72	1.51
Sept.	27,	1966	7.71	6.20	16.54	3.36	-8.82	5.17
Oct.	5,	1966	22.47	1.94	9.77	2.18	13.20	2.24
Oct.	13,	1966	13.55	2.24	6.44	1.71	7.11	2.07
Oct.	20,	1966	33.98	5.80	9.29	3.91	24.69	5.15
Nov.	2,	1966	12.56	4.29	6.22	3.10	6.34	1.93
Nov.	11,	1966	28.25	4.27	6.81	4.18	21.42	2.58
Dec.	26,	1966	6.79	2.84	2.52	2.74	4.27	3.64
Jan.	6,	1967	6.63	2.56	1.89	2.37	4.73	3.16
Jan.	15,	1967	5.31	2.88	2.94	2.00	2.38	2.00
Feb.	2,	1967	5.41	1.92	2.82	1.08	2.58	0.66
Feb.	17,	1967	6.39	1.92	3.44	1.75	2.95	1.92
Mar.	9,	1967	3.04	0.05	1.97	0.67	1.08	0.89
Mar.	23,	1967	34.32	5.84	4.43	4.41	29.89	4.35
Apr.	9,	1967	4.84	0.65	2.50	1.99	2.35	0.24
Apr.	22,	1967	30.94	2.02	9.70	1.95	21.24	2.75
May	9,	1967	19.54	3.40	5.43	2.15	14.11	2.33
May	25,	1967	17.82	5.21	4.38	3.62	15.63	4.41
June	7,	1967	30.24	2.05	8.32	1.75	21.92	1.62
June	15,	1967	26.21	2.46	5.09	1.44	21.12	2.05
July	25,	1967	14.47	3.85	6.65	3.61	7.82	3.66
Aug.	28,	1967	15.26	2.21	9.78	2.24	5.48	2.49
Sept.	26,	1967	18.49	3.02	7.29	1.81	11.20	2.75

Respiration

Respiration (R) demonstrated its maximum only in the period of late summer and early fall without any second distinct peak for another seasons. The mean rate of the maximum period amounted to 16.93 mg C/m³/hr (SE±1.000). However, the high rates were much retarded starting in the late September, and the R of October-November fluctuated between 6 and 10 mgC/m³/hr. The decrease eventually resulted in the lowest rates during winter and early spring. R over this depressed period proceeded at a rare of 2.52 mg C/m³/hr (SE±0.313). There is a trend to show an initial increase in the late March. But it was too slight to exceed a level of 10 mgC/m³/hr.

R was quite different from the Pg in the pattern of seasonal variation. On the average, the maximun rate of R for the late summer and early fall exceeded the winter miximum by a factor of 6.5 (Student's t=23.192, where t (.995)=2.878).

Net Photosynthesis

Net photosynthesis (Pn), the algebraic remainder of Pg and R, all yielded negative values in the late summer and early fall. But in October-November a peak was attained. In the winter it falled off below 5 mgC/m³/hr. Highest levels appeared from the late March, and were maintained throughout the spring and early summer.

Pn followed a pattern similar to Pg in seasonal changes with a wider range. The negative values averaged -12.27 mg C/m³/hr(SE±1.156), while the spring Pn given a mean of 18.75 mg C/m³/hr (SE±0.844).

DISCUSSION

Seasonality of organic production in the open ocean agrees with that of vertical stability of the water (Sverdrup, 1953; Riley, 1939, 1941, 1957). However this can not be the case with shallow water areas which are at all times subject to strong turbulence to exert its effect to the bottom.

A comparison of plankton-metabolism curve with temperature one shows that the pattern of seasonal R coincides well with that of temperature, while more or less marked discrepancies are found for the case of Pg. This perhaps reflects that the rate of Pg is less sensitive, or related indirectly, to temperature compared with R. Steemann-Nielsen and Hansen(1959) found that the photosynthesis of natural plankton population was moderately independent of temperature. However, there has been reported a correlation of temperature with the rate of production in at least a limited period throughout the year (Steemann-Nielsen, 1958; McFarland, 1963). In winter low temperature obviously limited the rate of Pg in Suyong Bay, and the vernal bursts of Pg might be triggered by the initial rise in water temperatures in early spring.

Steemann-Nielsen (1964) reported that in two Danish waters the rate of production at the surface tended to increase with increasing salinity although salinity scarcely may be considered as a factor of direct importance. No marked correlation was found between the rate of Pg and salinity in the present study, but examination of the seasonal salinity curve indicates that the low levels for the late summer and early fall can be related to the radical fluctuation in salinity. This is more convincingly supported by a sudden fall maximum occurring at another station which is less liable to variation in salinity. However, it is not clear that the maximum rate of Pg appeared before October at the new station.

R by plankton tends to rise and fall with temperature. McFarland (1963) reported that in the surf zone of a south Texas beach the high R was correlated with sudden increases in salinity. In the present investigation it was impossible to find any notable correlation between salinty and rate of R, whereas bursts of high R of the late summer and early fall may be related to the sudden changes in salinity. The radical changes might lead the phytoplankton population to a dying fate. Cultural study shows that R grows much higher if the culture is dying (Ryther, 1954). It should be pointed out that the bottled plankton includes organic detritus and its associated bacterial flora. A combined effect ofhigh temperature and bacteria which were much proliferated due to the detritus may be expected to increase the R to the highest level with deppressing Pg accompanied. Thus heterotrophy occurred throughout the period of experiment.

Data on light condition are given in the amount of cloud expressed in tenths of the whole sky. A sudden reduction of Pg in April was correlated probably with the amount of cloud. Steemann-Nielsen (1958 c) reported that any decrease in light intensity due to clouds seriously affect the rate of production. During the winter season sky clearance exerted little effects on the rate of Pg. This suggests that light acts as a major regulating factor only when production runs as a high rate. In winter, the exertion of light as a regulating factor may be frustrated by low temperature. Yentsch (1963) suggested that in the coastal waters the phytoplankton populations would not suffer severe light limitation in winter because of turbulence.

Measurements of primary production for the waters of Suyong Bay are limited to the work of Choe and Chung (1966) by the *in situ* carbon-14 technique. Their study was confined only to two seasons, spring and fall. Their results are obscure to interpret that they mean but possibly represent values near to net photosynthesis. The surface primary production in the bay was estimated to be

17.64 mg C/m³/hr in May 1964, 4.63 in October 1964 and 6.92 in June 1965. The present investigation revealed an average of 23.33 mgC/m³/hr (13.55–33.98) in October 1966 and 18.68 (17.82–19.54) in May 1967.

Estimates of primary production in the North Pacific and its adjacent seas were carried by many workers. Bogorov (1958) made an estimation of the northwestern part of the ocean using the light and dark bottle method, and reported that in the fall of 1954 primary production was below 0.1 mg C/liter/day in the vicinity of Kurile Islands, 0.3 about miles off the islands, below 0.16 further southwards, and below 0.027 in warm Kuroshio waters south of about 40°N. Suyong Bay yielded a mean of 0.176 mg C/liter/day throughout the fall season from September to November.

Kawamura (1963) estimated the surface primary production in the northern part including the Bering Sea to be 0.28–24.13 mgC/m³/hr with a mean of 1.86 in June-August 1960. Saijo and Ichimura (1960) reported 0.1–0.7 mg east off the north Japan. Ichimura and Saijo (1959) estimated of the Kuroshio waters off the central Japan to be 1–4 mg C/m³/hr for coastal areas and 0.1–0.6 for oceanic ones.

Holmes (1958) carried out a study which was made on the eastern Pacific in summer. Low surface primary production of less then 2 mgC/m³/day was reported for the region off the western U.S. and Mexico. Higher values with a range of 9.0 to 20 mgC/m³/day were determined in the region of the northern boundary of the Equatorial Countercurrent (ca. 10°N). Surface production of 15 mg C/m³/day was found in the region of the northern boundary of the Peru Current, 29 mg C/m³/day in the Channel Island area off the coast of southern California, and 71 mgC/m³/day in the Bering Sea.

Seasonal phytoplankton production studies conducted in the Pacific seems to be much limited. Anderson (1964) estimated the primary production off the Washington and Oregon coasts from January 1961 to June 1962. The seasonal variation of the area in primary production was typical; a winter minimum of 1 to 2 mg C/m³/day, a spring maximum of 5 to 50, a short summer minimum of 2 to 5, and a second maximum of 5 to 30 in the late summer. In coastal waters high production persisted nearly for the entire summer. Oceanic waters would not exceed a level of 0.75 mgC/m³/day without a marked seasonal cycle.

Recently in Japan, intensive studies on phytoplankton production were made on bays throughout the country all the year round(Matsudaira, 1964). Only two areas, Tokyo Bay on the Pacific and Maizuru Bay on the Japan Sea, which are located nearly at the same latitude with Suyong Bay, will be considered. Tokyo Bay was appreciated to be one of the most productive bays in Japan. It varied within the range of 10 to 180 mg C/m³/hr, and two peaks encountered in July and in November. Maizuru Bay was found to be one of the least productive areas, and varied with the range of 1 to 23 mg C/m³/hr. The highest value occurred in October and the lowest in January.

These data reflect that Suyong Bay is a relatively high production waters compared with others in the North Pacific and its adjacent seas.

SUMMARY

(1) Seasonal variation in the primary production of surface water in Suyong Bay, Pusan, was estimated for August 1966 through July 1967 using the light and dark bottle method. Simultaneously data were recorded on water temperature, salinity, tidal change and light.

(2) Results show a gradual change in temperature from low values of 10° to 20°C in winter to high values of more than 24°C during late summ-

er and early fall. Salinity followed a more or less distinct change within a very limited range at an outer part of the bay, but the surf zone was subject to surprisingly radical fluctuation.

(3) Gross photosynthesis followed a distinct pattern with two peaks in spring and fall. The spring gross photosynthesis value of 26.90 mg $C/m^3/hr$ exceeded the late summer and early fall. The average value of this period amounted to 16. 93 mg $C/m^3/hr$, exceeding the winter value of 2.52 $mgC/m^3/hr$ by a factor of 6.5. Net photosynthesis is more variable throughout the year, but followed a seasonal change similar to gross photosynthesis.

(4) The pattern of seasonal temperature coincides well with that of respiration, but little with gross or net photosynthesis except for limited periods throughout the year. Radical salinity fluctuation leads to decreasing gross photosynthesis, to increasing respiration and to resulting negative net photosynthesis. Cloudiness exerts serious effect on gross photosynthesis in spring and fall when production runs at a high rate.

(5) Suyong Bay seems to be relatively high production waters in comparison to another waters such as the North Pacifiic and its adjacent seas.

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