TOTAL PLANKTON RESPIRATION IN THE CHESAPEAKE BAY PLUME

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SUMMARY

Total plankton respiration (TPR) was measured at 17 stations within the Chesapeake Bay plume off the Virginia coast during March, June, and October 1980. Elevated rates of TPR, as well as higher concentrations of chlorophyll *a* and phaeopigment *a*, were found to be associated with the Bay plume during each survey. TPR rates within the Bay plume were close to those found associated with the Hudson River plume for comparable times of the year. The data examined indicate that the Chesapeake Bay plume stimulates biological activity and is a source of organic loading to the contiguous shelf ecosystem.

INTRODUCTION

Total plankton respiration (TPR) is the consumption of dissolved oxygen by planktonic organisms in the water column. TPR represents the rate of assimilation and decomposition of organic matter and is partially responsible for the recycling of nutrient materials to support primary production in the marine ecosystem.

Few measurements of oxygen consumption by plankton exist for the region off the Virginia-North Carolina coast. Thus, the objective of this research was to quantify TPR in near-coastal waters off the Chesapeake Bay with particular emphasis on studying the effects of the Chesapeake Bay plume on the biological activity (TPR) of the planktonic community.

METHODS

Samples for salinity, chlorophyll *a*, phaeopigment *a*, and TPR were collected from 17 stations north of the Virginia-North Carolina border (ref. 1, figure 5) during the three Superflux cruises. The periods were March 12-15, June 18-21, and October 16-18. Samples were taken from surface (1 m) to bottom (3 to 6 depths per station) in 5-, 10-, or 12-l Niskin bottles. Water column temperatures were measured using an expendable bathythermograph (XBT) to the nearest $0.1^{\circ}C$.

Water for chlorophyll (chl *a*) and phaeopigment *a* (phaeo *a*) determinations was drawn from the Niskins into opaque polypropylene bottles after first passing the sample through a 300-μm nylon screen to remove larger zooplankton. Under subdued light each sample was filtered through a Whatman Gf/F filter. The filter

was ground in 90% spectral grade acetone for one minute and centrifuged for five minutes, and the extracted chlorophyll solution was transferred to a fluorometer. After chl *a* determination, two drops of 5% HCL were added to the tube containing the extract, mixed, and the concentration of phaeo *a* was determined fluorometrically. Corrected concentrations of chl *a* and phaeo *a* expressed in mg/m^3 were calculated by the equations in reference 2.

As soon as they were recovered, samples for TPR were drawn from the Niskins into 300-ml acid-washed and baked ($232^{\circ}C$ for one hour) BOD bottles. Five replicates were taken from each depth samples. Two (unincubated) of the five were fixed immediately for dissolved oxygen determination, while the remaining three were incubated at $\pm 1^{\circ}C$ of *in situ* temperature in the dark on shipboard for approximately 24 hours. Following incubation these three were also fixed for dissolved oxygen determination. Oxygen concentrations were measured by the method of Strickland and Parsons (ref. 2) with the modification of using 0.0375 N phenylarsine oxide (PAO) in place of sodium thiosulfate and amylose in place of soluble starch (refs. 3 and 4). Respiration rates (TPR) were calculated by the formula

$$\text{TPR (ml } O_2/m^3/h) = \left(\frac{S_u - S_i}{t}\right)(0.7 \times 1000)$$

where S_u is the mean dissolved oxygen concentration in (mg O_2/l) of the unincubated samples, S_i is the mean dissolved oxygen concentration (mg O_2/l) of the incubated sample, and t is the period of incubation in hours. The constants 0.7 and 1000 are to convert mg O_2 to ml O_2 and volume from liters to m^3, respectively. Salinity samples were taken from each Niskin and measured on a Guildline Autosal model 8400 salinometer.

RESULTS

Hydrography

Figures 1 to 3 show surface (1 m) views of σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for March, June, and October 1980. Figures 4 to 7 show lengthwise sections of the Chesapeake Bay plume for σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980. In March the density plume ($\sigma_t \leq 24$) exiting from the Chesapeake Bay mouth extended from the Virginia coast to 16 km offshore and from inside Cape Henry to just south of the Virginia-North Carolina border (>42 km south of Cape Henry) (fig. 1(a)). The water column was essentially isothermal but vertical salinity stratification was evident. The strongest pycnocline (halocline) was near the Bay mouth (station 69) with a six-σ_t-unit difference between surface and bottom waters. South of station 69 stratification was still present, although weaker, with only three σ_t units separating surface and bottom waters. The nearshore density plume was as deep as 14 m near station 69 and had risen to 8 m by station 71 off the Virginia-North Carolina border.

In June the water column was strongly stratified vertically due to temperature and salinity differences from the surface to bottom. The density plume extended from 22 km (station 804) to 32 km (station 813) offshore and south of the Virginia-North Carolina border (fig. 2(a)). A strong pycnocline existed throughout the entire area of study (5 σ_t units). The depth of the density plume varied from 6 to 9 m.

October's water column was essentially isopycnal except near the Bay mouth (<2 σ_t units). The density plume did not extend seaward beyond station 69 (fig. 3(a)) and was not deeper than 4 m at this station. This restricted plume extension is attributed to very low rainfall and runoff of fresh water (ref. 5).

Chlorophyll

Chl *a* and phaeo *a* in March ranged from 1.60 to 14.44 mg/m^3 ($\bar{X}$ = 5.41 ±2.97) and ~0.0 to 11.04 mg/m^3 ($\bar{X}$ = 1.61 ±2.07), respectively, within the plume waters, while in surrounding water concentrations ranged from 0.43 to 12.11 mg/m^3 ($\bar{X}$ = 2.86 ±2.57) and ~0.0 to 3.11 mg/m^3 ($\bar{X}$ = 0.70 ±0.83) (figs. 1(b) and 1(c)). Chl *a* and phaeo *a* concentrations near the Bay mouth (stations 69-802) were higher within the plume waters; however, at stations 808-809 and southward phaeo *a* concentrations had increased in waters below the plume and exceeded adjacent plume concentrations.

June chl *a* and phaeo *a* concentrations were highest in surface waters within the plume north of stations 808-809 (figs. 2(b), 2(c), 4(b), 4(c), 5(b), and 5(c)). Concentrations ranged from 0.66 to 7.75 mg/m^3 ($\bar{X}$ = 2.35 ±1.90) for chl *a* and 0.13 to 4.12 mg/m^3 ($\bar{X}$ = 0.81 ±0.88) for phaeo *a*. South of stations 808-809 chl *a* and phaeo *a* concentrations increased in waters below the plume and ranged from 0.35 to 5.27 mg/m^3 ($\bar{X}$ = 1.58 ±1.03) and 0.08 to 2.08 mg/m^3 ($\bar{X}$ = 0.64 ±0.53), respectively (figs. 6(b), 6(c), 7(b), and 7(c)).

During the October cruise measured concentrations of chl *a* and phaeo *a* within the contracted plume ranged from 2.59 to 4.58 mg/m^3 ($\bar{X}$ = 3.35 ±0.75) and 0.55 to 0.98 mg/m^3 ($\bar{X}$ = 0.78 ±0.15) (figs. 3(b) and 3(c)). In the surrounding waters, south and seaward of station 69, the ranges were 0.29 to 6.23 mg/m^3 ($\bar{X}$ = 2.13 ±1.27) and 0.11 to 3.48 mg/m^3 ($\bar{X}$ = 0.85 ±0.71). Chl *a* and phaeo *a* within the plume were fairly homogeneous from surface to bottom. Outside of the plume, chl *a* and phaeo *a* increased from surface to bottom along the transect (stations 69-804) just off Cape Henry. Throughout the remainder of the study area, chl *a* showed a nearshore-to-offshore decreasing gradient with concentrations of less than 3 mg/m^3 except at station 808 where they exceeded 4 mg/m^3. Phaeo *a* continued to show a surface-to-bottom increase with concentrations of greater than 2 mg/m^3. The exception to this occurred at stations 808-809 where values in excess of 3 mg/m^3 were measured near the bottom and a nearshore-to-offshore decreasing gradient was present.

Respiration

TPR rates in March within the area defined by the density plume ($\sigma_t \leq 24$) ranged from 0.47 to 13.36 ml O_2/m^3/h ($\bar{X}$ = 7.27 ±2.94) consumed (fig. 1(d)). In the waters surrounding the plume the range was 1.01 to 11.53 ml O_2/m^3/h ($\bar{X}$ =

5.23 ±2.18). Thus, the waters within the plume exhibited greater TPR rates than adjacent waters. Rates greater than 10 ml $O_2/m^3/h$ were found at station 805 from surface to bottom, at station 70 in the upper 5 m, and at station 800 at 5 m. TPR rates decreased south of station 805 to less than 5 ml $O_2/m^3/h$.

In June TPR rates within the plume ($\sigma_t \leq 22$) ranged between 1.46 and 20.99 ml $O_2/m^3/h$ ($\bar{X}$ = 11.29 ±4.63) and outside of it from 2.88 to 22.21 ml $O_2/m^3/h$ ($\bar{X}$ = 10.24 ±4.87) (fig. 2(d)). Highest rates occurred within or just beneath the plume, with rates decreasing southward of transect 69-804 and from surface to bottom. Rates excedded 10 ml $O_2/m^3/h$ in the upper water column from transect 808-811 northward (figs. 4(d), 5(d), and 6(d)).

TPR rates in October, although not as high as in June, were still elevated. TPR rates ranged from 6.15 to 18.02 ml $O_2/m^3/h$ ($\bar{X}$ = 10.18 ±4.32) within the plume ($\sigma_t \leq 22$) and from ∿0.0 to 15.01 ml $O_2/m^3/h$ ($\bar{X}$ = 6.19 ±4.69) in surrounding waters (fig. 3(d)). TPR rates were highest within the Bay mouth (station 801); proceeding southward, elevated rates were found approximately 12 to 17 km offshore and in the upper water column. These rates decreased southward to station 805 and then increased to station 809, where they exceeded 12 ml $O_2/m^3/h$. Further south (station 812) they exceeded 14 ml $O_2/m^3/h$. These higher rates did not appear to be related to the plume. TPR rates in bottom water (>8 m) along transects 805-807 and at station 810 were too low to detect (<0.02 ml $O_2/m^3/h$) by the method used. These were the lowest TPR rates measured during the three studies.

DISCUSSION

Few measurements of TPR have been made along the Atlantic coast of the United States (Table I and refs. 6 to 15). For comparative purposes our mean rates for March, June, and October were 6.25, 10.86, and 6.42 ml $O_2/m^3/h$, respectively. These rates were of the same magnitude, for similar time periods, as values given for the Hudson River plume (ref. 9) and the shelf south of Cape Hatteras (ref. 12). Both the Hudson River plume and Chesapeake Bay plume are regions representative of estuarine outwellings and thus one would possibly expect the rates to be similar. However, the Hudson plume is reported to be more highly eutrophic (ref. 9), and thus it would be expected to exhibit higher respiration rates than the Chesapeake plume. This may indeed be the case, but due to the lack of supporting data for other periods of the year in the Chesapeake Bay plume no clear conclusions can be made. Barlow et al. (ref. 6), Sirois (ref. 7), and Taft et al. (ref. 8) all reported rates in excess of ours. Their rates are higher based on their sampling further up estuaries where conditions are more eutrophic due to increased organic loading. Rates presented by Pomeroy and Johannes (refs. 12 and 13) are generally lower than the ones presented in this study, and their rates are more representative of shelf and oceanic conditions. Georges Bank (refs. 14 and 15) appears to be an enriched system nearly comparable to the estuarine plumes.

Elevated chl *a* and phaeo *a* concentrations and TPR rates are associated with the density plume emanating from the Bay for the three periods examined. This would tend to suggest that the Bay plume stimulates phytoplankton growth and metabolic activity.

Marshall (ref. 16) cites higher phytoplankton cell numbers within the plume waters, and Kator and Zubkoff (ref. 17) found elevated bacterial biomass and heterotrophic uptake rates for the same area. In order to support this elevated biological activity, the Bay plume has to be an area of increased organic supply to the ecosystem either from autochthonous or allochthonous sources. For October 1980, dissolved organic carbon concentrations ranged from 0.8 to 3.3 mg/l. These concentrations are similar to those for the Hudson plume (ref. 9). Additional evidence for allochthonous inputs is shown in the data presented in references 18 and 19 for increased coprostanol and hydrocarbon concentrations found within the plume. However, without primary productivity data (including released dissolved fractions) it is difficult to determine which source is responsible for providing the bulk of the energy necessary to support TPR.

During both the March and June samplings, elevated chl *a* and phaeo *a* concentrations and TPR rates were found within the plume waters north of station 808 (figs. 4(b), 4(c), 4(d), 5(b), 5(c), and 5(d)), but by station 808 there is the indication of a decoupling of the particulates from the plume (figs. 6(b), 6(c), 7(b), and 7(c)) as shown by increased concentrations of particulates in bottom waters. TPR rates are still higher in the plume, but there is also increased activity in bottom waters probably due to the "raining out" of organic material from the plume. Brown and Wade (ref. 18) also found increasing concentrations of coprostanol in bottom waters. This settling of particulate materials to the benthos down the length of the plume may be a method of transporting contaminants as well as food to the seabed and ultimately into the benthic food web.

CONCLUSIONS

Total plankton respiration rates were elevated in the Chesapeake Bay plume over those in surrounding waters, and thus the Bay plume represents a source of labile organic material to the adjacent shelf waters and seabed. This is supported by the increased biomass concentrations of chlorophyll *a*, phaeopigment *a*, phytoplankton cell numbers, and bacterial cell numbers also found associated with plume waters. This initial look also suggests that TPR rates found within the Bay plume may be nearly comparable to those in the supposedly more heavily eutrophic Hudson River plume. Based on the results of this study, it appears that the plume exiting the Chesapeake Bay acts to stimulate biological activity over the contiguous shelf.

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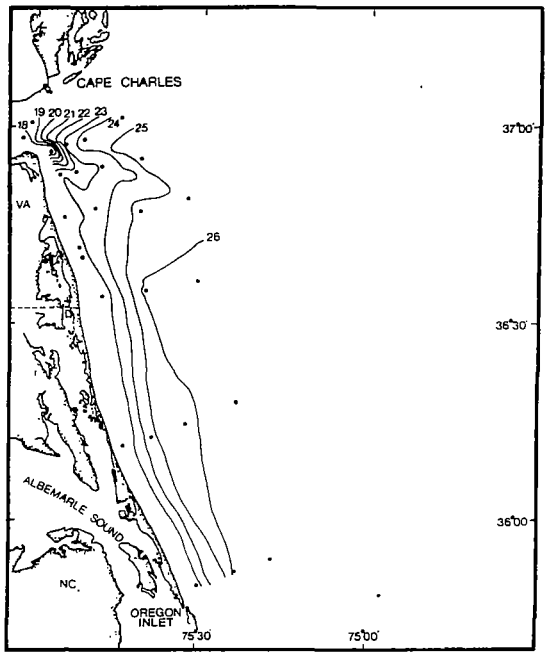
TABLE I.- A COMPARISON OF RESPIRATION RATES FROM COASTAL WATERS NEAR VIRGINIA WITH VALUES FROM OTHER AREAS ALONG THE NORTHEAST COAST OF THE UNITED STATES

Authors	Area	Month	Mean Respiration Rates ml $O_2/m^3/h$
Barlow et al. (ref. 6)	Forge River estuary	June-September	272.0
Sirois (ref. 7)	Hudson River (upper)	July	44.0
		September	24.0
	Hudson River (lower)	July	72.0
		September	53.0
Taft et al. (ref. 8)	Chesapeake Bay (upper)	February	9.6-37.1
		April	10.8-56.3
		August	22.5-79.6
Present study	Chesapeake Bay mouth - Virginia-North Carolina border	March	6.25
		June	10.86
		October	6.42
Thomas et al (ref. 9)	Hudson River plume	March	6.2
		May	9.5
		July	13.5
		November	4.4
Thomas et al (ref. 10)	New York Bight apex	August	35.1
Thomas et al. (ref. 11)	New York Bight apex	August-September	7.0*
Pomeroy and Johannes (ref. 12)	Cape Hatteras shelf (north)	July	0.6
	Cape Hatteras shelf (south)	July	9.5
	Cape Hatteras slope	May	0.1
Pomeroy and Johannes (ref. 13)	Cape Hatteras slope (upper 10 m)	April	1.3
Thomas et al. (ref. 14)	Georges Bank	March-April	4.1
		July	3.5

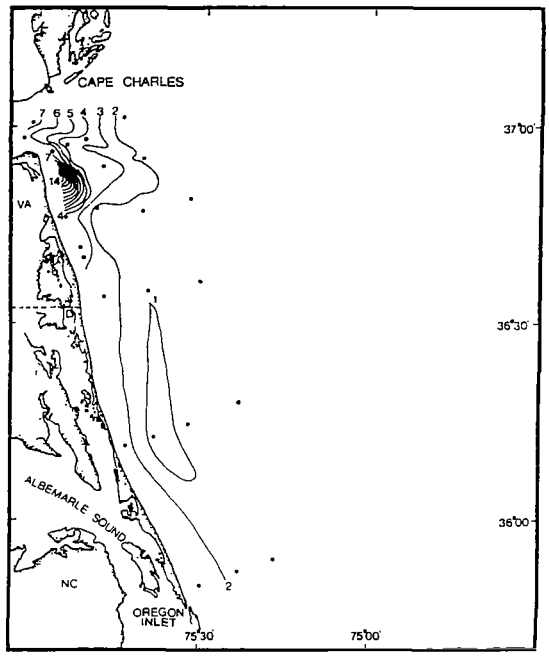
* Rate measured during an anoxic episode in 1976.

TABLE I.- Concluded

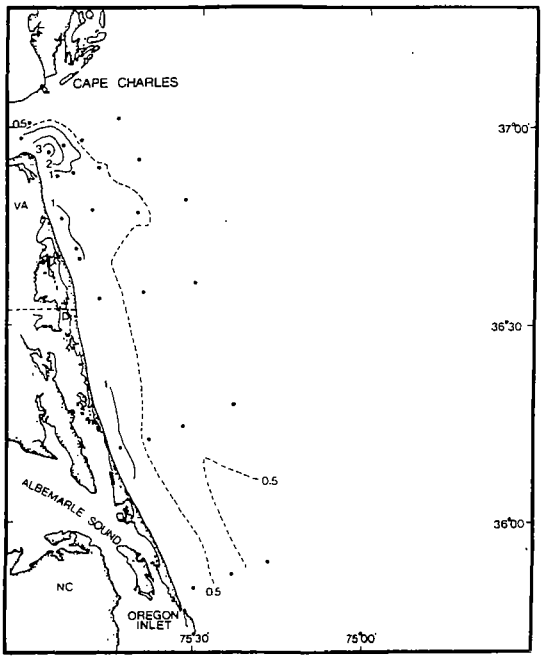
Authors	Area	Month	Mean Respiration Rates ml $O_2/m^3/h$
Riley (ref. 15)	Georges Bank	January	0.2
		March	4.0
		April	8.4
		May	5.1
		June	8.3
		September	6.5



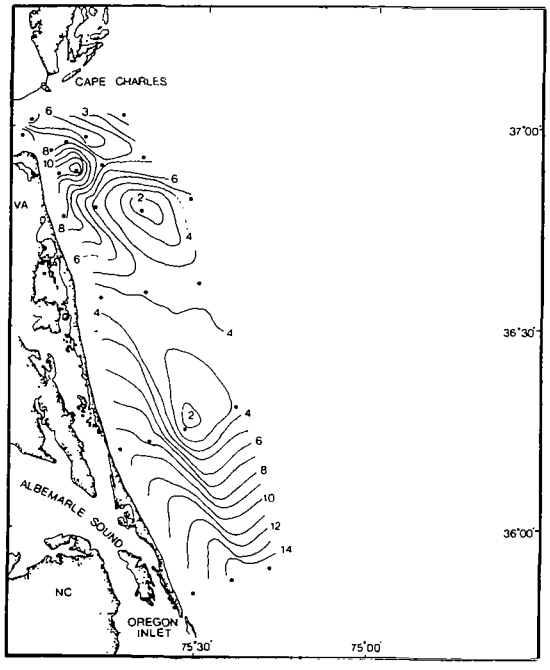
(a) σ_t.



(b) Total chlorophyll (mg chl a/m^3).

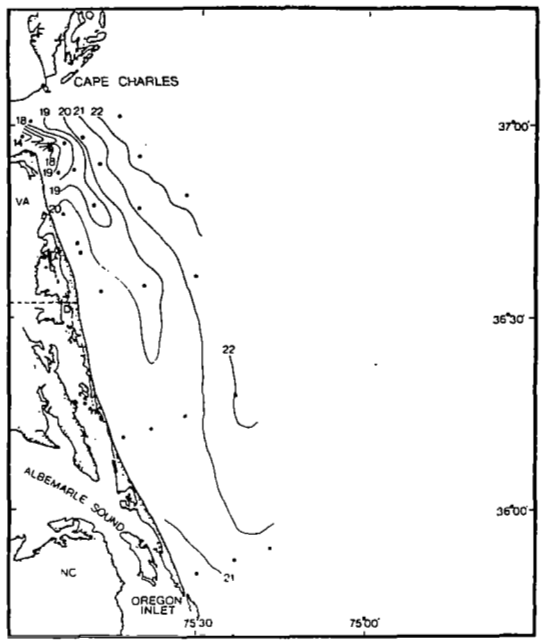


(c) Total phaeopigment (mg phaeo a/m^3).

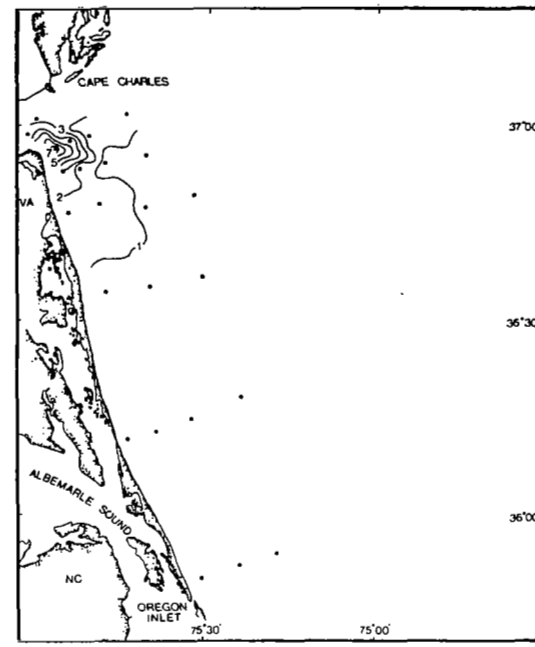


(d) Total plankton respiration (ml $O_2/m^3/h$).

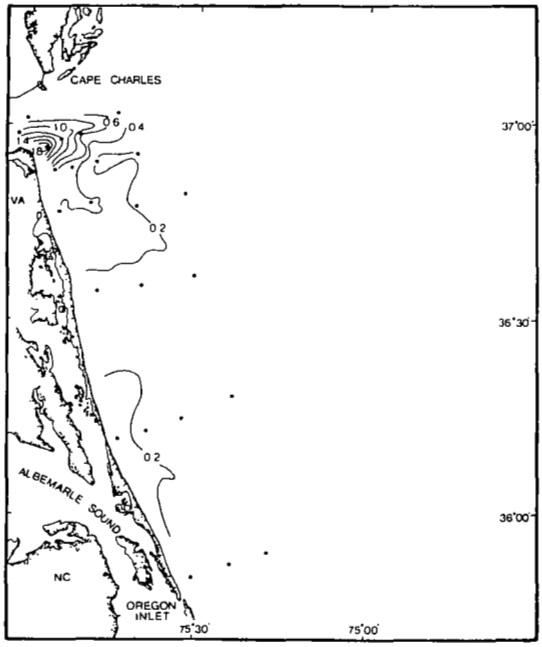
Figure 1.- Surface views (1 m) of σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for March 1980.



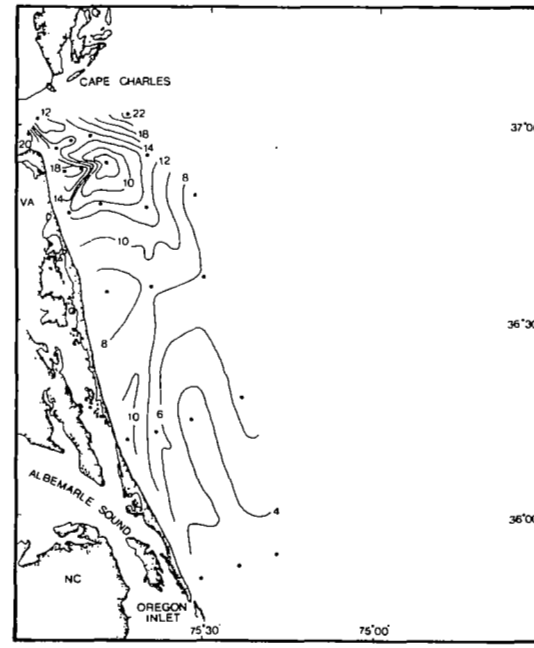
(a) σ_t.



(b) Total chlorophyll (mg chl a/m^3).

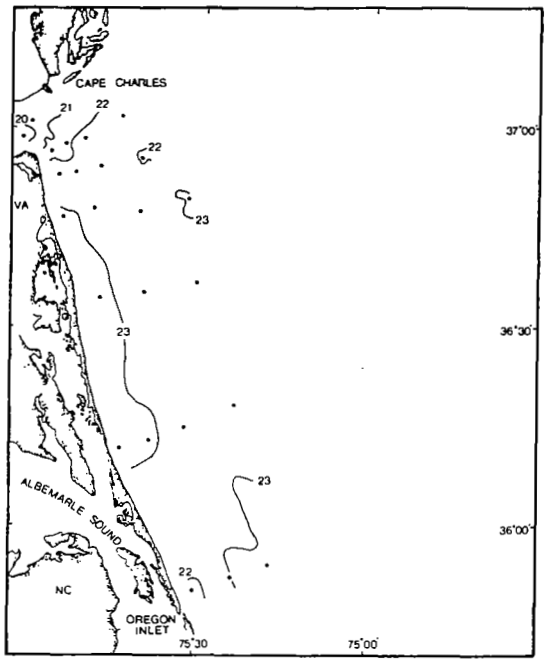


(c) Total phaeopigment (mg phaeo a/m^3).

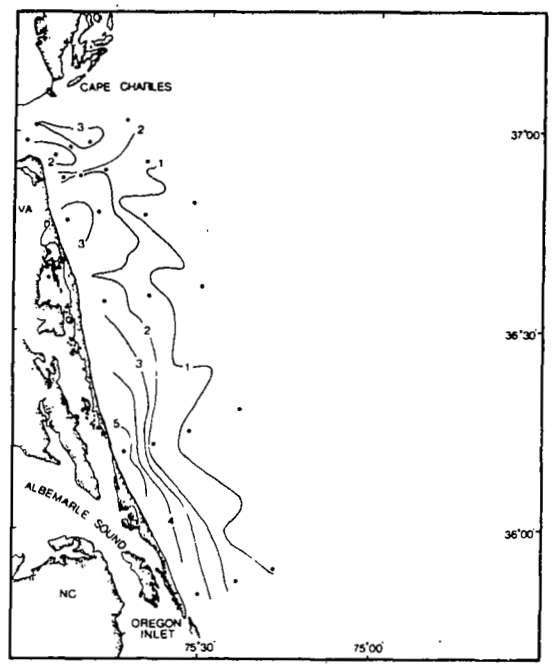


(d) Total plankton respiration (ml $O_2/m^3/h$).

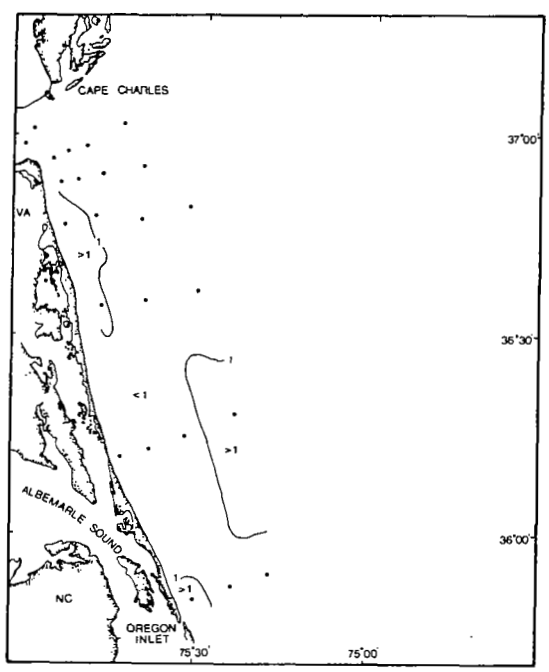
Figure 2.- Surface views (1 m) of σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980.



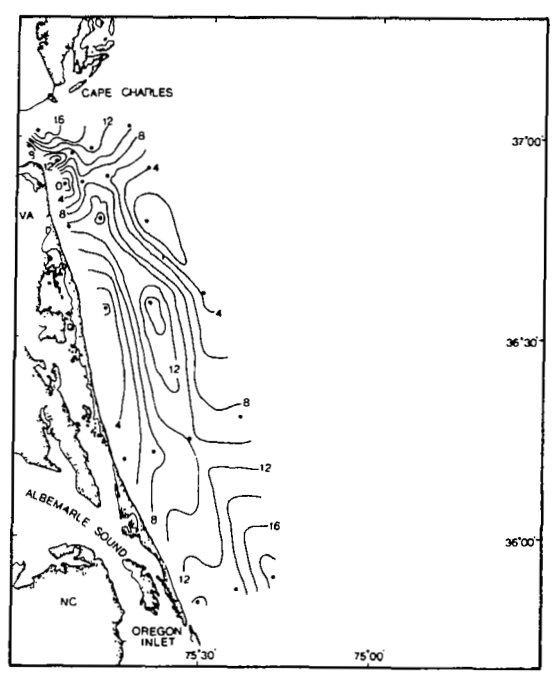
(a) σ_t.



(b) Total chlorophyll (mg chl a/m^3).



(c) Total phaeopigment (mg phaeo a/m^3).



(d) Total plankton respiration (ml $O_2/m^3/h$).

Figure 3.- Surface views (1 m) of σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for October 1980.

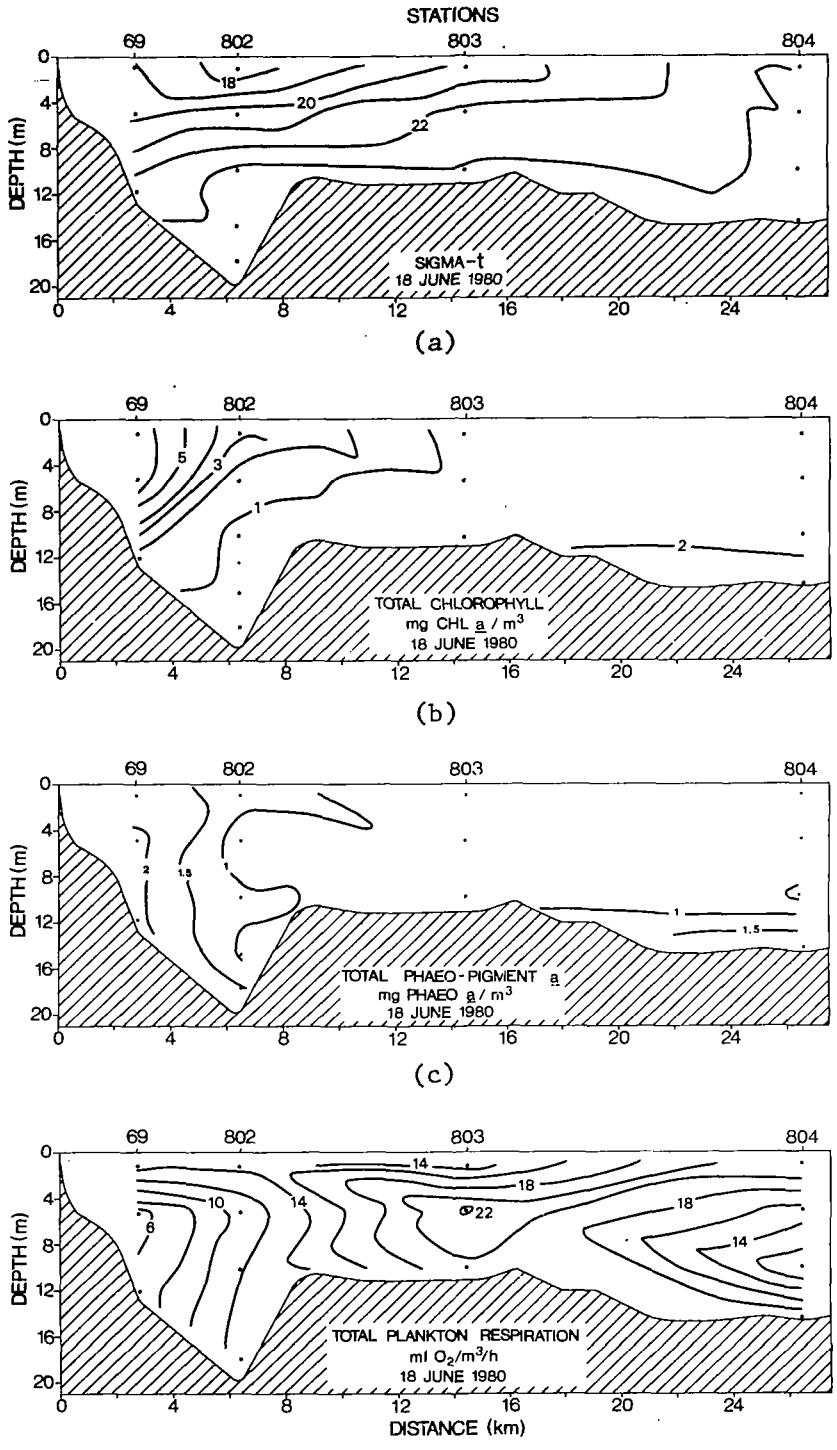


Figure 4.- Lengthwise section (stations 69-804) of the Chesapeake Bay plume for σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980.

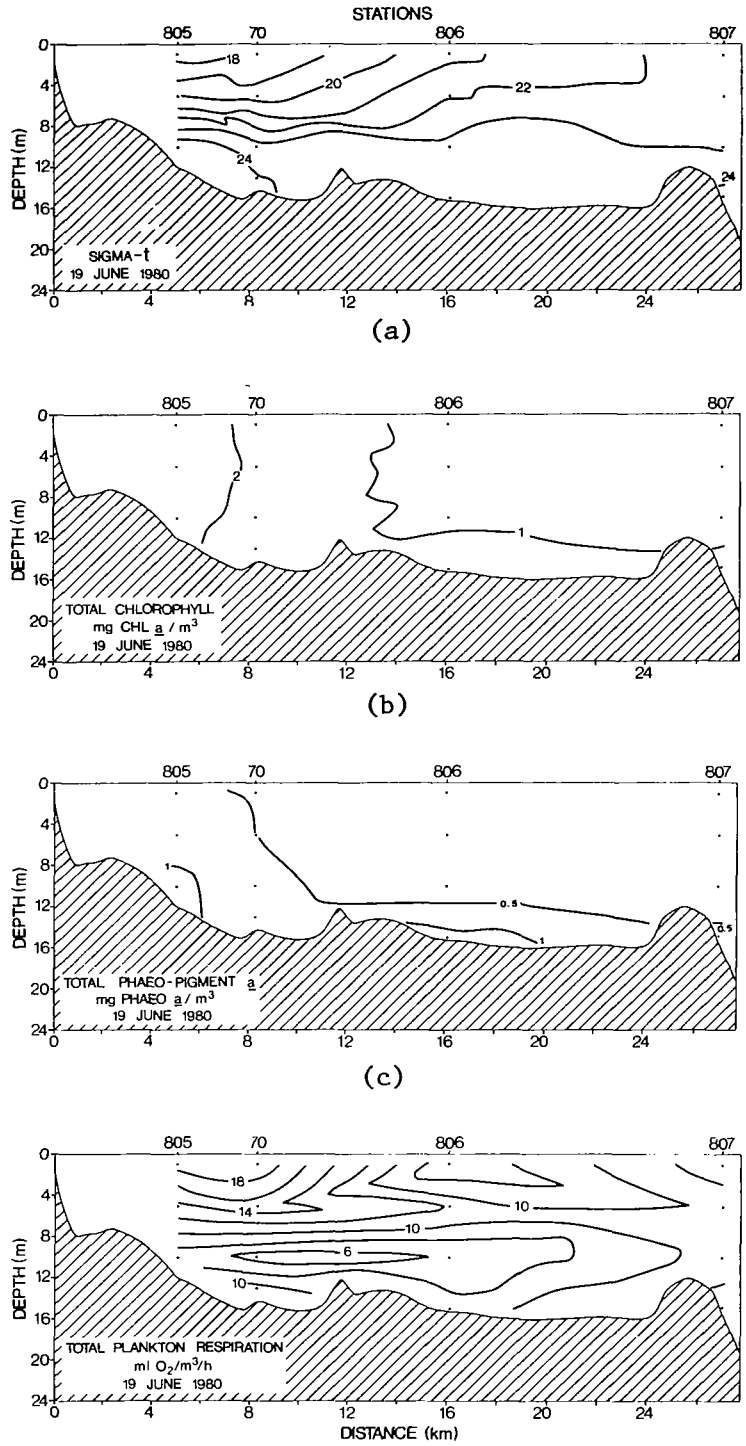


Figure 5.- Lenthwise section (stations 805-807) of the Chesapeake Bay plume for σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980.

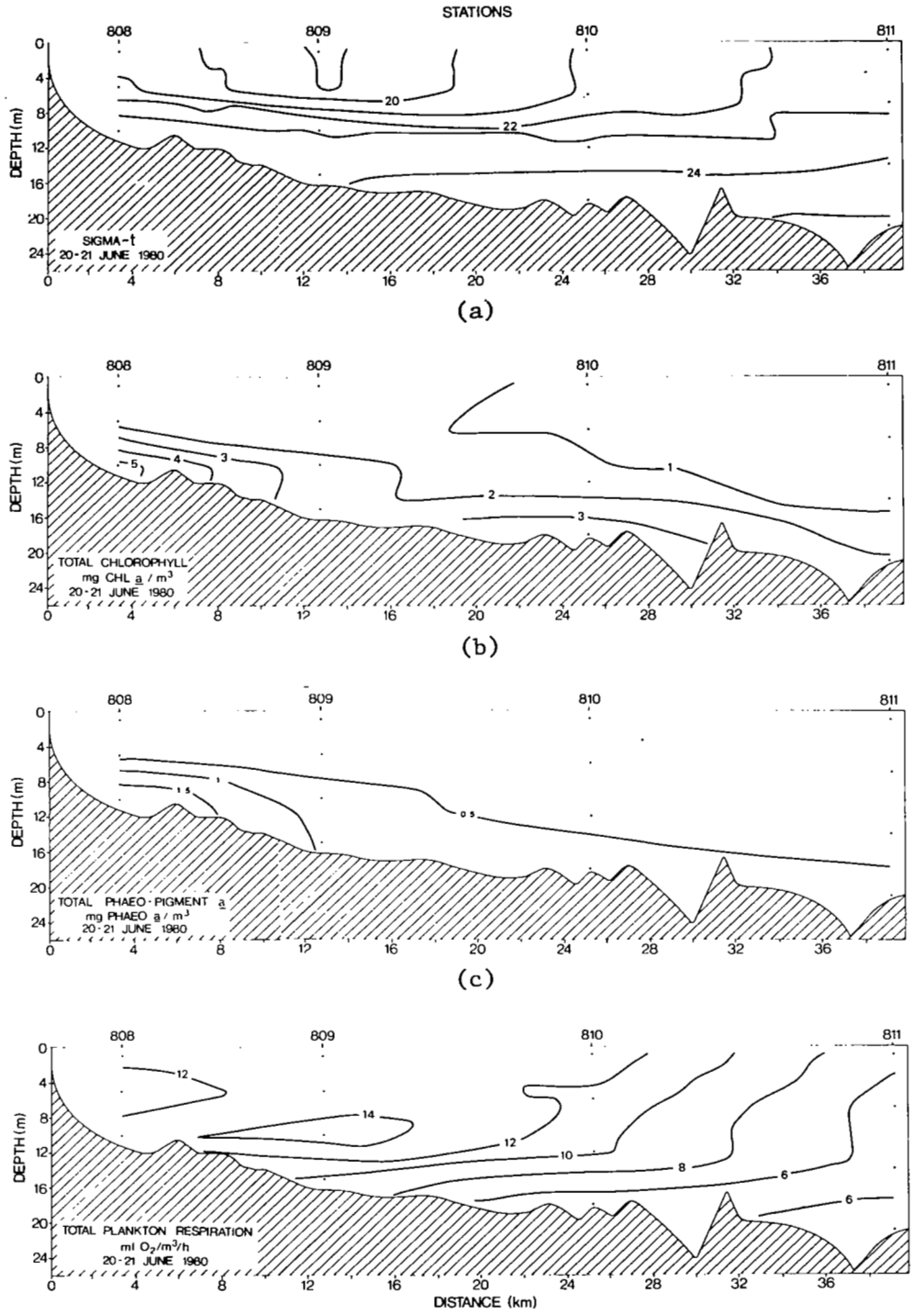


Figure 6.- Lengthwise section (stations 808-811) of the Chesapeake Bay plume for σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980.

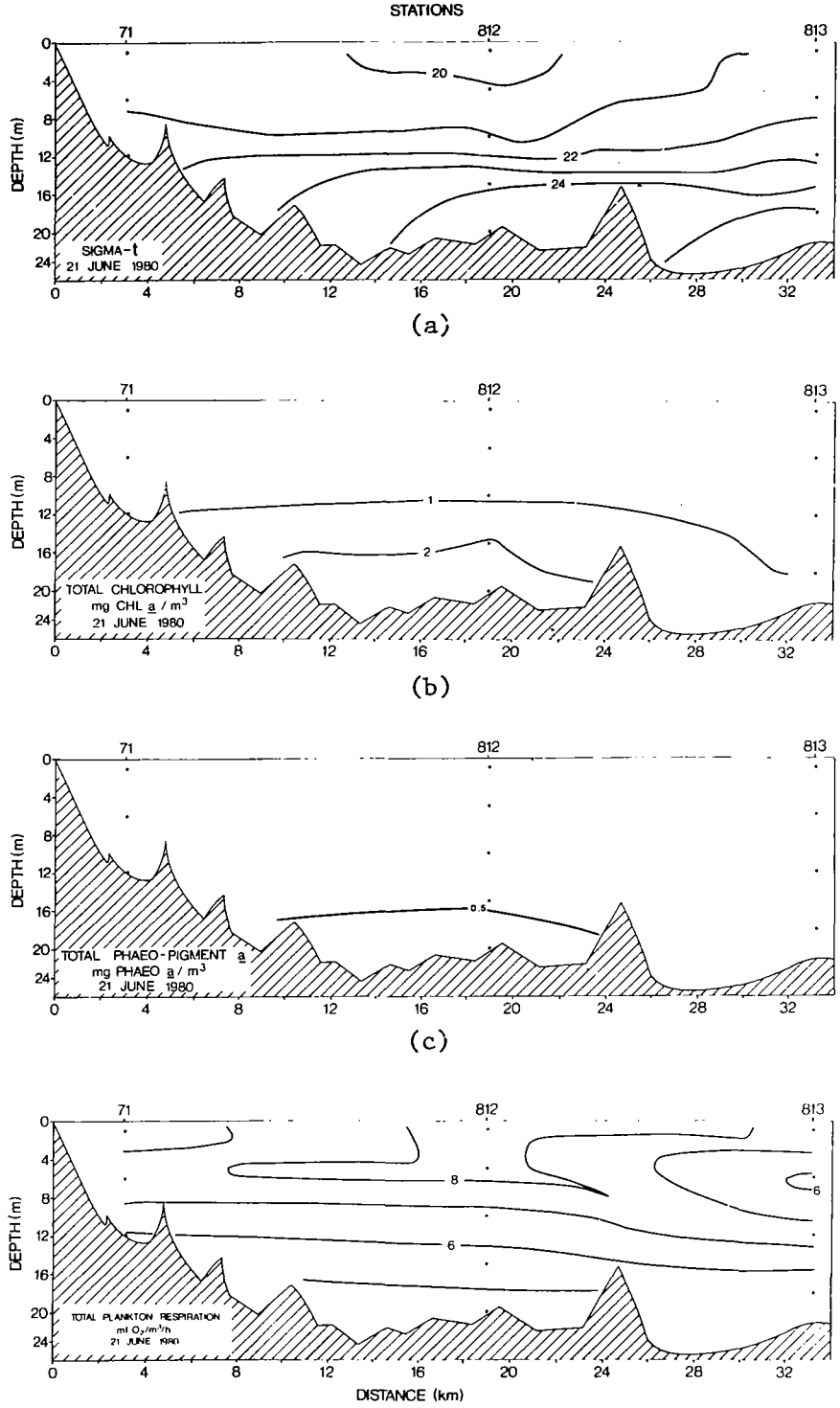


Figure 7.- Lengthwise section (stations 71-813) of the Chesapeake Bay plume for σ_t, total chlorophyll, total phaeopigment, and total plankton respiration for June 1980.