NOTES

TWO BLOOMS OF *GYMNODINIUM SPLENDENS*, AN UNARMORED DINOFLAGELLATE

Little is known about the ecology and physiology of an unarmored dinoflagellate (30 to 50 μm), *Gymnodinium splendens* Lebour, although feeding experiments have shown it to be an important food source for certain marine herbivores. Lasker et al. (1970) found that anchovy larvae may be reared the first week upon unialgal suspensions of *G. splendens* while Paffenhöfer (1970, 1971) and Barnett (1974) showed it to be a preferred food for *Calanus finmarchicus* and larval stages of *Labidocera trispinosa*. Pokorny and Gold (1973) reported on cell ultrastructure of *G. splendens*, Sweeney (1954) observed vitamin B_{12} requirements, and Thomas et al. (1973) described optimal light and temperature requirements. In addition to these laboratory studies, Loftus et al. (1972) have noted *G. splendens* in a bloom of diverse dinoflagellate species in Chesapeake Bay.

This note reports upon two field studies of blooms of *G. splendens*. The first observation was made in Coyote Bay of Bahia Concepción, Gulf of California, where *G. splendens* was the dominant phytoplankter in March 1971. The second observation was made in March 1974, when large concentrations were observed in coastal waters of the Southern California Bight. In both occurrences *G. splendens* dominated the phytoplankton crop so that measurements of primary production and the chemical composition of suspended particles allowed a reasonable description of this species.

Gymnodinium splendens in Coyote Bay

Coyote Bay (lat. 26°43.0'N, long. 111°53.0'W) of Bahia Concepción is well protected and shallow. Chemical and physical observations were made while the ship (RV *E. B. Scripps*) was at anchor in 20 m of water and included measurements of particulate adenosine triphosphate (Holm-Hansen and Booth 1966) and chlorophyll (Yentsch and Menzel 1963; Holm-Hansen et al. 1965), microscopic examination of water samples preserved in 5% (V/V) buffered Formalin[1] (Utermöhl 1958), and determinations of primary production based upon rates of incorporation of radioactive carbon (Steemann Nielsen 1952). The depth distribution of phytoplankton was recorded at regular intervals by continuous vertical profiles to the bottom with both a submersible transmissometer (Petzold and Austin 1968) and a fluorometer attached to a hose and submersible pump (Lorenzen 1966; Kiefer and Austin 1974). The continuous profiles of in situ fluorescence were translated into chlorophyll *a* concentrations by frequent calibration with discrete samples which were analyzed fluorometrically for chlorophyll and phaeophytin concentration (Kiefer 1973).

The five phytoplankters which occurred together and were numerically most abundant in Coyote Bay were: *G. splendens* (1.0×10^5/liter), *Leptocylindrus danicus* (3.4×10^4/liter), *Skeletonema costatum* (1.4×10^3/liter), *Cerataulina bergonii* (1.4×10^3/liter), and *Thalassiothrix frauenfeldii* (4.0×10^3/liter). Chlorophyll concentration varied with depth and ranged from 4.4 μg/liter to 13 μg/liter for numerous samplings of the 20-m water column. Figure 1 shows a time sequence of profiles of in situ fluorescence of chlorophyll. Profiles of light transmission displayed a similar stratified structure. The increase in depth of the upper chlorophyll maximum between 1845 and 2300 and the decrease in depth between 2300 and 0720 the following day indicated a diel migration of *G. splendens*. This suggestion was supported by the predominance of *G. splendens* in the maxima and by the improbability of physical factors such as advection or internal waves affecting such variations. Conditions were calm at the sea surface and the water column was isothermal with depth.

The upper chlorophyll maximum (Figure 1) moved downward at sunset with a velocity of approximately 1.7 m/h. Such velocities are similar to those of other dinoflagellates. For example, a natural bloom of *Ceratium furca* occurring off the southern California coast was observed to migrate downward at 2 m/h and mass cultures of *Cachonina niei* and *Gonyaulax polyedra* displayed migratory rates of 1 to 2 m/h (Eppley et al. 1968). Our observations suggested that a portion of the *G. splendens* population moved upward between 2300 and 0400 the following day. Since sunrise was

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

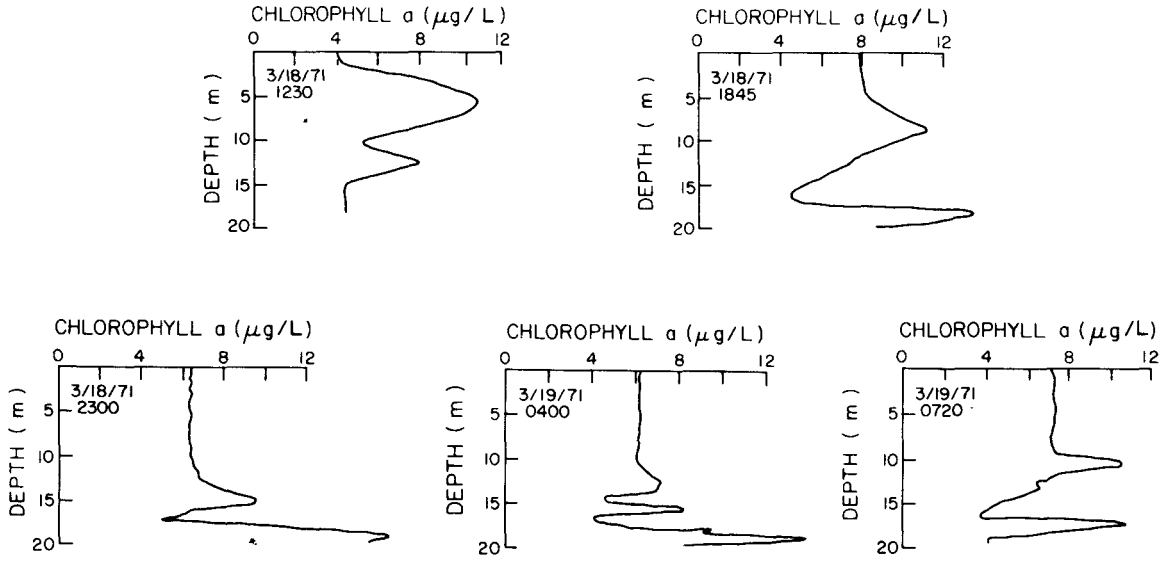

FIGURE 1.—Profiles of the concentration of chlorophyll *a* based upon fluorescence profiles. The upper layer of *Gymnodinium splendens* at 1230 h was concentrated at 6 m; by 1845 it had moved to 8 m and reached 15 m by 2300. Movement upward commenced at 0200 reaching 10 m by 0720. The lower layer remained relatively close to the bottom during this time.

around 0600, this movement may originate from a biological clock rather than from a phototactic response. These observations partially conflict with laboratory studies of phototaxis in *G. splendens* (Forward 1974). He found that not only was the cell strongly phototactic but that the strength of the response was subject to a circadian rhythm, being strongest at the end of the entrained dark period.

By assuming that *G. splendens* dominated the production as well as the standing crop of phytoplankton in Coyote Bay, we obtain information on the steady state doubling time for the species. Water samples were collected from four depths, 0, 5, 10, and 18 m, inoculated with $NaH^{14}CO_3$, and incubated from sunrise to sunset in situ. Primary production was then determined from rates of light-induced incorporation of ^{14}C into particles removed by filtration. The water samples were also analyzed for concentrations of chlorophyll *a* and adenosine triphosphate (ATP). By multiplying the concentration of ATP by 250, we obtained an estimate of "living-carbon" (Holm-Hansen and Booth 1966); this estimate allowed a crude determination of doubling time t_d from the steady-state equation:

$$t_d = \frac{\ln 2}{\mu} = \frac{C \cdot \ln 2}{\Delta C/\Delta t}$$

where μ is the specific growth rate and equal to the rate of carbon assimilation, $\Delta C/\Delta t$, divided by C, the concentration of cell carbon. On this basis, the doubling time for *G. splendens* at 0, 5, 10, and 18 m was 2.3, 2.6, 2.7, and 62 days, respectively (Table 1). These estimates of doubling time for a natural population of *G. splendens* may be compared with a maximal doubling time of 1.6 days for cells grown in the laboratory (Thomas et al. 1973). We also note that our estimates of the chlorophyll *a* concentration per cell yielded a value of approximately 100 pg/cell, typical for laboratory cultures (Bailey 1974).

TABLE 1.—Production, chlorophyll *a*, ATP, and doubling time for a *Gymnodinium splendens* bloom in Coyote Bay, Gulf of California.

Depth (m)	Production (μg C/liter•day)	Chlorophyll *a* concentration (μg/liter)	ATP (μg/liter)	Doubling time (days)
0	125	5.8	1.7	2.3
5	108	5.3	1.6	2.6
10	126	6.2	1.9	2.6
18	35	4.7	1.3	62

Gymnodinium splendens in the Southern California Bight

A second bloom of *G. splendens* was observed in March 1974, along the southern coast of California,

during a cruise on RV *David Starr Jordan*. Stations in the sampling program extended along the 20-fathom contour from Malibu (lat. 34°00.8'N, long. 118°40.6'W) south to San Onofre (lat. 32°56.0'N, long. 117°17.4'W). Intermediate stations included Manhattan Beach (lat. 33°52.5'N, long. 118°27.0'W), Seal Beach (lat. 33°36.5'N, long. 119°04.3'W), and Dana Point (lat. 33°26.3'N, long. 117°42.8'W). A sixth station was on the 270-fathom contour off Laguna Beach (lat. 33°30.8'N, long. 117°50.3'W).

Continuous vertical profiles of in situ chlorophyll fluorescence were made to a depth of 35 m. Water from the outflow of the fluorometer was collected at the surface and within the fluorescence maximum. Three analyses were made on subsamples of water from the two depths. First, the size distribution of suspended particles was immediately determined with an electronic particle counter (model T_a Coulter Counter). We accumulated counts in the upper nine channels which gave us a frequency distribution for particles with equivalent diameters ranging from 20 to 128 μm. Second, subsamples were preserved in 5% Formalin for species determination. Third, the chlorophyll *a* concentration in each subsample was determined fluorometrically for acetone extracts of filtered particles.

Vertical profiles made at various times of the day and night at each of the six stations on the 20-fathom contour were characterized by a unimodal distribution of chlorophyll. The chlorophyll maximum varied little in depth from 15 to 20 m within a moderately developed thermocline, and was most often less than 4 m thick. At these stations, *G. splendens* contributed most of the phytoplankton crop within the maxima. However, in surface waters it contributed a much smaller fraction of the crop. The highest concentration (Figure 2) of *G. splendens* was within the well-defined maximum at Seal Beach where its concentration reached 4×10^5 cells/liter (chlorophyll a = 42.0 μg/liter). The lowest concentration within a maximum was at Manhattan Beach, 1.2×10^4 cells/liter (chlorophyll a = 1.3 μg/liter.

The predominance of *G. splendens* in the chlorophyll maximum was also evident from the particle size distributions obtained with the electronic particle counter. Within the maximum, particles with equivalent diameters between 36 and 57 μm far outnumbered smaller- and larger-sized particles. In surface waters the smaller-sized

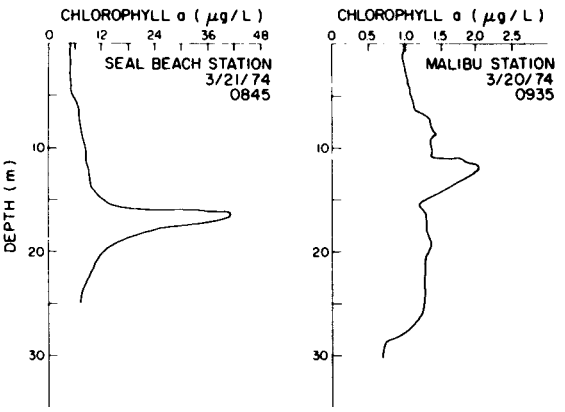

FIGURE 2.—Profiles of the concentration of chlorophyll *a* based upon fluorescence profiles at two stations along the 20-fathom contour of the Southern California Bight. The subsurface maxima are predominantly composed of *Gymnodinium splendens*.

particles outnumbered particles of the size of *G. splendens*. The other phytoplankton in surface waters included *Ceratium furca* and *C. kofoidii*, *Dinophysis acuminata*, and a species of *Gyrodinium*. Very few diatoms were present.

It appeared that the bloom of *G. splendens* dissipated seaward since the subsurface chlorophyll maximum was poorly developed at the Laguna Beach station which was on the 270-fathom contour. Here the concentration of chlorophyll in the maximum was only 0.76 μg/liter, while the concentration at the surface was 0.63 μg/liter. In addition, both the particle size distribution and microscopic counts indicated a more diverse assemblage of dinoflagellate species at this station, with the unarmored dinoflagellate *Cochlodinium catenatum* being most abundant.

Thus, the bloom of *G. splendens* appeared to be limited to nearshore waters, in a band extending as far as 100 km along the coast. This subsurface bloom was presumed to be a large food source for planktonic herbivores, but more field sampling is necessary to determine whether the bloom is a seasonal occurrence. In another paper, Lasker (1975) describes the feeding responses of anchovy larvae to these natural concentrations of *G. splendens*.

Acknowledgments

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