

OBSERVATIONS ON THE PRIMARY MARINE PRODUCTIVITY OF NORTHWESTERN INDONESIAN WATERS ¹⁾.

by

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During the fall months of 1957, a scientific cruise was completed in some of the more northwestern fishery areas of Western Indonesia (Fig. 1) on the Indonesian research vessel "Samudera". One of the principal objectives of this cruise was to determine the rates at which inorganic carbon is converted to organic material relative to the waters of the Pacific further east. The physical nature of the waters and the hydrographic results of related cruises have been reported (*e.g.*, SOERIAATMADJA, 1956a & b; SJARIF, 1959; WYRTKI, 1961) elsewhere.

PRIMARY PRODUCTIVITY RESULTS

The isotopic carbon method as applied by DOTY & OGURI (1958, 1959) and ANGOT, DOTY & OGURI (1958) was used to measure primary productivity (Appendix A) at over sixty stations (Fig. 1) in terms of the weight in milligrams of inorganic carbon converted to organic carbon per hour per cubic meter of sea water. The samples were exposed at uniform light intensities of 1500 to 1800 foot candles regardless of the depth from which they came.

For various reasons, now under active discussion in the literature on primary productivity, it seems wise to treat productivity values obtained by the techniques used during this cruise as relative rather than absolute. Thus, though spoken of as merely "productivity", in this paper, the thought is that we are concerned only with relative measurements of net primary

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Productivity per unit of area of the sea can be obtained by integrating the cubic meter values from the different depths (Appendix A) or by extrapolating from the surface cubic meter values. The method of integration simply involves using the sample values from the different depths as values typical for the water from halfway toward the adjacent samples above and below, so that values are available for each cubic meter of the water in a square meter column from the surface to a distance below the lowest sample level equal to half the distance to the next sample above the bottom sample.

The extrapolation methods are a bit more complex. Of the several methods possible, that chosen here was to determine the regression of the integrated square meter column values (gm C/dy/m^2) on the respective cubic meter surface values (mg C/hr/m^3) for the same stations. The regression obtained, $y = 0.080X + 0.116$, was used to calculate the values shown for square meter productivity in Appendix A. A factor of 12 was applied to the hourly square meter rates to adjust them to a quasi-daily figure. The integrated productivity values used, in g C/hr/m^2 , in obtaining the statistics are given in Appendix A in parentheses with the related surface values. Figure 1 gives the location of the stations, including three from STEEMANN - NIELSEN & AABYE - JENSEN'S (1957) study of data from the *Galathea* expedition.

Figure 2 presents both the integrated data and those extrapolated by the method described above. A discussion of these adjusted productivity values is found below in the section titled "Productivity of the different offshore areas".

VARIABLES IN THE RAW PRODUCTIVITY DATA OF APPENDIX A

The authors are aware of several variables, some of which are discussed below, but no corrections were made for them in concluding our analyses. None of the corrections of which we are aware seems justifiable either for the reason of biological uncertainty or for the reason that statistical confidence limits are so low. However, discussion of some of the phenomena found in the course of this work seems desirable.

One of the principal phenomena, often interfering with horizontal plotting of the data, is that of the daily periodicity in the ability of the phytoplankters to photosynthesize. When a plot is made of the productivity measured as a function of the time of sampling, it is usually found that from 09 :00 until 19 : 00 successive values are lower. This is in line with the daily periodicity observed (DOTY & OGURI, 1957) in the ability of

natural phytoplankton populations to photosynthesize. Perhaps the most serious effect of this phenomenon (discussed below) revealed in the data is the low values of Figure 2 from near Biliton Island.

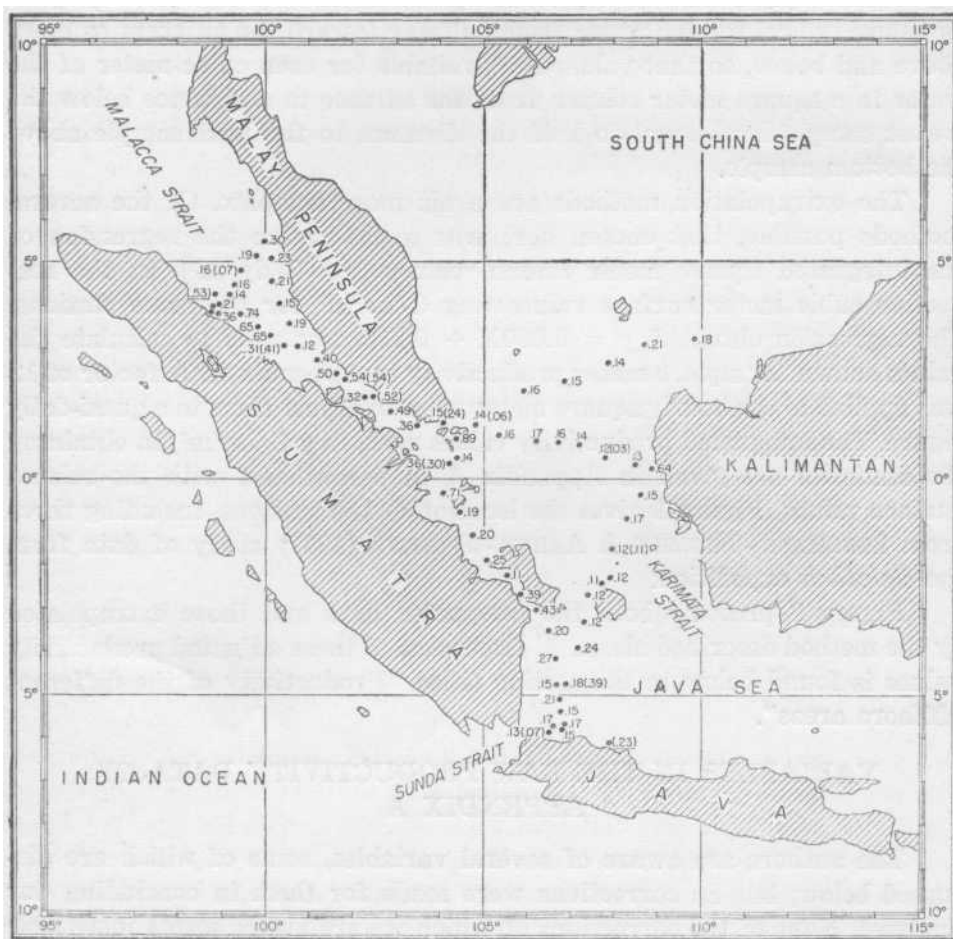


FIGURE 2.

Productivity of the Northwestern Indonesian waters computed from surface cubic meter values except in the cases of numbers which are in parentheses or the underscored values from the "Galathea" expedition. The "Samudera" and "Galathea" values in parentheses were integrated from measurements made at several depths. All values are in terms of grams of carbon fixed per square meter per day.

Unfortunately, not enough similar measurements are available to permit analysis of this periodicity for an entire day. However, a selected set of data from the present cruise (Table I) was assembled for a study

of this point. Among the data of Table I, it is interesting to note a ratio of about five between the mean (1.7 mg C/hr/m^3) of the more open sea surface productivity values obtained between 08 : 00 and 10 : 00 and the mean (0.34 mg C/hr/m^3) obtained between 17 : 00 and 19 : 00. This is quite in line with the difference found elsewhere (KING, AUSTIN & DOTY, 1957; DOTY & OGURI, 1957) or perhaps a little less than would be expected from DOTY'S hypothesis (1959) for these latitudes.

A series of experiments, following a different approach, was conducted with the hope of obtaining a set of correction factors to be used in making adjustments for the difference in the ability of the phytoplankton

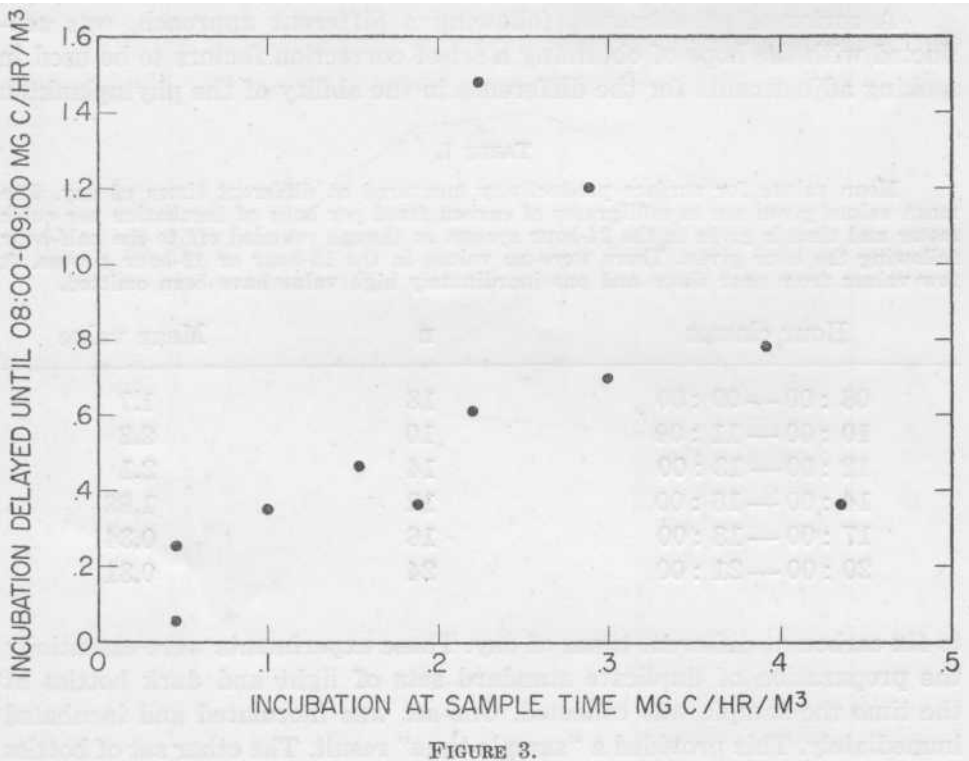
TABLE I.

Mean values for surface productivity measured at different times of day. The mean values given are in milligrams of carbon fixed per hour of incubation per cubic meter and time is given in the 24-hour system as though rounded off to the half-hour following the hour given. There were no values in the 15-hour or 19-hour classes. A few values from near shore and one inordinately high value have been omitted.

Hour classes	n	Mean value
08 : 00 — 09 : 00	18	1.7
10 : 00 — 11 : 00	10	2.2
12 : 00 — 13 : 00	14	2.1
14 : 00 — 16 : 00	12	1.88
17 : 00 — 18 : 00	16	0.34
20 : 00 — 21 : 00	24	0.81

to fix carbon at different times of day. These experiments were essentially the preparation of duplicate standard sets of light and dark bottles at the time the sample was collected. One set was inoculated and incubated immediately. This provided a "sample-time" result. The other set of bottles was held under normal conditions of light and temperature until the following 09 : 00 period when it was inoculated and incubated. This provided a "standard-time" result. The hope was that useful factors for adjusting different "sample-time" results to "standard-time" values would be found. The results of this experiment were merely that the "standard-time" set usually produced a higher productivity value than did the "sample-time" set. The sampling times (around 20 : 00 hours) were such that the carbon fixation by phytoplankton was at its lowest rate for the day, whereas the incubation of the "standard-time" set (near 08 : 00 — 09 : 00 hours) was thought to be (DOTY & OGURI, 1957; YENTSCH & RYTHER, 1957; SHIMADA, 1958) at a time the high rates of photosynthesis are measured

during the day. It is interesting to note the close adherence of seven of the twelve points in Figure 3 to a line and that the average delayed incubation value is nearly twice that of the previous night's incubation. The regression of delayed incubation value on sample time value for the results illustrated is $y = 0.480 + 0.547X$ and the correlation of sets of these values is 0.75.



Plot of values from paired sets of subsamples, one set of which was incubated at the time of sampling"; the other, the next morning. One pair of values is omitted. The delayed value from this pair was 2.036 and the sample time value was 2.937.

When the productivity values from stations where measurements were made at several depths are plotted (Fig. 4) as a function of depth, a family of curves is obtained which supports the idea that productivity is lower at the surface though light intensity is higher. Indeed the curves obtained do not particularly resemble those (*e.g.*, STEEMANN - NIELSEN, 1958) so often advertised as typical of this situation and in our case the most conspicuous case of surface depression was at Station 291, collected and incubated at 21 :15 hours.

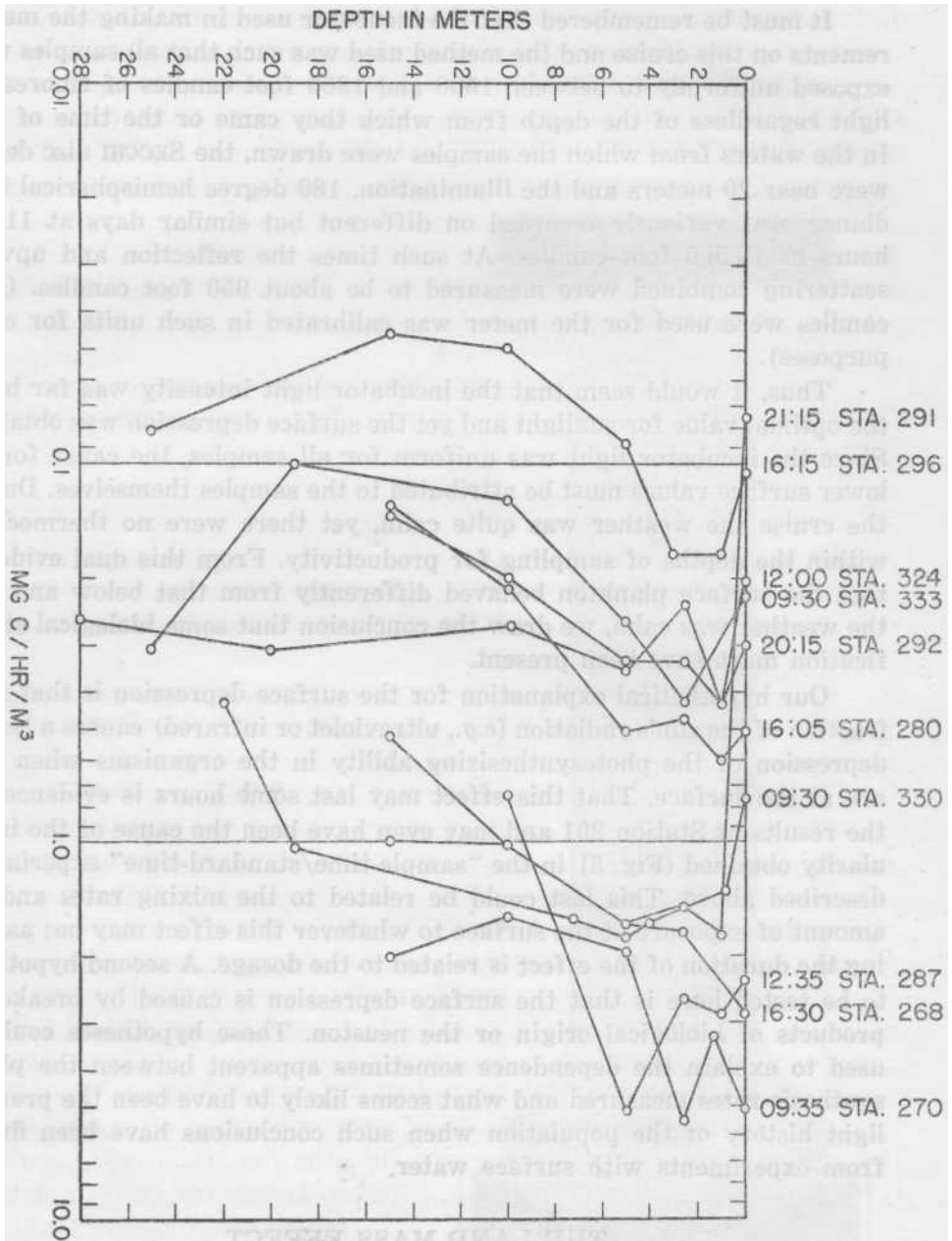


FIGURE 4.

Productivity, plotted on a logarithmic scale, as a function of depth for the stations where measurements were made for several depths. The sample time and the station number are given opposite the surface sample in each case.

It must be remembered that the incubator used in making the measurements on this cruise and the method used was such that all samples were exposed uniformly to between 1500 and 1800 foot candles of fluorescent light regardless of the depth from which they came or the time of day. In the waters from which the samples were drawn, the SECCHI disc depths were near 20 meters and the illumination, 180 degree hemispherical irradiance, was variously recorded on different but similar days at 11 : 30 hours as 10,500 foot candles. At such times the reflection and upward scattering combined were measured to be about 950 foot candles. (Foot candles were used for the meter was calibrated in such units for other purposes).

Thus, it would seem that the incubator light intensity was far below the optimal value for sunlight and yet the surface depression was obtained. Since the incubator light was uniform for all samples, the cause for the lower surface values must be attributed to the samples themselves. During the cruise the weather was quite calm, yet there were no thermoclines within the depths of sampling for productivity. From this dual evidence, that the surface plankton behaved differently from that below and that the weather was calm, we draw the conclusion that some biological stratification must have been present.

Our hypothetical explanation for the surface depression is that some fraction of the sun's radiation (*e.g.*, ultraviolet or infrared) causes a lasting depression of the photosynthesizing ability in the organisms when they are at the surface. That this effect may last some hours is evidenced by the results at Station 291 and may even have been the cause of the irregularity obtained (Fig. 3) in the "sample-time/standard-time" experiments described above. This last could be related to the mixing rates and the amount of exposure at the surface to whatever this effect may be; assuming the duration of the effect is related to the dosage. A second hypothesis to be tested here is that the surface depression is caused by breakdown products of biological origin or the neuston. These hypotheses could be used to explain the dependence sometimes apparent between the photosynthesis rates measured and what seems likely to have been the previous light history of the population when such conclusions have been drawn from experiments with surface water.

THE LAND MASS EFFECT

Since much of the Indonesian marine fishery is concerned with shallow-water forms, special attention was given to the productivity of

such waters. DOTY & OGURI (1956) were able to show that an increase in productivity of several orders of magnitude can be expected as one approaches the shore from the open ocean. This has been referred to as the land mass effect⁵⁾ and may be explained as the result of the action of two processes. One is the accumulation of fertilizer material in the shallow water where the euphotic zone extends to the bottom, a process believed to be brought about in a primary fashion by the benthic algae. A second process leading to higher productivities near shore is, undoubtedly, the addition of fertilizer elements brought into the sea by run-off water from the land. A third factor, turbulence induced by oceanic tides and currents interrupted in their course by the sea bottom rising into the euphotic zone, is thought to be less important here.

In order to be able to demonstrate the land mass effect, several stations at close intervals (Table II) were occupied as the "Samudera" approached Belawan harbor, one of the busiest harbors on the east coast of Sumatra. The distances from the mouth of the Deli River in which Belawan harbor is located are approximate but their use allows us to illustrate what we feel to be a typical situation in reference to the hydrology and productivity of such shores.

The results of the hydrographic as well as the productivity measurements, when plotted (Fig. 5) as a function of distance from the harbor, reveal marked changes in the hydrographic conditions as well as marked increases in productivity as shore is approached. The value recorded for productivity at Station 316 is probably within the range of sample error for the population distribution in the waters sampled. Although one of the productivity values was missing (Station 318), it is clear that productivity increased considerably as the harbor was approached from the open sea. The increase recorded was more than 20-fold, *i.e.*, 1.1 mg C/hr/m³ at Station 283 to 24.5 mg C/hr/m³ at Station 319.

Calculation indicated that the percentage saturation for oxygen decreased with lessening distance from shore (100% saturation at Station 283 and 87% saturation at Station 319, corrected for both salinity and temperature). The salinity, as one would expect, decreased to about 25‰ at Station 319, whereas the temperatures increased slightly.

It is interesting to postulate that both of the hypothetical causes of increases in productivity with nearness to shore, listed above are illustrated in Figure 5 by the changes in productivity recorded. The increase in

5) A term suggested by Mr. H. R. JITTS of the C.S.I.R.O. at Cronuila, N.S.W., Australia.

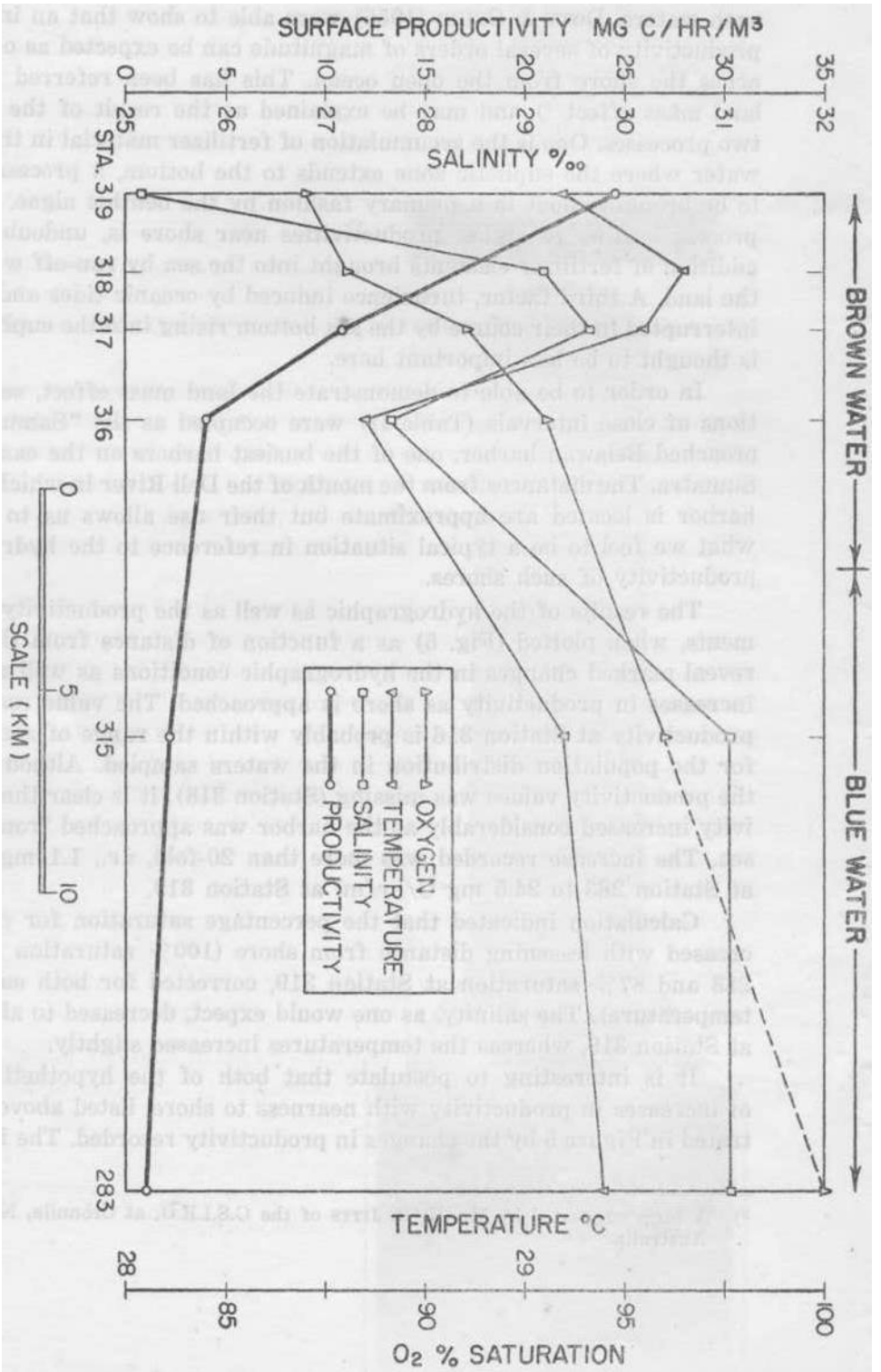


FIGURE 5.

Values from stations sampled off the Port of Belawan plotted as a function of distance offshore with an indication of the water color. There was no productivity value for Station 318. Station 319 was approximately 4 kilometers seaward from the most downstream wharf on the east bank at Belawan.

TABLE II.

Data from the surface water at a series of stations along a line extending offshore from Belawan harbor, Sumatra.

Station number	Km from shore line	Depth to bottom in meters	Temp. °C	Salinity ‰	Oxygen ml/l	Oxygen % sat.	Surface productivity mg C/hr/m ³
283	28.3	32	29.2	31.06	4.72a)	100a)	1.1
315	17.4	30	29.1	31.06	4.53	96	2.2
316	7.7	16	28.6	27.65	4.49	93	4.0
317	4.00	9	29.3	29.65	4.30	91	10.8
318b)	1.96	9	29.4	29.20	4.13	88	—
319	0.00c)	8	29.1	25.17	4.23	87	24.5

productivity as shore is approached while still in blue water may be due to the accumulation and cycling of fertilizer materials in the area by the benthic algae and other near-shore populations. The much steeper increase inshore in the brown water area might be postulated as being due to the large amount of fertilizer and organic material being brought in by, largely, the Deli River.

STEEMANN - NIELSEN (1959) has postulated that bacterial re-cycling in such rich water is probably a contributing factor to high productivity. Indeed the two most landward stations along this profile produced dark bottle fixations much higher than usual for this cruise but such high values were found sometimes in the more open waters. Thus, we cannot say from dark bottle fixation alone that bacterial re-cycling was a factor here. However, the high fish population in this area would auger well for re-cycling through the usual food pyramid which certainly involves micro-bial mineralizers. The drop in oxygen content to values below saturation would also indicate destruction of organic matter most likely by bacterial or fungal action.

EFFECTS OF FILTERING ON THE PHOTOSYNTHETIC ABILITY OF MARINE PHYTOPLANKTON

We wondered whether the periodicity mentioned above might not be due to the zooplankters' feeding habits as well as to variation in the photo-

- a) The value at the 10 meter level was 4.63. No surface value was measured and this value was determined as the saturation value from temperature and salinity.
 b) Since the productivity measurement was lost, this station number does not appear in Appendix A.
 c) Estimated as 4 km from end of the most seaward wharf.

synthetic or other activities of the many phytoplankters which pass the smallest bolting silk nets. To answer this question, samples of water were collected at intervals and mixed in an acid-cleaned plastic bucket from which sets of subsamples were drawn. One set of subsamples was filtered through WHATMAN 4=40 filter paper or through No. 25 bolting silk while another set (nonfiltered) was treated only by the standard method. Both sets were then incubated under the same conditions to obtain comparisons of their productivity.

The productivity of both subsample groups, as a function of sampling time, revealed that, although the filtered samples showed lower productivities, they yielded a pattern of daily periodicity similar to that of the unfiltered samples. This includes the gradual rise to a peak at about 16 :00 hours found in more detailed work elsewhere (unpublished) as well as the precipitous decline toward 20 : 00. If the ratio of the productivity values obtained from the pairs of non-filtered and filtered samples is plotted as a function of sample time (Fig. 6), it appears that there is possibly a greater change in the ability of the larger phytoplankton to photosynthesize during the day than there is in that of those passing the filters.

In only three cases was the nannoplankton passing the filters responsible for more than 50 per cent of the fixation. These are the cases in Figure 6 where the ratio is less than 2. Nannoplankters being rather delicate, it is possible that many of them were damaged in the filtering process and thus photosynthesis by the filtered fractions lowered.

PRODUCTIVITY OF THE DIFFERENT OFFSHORE AREAS

The two principal areas discussed here are recognized on the basis of adjusted productivity values given in Figure 2. There are two major areas to be considered and these bear a relationship to the circulation patterns (WYRTKI, 1961), turbulence and runoff. High values found near shore as at Station 311 and near Belawan, which are believed to be more land mass effects, are not considered as typical of these areas.

1. Malacca Strait:

It is evident that productivity decreases northwest of Station 267 as the Gulf of Bengal is approached. This is possibly due to a combination of fertilizer-enriched (runoff) coastal waters being diluted with South China Sea water and dissipated in the Gulf of Bengal, the turbulence in the shallow narrowest parts of the Strait tending to protract and enhance the high productivity phenomenon.

It would appear that the high productivity of the southern part of the Strait was related in part to the turbulence in these shallow northwest moving waters. Such mixing has been described by SOERIAATMADJA (1956b) for One Fathom Bank, about 3°N. According to WYRTKI (1961)

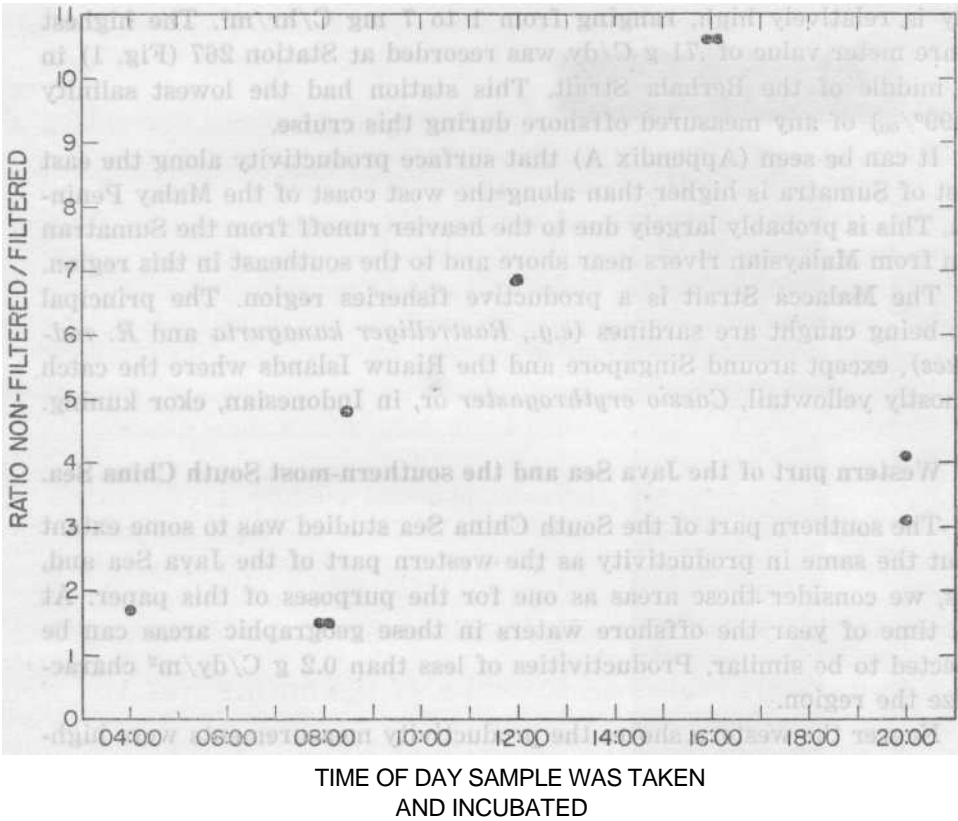


FIGURE 6.

The ratio of productivity of the large plus the small plankters (non-filtered samples) to small ones (filtered) plotted as a function of the time of day the samples were taken and incubated.

the continuously northwestward moving water in the Malacca Strait is completely mixed by the tidal currents; though during the rainy season of September to January sufficient rain falls that a drop of 0.7 parts per thousand may occur between the salinity at the surface and that 30 meters below. That this phenomenon was operating during the present cruise is attested by the fact that the hydrographic data from the stations located

in that area (Stations 270, 271, 272, 273, 288 and 313) indicated almost no stratification at all.

The influence on productivity of runoff water can be demonstrated by our data from the coasts of Sumatra and the Malay Peninsula. The surface productivity at stations located in these parts of the Strait generally is relatively high, ranging from 1 to 7 mg C/hr/m³. The highest square meter value of .71 g C/dy was recorded at Station 267 (Fig. 1) in the middle of the Berhala Strait. This station had the lowest salinity (27.99‰) of any measured offshore during this cruise.

It can be seen (Appendix A) that surface productivity along the east coast of Sumatra is higher than along the west coast of the Malay Peninsula. This is probably largely due to the heavier runoff from the Sumatran than from Malaysian rivers near shore and to the southeast in this region.

The Malacca Strait is a productive fisheries region. The principal fish being caught are sardines (*e.g.*, *Rastrelliger kanagurta* and *R. rod-rigiies*), except around Singapore and the Riau Islands where the catch is mostly yellowtail, *Caesio erythrogaster* or, in Indonesian, ekor kuning.

2. Western part of the Java Sea and the southern-most South China Sea.

The southern part of the South China Sea studied was to some extent about the same in productivity as the western part of the Java Sea and, thus, we consider these areas as one for the purposes of this paper. At this time of year the offshore waters in these geographic areas can be expected to be similar. Productivities of less than 0.2 g C/dy/m² characterize the region.

Nearer the western shores the productivity measurements were higher, even though they were not as impressively high as those from the Malacca Strait area. Near the coast the measurements were often above 0.2 g C/dy/m². As indicated above it is assumed this is another demonstration of land mass effects.

The area between Pontianak and Biliton Islands was seemingly unproductive. In fact, one of the lowest surface productivity values measured (below 0.1 mg C/hr/m³) during the whole cruise was obtained in this region. Such very low values were unexpected, for the waters around Biliton and Bangka Islands are some of the most important regions for yellowtail fisheries. Thus it would seem that the measurements made here, since they were made at the low point in the diurnal photosynthetic cycle, would have been more acceptable if corrected for the time of day the sampling was done.

We cannot say much about the productivity of the west coast of Kalimantan since there was only one station (Station 298) close enough to be influenced by its shores. The results from this station, however, were high and lead us to believe that probably all the way along the coast of Kalimantan productivity is high because there are many big rivers bringing inorganic and organic materials into the sea from the jungles inside this island. This hypothesis is supported also by the fact that this coast of Kalimantan is noted for its mackerel (*Rastrelliger* spp.) fishery areas.

COMPARISON WITH OTHER MEASUREMENTS IN INDONESIAN WATERS AND IN THE NEARBY PACIFIC OCEAN

STEEMANN - NIELSEN & AABYE- JENSEN (1957) reported 12 productivity measurements made in Indonesian waters during the cruise of the research vessel "Galathea" in 1950 -1952. Of these, Stations 325 and 327 are in the Malacca Strait area and Station 458 is located in the western part of the Java Sea off Djakarta. The rest are scattered in the central and eastern parts of the Java and Banda Seas, largely to the east of the area being reported upon here. It is to be noted that their measurements were made in May, a period of minimum wind and maximum salinity like that during which our November measurements were made. Thus, it is not altogether surprising to find the close similarity between "Galathea" and "Samudera" daily square meter column values (Fig. 2); though the measurements were made several years apart. STEEMANN - NIELSEN & AABYE - JENSEN indicated that all their stations in relatively shallow water of the Indo-Malayan area yielded high rates of production, *i.e.*, between 0.24 and 1.08 g C/dy/m².

KOBLENTZ - MISHKE listed (1960) the primary productivity of the more eastern parts of Indonesia as about 10 mg C/dy/m³ near the Kei Islands, about 5 mg C/dy/m³ in the Celebes Sea, and less than 0.1 mg C/dy/m³ in the northern part of the Moluccas Islands. She made no measurements in the western Indonesian waters which are the geographic province of the present paper

The values given by KOBLENTZ - MISHKE for the much deeper and perhaps less land-influenced waters of the eastern part of the archipelago are lower than ours. However, they do approach our lowest measurements for the South China Sea areas, the deepest waters with which we were concerned. As an inspection of Figure 2 shows, STEEMANN - NIELSEN & AABYE - JENSEN'S conclusion in reference to shallow water is supported in a general way by the results from the present cruises.

SUMMARY COMMENTS

The results of this investigation indicate that the shallow Indonesian waters are as productive of organic matter as the most productive waters elsewhere in the tropics of Asia, in New Zealand or in the Americas, and far more productive than either the deeper waters nearby or the Central Pacific away from the Equator. There are, however, many gaps in this research study which might be filled through further such studies. Beyond the obvious need for repeated and more extensive measurement of productivity itself, it is desirable that light measurements and standing crop measurements of phytoplankton be made concurrently in order to carry this productivity study more properly to completion for the vast marine areas of Indonesia. Quantitative determination of such fertilizer salts as the nitrates, phosphates and silicates should accompany the biological measurements in addition to the conventional hydro-graphic measurements. By making measurements at different times during the year, a clear picture of the potential productivity of this area can be developed and related to variations in fisheries catch and other phenomena.

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