Note on the Planktonic Primary Production in Fanning Island Lagoon[1]

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ABSTRACT: A single series of representative observations indicates that both the productivity and standing crop of phytoplankton in Fanning Lagoon are much greater than reported in the lagoons of other Pacific atolls. Productivity, as measured by the radiocarbon method, averaged 9.29 mg C/m^3/hr, while chlorophyll *a* averaged 0.548 µg/liter. Phytoplankton, principally dinoflagellates with some diatoms and coccoid blue-greens, averaged 12.6 $\times$ 10^4 cells/liter. The relative richness of this lagoon compared with others appears to be due to the greater availability of nutrients which, in turn, is caused by the unique geographic features of the atoll.

VARIOUS INVESTIGATIONS, notably those of Sargent and Austin (1949) and Odum and Odum (1955) on Rongelap and Eniwetok atolls in the Marshall Islands, have demonstrated the remarkably high productivity of reef communities. In contrast, the few measurements made in the lagoons associated with these and other atolls indicate that both phytoplankton production and standing crop are quite low, often not significantly higher than in the surrounding open sea (Sargent and Austin, 1949). As a result of these observations, the concept has emerged that a "typical" tropical Pacific atoll consists of highly productive reefs encircling a relatively unproductive lagoon.

As part of a larger University of Hawaii program, planned as a multidisciplinary synoptic study of Fanning Atoll, an attempt was made to assess the applicability of this concept to this particular atoll.

METHODS

Observations were restricted to a single station in the northwestern part of Fanning Lagoon (Fig. 1) on January 9, 1970. This station (no. 26) was located in Suez Pond in 8 m of water, about 200 m from the closest line reef. Water samples for productivity measurements, chlorophyll analyses, phytoplankton enumeration, and enrichment for cultivation were collected at fourth depths (0.5, 2.5, 4.5, and 7.0 m) using an *in situ* pump (Schiesser, 1970). Productivity was determined using the radiocarbon method as outlined by Strickland and Parsons (1968). Two light and two dark bottles from each sampling depth were innoculated with radiocarbon bicarbonate solution (1.49 $\times$ 10^7 dpm/2 ml). These were then attached to a weighted line and suspended from a buoy at their depths of collection. Light bottles were covered during the preliminary handling with aluminum foil to prevent excessive sun exposure. Following a 3-hr incubation period (1122 to 1430 hours), the contents of each bottle were filtered through a 25-mm, 1.2-µ Millipore filter which was subsequently rinsed with filtered seawater, placed on a copper planchet, and stored in a desiccator. The filters were counted 1 month later in a Nuclear Chicago model 1042 geiger counter. Both the efficiency of the Geiger counter and the absolute activity of the radiocarbon solution were determined by liquid scintillation counting, according to the method of Wolfe and Schelske (1967).

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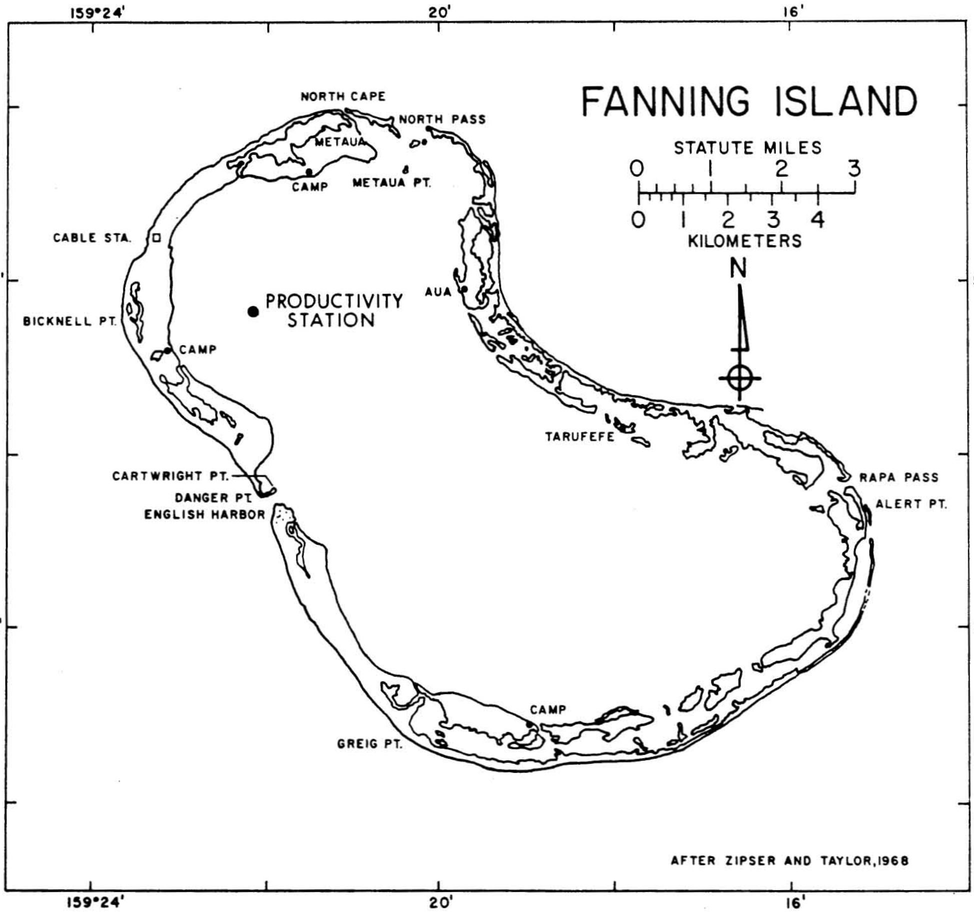

FIG. 1. Fanning Island. Productivity Station (no. 26) is indicated in the lagoon area.

Chlorophyll *a* was determined using the procedure of Strickland and Parsons (1968). Phytoplankton enumeration was carried out solely on Millipore filters. This was accomplished by filtering 100 ml of seawater through a 25-mm, 1.2-μ filter, followed by a distilled water rinse, desiccation, and eventual clearing and mounting on a slide with Permount. Cultivation was attempted by adding variable amounts of seawater to previously prepared screw-top tubes containing three different sterile media: "AM" medium (Antia and Kalmakoff, 1965), "B" medium (Antia and Strickland, unpublished), and ErdSchreiber medium. Enriched samples were stored in an air-conditioned room out of direct sunlight until they could be placed in a proper incubator upon return to Hawaii several weeks later.

RESULTS

The data collected are summarized in Table 1, along with some relevant physical and chemical observations from the same station reported by Gordon (Pacific Science, this issue), Gordon and Schiesser (1970), and Smith, et al. (Pacific Science, this issue). These observations indicate that the water at the station is well mixed.

The mean of the productivity for the four samples was 9.29 mg C/m^3/hr, whereas the range was from 7.30 to 11.58 mg C/m^3/hr. The maximum rate of photosynthesis occurred at 2.5 m where the light intensity was measured to be 25 percent of that at the surface. If we integrate these data over the 8-m water column, we find that the production at this station equaled 67 mg C/m^2/hr.

TABLE 1

SUMMARY OF OBSERVATIONS MADE ON JANUARY 9, 1970 AT THE PRODUCTIVITY STATION IN FANNING LAGOON

	DEPTH (m)			
	0.5	2.5	4.5	7.0
Mean Absolute CPM, Light	16,625	22,760	18,953	14,309
Mean Absolute CPM, Dark	297	434	284	223
Photosynthesis (mg C/m^3/hr)	8.63	11.58	9.68	7.30
Chlorophyll *a* (μg/liter)	0.515	0.562	0.567	0.546
Photosynthesis/Chlorophyll *a*	16.7	20.6	17.1	13.4
Cells per Liter ($\times 10^4$)	19.2	13.1	5.7	—
Total Organic Carbon (mg/liter)	1.78	1.61	1.64	1.95
Carbonate Alkalinity (mg/liter)	2.09	2.05	2.05	2.05
pH	8.06	8.08	8.09	8.09
Salinity (‰)	35.147	35.153	35.165	35.175
Oxygen (ml/liter)	4.06	4.09	4.06	4.24
Relative Light Intensity (%)	50	25	14	9

The chlorophyll *a* values were relatively constant: 0.515–0.567 μg/liter. If photosynthesis is expressed as a function of chlorophyll *a* concentration, a mean of 16.9 mg C/m^3/hr/mg chlorophyll *a* is obtained, whereas the range obtained varies from 13.4 to 20.6. The maximum value was found at 2.5 m; this value presumably is related to the high productivity measured at this depth. These ratios are high and have undoubtedly been affected by the necessity of freezing the filters and conducting extractions a month later in Hawaii. Unfortunately the magnitude of this error is unknown.

Since filters permit observation of only those organisms capable of withstanding the rigors of the procedure, the resultant cell counts must be considered as minimal estimates. Such is the case with the cell numbers presented in Table 1, yet despite this limitation it is obvious that quite a sizable phytoplankton standing crop was present at the time the radiocarbon observations were conducted. The numbers of phytoplankters ranged from a high of 19.2×10^4 cells/liter at the surface to a low of 5.7×10^4 cells/liter at 4.5 m, the deepest depth from which a sample was obtained. The mean of these three observations is 12.6×10^4 cells/liter.

The standing crop, as seen on the filters, comprised diatoms, coccoid blue-greens, and dinoflagellates, with the latter group dominant. In fact, the dinoflagellates were so abundant that they were the overwhelming majority of the cells enumerated. The single most prominent dinoflagellate was a gymnodinioid organism which possessed a cell wall of sufficient strength to resist disruption on the filters. These same organisms were also observed in the cultures although there the diatoms and blue-greens predominated, apparently because of their greater adaptability to culture conditions. Nothing can be said about the phytoflagellate contribution to this standing crop since, even if present originally, they were undoubtedly destroyed by the filtration process.

DISCUSSION

A single series of four observations made at one station does not constitute a comprehensive survey. However, several factors suggest that, although the absolute values of productivity varied somewhat, the level of these values was representative of most of the lagoon. The physical and chemical observations of Gordon, (Pacific Science, this issue), Gordon and Schiesser (1970), and Smith et al. (Pacific Science, this issue) reveal that the conditions at the site of the productivity station were, with the sole exception of depth, quite representative of the lagoon as a whole. In addition, the well-known absence of seasonality (or conversely, the high degree of stability) in tropical phytoplankton cycles suggests that the level of these observations would vary only slightly with time.

If we assume that the station is representative of the entire lagoon and that the level of both productivity and standing crop measurements are relatively accurate, then it becomes immediately obvious (Table 2) that, in terms of these parameters, Fanning Lagoon is unique among those lagoons which have been studied to date. It contained a large standing crop of phytoplankton capable of fixing approximately 10 times more carbon per unit volume than was observed in both Eniwetok and Rongelap lagoons (Sargent and Austin, 1949; Doty and Capurro, 1961) and six to seven times more carbon per unit area than that measured in the lagoon at Palau (Motoda, 1969). In fact, the productivity in Fanning Lagoon was so high that it compares favorably with measurements made in Kaneohe Bay (Doty and Capurro, 1961), a partially polluted embayment on the windward coast of Oahu, Hawaii.

The relatively high productivity and standing crop in Fanning Lagoon were due to very favorable growth conditions—principally the availability of nutrients and, to a lesser extent, the turbidity of the water—which were not found in the other lagoons studied.

The level of nutrients in Fanning Lagoon was closely linked with four interrelated factors: (1) lagoon area, (2) nature of the surrounding land and precipitation, (3) lagoon depth, and (4) the residence time of water within the lagoon.

With an area of 103 km^2 (Fig. 1) Fanning Lagoon is considerably smaller than those found in the Marshall Islands. Bikini and Rongelap lagoons are about 700 km^2 and 800 km^2, respectively. In addition to influencing the volume of the lagoon, this smaller area means that no point within the lagoon is ever far from a rich supply of nutrients in the form of a highly productive reef, the shoreline, or the islands themselves.

Fanning Atoll is one of only six atolls in the entire Pacific having dry land around virtually the entire rim. The only breaks in the land are the three narrow passes (Fig. 1). This land is completely vegetated, principally by coconut palms which support a copra industry employing the approximately 300 Gilbertese inhabitants of the atoll. Phosphate rock, presumably originating from guano deposits, is widespread (K. Roy, personal communication). The land, therefore, constitutes an important source of nutrients which would be carried into the lagoon by runoff. Fanning Atoll does, in fact, receive a moderate amount of rainfall: 81 inches/year compared to 53 inches/year at Eniwetok (Wiens, 1962). The presence of considerable runoff from the islands into Fanning Lagoon is indicated by the low salinities reported by Gordon and Schiesser (1970). The maximum rainfall generally occurs during April–May, so nutrient levels and, therefore, productivity at and just after that time might even be greater than reported herein for January.

The mean depth of Fanning Lagoon is approximately 5 m which makes it quite shallow compared to the 49-m average for the lagoons of the northern Marshall Islands (Sargent and Austin, 1949). These shallow conditions allow the wind to mix the entire water column, thereby aiding the circulation of nutrients and generally helping the entire regenerative process to operate at a high rate of efficiency.

The final factor which influences nutrient availability is the flushing time of the lagoon, or, in other words, the residence time of the nutrients already in the system. The shorter the flushing time, the lower the productivity since nutrient-rich water would continually be replaced by nearby, nutrient-poor ocean water. Using the current data of Gallagher et al. (Pacific Science, this issue), Gordon (Pacific Science, this issue) calculated a flushing time of approximately 230 days. This is about seven times slower than the 35 days estimated for Bikini Lagoon (Von Arx, 1954), which is quite similar to the lagoons at Eniwetok and Rongelap. This long flushing or residence time is probably the single most importanct factor governing the size of the standing crop since it would allow a larger number of organisms to recycle the available material.

Due to the high suspended load, composed principally of calcium carbonate particles, the waters of Fanning Lagoon were extremely turbid, except for a clear water area just inside English Harbor (Smith et al., Pacific Science, this issue). As a result, half of the incident radiation was absorbed in the first one-half meter (Table 1). Therefore, most of the water column had relatively low light intensities which

TABLE 2

SUMMARY OF PRODUCTION AND CHLOROPHYLL *a* DATA FROM PACIFIC LAGOONS

LOCATION	METHOD	PRODUCTION mg C/m^3/hr	PRODUCTION mg C/m^2/hr	CHLOROPHYLL *a* µg/liter	REFERENCE
Marshall Islands					
Eniwetok Lagoon	oxygen	1.67	—	0.331	Sargent and Austin (1949)
Eniwetok Lagoon	radiocarbon	0.75	—		Doty and Capurro (1961)
Rongelap Lagoon	oxygen	0.42	—	0.174	Sargent and Austin (1949)
Rongelap Lagoon	radiocarbon	0.44	—		Doty and Capurro (1961)
Palau					
Iwayama Bay	Ryther and Yentsch (1957)	—	7	—	Motoda (1969)
Anchorage	Ryther and Yentsch (1957)	—	8	—	
Hawaii					
Kaneohe Bay	radiocarbon	5.39	70*	0.925	Doty and Capurro (1961)
Line Islands					
Fanning Lagoon	radiocarbon	9.29	49**	0.548	

* An average depth of 13 m is assumed.
** An average depth of 5 m is assumed.

are the most favorable for photosynthesis. In contrast, the water in Rongelap Lagoon had a very small suspended load and an average Secchi disc reading of 18 m (Sargent and Austin, 1949). In such cases, light intensities in the upper part of the water column are probably high enough to inhibit photosynthesis considerably.

In conclusion, it appears that both the phytoplankton production and standing crop in Fanning Lagoon are much higher than has been previously measured in the lagoons of other atolls, principally those of the Marshall Islands. These higher measurements are believed to be due primarily to the greater input and retention of nutrients in the lagoon which, in turn, are due to the geographic features of the atoll.

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